

Calculation of building air infiltration and exfiltration with an Excel calculation tool



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Background

The air flow around and through a building with several rooms belongs among the most difficult issues of the aerodynamic. Exemplary for the complexity of the influences are the interaction between adjacent buildings, the overlap of wind and thermal lift, as well as the simple effect of an open or closed inner door. In the specialist literature but also in the relevant standards, such as EN 15242:2007, the physical models to calculate the determination of air flow rates in buildings are described in detail. For the practical application of these algorithms for example in the planning of ventilation systems a description of mathematical approaches for iterative processes is missing. As suggested and commissioned by the European Ventilation Industry Association (EVIA) an Excel tool to calculate the air flow rates in buildings including infiltration on the basis of EN 15242 was made by the authors. This Excel tool is generally applicable even after reviewing this standard in the course of the EPBD mandate 480 (the future EN 16798-7 "Energy perfor-

mance of buildings – Part 7: Ventilation for buildings – Module M5-1, M5-5, M5-6, M5-8 – Calculation methods for the determination of air flow rates in buildings including infiltration").

Calculation method

The calculation algorithm is based on a mesh model. So-called mesh networks occur in many technical areas, for example in gas and water supply networks. Each building plan can be converted into a meshed system. For the calculation of the airflows through a building the mesh method is a highly universal method also for viewing complex flow processes. The consideration of internal and external interference factors is possible. The aim of the method is to determine the air mass flows through the flow paths of a building. The building must be converted for the use of the method in a so-called airflow network that includes all flow paths, and their characteristics in terms of pressure losses and pressure profits, see **Figure 1**. This network consists essentially of loops (links) and nodes (rooms).

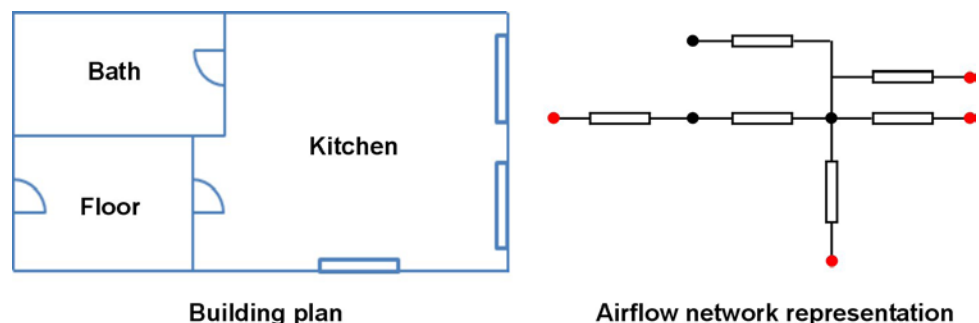


Figure 1. Conversion of a building plan into a meshed system.

Along a loop the mass flow remains constant. In flow direction there is a pressure drop caused by friction. Nodes are characterized by varying mass flows, but firm pressure conditions.

To solve this mesh network there exist a number of calculation methods. Together, all have the need to form meshes. A mesh in this case represents a closed flow path whose starting and ending points are identical.

The chosen mesh-based method needs a specified mass flow distribution at the beginning. This should lead to the fulfillment of all nodes conditions. During the solution process, the respective mass flows are then constantly changed until the mesh-conditions are satisfied.

A very common and well-proven mesh-oriented solution method is the Hardy-Cross method, which is often used in water and gas distribution networks. Due to its easy traceability and good data base, this method is implemented in the Excel tool.

There are basically two types of these methods: Sequential and simultaneous process. In the sequential method, each mesh is considered individually, taking into account the outcome of the consideration in the next mesh. An iteration step is complete when each mesh was calculated individually. In the simultaneous method always all meshes of the system are considered simultaneously. So a convergence is achieved faster. The disadvantage is the higher complexity of programming these processes and the traceability of intermediate results is limited.

The Hardy-Cross method is an easy understandable iteration algorithm and calculable by hand. It is based on Newton's approximation method (**please see insert on the next page**).

Structure of the tool

The handling of the tool has been made easier for the user by using a color-scale showing if all required input data are completely and in the right form (**Figure 2**).

In general, by clicking on the "Save data" button all entered

data are saved and can be used for the calculation. The "complete form" button changes into green showing that all data are in the correct form. Activating the "Complete form" button closes the current input mask and the "Overview" window or the next input mask appears.

With the Excel tool it is possible to calculate the air flow through the building with up to 20 rooms distributed over one or more floors, see **Figure 3**. The maximum of connections (e.g. windows, doors, air inlets) of one room is bounded to 20 connections. For each room a supply and/or exhaust air volume flow can be defined by a ventilation system. It has to be pointed out that the defined air volume flows are constant and independent of pressure conditions in the building minimizing the calculation effort. The calculation of the building air infiltration and exfiltration under steady-state conditions is performed with constant conditions defined by the user, see **Figure 4**.

Using the defined conditions following data can be determined / calculated:

- Aerodynamic pressure factor for each connection of the building (C_p -value)
- air tightness, which is split relatively (ratio of the area of the outer walls or fixed portion) to the respective external connection
- pressure difference for each opening

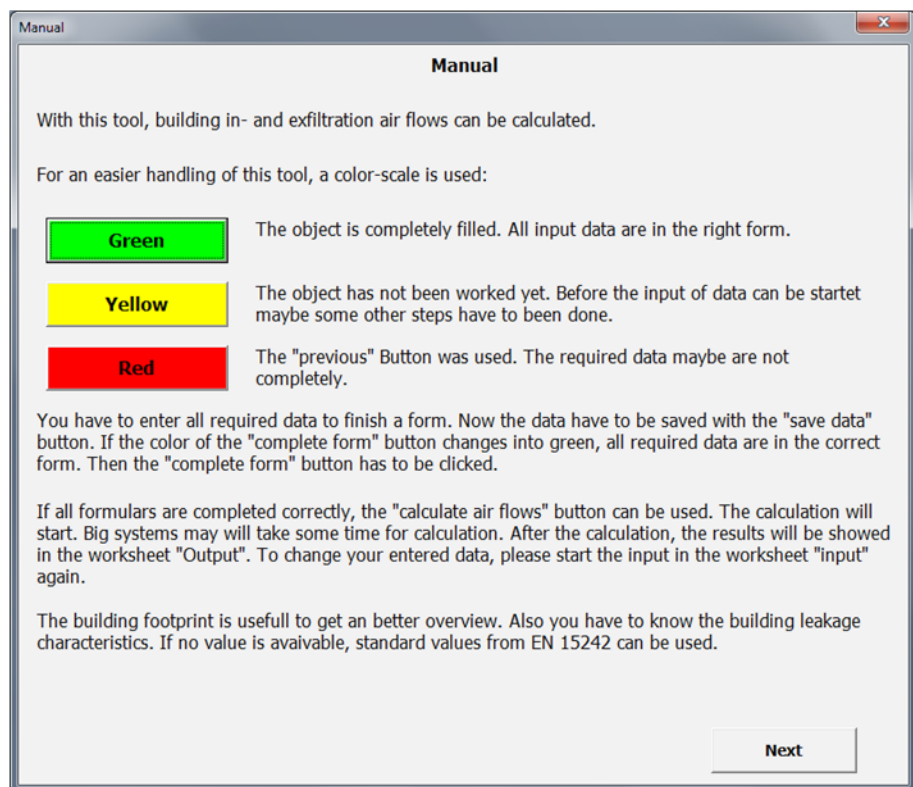


Figure 2. Information window – short description of the calculation tool.

Explaining application Hardy-Cross method

For this method, it is necessary to use a starting value x_0 of unknown size. The closer this starting value to the actual solution x_0 of the system (equivalent to zero), the faster convergence is achieved. In the following recommendations the term convergence refers to situation when a predetermined error bound is reached. At each iteration step a correction increment is calculated, which is then subtracted from the initial value of the iteration. The calculation of the correction increment k occurs by solving equation (1).

$$k = \frac{f(x)}{f'(x)} \quad (1)$$

$f(x)$ the function value at the point x

$f'(x)$ the function value of the first derivative at the point x

This procedure is used principally in the Hardy-Cross method. The variable x , which is modified during iteration, is equivalent to the mass flow along a loop. The function of which the root is determined describes the pressure balance along a closed loop system. Therefore it is necessary to know the fixed pressure differences (pressure sources), and the variable pressure differentials (flow resistance) and their functional relationship along a mesh. The pressure balance along an arbitrary loop m with o compounds can be calculated as follows:

$$0 \equiv \Delta p_m = \Delta p_{w,m} \sum \Delta p_{A(i,i+1)} - \sum_{i=1}^o \Delta p_{v,i}(\dot{m}_i) \quad (2)$$

Δp_m Pressure balance around the loop m

$\Delta p_{w,m}$ Differential pressure caused by wind between the starting and the ending point of a loop

$\Delta p_{A(i,i+1)}$ Pressure due to thermal lift between the compounds i and $i+1$

$\Delta p_{v,i}(\dot{m}_i)$ Pressure drop over the connection i , as a function of the current mass flow through this connection

o Number of connections of the loop m

The functional relationship of flow resistance of a connection as a function of the mass flow through

this connection may be arbitrary. The flow resistance depends normally on a coefficient and an exponent.

According to equation (2) the pressure balance is calculated along each mesh. This must be differentiated according to the Hardy-Cross method with respect to the mass flow rate in order to calculate the correction mass flow $\delta \dot{m}$. For this purpose, it is only necessary to form the first derivative of single pressure losses of the flow resistance, since the pressure differences generated by pressure sources do not depend on the mass flow through the respective connections. The derivative of the pressure balance for a mesh m with o compounds can be determined in accordance with equation (3):

$$\frac{\delta \Delta p_m}{\delta \dot{m}} = \sum_{i=1}^o \frac{\delta \Delta p_{v,i}}{\delta \dot{m}_i} \quad (3)$$

$\frac{\delta \Delta p_m}{\delta \dot{m}}$ first derivative of the pressure balance along the mesh m

$\sum_{i=1}^n \frac{\delta \Delta p_{v,i}}{\delta \dot{m}_i}$ sum of all the first derivatives of the pressure loss of the compounds of the mesh

Therefore, the pressure balance and its first derivative are determined along a loop. The resulting correction mass flow $d\dot{m}$ can be calculated according to equation (4):

$$d\dot{m} = \frac{\Delta p_m}{\Delta p'_m} \quad (4)$$

Δp_m pressure balance of the mesh m

$\Delta p'_m$ first derivative of the pressure balance of the mesh m with respect to the mass flow

This correction mass flow is now subtracted from each mass flow, which is contained in the compound. The corrected mass flows are then used as starting values for the consideration of the next loop of the system. An iteration step is complete when all meshes were once considered. To check the accuracy of the resulting mass flows, the sum of the amounts of formed correction mass flows of the iteration step is used. If the sum drops below a certain value, the iteration procedure can be aborted and the results are displayed in the corresponding form.

- Summing up, the result of the tool are air flow rates for defined steady-state conditions in consideration of wind pressure, thermal lift and – if there is one – the ventilation system.

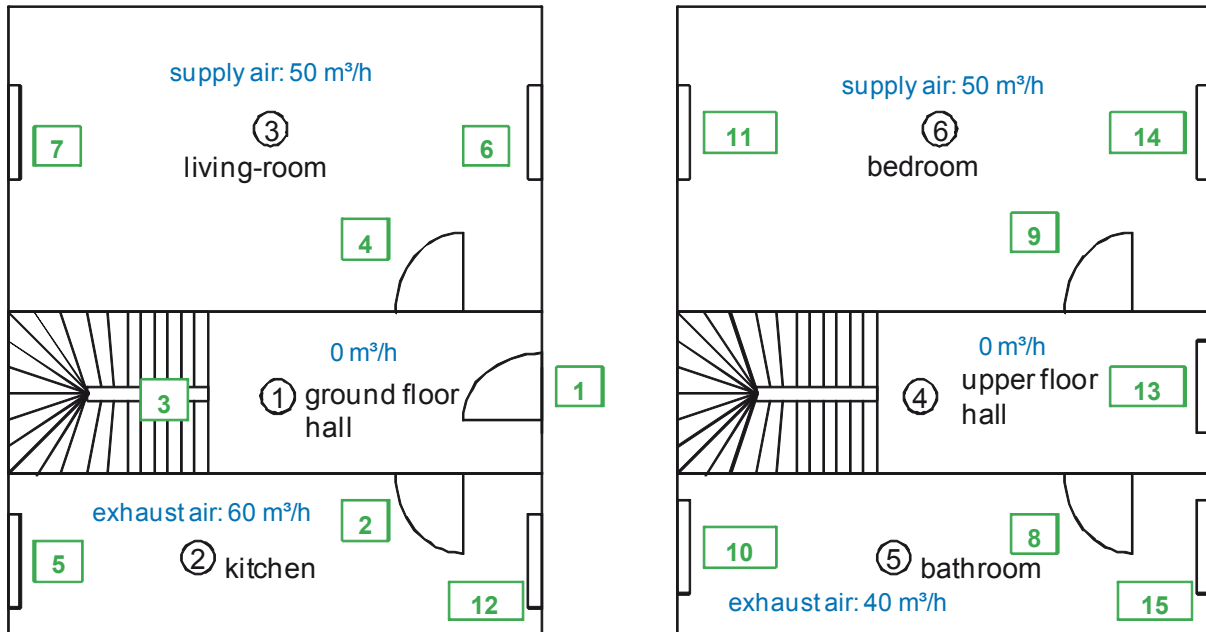


Figure 3. Floor plan of a mid-terrace house (left: ground floor, right: upper floor) with supply and exhaust air flow rate of the rooms (boundary conditions: 6 rooms, 15 connections, 2 floors, balanced ventilation system, temperature ratio of 80%).

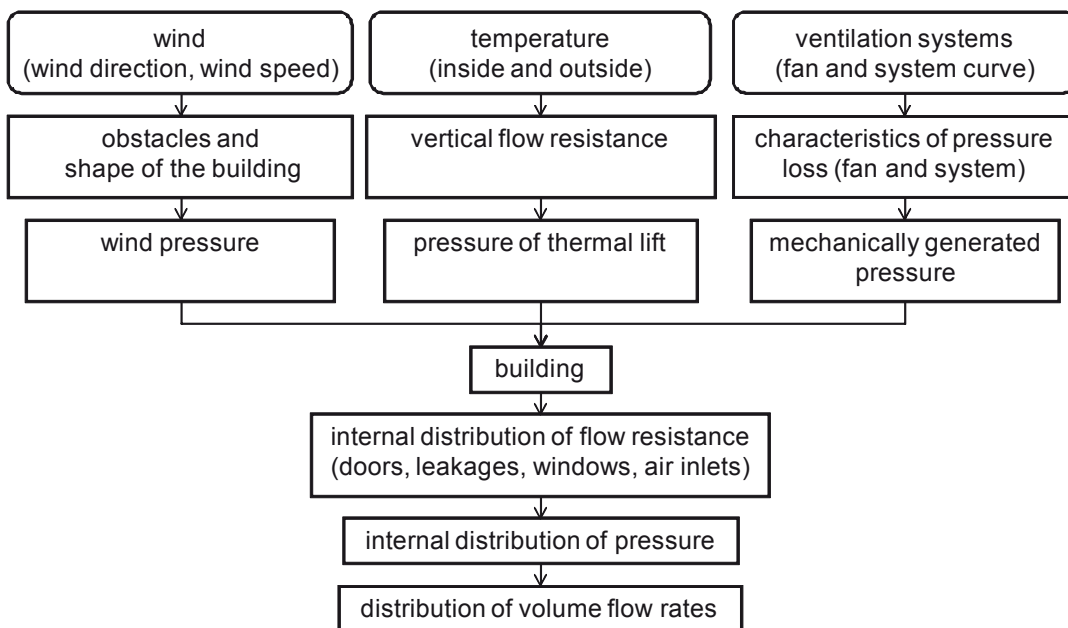


Figure 4. Factors influencing the air flow in building according to [Nowotny].

Operation of the tool

In the input mask "Overview" (Figure 5) under the heading project details and object details the user can provide several information. After choosing the calculation unit: m³/h, m³/s or l/s further input fields are enabled.

Data of the building

The input mask "General building information" is divided into three aspects:

- General building information
- Information of the calculated flat
- Ventilation system

In the aspect "General building information" the user can provide details about:

- Number of rooms (up to 20 rooms possible)

- Building height in m
- Width of the building (in wind direction) in m
- Roof slope in °
- Leakage characteristics (n [relative to indoor volume], q [relative to outer envelope] or w [relative to floor area])
- Pressure difference of leakage characteristics in Pa
- Value of air tightness in m³/(h·m²)
- Exponent n (registered default value 0,67)

In the aspect "Information of the calculation flat" the input field, which is needed for the calculation, is highlighted in yellow depending on the selected leakages characteristics. The three possible input fields are:

- Indoor volume in m³ (selecting n [relative to indoor volume])
- Outer envelope in m² (selecting q [relative to outer envelope])
- Floor area in m² (selecting w [relative to floor area])

Figure 5. Filled input mask "Overview" for the example with enabled input fields.

Information regarding the air-handling system can be given in the aspect "Ventilation system", see **Figure 6**.

Figure 7 shows the filled input mask "General building information" for the mid-terrace house.

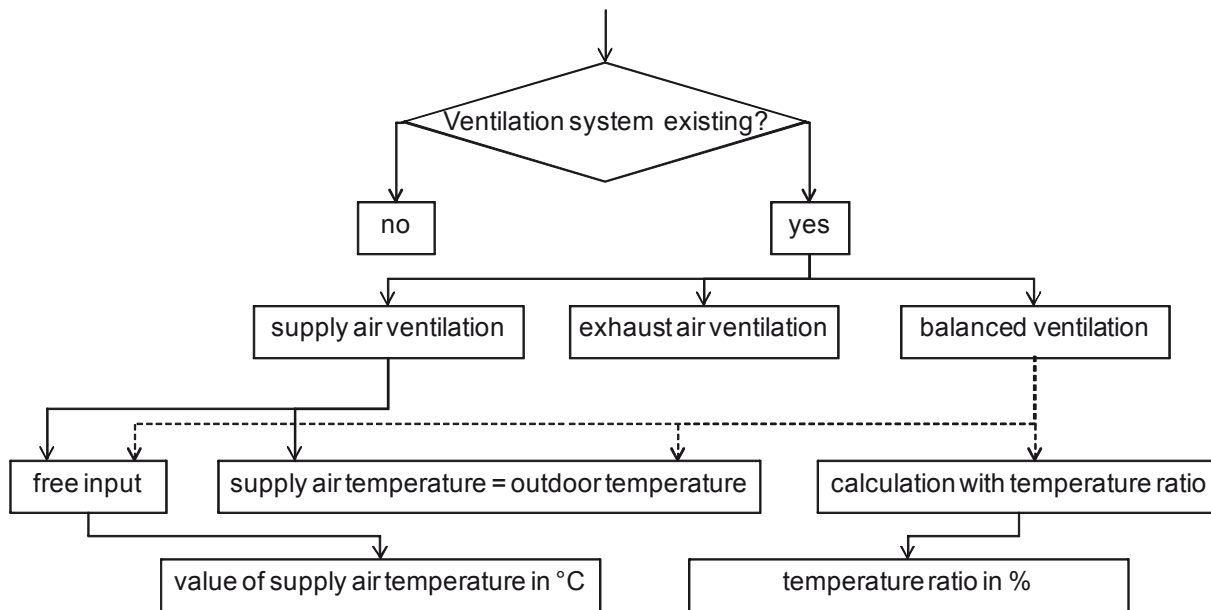


Figure 6. Input data regarding the ventilation system.

General Building information			
Number of rooms	6	Leakages characteristics	n (relative to indoor volume)
Building height	8 m	Pressure difference for leakage characteristics	50 Pa
Width of the building (in wind direction)	8 m	Value of airtightness	2 1/h
Roof slope	10 ° - 30 °	Exponent n	0,67 -
Information of the calculated flat			
Indoor volume	200 m ³		
Outer envelope		Floor area	
Ventilation System			
Ventilation system existing?	Yes	Supply air temperature?	calculation with temperature ratio
System	Balanced ventilation		
		Temperature ratio	80 %
Save data		Previous	Complete form

Figure 7. Filled input mask "General building information" for the example after saving the entered data.

Climate parameters

In the input mask "Climate parameters" (Figure 8) information regarding the following values has to be completed:

- External (outdoor) temperature in °C
- Reference wind speed (at reference height) in m/s
- Reference height in m (registered default value 10 m)
- Wind direction

Terrain information

Depending on the selection made in the input mask "General terrain information" (Figure 9) different input fields have to be filled with information from the user:

- Terrain class (open terrain, country or urban/city)
- Are there obstacles next to the building?

Figure 8. Filled input mask "General climate parameters" for the example after saving the entered data.

Figure 9. Filled input mask "General terrain information" for the example after saving the entered data.

If there are obstacles next to the building, which are at least half of the height of the building further input fields are enabled:

- Orientation of the obstacle(s) (north, east, south or west)
- Height of the obstacles in m
- Width of the obstacles in m
- Distance between building and obstacles in m

Input building characteristics

Before the rooms are configured, it is possible to name the rooms for easy entry. If the possibility is not chosen, the rooms will retain their nomenclature like "room 1", "room 2" etc. and the configuration of the individual rooms can start. If the possibility is chosen to name the rooms, another window will open where the individual nomenclature can be entered.

The data entered in this input mask "General information of the room" refer to the selected room and following values:

- Temperature in °C
- Volume in m³
- Height of the floor (relative to ground) in m

- Air flow caused by ventilation system? (depending to the selected ventilation system: supply air flow in m³/h, exhaust air flow in m³/h, or both air flows in m³/h)
- Number of connections (doors, windows etc.) (up to 20 connections per room possible)

Figure 10 shows exemplary the input mask "General information of the room" for a supply air space.

In addition to the information about which room is selected and the global connection number further data are required in the input mask "Connection data", see **Figure 11** next page. Depending on which connection and which type is chosen further information is necessary, for example

- Connection: Orientation
- Door (if closed): air tightness of the door
- Wall: Outer area
- Air inlet: Differential pressure

Rooms with only one connection like storerooms with a door and no window are not taken into account in

living-room Configuration of the rooms

Room number: 3

General information of the room

Name: living-room

Temperature: 22 °C

Volume: 50 m³

Height of the floor (relative to ground): 1 m

Air flow caused by ventilation system? Yes

Supply air flow: 50 m³/h

Exhaust air flow: 0 m³/h

Number of connections (doors, windows etc.): 3

Connection 4 to gf hall

Connection 6 outward

Connection 7 outward

Save data Previous Complete form

Figure 10. Filled input mask "General information of the room" for the living-room (supply air space) of the mid-terrace house.

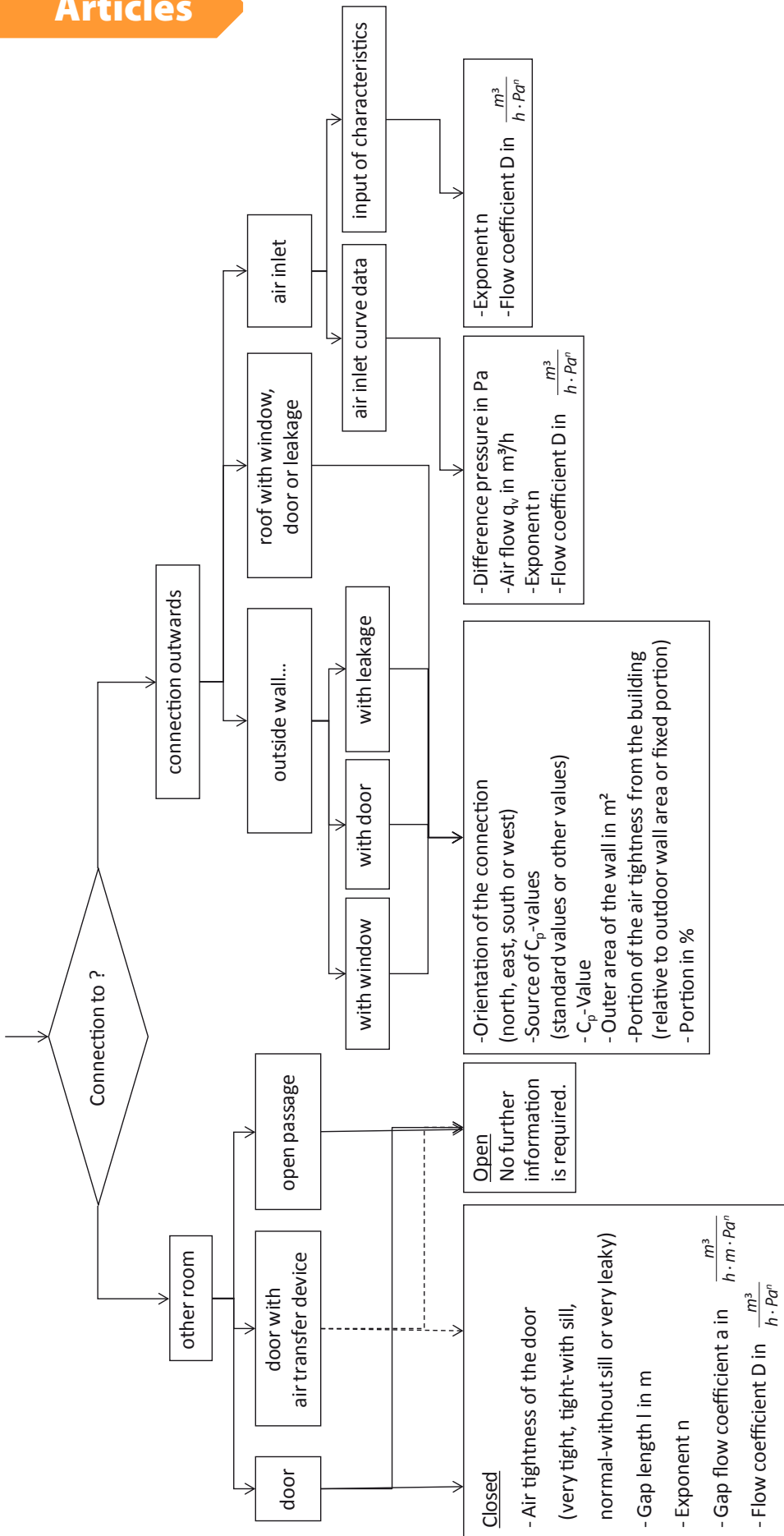


Figure 11. Input data regarding the connections of a room.

the calculation. Under steady-state conditions there is only very small air flow volume along the joints of the door due to the thermal lift between the lower and the upper joint of the door. Nevertheless, if these rooms should be taken into account in the calculation the door has to be split into two or more connections with different heights. The resulting air flow volumes are very small and there is a short-circuit flow around the door. The calculated air exchange rate does not represent the real local air exchange rate of the room.

Figure 12 shows exemplary the input mask "Connection data" for connections from the ground floor hall to the living-room, the upper floor hall and outwards.

Activating the "Calculate air flows" button the calculation starts and the results are shown in the worksheet "Output", see Table 1 and Table 2.

Changes of the input data / Calculation of variants

It is possible to calculate variants by changing conditions like wind direction, air tightness of the building envelope, ventilation systems etc. in relevant input masks. All changes have to be saved and completed.

Changing the number of rooms (adding rooms or reducing the number of rooms) can be done in the input mask "General building information" as long as there do not exist the first connection. After entering the first connection it is not possible to change the number of rooms in this project and a new project has to be started.

living-room

Room number: 3

General information of the room

Name:

Temperature: °C

Volume: m³

Height of the floor (relative to ground): m

Air flow caused by ventilation system?

Supply air flow: m³ / h

Exhaust air flow: m³ / h

Number of connections (doors, windows etc.):

Buttons: Connection 4 to gf hall, Connection 6 outward, Connection 7 outward

Buttons: Save data, Previous, Complete form

Figure 12. Filled input mask "Connection data" for the connection from ground floor hall to the outside of the mid-terrace house (connection to outwards).

Table 1. Calculation results for the mid-terrace house with regard to calculation details (excerpt).

Designer		Building air infiltration and exfiltration - calculation tool										
Date	26.03.2015	Object										
Comments		Name		Joe Bloggs								
		Street		Sample Street 1								
		Code		12345								
		Location		Sampleburg								
		Country		Germany								
Calculation details												
Room	Temperature [°C]	Volume [m ³]	Height [m]	Supply air flow [m ³ / h]	Exhaust air flow [m ³ / h]	Supply air temperature [°C]	Outdoor - air change rate -incl. supply air- [1/h]	Air change rate [1/h]	Connection to	Connection number	Air flow through the connection [m ³ / h]	Pressure losses Δp [Pa]
gf hall	20	25	1	0	0	19,27	0,1	2,19	outwards	1	-2,4	1,3
									kitchen	2	51,3	0,9
									uf hall	3	3,07	0
									living-room	4	-52,25	0
kitchen	20	25	1	0	60	19,27	0,34	2,39	gf hall	2	-51,3	0,9
									outwards	5	-5,6	4,6
									outwards	12	-2,8	1,6
...												

Table 2. Calculation results for the mid-terrace house with regard to connection data (excerpt).

connection data										
Start	End	Number	Type	Orientation	Cp-value [-]	Wall area [m ²]	Portion of building leakage [%]	Height (absolut) [m]	Flow coefficient [m ³ /(s*Pa ⁿ)	Exponent n [-]
gf hall	outwards	1	Outside wall with door	East	-0,7	5	7,14	2	-	0,67
Kitchen	gf hall	2	Door	-	-	-	-	2	1,50E-02	0,67
uf hall	gf hall	3	Open passage	-	-	-	-	3,625	2,78E+02	0,67
...										

Changes of the connection of rooms like orientation, type or increase the number of connections can be done without problems in the relevant windows "General information of the room". However to reduce the number of the connection, a new project has to be started or a saved version has to be used.

Summary

On behalf of the European Ventilation Industry Association (EVIA) an Excel tool was developed to for example use the in EN 15242 described physical models to calculate air flow rates in buildings for daily work of building and system planers. This provides users with a convenient facility to determine air flow rates room by room caused by leakages and externally mounted air transfer devices under variation of essential boundary conditions and under steady-state conditions. The Excel calculation tool can be obtained free of charge and together with a detailed manual in the

EVIA download area (<http://www.evia.eu/en/Media-Centre/Download/>) of the EVIA homepage (English or German version). ■

Literature

- EN 15242:2007 Ventilation for buildings – Calculation methods for the determination of air flow rates in buildings including infiltration.
- prEN 16798-7:2015 Energy performance of buildings – Part 7: Ventilation for buildings – Module M5-1, M5-5, M5-6, M5-8 - Calculation methods for the determination of air flow rates in buildings including infiltration.
- Nowotny, S. & Feustel, H.E. 1996. Lüftungs- und klimatische Gebäudeausrüstung – Grundlagen und Berechnungsmodelle, Wiesbaden; Berlin: Bauverlag. Ventilation and air conditioning building services – Basics and calculation models.

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