

## 1. Introduction

This document provides a step-by-step guide to implementing control actions in VOLTRA models. It outlines the general workflow for setting up temperature-driven control logic and demonstrates how these strategies can be applied in practice. The methodology is illustrated through two case studies: a 2D electric floor-heating model and a night-ventilation model. In the electric floor-heating case, the control parameters and their use within VOLTRA are explained in detail, offering a complete example applicable to any functions in the software. The second case study focuses on ventilation flow functions, which introduce additional parameters. Together, these examples show how target-temperature-based control can be configured and adapted for different system types.

## 2. Case study 1: 2D electric floor-heating system

[part 1 comfort room sensor.vtr](#)

[part 2 floor sensor.vtr](#)

The control of an electric underfloor heating system can be modelled in VOLTRA. To implement the control logic, the user must define both a target temperature function and a heat flux control function.

This document provides a step-by-step guide to modelling the control strategy for an electric underfloor heating system in VOLTRA.

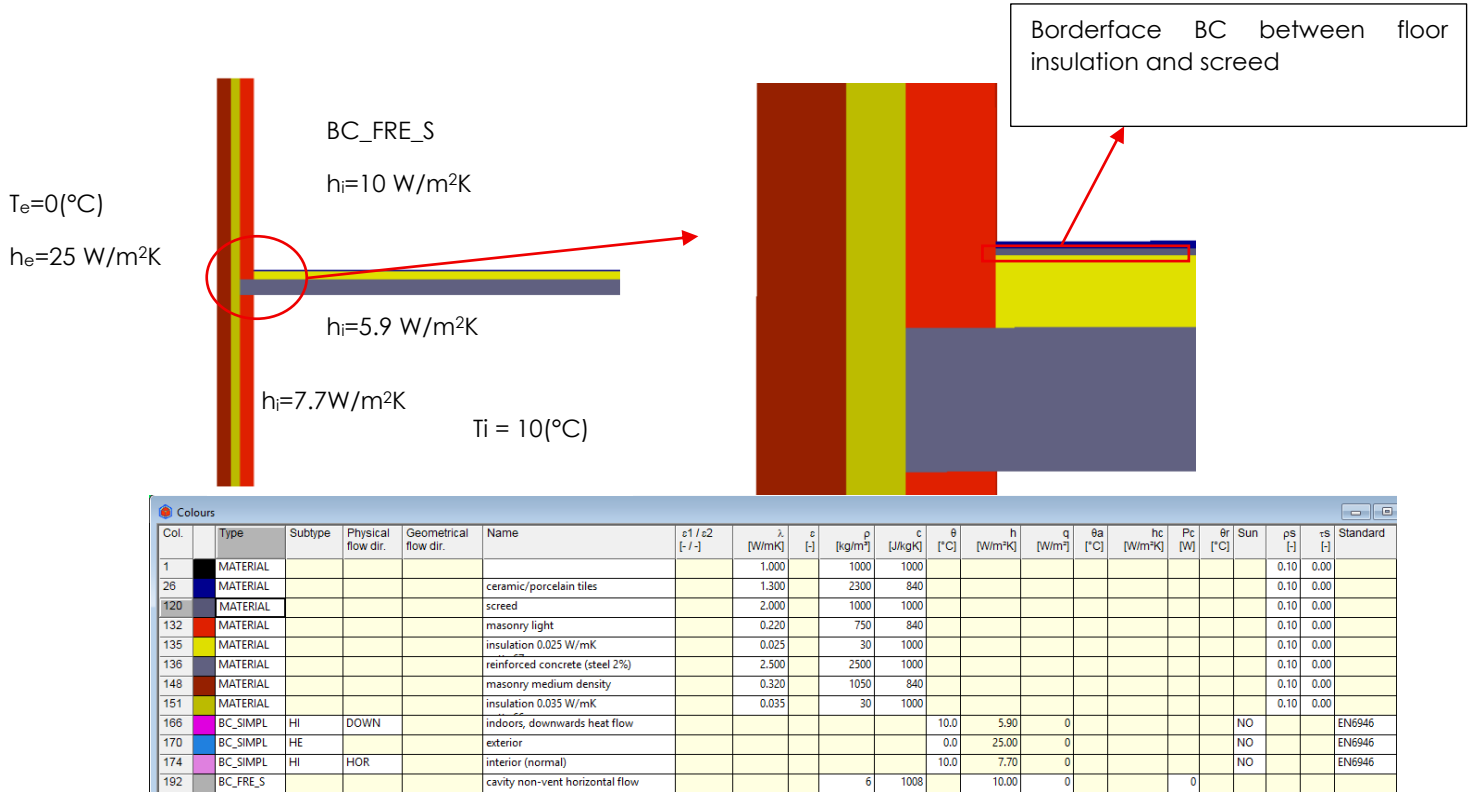
### Objectives

- Understand the principles of control mechanisms in VOLTRA
- Define control functions for target temperature and heating
- Use output nodes as virtual temperature sensors
- Postprocess and analyse calculation results

### 2.1. Model geometry, material properties:

The thermal effect of the electric mat can be represented using a borderface boundary condition (Edit → Borderface BCs).

The electric heating mat is positioned on top of the insulation layer, and a self-levelling screed is applied above the mat. To mimic the heat load produced by the electric mat, a heat flux function is defined between insulation and screed.



**Figure 1 Materials and boundary conditions**

An intermediate floor configuration is modelled in this example. The room has a wall height of 2.4 m. The exterior wall consists of 15 cm of heavy masonry, 10 cm of thermal insulation with a thermal conductivity of 0.035 W/mK, and 15 cm of lightweight masonry.

The floor has a width of 4 m and consists of 20 cm of concrete, 10 cm of insulation with a thermal conductivity of 0.025 W/mK, followed by a 1 cm screed layer containing the electric heating mat, and a 1 cm ceramic tiles.

The outdoor air temperature is set to 0 °C, with an external heat transfer coefficient of 25 W/m²K.

The lower indoor space is unheated and assumed at a temperature of 10 °C. The corresponding global heat transfer coefficients are 7.7 W/m²K for horizontal surfaces and 5.9 W/m²K for upper surfaces.

The upper room is the controlled space in this model. Therefore, a BC\_FRE\_S boundary condition is applied, resulting in a floating room temperature calculated during the simulation. To account for the thermal mass of furniture and occupants in residential areas, the effective room density is assumed to be 6 kg/m³, resulting in a fivefold increase in volumetric specific thermal capacitance.<sup>1</sup>

<sup>1</sup> Parys, W., Hens, H., & Saelens, D. (2013). Cost Optimization of Cellular Office Buildings based on Building Energy Simulation (Kostenoptimalisatie van kantoorgebouwen met individuele kantoorcellen op basis van gebouwenergiesimulatie).

To monitor the room temperature, a floating control sensor is introduced. In VOLTRA, output nodes act as sensors; however, a material must be present to evaluate node temperatures. For this purpose, a material with colour code 1 is placed at the centre of the upper room. An output node will be assigned to this material in subsequent modelling steps to monitor the room air temperature.

## 2.2. Part 1: Comfort room sensor

### 2.2.1. Defining functions and control parameters

Figure 2 illustrates Controls Window with its corresponding parameters.

No.	Sensor node	$\theta$ target [T##]	Sens.up [°C]	Sens.dn [°C]	Purpose	Time on [min]	Time off [min]	Function from	Function to	Test $\Delta\theta$	$\Delta\theta$ [°C]	Zone $\theta 1$	Zone $\theta 2$
1	1	T01	0.5	0.5	HEATING	0.0	0.0	I01	I02				

Figure 2 Controls parameters in Controls Window

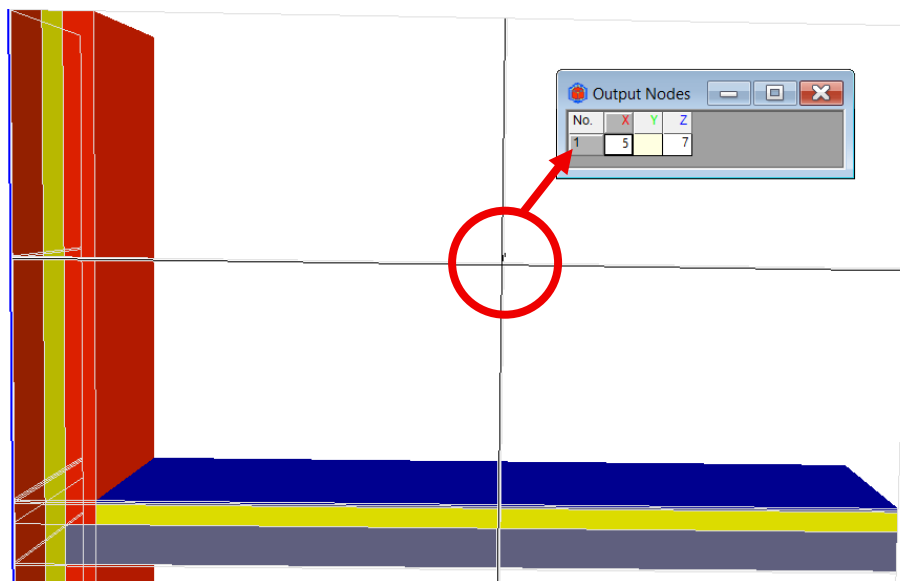
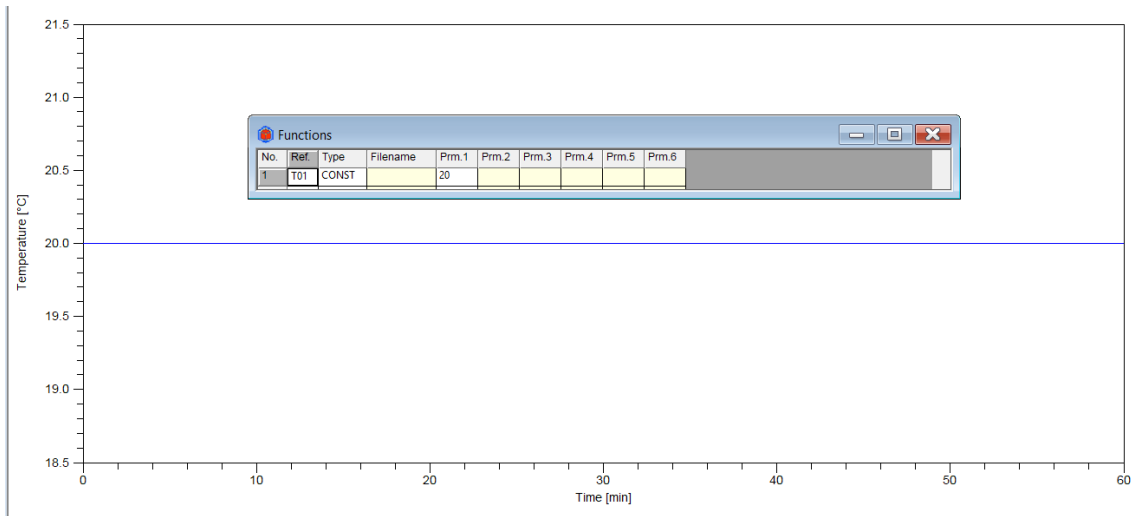


Figure 3 Output node

**Sensor node:** This parameter refers to an output node. In this example, the output node is assigned to the floating room temperature sensor located in the upper room as can be seen in the Figure 3. The temperature evaluated at this node is used as the input signal for the control logic.

**$\theta$  target:** The target temperature is a key parameter for control purposes. The temperature of the sensor node is compared with the target temperature in each time step, and the control action is activated based on the control logic and the resulting temperature difference.

In VOLTRA, the target temperature can be defined as a function. This allows both constant and time-dependent setpoints to be used. In this example, a target temperature of 20 °C is defined as a constant function in the Functions window and assigned as the target temperature for the control system.



**Figure 4 Temperature function**

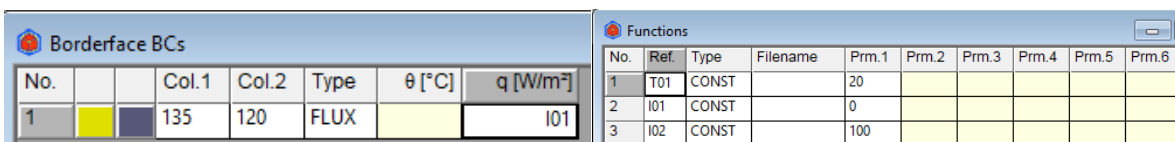
**Sens up / Sens down:** The sensitivity parameters are defined to prevent rapid on/off switching of the control system. These parameters introduce a hysteresis band around the target temperature. The control logic compares the sensor node temperature with the target temperature  $\pm$  the defined sensitivities to determine whether an action should be taken.

**Purpose:** This parameter defines whether the control is used for heating or cooling. In this example, heating is selected. The control is activated when the sensor temperature drops below the target temperature minus the downward sensitivity. Conversely, the control is deactivated when the sensor temperature exceeds the target temperature plus the upward sensitivity.

**Time on / Time off:** These parameters define the minimum duration for which the control must remain in the ON or OFF state. Even if the sensor temperature exceeds the target temperature plus the upward sensitivity, the control may remain active until the specified minimum ON time is reached. The same principle applies to the OFF state, ensuring stable operation and avoiding frequent switching.

**Function from / Function to:** The 'Function to' field contains a function reference (e.g., I02). When the control is active, this function replaces all functions referenced in 'Function from' (e.g., I01) throughout the VOLTRA model. This mechanism allows the control system to dynamically switch between different functions based on the control state.

For this study, two heat flux functions are defined: I01 and I02. Function I01 is defined as 0 W/m<sup>2</sup>, representing the heating system in the OFF state, while I02 is defined as 100 W/m<sup>2</sup>, representing the heating system in the ON state. These functions are imposed as borderface boundary condition between insulation and screed.



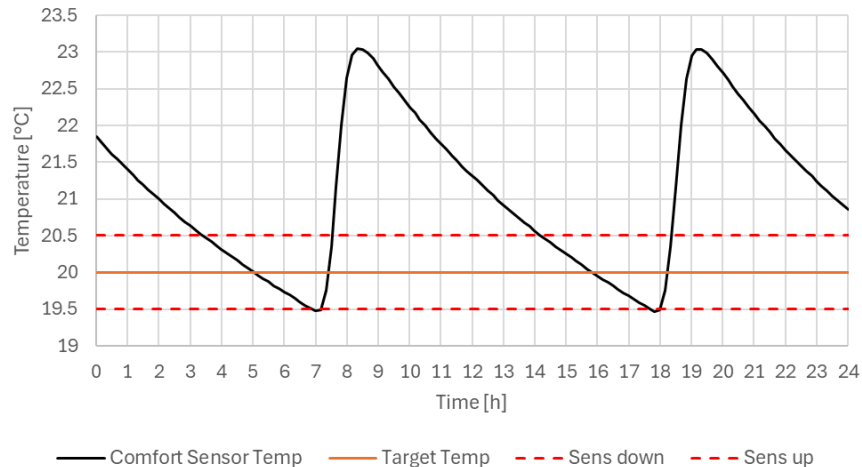
**Figure 5 Heat flux function imposed as Borderface BC**

Two heat flux functions are defined to enable the heating system. When the sensor temperature falls below the target temperature minus the downward sensitivity, the control system switches ON. As a result, the active function changes from I01 to I02, and electric underfloor heating is activated.

### 2.2.2. Results

The simulation is performed for one day, preceded by a three-day start-up (initialization) period to ensure thermal stabilization of the model with a time step of 10 minutes.

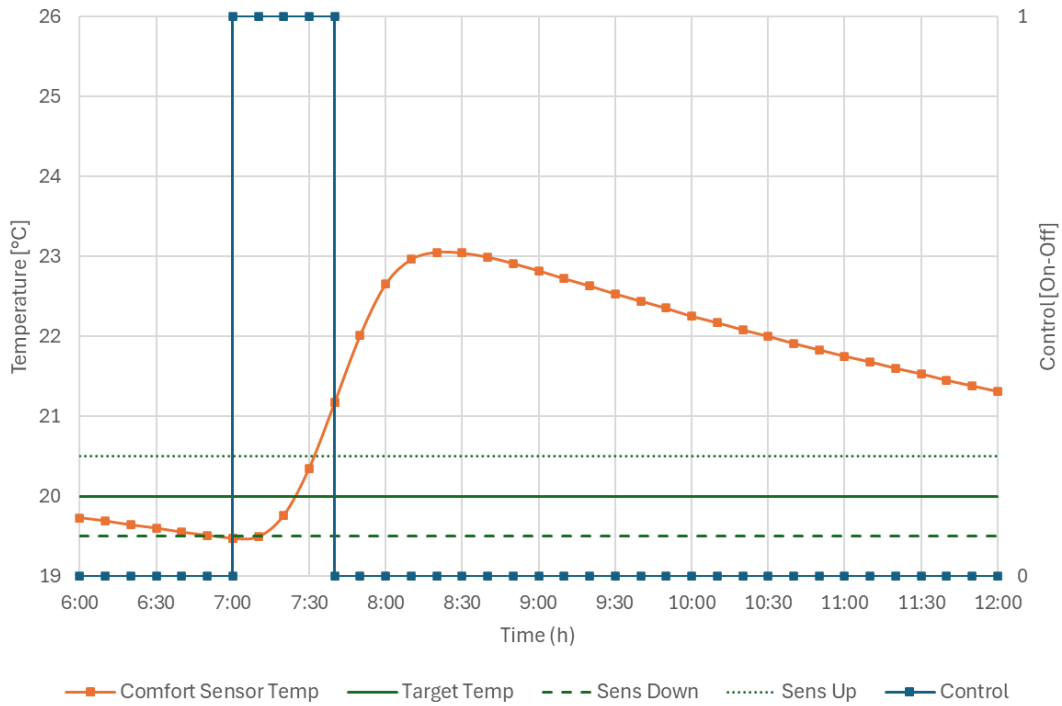
The Figure 6 illustrates the comfort sensor temperature together with the target temperature. The purpose of the control system is to maintain the sensor temperature within the range of 19.5 °C to 20.5 °C.



**Figure 6 Comfort sensor temperature vs time**

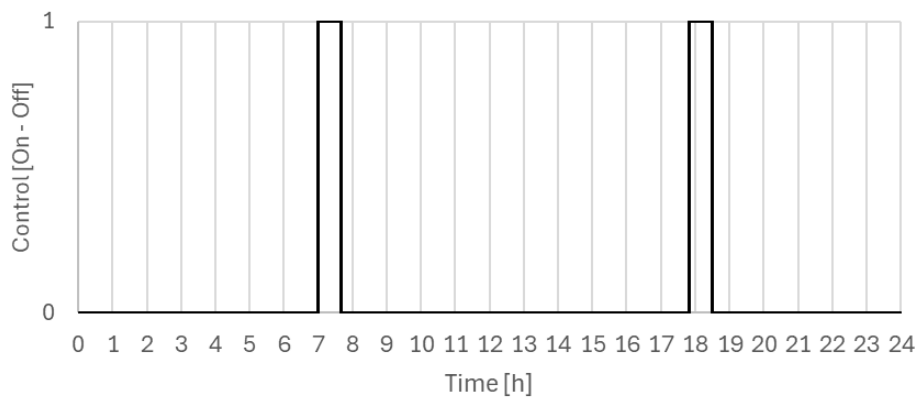
The results show that the minimum temperature is maintained close to 19.5 °C, while the maximum temperature exceeds 20.5 °C. This overshoot occurs due to the thermal inertia of the floor construction. Even after the heating system is switched off, the stored heat in the screed and floor layers continues to be released to the room, causing a further rise in room temperature.

The Figure 7 zooms in the morning peak, illustrating that the control system switches ON when the sensor temperature drops below 19.5 °C and switches OFF once the sensor temperature exceeds 20.5 °C.



**Figure 7 Comfort sensor temperature and control state vs time**

The Figure 8 illustrates when and for how long the control action is active. Over the 24-hour simulation period, the control system, corresponding to the electric underfloor heating being ON, is active for a total of 80 minutes. This results in a total energy use of 533.33 Wh.



**Figure 8 Control state vs time**

## 2.3. Part 2: Floor sensor

### 2.3.3. Defining functions and control parameters

To avoid this overshooting, it is common practice in electric underfloor heating systems to install a temperature sensor within the floor. In the second part of this study, the effect of incorporating a floor-embedded temperature sensor into the control strategy is analysed.

No.	Sensor node	$\theta$ target [T##]	Sens.up [°C]	Sens.dn [°C]	Purpose	Time on [min]	Time off [min]	Function from	Function to	Test $\Delta\theta$	$\Delta\theta$ [°C]	Zone $\theta$ 1	Zone $\theta$ 2
1	2	T01	0.0	0.0	HEATING	0.0	0.0	I01	I02				

Figure 9 Controls parameters

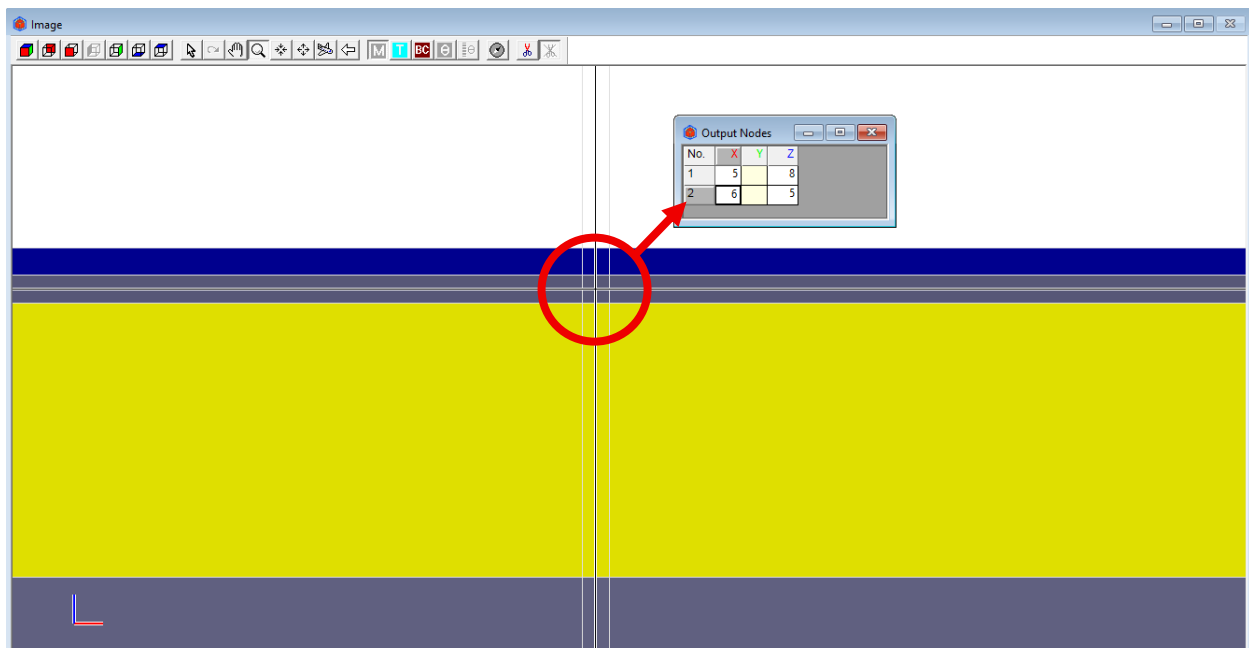
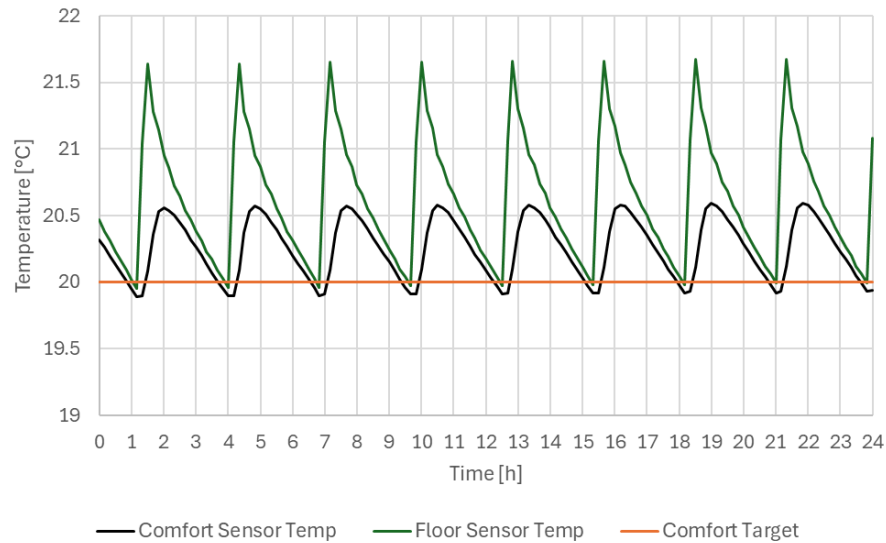


Figure 10 Output node

In this configuration, the sensor node is positioned at the centre of the screed layer as shown in the Figure 10. The target temperature is set to 20 °C, consistent with Part 1 of the study; however, in this case, the objective is to maintain the floor temperature at 20 °C rather than the room air temperature.

The heat flux functions remain unchanged from Part 1, with the same function applied to the borderface between insulation and screed. For Part 2, the sensitivity values are set to zero. Since the sensor is located directly within the heated floor layer and the system is based on electric on/off heating, the introduction of a hysteresis band is not essential for stable control. This setup allows a more direct response of the heating system to floor temperature variations and facilitates analysis of the impact of floor-based sensing on control performance.

### 2.3.4. Results

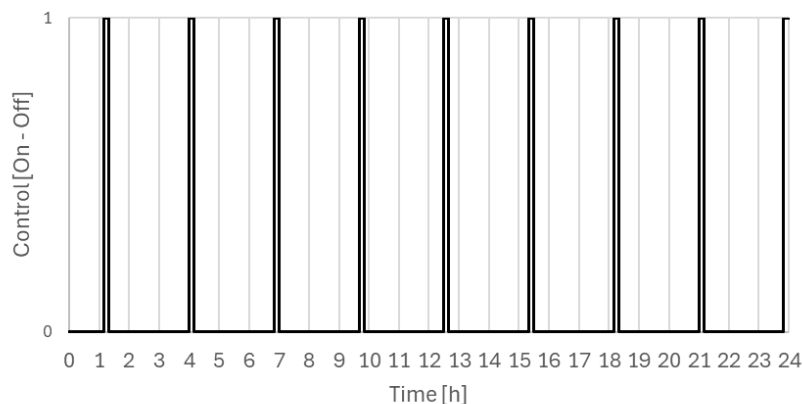


**Figure 11 Comfort and floor sensor temperatures vs time**

The Figure 11 presents both the floor sensor temperature and the comfort sensor (room air) temperature. As shown, the floor sensor temperature briefly drops below the setpoint of 20 °C. Because no sensitivity band is applied in this control strategy, the control action is activated immediately when the floor sensor temperature falls below 20 °C and is deactivated as soon as it exceeds 20 °C.

Similar to the behaviour observed in Part 1, the effect of thermal inertia is evident: even after the control system switches OFF, both the floor and comfort sensor temperatures continue to increase for several additional time steps. This occurs because the floor retains stored thermal energy and continues to release heat into the room after the heating power is removed.

This study demonstrates that floor-based control can improve temperature stability and reduce overshoot in electric underfloor heating systems with significant thermal mass.



**Figure 12 Control state vs time**

The Figure 12 illustrates the control action over a 24-hour period. Over the course of the day, the electric underfloor heating system is active for a total of 90 minutes. This operating time corresponds to a total energy consumption of approximately 600 Wh.

### 3. Case study 2: Night ventilation

[Case1\\_No\\_ventilation.vtr](#)  
[Case2\\_Night\\_Ventilation.vtr](#)

This second study focuses on applying control actions to ventilation flows. A night-ventilation scenario is used to illustrate the method.

The analysis is carried out for a room with South and West oriented façades containing windows and two internal wall.

Control logic is implemented to manage night ventilation. When the indoor air temperature exceeds the target value, and the outdoor temperature is at least 3 °C cooler than the indoor air, the control action activates the ventilation system. This study provides a step-by-step explanation of how to select the relevant parameters, obtain results, and apply control actions in VOLTRA.

Additional objectives compared to the first study

- Define ventilation-flow functions and implement them using control actions.
- Understand the additional control parameters related to ventilation flows (Test $\Delta\theta$ ,  $\Delta\theta$ , Zone  $\theta 1$  and  $\theta 2$ ).

#### 3.1. Model geometry, material properties and climate:

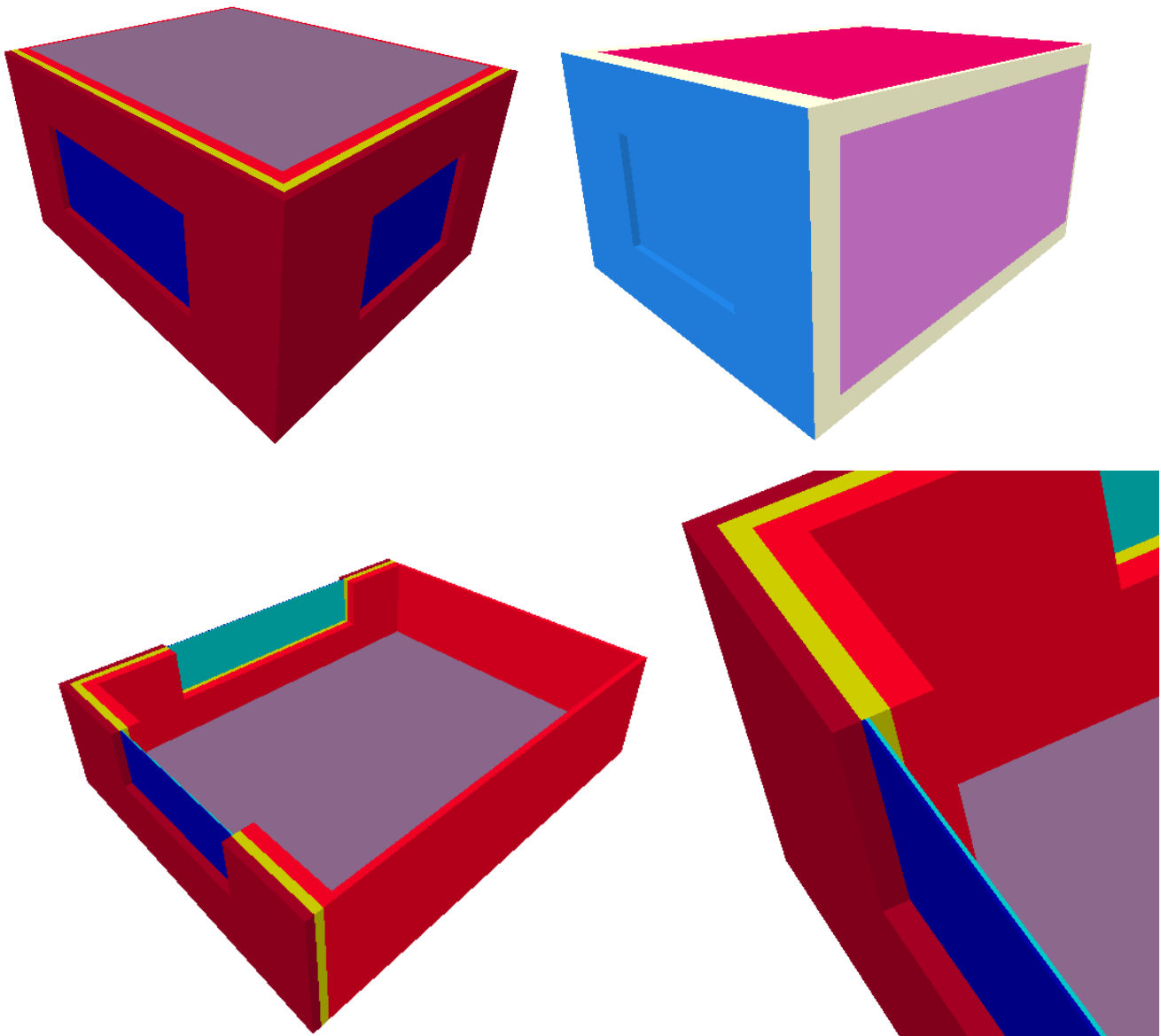
The study is carried out over a three-day period (10<sup>th</sup> –12<sup>th</sup> August) in Brussels. These dates were selected because they correspond to conditions with high thermal loads on the south and west façades. The model is exposed to the exterior on these two façades, each containing a window. The remaining two walls are interior partitions maintained at a constant temperature of 20 °C. The floor and ceiling are also held at 20 °C.

##### **Definition of an equivalent layer for the double glazing unit (DGU)**

The double glazing unit has a U-value of 1.1 W/m<sup>2</sup>K and a thickness of 4mm/16mm/4mm. In the simulation the interest lies on the overall solar gains through this glass, not on the glass temperature distribution. As a consequence, the glass can be simplified to an equivalent solid layer of 24mm with a conductivity 0.032 W/mK. Herein, two colours are used to allow separate definitions of equivalent reflectivity and transmissivity for the inner and outer surfaces. (18 and 21)



Figure 13 below illustrates the model geometry in detail, including the material layers and boundary conditions applied.



Col.	Type	Subtype	Physical flow dir.	Geometrical flow dir.	Name	$\epsilon_1 / \epsilon_2$ [-/-]	$\lambda$ [W/mK]	$c$ [J]	$\rho$ [kg/m <sup>3</sup> ]	$c$ [J/kgK]	$\theta$ [°C]	$h$ [W/m <sup>2</sup> K]	$q$ [W/m <sup>2</sup> ]	$\theta_a$ [°C]	$h_c$ [W/m <sup>2</sup> K]	$P_c$ [W]	$R_f$ [°C]	Sun	$p_s$ [h]	$\epsilon_s$ [h]	Standard
1	MATERIAL						1.000	0.90	1000	1000									0.10	0.00	
18	MATERIAL				glass1		0.032	0.84	835	630									0.28	0.69	
21	MATERIAL				glass2		0.032	0.84	835	630									0.27	0.67	
72	MATERIAL				concrete density 1800 kg/m3		1.150	0.90	1800	1000									0.10	0.00	
135	MATERIAL				insulation 0.025 W/mK		0.025	0.90	30	1000									0.10	0.00	
136	MATERIAL				reinforced concrete (steel 2%)		2.500	0.90	2500	1000									0.10	0.00	
151	MATERIAL				insulation 0.035 W/mK		0.035	0.90	30	1000									0.10	0.00	
164	MATERIAL				masonry semi-heavy		0.600	0.90	1350	840									0.10	0.00	
166	BC_SIMPL	HI	DOWN		indoors, downwards heat flow						20.0	5.90	0					NO			EN6946
170	BC_SIMPL	HE			exterior						T02	25.00	0					YES			EN6946
174	BC_SIMPL	HI	HOR		interior (normal)						20.0	7.70	0					NO			EN6946
180	MATERIAL				masonry heavy		0.900	0.90	1850	840									0.10	0.00	
190	BC_SIMPL	HI	UP		indoors, upwards heat flow						20.0	10.00	0					NO			EN6946
192	BC_FREE	NIHIL			room				1.2	1008					3.00	0					

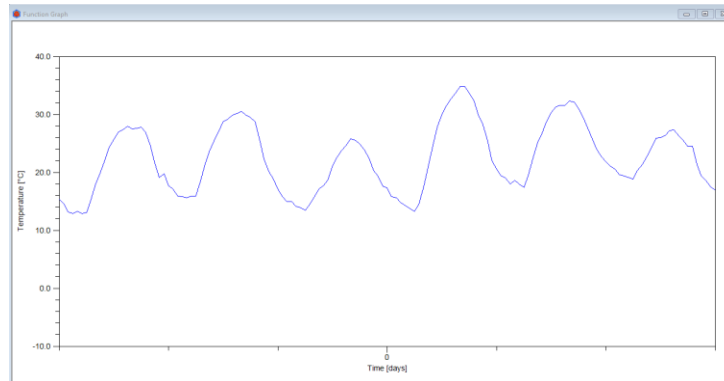
**Figure 13 Geometry, materials and boundary conditions**

The BC\_FREE boundary condition (Colour 192) is used for the inner room. Similar to the upper room in the first study, the inner room represents the controlled space in this model. The BC\_FREE condition results in a floating room temperature that is computed dynamically during the simulation. This

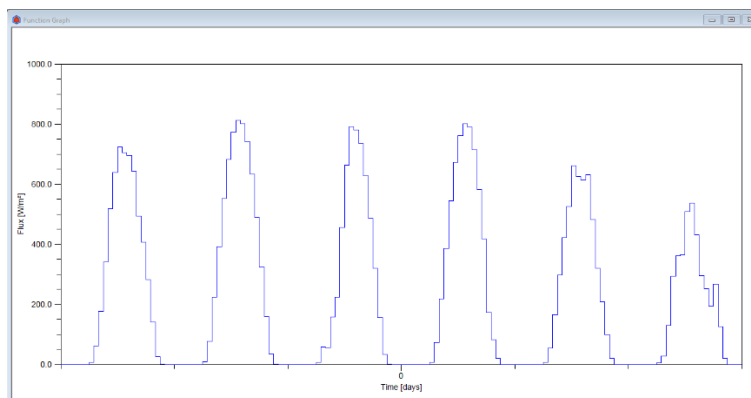
boundary type also accounts for detailed radiative heat exchange, allowing the influence of solar radiation to be captured more accurately.

Because a defined ventilation flow enters the room, the air temperature at this boundary must remain an unknown variable that is affected by the incoming ventilation air. This interaction is explained in more detail in the next section.

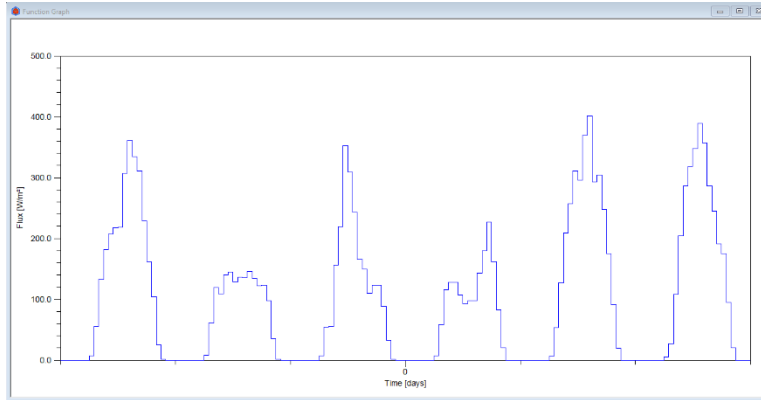
The calculation is performed over a three-day evaluation period, preceded by a three-day start-up (initialization) period. A time step of 20 minutes is used throughout the simulation. Weather conditions for Brussels (including outdoor air temperature, horizontal global radiation, and diffuse solar radiation) are imported from an EPW file. Figure 14, Figure 15, Figure 16 below present these weather conditions for the full six-day simulation period.



**Figure 14 Temperature**



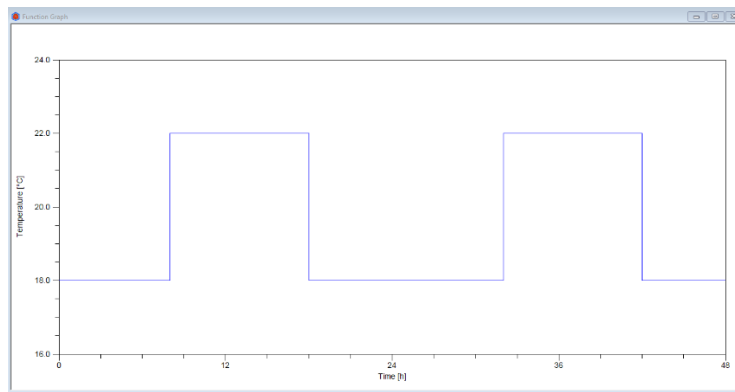
**Figure 15 Horizontal global solar radiation**



**Figure 16 Horizontal diffuse solar radiation**

The target indoor temperature for the office room is set to 22 °C during working hours (08:00–18:00) and 18 °C during the remaining hours of the day.

Figure 17 illustrates the target-temperature function used in the simulation.



**Figure 17 Target temperature function**

### 3.2. Defining functions and control parameters

Ventilation Flows													
No.		From Col.1	To Col.2	Flow [m³/s]									
1		170	192	V01									

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	1	T01	0.0	0.0	COOLING	0.0	0.0	V01	V02	YES	3.0	170	192

**Figure 18 Ventilation flow function and control parameters**

Ventilation flows can be defined from any type of boundary condition toward a boundary condition of type BC\_FREE\_S or BC\_FREE, where the air temperature is unknown and influenced by the incoming ventilation flow. In this study, two ventilation-flow functions V01 and V02 are defined for use in the control action. V01 corresponds to no ventilation (0 m<sup>3</sup>/s), while V02 represents a ventilation rate of 0.03 m<sup>3</sup>/s, which is equivalent to 2.25 ACH for the room.

The sensor node is placed at the centre of the room, as in the previous study. The general control parameters introduced earlier are not repeated here. Instead, the focus is on the additional parameters that become available when Function From and Function To in the control settings are assigned ventilation-flow functions. Under these conditions, four new parameters are activated specifically for controlling ventilation.

Test  $\Delta\theta$ : is used to evaluate the temperature difference between two zones along a ventilation path. It serves as an additional condition that must be satisfied for a ventilation control action to be activated.

For heating: Control is enabled if Zone  $\theta_1$ , is higher than Zone  $\theta_2$  by at least the specified minimum temperature difference.

For cooling: Control is enabled if Zone  $\theta_1$ , is lower than Zone  $\theta_2$  by at least the specified minimum temperature difference.

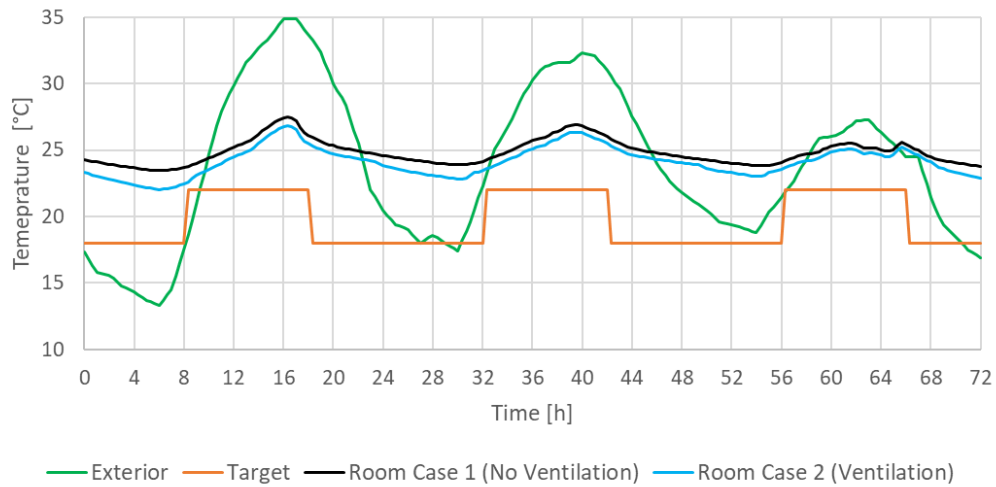
$\Delta\theta$ : Minimum required temperature difference between two zones, here 3°C.

Zone 1 and Zone 2 are required inputs for the temperature-difference test. They are specified using their colour numbers, and both of these colour numbers must be in the ventilation path.

### 3.3. Results

Two cases are simulated in this study. Case 1 represents the condition without night ventilation, serving as a baseline to observe the thermal effect of introducing night ventilation. Case 2 includes the control parameters that activate night ventilation based on temperature conditions.

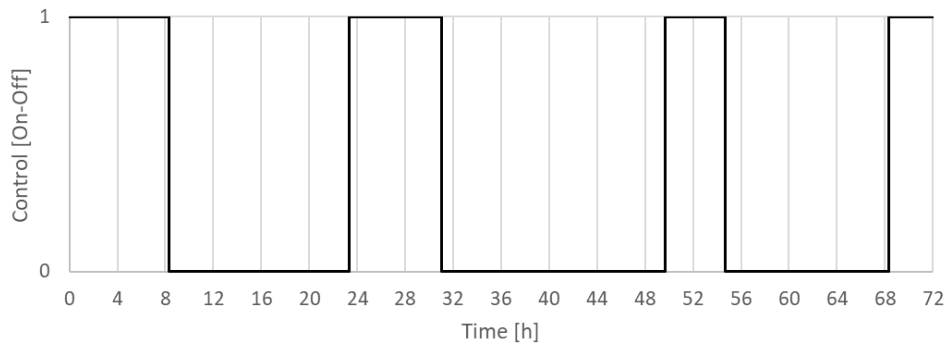
Figure 19 shows exterior air temperature, target temperature, and room sensor temperature for both cases over the three-day simulation period. As expected, the room temperature in Case 2 remains slightly lower than in Case 1, demonstrating the cooling effect of night ventilation. The maximum indoor temperature in Case 1 reaches 27.5 °C, whereas the maximum in Case 2 is 26.8 °C. The average indoor temperatures are 24.8 °C and 24.1 °C, respectively.



**Figure 19 Exterior, room and target temperatures vs time**

Figure 20 illustrates the periods when the control action (night ventilation) is activated. As explained earlier, the primary condition for enabling the control is the target temperature. When the temperature at the sensor node exceeds the target temperature, the control should activate.

However, as shown in Figure 19, even though the room temperature is consistently above the target temperature, the ventilation is not activated throughout the day. This is due to the second condition applied in the ventilation-flow control settings. When the Test  $\Delta\theta$  option is enabled, a minimum temperature difference between the two selected zones must be satisfied. Since during daytime the exterior temperature is not at least 3 °C cooler than the indoor temperature, this condition is not met. As a result, the control action is not triggered and the ventilation remains off.



**Figure 20 Control state vs time**