EVALUATION OF THE FEASIBILITY OF NATURAL VENTILATION CONCEPTS IN A SIMPLE STEADY-STATE POINT-IN-TIME CASE

Introducing a Quick Excel-Based Tool Designed to Evaluate the Success of Natural Ventilation Concepts in Buildings

ABSTRACT:

Designing a building for natural ventilation entails many considerations throughout the design process. Examples of these may include quantity and dimension of openings/vents, and ventilation flow paths, which are often difficult to estimate appropriately for natural ventilation during the conceptual design stage. This paper discusses a quick excel based tool to evaluate the feasibility of natural ventilation concept in a building. It is a simplistic, steady-state, point-in-time tool to calculate pressure drop across the proposed ventilation inlet(s) and outlet(s).

The tool takes as an input the definition of the building heights and opening elements across the proposed ventilation / air flow-path. Users can also input optional parameters to define a solar chimney. The tool provides the user with a simple pass/fail test to determine whether the ventilation openings are sized and located appropriately for a successful building ventilation concept. The paper discusses the various inputs and outputs of the tool with the help of a solved example. The tool is currently limited to evaluating winter ventilation concept i.e. when indoor temperature is more than ambient temperature.

INTRODUCTION:

This Excel tool is based on defining the building elements and then testing specified flow paths, forming a flow network, inside the building. The flow paths start at the windows' inlet points, pass through transfer openings, and end by collecting then exiting from the outlet/exhaust point. Each flow path offers an option of either an obstacle-free path leading directly to the outlet, or a path with obstacles or divided zones (by offering the option of defining transfer openings). Several paths are gathered at one point leading to other obstacles/zones in the flow network or leading directly to the outlet.

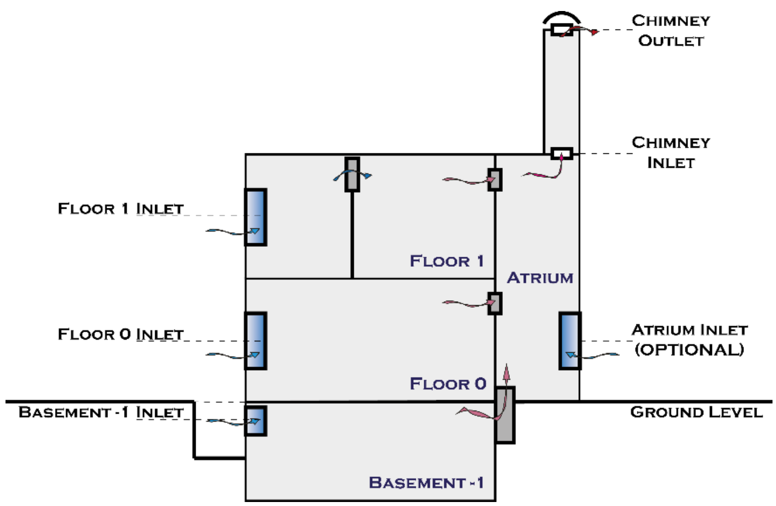
Those options help simplify the flow paths to be evaluated in the proposed design by dividing them into zones with consideration of transfer points affecting the pressure drops. Depending on the design, the prospect user of this tool should decide how the flow path is collected or divided until it reaches the inlet of the solar chimney and use the provided options in this example that support the user's design.

SHEET #1:

PROJECT ELEMENTS DEFINITION:

On the top of this sheet and every other sheet in this tool, there is a color legend that helps the user to understand the different cell colors used throughout the tool.

Color Legend	Titles / Description / Units	Automatic Calculation	List Input	Manual Input	Drop-Down List Choices



When first using the 'Natural Ventilation Calculation' tool, the project elements and components should be defined in the 'Project Element Definition' sheet. In the beginning, the constant values including specific heat capacity, density, gravity, standard pressure, and the gas constant should be defined.

A list defining the different discharge coefficient values according to the type and complexity of openings can also be edited according to different definitions related to the project.

Constants				
Specific Heat Capacity	Density	Gravity	Standard Pressure	R, Gas Constant
kJ/kg-K	kg/m³	m/s²	Pa	J/kg.K
1.006	1.204	9.81	101350	287

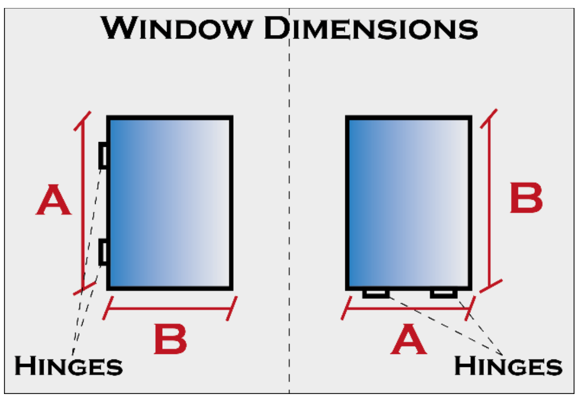
Discharge Coefficient Values Definition	
Simple Window/Opening	0.65
Small Filtered/Hidden Opening	0.3
Manual Input	
Manual Input	
Manual Input	
Manual Input	

Windows/Openings:

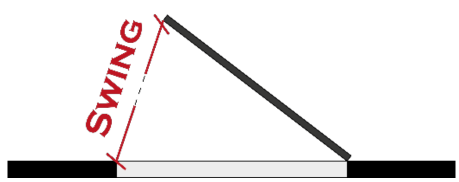
The next step is to define the windows and openings used in the selected project by modifying the data entries in the table ‘Windows/Openings Definition’.

Windows/Openings Definition										
Type	Description/Name	Dimension A	Dimension B	Swing	Free Area Factor	Sliding Percentage	Discharge Coefficient	Opening Angle Info	Opening Angle Info	Open Area
	Write down a description/name	(Hinge Side)	(Hinge-free Side)		For porous elements such as grills and mosquito nets	For a Sliding Window	(C_d)	(in Radians)	(in Degrees)	Calculation: total open area for sliding/hinged windows by default
				Sliding Window = 0	the factor of air passing through a porous element	the percentage of the biggest possible opening to the total area of the window frame				Edit Formulas for other types of windows/openings
Code by no.		m	m	m		%		Radians	Degrees	m^2
1	Sliding	1.0	2.0	0.0	0.5	50%	0.65	0	0	0.50
2	Hinged	2.0	3.0	1.5	0.5	0%	0.65	0.50536051	28.95502437	5.18

For each window/opening definition, the window type is the reference code or number that refers to its properties when later used in the second sheet. The description or name of each opening is manually defined by the user.
After that, the linear dimensions of the window opening should be defined as dimensions A and B. In case of defining a hinged window, dimension A refers to the linear dimension of the window where the hinge is located, while dimension B refers to the hinge-free linear dimension of the window opening.



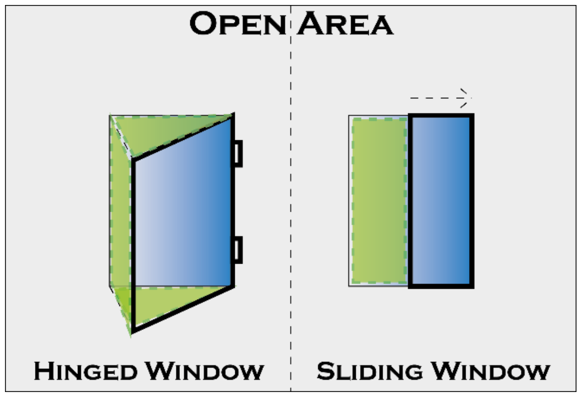
In the following column, the user should define the swing value, which is the linear dimension of the open hinged window on the opposite side of the hinge measured -in plan- from the window frame to the edge of the open window. In case of selecting a sliding window, the input in this column should be 0.



After defining the swing, the free area factor should be defined. This input refers to the effect of porous elements or filtration layers -such as mosquito nets- on the free area for the flow into the zone.
In case of defining a sliding window, the sliding percentage input should be defined based on the biggest possible opening to the total area of the window frame.

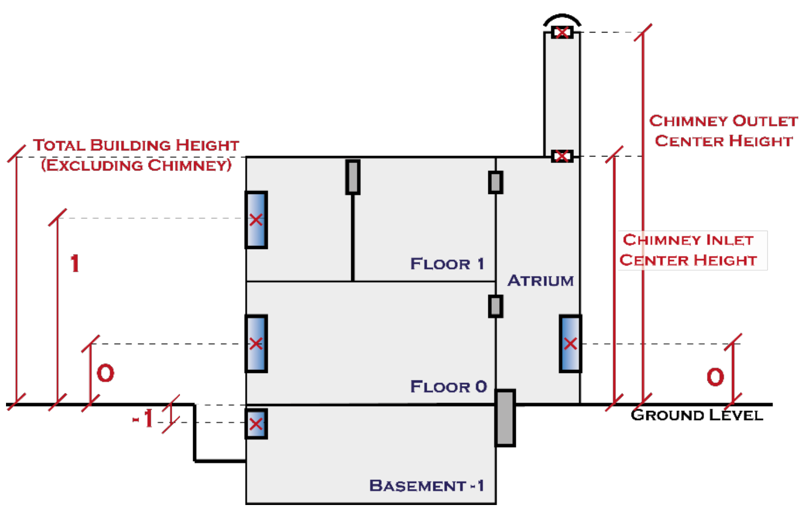
Next, the user defines the discharge coefficient by selecting a predefined value from the provided drop list.

In the next columns, the opening angle is calculated in both radians and degrees and is used as part of the calculation of the open area of the window. This is later used to calculate the free opening area in the 'Pressure Drop Calculation' sheet.



Inlets Data:

After defining the openings, the inlets values for each floor are calculated by defining a few elements including: total building height (excluding chimney), floor-to-ceiling height, total floor height, and a simple definition of the height of the inlets -to the center of the window opening- assuming that all windows on the same floor have the same inlet height.



Total Building Height (excluding chimney)	Floor-to-Floor Height	Total Floor Height	Inlet Height (Center of Window)
from ground plane	Finished Floor to Finished Ceiling LVL	Finished Floor to Finished Floor	from Finished Floor Level
			= Floor Elevation +
m	m	m	m
7	3	3.2	1.5

Note: In case of defining more complex and variable inlets on the same floor, this definition could be manually changed to define the inlet height for either individual window openings or several groups of windows on the same floor.

Define Number of Floors	
Floor no.	Inlet Height (Center of Window)
Chimney Inlet	7
0	1.5
1	4.7
-	0
-	0
-	0
	Basement Inlet Height (Center of Window)
-1	
-2	

Solar Chimney Heat Gain:

In this set of tables, several inputs related to the solar chimney are defined. The first table define the solar incident occurring at the base (skylight), SHGC value (G Value), and the glazed area at the base of the solar chimney; used for the calculation of the heat gain value in the following column.

Heat Gain at the Base of the Chimney 'Skylight' (Heat Gain 0)				
Incident Solar	SHGC	Glazed Area	Heat Gain	Temperature at the Chimney Inlet
W/m²	G Value	m²	W	C°
110	0.6	2	132	26.18

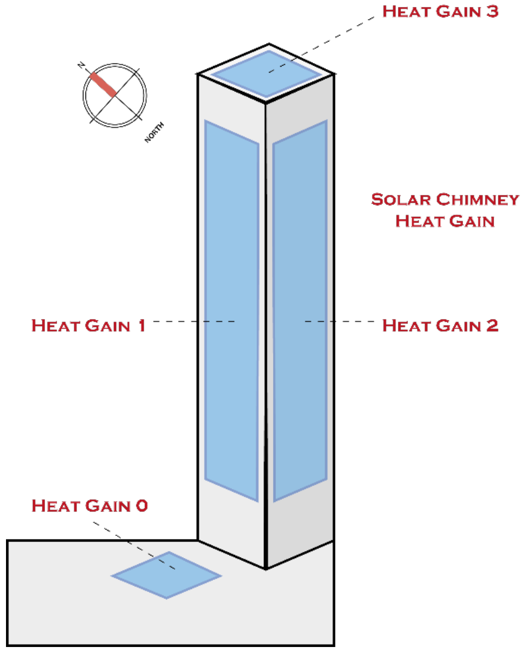
The following three inputs define the solar incident occurring at the glazed part of the chimney, SHGC value (G Value), and the glazed area of the solar chimney; used for the calculation of the heat gain value in the following column. This is a special case and can be redefined according to each project.

Chimney Heat Gain 1			
Incident Solar	SHGC	Glazed Area	Heat Gain
W/m²	G Value	m²	W
200	0.4	6	480

Chimney Heat Gain 2			
Incident Solar	SHGC	Glazed Area	Heat Gain
W/m²	G Value	m²	W
200	0.4	6	480

Chimney Heat Gain 3			
Incident Solar	SHGC	Glazed Area	Heat Gain
W/m²	G Value	m²	W
110	0.6	2	132

In this example, all three tables are filled according to the sketch below.



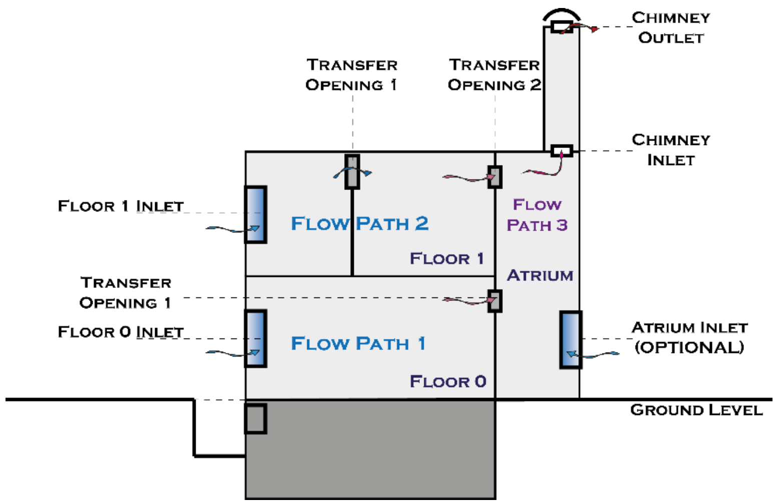
The total heat gain in the chimney is then calculated. Other inputs including the chimney inlet center height, chimney outlet/exhaust center height, the free area of both the inlet and exhaust of the chimney -with an equal value for both-, and the discharge coefficient value for the chimney are manually defined in this table.

Solar Chimney Definition				
Total Heat Gain in Chimney	Chimney Inlet Center Height from Ground Plane	Chimney Outlet/Exhaust Center Height from Ground Plane	Inlet and Exhaust Free Area (Each)	Discharge Coefficient (C_d)
W	m	m	m^2	
1092	7	11	3.5	0.65

These values are later used to calculate the free opening area for both inlet and outlet of the chimney in the 'Pressure Drop Calculation' sheet.

<u>Note:</u> In case of defining a building without a chimney, a simple change in the chimney inputs can be made to avoid completely changing the tool. The first step is to manually input the total heat gain value and keep it restrained to the size of the outlet opening according to the design (minimum value > 0). Then, the height of the chimney outlet should be modified to be as close as possible to the height of the chimney outlet; therefore, creating a micro chimney that is modeled as an outlet/exhaust for the building.

SHEET #2:
PRESSURE DROP CALCULATION:



This is the case specific sheet where the flow paths are defined and modified in order to optimize the proposed openings in each path according to the pressure imbalance result shown as a YES/NO output under the column titled "Opening Size is Enough?".

Case Specific Input:

In this table, both ambient temperature and indoor temperature are defined according to the case. The temperature values should be in Celsius.

Case Specific Input	
	°C
Ambient Temperature	8
Indoor Temperature	26

Target Flow Rate (ACH):

In this table, zone names are defined as a room type definition according to activity. This definition is then related to a predefined target flow rate to define the air changes per hour (ACH) as manual entry values.

Define Target Flow Rate Per Zone	
Zone Name	Target Flow Rate (ACH)
Classroom	8
Office	11
Atrium	8

Step 1

Flow Path Definition:

In this section of the tool, the user can decide on the number of flow paths depending on the project.

STEP 1					
Flow Path Definition					
Flow Path	Floor	Zone Name	Floor Area m²	Inlet Height (Center of Window) m	Target Flow m³/h
1	0	Classroom	40	1.5	960
2	1	Office	30	4.7	720
3	0	Atrium	20	1.5	480

In the first column, a number can be given to each flow to trace them back later when combining or dividing flows at a later stage. This part makes it easier to simplify flows and create linear diagrams tracking air movement while showing pressure drops (for a single steady-state condition) at each step or node.

Note: In this example, '*Flow Path 2'* is defined by the total area of the zone, not just the first part connected directly to the inlet. This clarifies the required air changes for the whole zone.

In the following column, the user can choose the floor number where the flow path starts; this option displays the inlet height (center of window) calculation in the 'Inlet Height' column.
After that, zone name is chosen from a drop list, leading to the calculation of the target flow in the flow path after manually defining the zone's floor area.

$$V_{FlowRate} = V \times ACH$$
$$V_{FlowRate} = A \times H \times ACH$$

Step 2

Actual Flow:

In this column, the actual flow is defined by default as:

$$Actual\ Flow = Target\ Flow$$

In case of testing different flow values than the target flow values previously calculated, the user should manually define them by changing or deleting the formula in this column.

Window/Vent Opening:

In this section, the first entry/resistance point for the flow path is defined. The user can choose the window type -predefined in the 'Project Elements Definition' sheet- by selecting the code number from a drop list and then type in the quantity of windows used in this entry point. After defining those two inputs, the free opening area is then calculated using the input and referred data of the open area connected to the window number.

$$Free\ Opening\ Area = Window\ Open\ Area\ \times Quantity$$

Velocity is also automatically calculated using the free opening area output and the target flow.

$$Velocity = \frac{Target\ Flow/3600}{Free\ Opening\ Area}$$

Delta P (Pressure) is finally calculated using the referred inputs along with the referenced discharge coefficient value for the window.

$$\Delta P = \left(\frac{Total\ Flow/3600}{C_d \times Free\ Opening\ Area}\right)^2 \times \frac{Density}{2}$$

STEP 2						
Actual Flow	Window/Vent Opening					
Actual Flow Default Mode: Copied from Target Flow m³/h	Window Type from Project Elements Definition	Quantity	Free Opening Area m²	Velocity m/s	Discharge Coefficient C_d	Delta P Pa
960	1	4	2.0	0.133	0.65	0.025330703
720	2	2	10.4	0.019	0.65	0.000531316
2160	2	1	5.2	0.026	0.65	0.019127376

Note: The actual flow in the atrium in this case is the total of flows 1 and 2 added to the required "fresh air flow" for the atrium.

Step 3

Transfer Opening 1:

This is the first resistance point after the air flow has entered the zone. This could be defined as an obstacle in one room or a connection between two zones through the same flow path. The opening type predefinition could be chosen through selecting the opening code number from the provided drop list which links it to the 'Windows/Openings Definition' table in the 'Project Elements Definition' sheet. After that, the user types in the quantity of transfer openings for the free opening area to be calculated.

$$Free\ Opening\ Area = Window\ Open\ Area\ \times Quantity$$

Like in the 'Window/Vent Opening' section, the referenced discharge coefficient value is shown as an output, and the velocity and Delta P (Pressure) are automatically calculated.

STEP 3						
Transfer Opening 1						
Total Flow m³/h	Opening Type from Project Elements Definition	Quantity	Free Opening Area m²	Velocity m/s	Discharge Coefficient C_d	Delta P Pa
960	1	1	0.5	0.533	0.65	0.40529
720	2	1	5.178553132	0.039	0.65	0.00213
2160	2	0	0	#DIV/0!	0.65	0

Step 4

Transfer Opening 2:

This is the second resistance point after the air flow has entered the zone. This could be defined as an obstacle in one room or a connection between two zones through the same flow path. The work process here regarding inputs and outputs is identical to the steps followed in the 'Transfer Opening 1' section.

STEP 4						
Transfer Opening 2						
Total Flow m³/h	Opening Type from Project Elements Definition	Quantity	Free Opening Area m²	Velocity m/s	Discharge Coefficient C_d	Delta P Pa
960	1	0	0	#DIV/0!	0.65	0
720	2	1	5.178553132	0.0386	0.65	0.00213
2160	2	0	0	#DIV/0!	0.65	0

Both 'Transfer Opening 1' and 'Transfer Opening 2' are optional according to the user's definition of the flow path in each case.

Note: If a transfer opening collects flow from more than one flow path, the user should copy the pressure drop for the transfer opening into all relevant flow paths. It is best to do this by putting a reference to the cell where the pressure drop is calculated. In addition, the airflows of all relevant paths should be summed for the calculation of the following transfer opening.

Result

RESULT		
Total Pressure Drop Pa	Pressure Imbalance Pa	Opening Size is Enough? YES/NO
0.514	-0.180	NO
0.089	0.434	YES
0.103	0.232	YES

Total Pressure Drop:

In this section, the total pressure drop is calculated by adding the previous Delta P (Pressure) values for each flow path; this includes the pressure drop in the 'Window/Vent Opening', 'Transfer Openings', 'Chimney Inlet', and 'Chimney Outlet' sections.

$$Pressure\ Drop = \sum \Delta P$$

Opening Size is Enough?

This column decides whether the openings in each flow path are suitable for the natural ventilation module or not. This question is answered by comparing the results of the total pressure drop to a parallel calculation of the stack effect pressure in the flow path and in the solar chimney as separate parts. The result of the pressure imbalance between the two parallel pressure calculations then decides whether the answer for the question is YES or NO. Pressure imbalance values are shown to give the user a general feeling of how close he is to achieving the target flow.

Chimney

CHIMNEY									
Chimney Inlet					Chimney Outlet				
Total Flow m³/h	Free Opening Area m²	Velocity m/s	Discharge Coefficient C_d	Delta P Pa	Total Flow m³/h	Free Opening Area m²	Velocity m/s	Discharge Coefficient C_d	Delta P Pa
2160	3.5	0.17142857	0.65	0.0418732	2160	3.5	0.17142857	0.65	0.0418732

Chimney Inlet:

In this section, the total flow is calculated by summing all the target flows for all flow paths.

$$Total\ Flow = \sum Target\ Flows$$

The free opening area and the discharge coefficient are referenced from the 'Solar Chimney' table in the 'Project Elements Definition' sheet. Velocity and Delta P (Pressure) are automatically calculated.

Chimney Outlet:

In this section, the total flow is calculated as the same total flow coming through the chimney inlet. The free opening area and the discharge coefficient are referenced from the 'Solar Chimney' table in the 'Project Elements Definition' sheet. Velocity and Delta P (Pressure) are automatically calculated.

Note: When defining a solar chimney with different free opening areas and/or different discharge coefficient values for the inlet and outlet of the chimney, a definition of those different values can be added to the 'Solar Chimney' table in the 'Project Elements Definition' sheet and then referenced in the 'Chimney Inlet' and 'Chimney Outlet' sections in the 'Pressure Drop Calculation' sheet. This should result in different values between the 'Chimney Inlet' and the 'Chimney Outlet' outputs.

<u>Note:</u> One flow could continue entirely in the same flow or be divided into two or more flows in separate rows of the sheet by using the 'Transfer Openings' sections. One flow could also be a result of the addition of two or more flows either by using the 'Transfer Openings' sections or at the 'Chimney Inlet' section according to the flow path.

<u>Key Results:</u>

This table shows the minimum, maximum, and average values of the previously mentioned 'Available Pressure Calculation'.

Key Results	
	Pa
Minimum Pressure Imbalance	-0.179746469
Maximum Pressure Imbalance	0.433643067
Average Pressure Imbalance	0.161881571

SHEET #3:
AVAILABLE PRESSURE CALCULATION:

This is the parallel pressure calculation sheet where the internal stack effect according to floor number and the solar chimney stack effect are calculated and used to calculated the pressure imbalance used as a YES/NO answer to the “Opening Size is Enough?” question.

Flow Path Definition		Internal Stack Effect		Solar Chimney		Available Pressure Calculation		
Flow Path	Floor	Height Difference m	Pressure Pa	Temperature °C	Stack Effect Pa	Available Pressure Pa	Total Pressure Drop Pa	Pressure Imbalance Pa
1	0	5.5	0.135	27.50	0.200	0.335	0.514	-0.180
2	1	2.3	0.322		0.200	0.522	0.089	0.434
3	0	5.5	0.135		0.200	0.335	0.103	0.232

<u>Flow Path Definition:</u>

In this section, the user copies the flow path and floor numbers from the ‘Pressure Drop Calculation’ sheet to calculate the ‘Internal Stack Effect’ values.

<u>Internal Stack Effect:</u>

In this section, the height difference is calculated in reference to the flow path number, which automatically checks the floor number and the correlated inlet height. The pressure for this section is calculated using the stack effect equation.

$$Pressure = -\left[\frac{Standard\ Pressure \times Gravity}{R\ Gas\ Constant \times Chimney\ Height} \times \left(\frac{1}{Temperature_{Indoor} + 273.15} - \frac{1}{Temperature_{Outdoor} + 273.15}\right)\right]$$

<u>Solar Chimney:</u>

In this section, the solar chimney’s temperature is calculated in reference to the total flow values from the ‘Pressure Drop Calculation’ sheet and from the heat gain, density, and specific heat capacity and the temperature at the chimney inlet values from the ‘Project Elements Definition’ sheet.

$$Temperature_{SolarChimney} = \left(\frac{Heat\ Gain}{Total\ Flow/3600} \times \frac{1}{Density\ \times Specific\ Heat\ Capacity\ \times 1000}\right) + Temperature_{ChimneyInlet}$$

The ‘Stack Effect Pressure’ value is calculated using the stack effect equation.

$$Pressure = -\left[\frac{Standard\ Pressure \times Gravity}{R\ Gas\ Constant \times Chimney\ Height} \times \left(\frac{1}{Temperature_{SolarChimney} + 273.15} - \frac{1}{Temperature_{Outdoor} + 273.15}\right)\right]$$

Available Pressure:

In this column, available pressure is calculated by adding the ‘Internal Stack Effect’ and the ‘Solar Chimney Stack Effect’ pressure values for each flow path.

$$Available\ Pressure = Internal\ Stack\ Effect\ Pressure\ + Solar\ Chimney\ Stack\ Effect\ Pressure$$

Pressure Imbalance:

In this column, the pressure imbalance is calculated by subtracting the ‘Total Pressure Drop’ values from the ‘Pressure Drop Calculation’ sheet from the correlated ‘Available Pressure’ values in the ‘Available Pressure Calculation’ sheet.

$$Pressure\ Imbalance = Available\ Pressure\ - Total\ Pressure\ Drop$$

This value decides whether the opening size is enough or not in order to achieve the target flow in the ‘Pressure Drop Calculation’ sheet. Values equal to or greater than 0 are represented as a YES, while negative values are represented as a NO in the “Opening Size is Enough?” column in the ‘Pressure Drop Calculation’ sheet.

SHEET #4:
PRESSURE CHART:

This sheet includes a table containing the pressure value outputs at each resistance point from the 'Pressure Drop Calculation' sheet and the available pressure calculation values from the 'Available Pressure Calculation' sheet.

Flow Path Definition	Window/Vent Opening	Transfer Opening 1	Transfer Opening 2	Chimney Inlet	Chimney Outlet	Available Pressure
Delta P [Pa] (Copy from Case)	Delta P [Pa] (Copy from Case)	Delta P [Pa] (Copy from Case)	Delta P [Pa] (Copy from Case)	Delta P [Pa] (Copy from Case)	Delta P [Pa] (Copy from Case)	Delta P [Pa] (Copy from Pressure Imbalance Calculation)
1	0.025330703	0.405291256	0	0.041873204	0.041873204	
						0.334621898
2	0.000531316	0.002125264	0.002125264	0	0	
						0.522171318
3	0.019127376	0	0	0	0	
						0.334621898

The values are then visually represented as a detailed pressure imbalance visualization. The bar chart shows the pressure drop at each opening according to the color legend defined below and shows the available pressure bar in green for a quick visual comparison.