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Algorithms in WIS on ventilation in gaps

Dick van Dijk, Leo Bakker

TNO Building and Construction Research
P.O. box 49, NL 2600 AA Delft, The Netherlands
H.vanDijk@bouw.tno.nl

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Contact:

On gap ventilation algorithms in WIS:

The authors of this report

On Thematic Network WinDat:

WinDat coordinator: Dick van Dijk, TNO Building and Construction Research, Delft, The Netherlands

Email: H.vanDijk@bouw.tno.nl

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Introduction

This note describes the ventilation equations used in WIS.

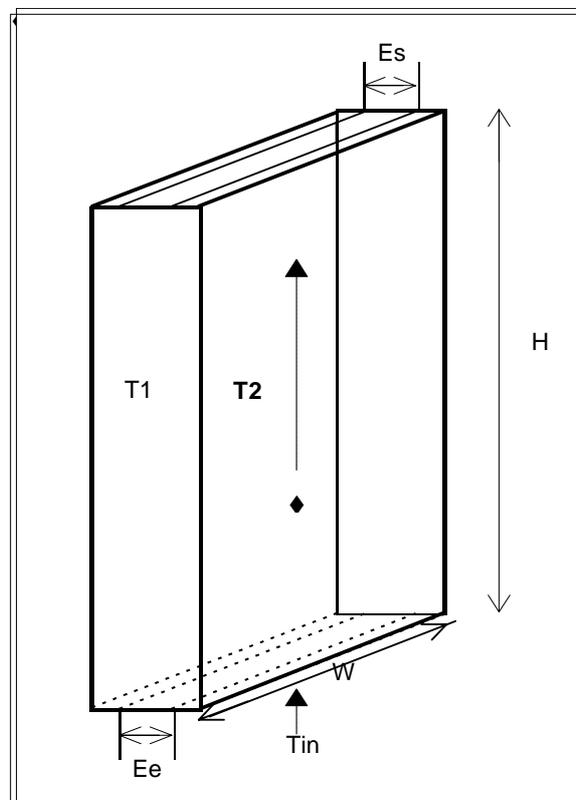
First the equations used in the current WIS version 1: extract from chapter 10 of the WIS Reference Manual

Secondly, the equations which are being implemented in the new WIS version currently under preparation: extract from chapter 7 of ISO-DIS 15099

10.2 - ventilation in cavities

10.2.1 air flow and temperature calculation

Let us consider the following schedule :



with :

- T_1 : uniform temperature of pane 1
- T_2 : uniform temperature of pane 2
- T_{in} : temperature of air entering the layer
- $t_a(x)$: air temperature at a distance x of the air inlet
- H : window height
- W : window width
- d : distance between the two panes
- V : air speed in the air layer
- Q_s : air flow in the air layer (m^3/s)
- h_{pi} : convective heat coefficient between pane and air

$$T_n = (T_1 + T_2)/2 - T_{in}$$

ρ_{air} (kg/m³) : volumic weight of air for standard conditions,
(i.c.: $\rho_{air} = 1.189$)

c_{air} (J/kg) : thermal capacity (i.c.: 1008)

then :

$$2h_{pi} (t_a(x) - T_{in}) dx W = - Q_s \rho_{air} c_{air} dt_a(x).$$

By introducing :

$$y = x / H$$

$$G_s = Q_s / (W.H)$$

$$2h_{pi} (t_a(y) - T_{in}) dy = G_s \cdot \rho_{air} \cdot c_{air} dt_a(y)$$

Ratio of heat transfer rate of fluid flow and fluid to pane:

$$\text{with } Gr = G_s \rho_{air} C_{air} / (2 h_{pi})$$

both Gr and y are nondimensional parameters

$$t_a(y) = T_n (1 - e^{-y/Gr}) + T_{in} \quad [1]$$

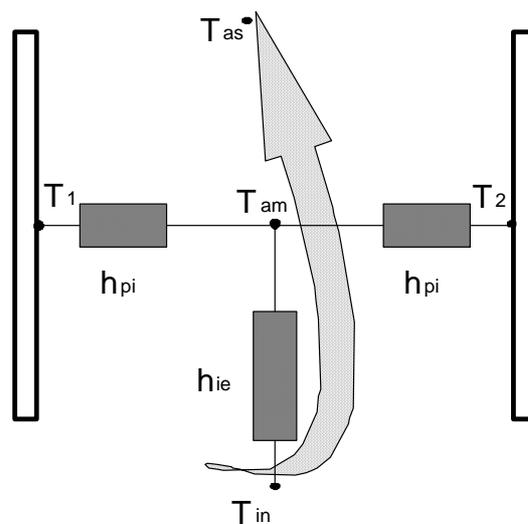
the mean value of $t_a(y)$ is :

$$T_{am} = T_n (1 - Gr (1 - e^{-1/Gr})) + T_{in}$$

the air temperature at the outlet is :

$$T_{as} = T_n (1 - e^{-1/Gr}) + T_{in}$$

Illustration:



10.2.2 application when air flow in the cavity is known

If the air flow within the air layer has a known value (for example due to mechanical ventilation), the above equations can be directly applied.

The heat exchanges between the pane temperatures T_1 and T_2 , the mean air layer temperature T_{am} and the temperature of the entering air T_{in} are calculated by the equivalent heat exchange coefficients h_{pi} (between T_1 or T_2 and T_{am}) and h_{ie} (between T_{in} and T_{am})

$$h_{pi} = 2 \cdot g_{cond} + A_v \cdot V$$

where g_{cond} is the thermal conductance of the closed air cavity. A_v is a coefficient which can be set to 4 W/m²K per m/s. (document 033-89-Passys-MVD-FP017 p 5.4).

$$h_{ie} = 2 \cdot h_{pi} \cdot (\text{abs}(T_n) - dT) / dT$$

with $dT = \text{abs}(T_{am} - T_{in})$

h_{pi} and h_{ie} are in W/(m².K), related to the window area (i.c. H*W)

10.2.3 application when air flow in the cavity is due to the stack effect

The air flow in the air layer due to the stack effect is:

$$G_s = C_d A_{eq} (2 dT g / (H \cdot T_{am}))^{0,5}$$

with $C_d = 0,61$ is the discharge coefficient

$$A_{eq} = (1/A_e^2 + 1/A_t^2)^{-0,5}$$

A_e (m²) is the area of the air inlet section

A_t (m²) is the a

rea of the air outlet section

$$dT = T_{am} - T_{in}$$

then:

$$G_s = C_2 dT^{0,5} [5]$$

with :

$$C_2 = 0,156 A_{eq} H^{-0,5}$$

An approximation for T_{am} is

$$T_{am} = dT + T_{in} = T_n / (1 + 1,5 Gr) + T_{in}$$

The equations to be solved are :

$$Gr = \rho_{air} \cdot c_{air} \cdot G_s / (2 \cdot h_{pi})$$

$$T_n = \text{abs} ((T_1 + T_2) / 2 - T_{in})$$

$$dT = T_{in} / (1 + 1.5 \cdot Gr)$$

$$G_s = C_2 dT^{1/2}$$

$$V = G_s \cdot H / d$$

$$h_{pin} = 2 \cdot g_{cond}$$

$$h_{pi} = h_{pin} + A_v \cdot V$$

The equation to be solved is then :

$$G_s^3 (H \cdot A_v / d + 0,75 \cdot \rho_{air} \cdot c_{air}) + G_s^2 h_{pin} - G_s (C_2^2 T_n A_v H / d) -$$

$$T_n C_2^2 h_{pin} = 0$$

Knowing G_s enables to calculate the various results as in 10.2.2

$$V = G_s \cdot H / d$$

$$h_{pi} = h_{pin} + A_v \cdot V$$

$$Gr = \rho_{air} c_{air} G_s / (2 h_{pi})$$

$$dT = T_n / (1 + 1.5 Gr)$$

$$h_{ie} = 2 \cdot h_{pi} \cdot (\text{abs}(T_n) - \text{abs}(dT)) / \text{abs}(dT)$$

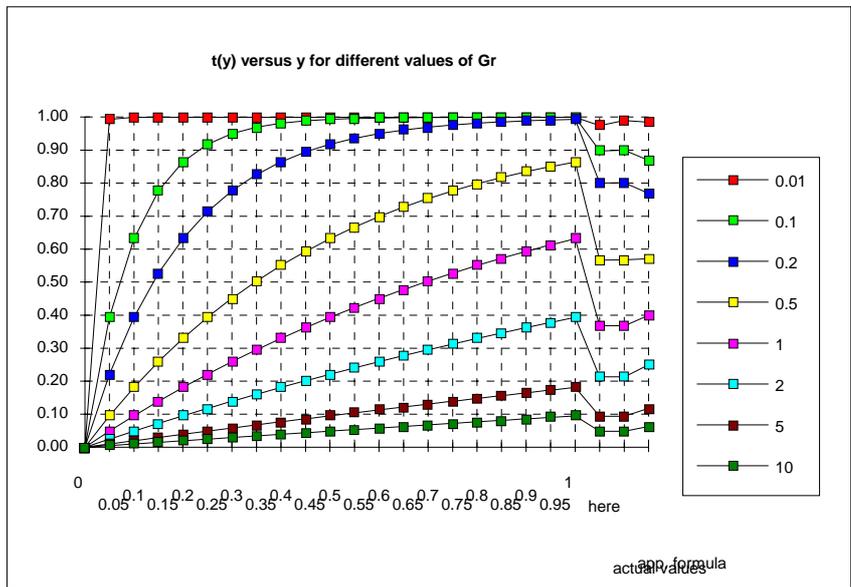
A side aperture area can be taken into account by introducing equivalent upper and lower opening areas . If E_l is the depth (m) of the side aperture (both on right and left part of the window), and considering that the neutral plane is at middle of the height, the equivalent values of E_e and E_s to be added to the actual ones are :

$$E_{esup} = E_{ssup} = E_l \cdot H / (2 W)$$

This is a safe way to simplify the calculation. If for example the actual value of E_s is equal to 0 , It could be considered that the above formula will underestimate E_{ssup} and then decrease the air flow. Nevertheless it is not sure in this case that the higher part of the air layer will be correctly ventilated, which would reduce the efficiency of the ventilation. An accurate calculation for such a situation would require a two dimensional CFD calculation, which is far beyond the acceptable level of simplification

Of course a detailed CFD calculation or measurements may be used to obtain equivalent top and bottom aperture areas for a certain type of geometry, which can then be used as input for WIS.

Tn = 1		Gr							
dy	y	0.01	0.1	0.2	0.5	1	2	5	10
0.1	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.1	0.05	0.99	0.39	0.22	0.10	0.05	0.02	0.01	0.00
0.1	0.1	1.00	0.63	0.39	0.18	0.10	0.05	0.02	0.01
0.1	0.15	1.00	0.78	0.53	0.26	0.14	0.07	0.03	0.01
0.1	0.2	1.00	0.86	0.63	0.33	0.18	0.10	0.04	0.02
0.1	0.25	1.00	0.92	0.71	0.39	0.22	0.12	0.05	0.02
0.1	0.75	1.00	1.00	0.98	0.78	0.53	0.31	0.14	0.07
0.1	0.8	1.00	1.00	0.98	0.80	0.55	0.33	0.15	0.08
0.1	0.85	1.00	1.00	0.99	0.82	0.57	0.35	0.16	0.08
0.1	0.9	1.00	1.00	0.99	0.83	0.59	0.36	0.16	0.09
0.1	0.95	1.00	1.00	0.99	0.85	0.61	0.38	0.17	0.09
0	1	1.00	1.00	0.99	0.86	0.63	0.39	0.18	0.10
avg	here	0.97	0.90	0.80	0.57	0.37	0.21	0.09	0.05
avg	actual values	0.99	0.90	0.80	0.57	0.37	0.21	0.09	0.05
	app. formula	0.99	0.87	0.77	0.57	0.40	0.25	0.12	0.06



7 Shading devices

7.1 Definitions

7.1.1 Introduction

This clause 7 provides the necessary equations for the effects of shading devices on the thermal and optical properties of a window system.

The scope is restricted to those kinds of shading devices which are or which may by proper approximation be treated as a layer parallel to the pane(-s) of the window.

The introduction of shading devices in the model of the window system leads to modifications of the main thermal and optical equations. In order not to complicate the presentation of equations given in clause 5, the necessary changes to those equations are not integrated in clause 5 itself, but given as amendments in this clause 7.

Information on calculation procedures and measurement techniques on shading devices can be found in references such as (17,18,19,20,21,22,23,24,and 25). In general, these references concern ongoing work. The contents of this clause are based on the most up-to-date procedures, with simplifying approximations where needed due to practical limitations with respect to modelling and computational efforts and availability of product data.

Shading devices can be divided into two basic types:

- Layer type of shadings, such as screens, curtains and venetian blinds which are located parallel to the pane(s), with intimate thermal-optical contact.

- Extra-fenestrial type of shadings, such as awnings and overhangs which are located less close to the panes. These types of shadings may be regarded as part of the window's environment, because of the limited thermal interaction. They have mainly an effect on the temperature and radiation conditions outside the window. In specific cases, however, the conditions and properties of the window itself may also influence the condition of this 'environment' (e.g. reflection of solar radiation, hot air pockets). These types of shadings are outside the scope of this standard.

7.1.2 Principle of the calculations

The thermal-optical interaction of a layer type of shading devices is, to a greater extent, similar to the panes and films. In this regard, the layer type of shading device may be defined in the model as a layer between two gaps. This thus defined layer exchanges heat with the other components and/or the environment by conduction and convection and by thermal radiation. It also absorbs, reflects and transmits solar radiation.

But due to its porous structure (open weave, slats,) the shading device is not only partially transmittant for solar radiation, but also for thermal (long wave) radiation. It shares this characteristic with some suspended thin films. This phenomenon is already covered in the equations by introducing in the equations transmittance for thermal radiation.

But the shading device is usually also permeable for air, either due to its porous structure or due to openings at its perimeter. Air may cross the shading device and thus move from one gap to the other or from the environment into the gap behind the shading device and vice versa. This phenomenon has not been previously covered by the equations in the previous clauses and will therefore be introduced in this clause.

Because the layer type of shading device is modelled as a one-dimensional layer similar to a pane or film, the two- or three-dimensional characteristics have to be translated into one-dimensional numbers. This is in particular the case for the optical properties. For instance, the optical properties of a shading device are a function of the geometry of the device and the position in the assembly. To consider a slat type of shading device such as a venetian blind, information on the optical properties of the slat material, together with the

geometry of the slats and their positions is used to determine the overall transmittance, reflectance and absorptance of the layer.

7.2 Optical properties; general

<<< skipped >>

7.3 Slat type of shading

<<< skipped >>

7.4 Ventilation

7.4.1 General

For a ventilated cavity the set of equations given in clause 5.3 shall be extended in the way described in clause 7.4.2.

7.4.2 Main heat balance equations

Principle:

Air spaces may be connected to the exterior or interior environment or to other spaces. For a ventilated gap, the heat balance in the gap requires an extra term, the amount of heat supplied to or extracted from the gap air. This implies that it is no longer sufficient to describe, as in clause 5.3, the conductive/convective heat exchange in a gap as the heat transfer from one surface to the other. It is necessary to make a split between the conductive/convective heat transfer from one surface to the air and from the air to the other surface as illustrated in Figure 5. In the heat balance equations for the gap the heat extracted from or supplied to the gap by ventilation is added to this air gap node.

The mean temperature of the air in the gap is given by equations for the heat exchange between the air flowing through the gap and the adjacent surfaces.

Note: There is no existing international standard for measurement of these properties. Until this testing standard is available, the calculation method of this clause shall be considered as provisional and is provided for information purposes only.

Equations:

Non-vented gap:

For the non-vented case (clause 5.3) the heat exchange by conduction/convection across a gap from one layer to the adjacent layer (pane, film or shading device) as given in 5.3.1: $q_{c,i} = h_{c,i}(T_{f,i} - T_{b,i+1})$, is split into two parts (see Figure 20), with the mean temperature of the air in the gap as variable:

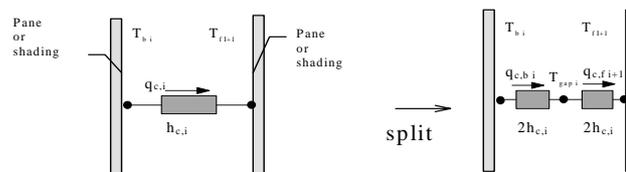


Figure 20 - Split convective heat transfer across gap; non-vented gap

$$q_{c,f,i} = 2h_{c,i}(T_{f,i} - T_{gap,i}) = q_{c,b,i+1} = 2h_{c,i}(T_{gap,i} - T_{b,i+1}) \quad (94)$$

where

- $q_{c,f,i}$ is the convective heat transfer from the one surface to the gap, in (W/m²);
- $q_{c,b,i+1}$ is the convective heat transfer from the gap to the other surface, in (W/m²);
- $h_{c,i}$ is the surface-to-surface heat transfer coefficient by conduction/convection for non-vented cavities, given by the equations in clause 5.3, in (W/(m²K))
- $T_{gap,i}$ is the equivalent mean temperature of the air in the cavity i , given in the next clause, in (°C)
- $T_{f,i}$ is the temperature of the surface of layer (pane, film or shading) i , facing the cavity i , see clause 5.3, in (°C);
- $T_{b,i+1}$ is the temperature of the surface of layer (pane, film or shading) $i+1$, facing the cavity i , see clause 5.3, in (°C).

Ventilated gap:

Amendments to equations in clause 5.3:

In a ventilated gap, due to the air movement, the convective heat exchange coefficient is increased (see Figure 21).

This increased coefficient is written as $h_{cv,i}$:

$$q_{c,b,i} = h_{cv,i}(T_{b,i} - T_{gap,i}) \quad , \quad \text{and} \quad q_{c,f,i+1} = h_{cv,i}(T_{gap,i} - T_{f,i+1}) \quad (95)$$

with $h_{cv,i}$ given by the equation:

$$h_{cv,i} = 2h_{c,i} + 4V_i \quad (96)$$

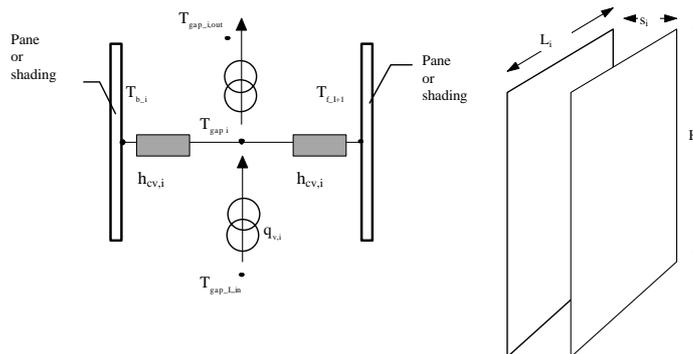


Figure 21 - Model of mean air- and outlet temperature and main dimensions

where

- $q_{c,b,i}$ is the convective heat transfer from the one surface to the gap, in (W/m²);
 - $q_{c,f,i+1}$ is the convective heat transfer from the gap to the other surface, in (W/m²);
 - $h_{cv,i}$ is the surface-to-air heat transfer coefficient by conduction/convection for vented cavities, given by eq. 96, in (W/(m²K));
 - $h_{c,i}$ is the surface-to-surface heat transfer coefficient by conduction/convection for non-vented cavities, given by the equations in clause 5.3, in (W/(m²K));
 - V_i is the mean air velocity in the gap, see clause 7.4.4, in (m/s);
- and with (same as for the non-vented case):
- $T_{gap,i}$ is the equivalent mean temperature of the air in the cavity i , given by eq. (103) in the next clause, in (°C)
 - $T_{b,i}$ is the temperature of the surface of layer (pane, film or shading) i , facing the cavity i , see clause 5.3, in (°C);
 - $T_{f,i+1}$ is the temperature of the surface of layer (pane, film or shading) $i+1$, facing the cavity i , see clause 5.3, in (°C).

For zero velocity, the equations for the ventilated gap reduce to the equations for the non-vented case.

Amendments to equations in clause 5.3:

Due to the ventilation, an extra term is added to the heat balance equations of the gap given in clause 5.3.

Extra term:

$$q_{v,i} = \rho_i \cdot c_p \cdot \varphi_{v,i} (T_{\text{gap}_i,\text{in}} - T_{\text{gap}_i,\text{out}}) / (H_i \times L_i) \quad (97)$$

Equations (98) to (103) in the next clause are formulated in such a manner to satisfy the following energy balance equation: $q_{v,i} = q_{cv,b_i} + q_{cv,f_{i+1}}$

where

- $q_{v,i}$ is the heat transfer to the gap by ventilation, in (W/m²);
- ρ_i is the density of the air in cavity k at temperature T_{gap_i} , in (kg/m³);
- c_p is the specific thermal capacity of air, in (J/(kg·K)) (i.c.: 1008);
- $\varphi_{v,i}$ is the air flow rate in cavity i , see clause 7.4.4, in (m³/s);
- $T_{\text{gap}_i,\text{in}}$ is the temperature at the inlet of the gap, in (°C);
- The heat transfer is normalised to 1 m² of the aperture area.
- The value of $T_{\text{gap}_i,\text{in}}$ depends on where the air comes from: either the indoor or outdoor air temperature or the outlet temperature $T_{\text{gap}_k,\text{out}}$ of the gap k with which the gap i exchanges air;
- $T_{\text{gap}_i,\text{out}}$ is the temperature at the outlet of the gap, see eq. 7.18 in next clause, in (°C);
- L_i is the length of the cavity i , see Figure 21, in (m);
- H_i is the height of the cavity i , see Figure 21, in (m).

Heat transfer to indoor environment

Extension of equations of clause 5:

The heat transfer to the indoor environment shall be extended in a similar way with a term $q_{v,k}$ for the heat transfer by ventilation by air coming from cavity k .

Following the convention from clause 5, with $i = n$ is the indoor environment:

for all cavities k with air flow to the indoor environment n :

$$q_{v,n} = \sum_i \rho_i \cdot c_p \cdot \varphi_{v,i} (T_{\text{gap}_i,\text{out}} - T_{\text{air},n}) / (H_i \cdot L_i) \quad (98)$$

The heat transfer is normalised to 1 m² of the aperture area.

where

- ρ_i is the density of the air in cavity i at temperature T_{gap_i} , in (kg/m³);
- c_p is the specific thermal capacity of air, in (J/(kg·K)) (i.c.: 1008);
- $\varphi_{v,i}$ is the air flow rate in cavity i , see clause 7.4.4, in (m³/s);
- $T_{\text{gap}_i,\text{out}}$ is the temperature of the air at the outlet of the gap from where the air originates, see eq. 102 in next clause, in (°C);
- $T_{\text{air},n}$ is the temperature of the air at the indoor environment, in (°C);
- L_i is the length of the cavity i , see Figure 21, in (m);
- H_i is the height of the cavity i , see Figure 21, in (m).

7.4.3 Temperatures in the cavity

Assuming the mean velocity of the air in the space is known (see next clause), the temperature profile and the heat flow may be calculated by a simple model.

Due to the air flow through the space, the air temperature in the space varies with height (see Figure 22).

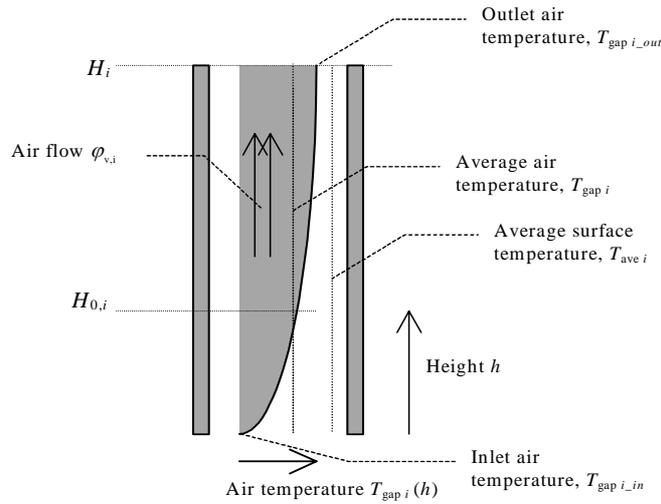


Figure 22 - Air flow in the gap of a window system

The temperature profile depends on the air velocity in the space and the heat transfer coefficient to both layers. The air temperature profile in the space i is given by:

$$T_{\text{gap},i}(h) = T_{\text{av},i} - (T_{\text{av},i} - T_{\text{gap},i,\text{in}}) \cdot e^{-h/H_{0,i}} \quad (99)$$

where

$T_{\text{gap},i}(h)$ is the temperature of the air in gap i at position h , in ($^{\circ}\text{C}$);

$H_{0,i}$ is the characteristic height (temperature penetration length), see eq. (101), in (m);

$T_{\text{gap},i,\text{in}}$ is the temperature of the incoming air in gap i , in ($^{\circ}\text{C}$);

$T_{\text{av},i}$ is the average temperature of the surfaces of layers i and $i+1$, given by equation:

$$T_{\text{av},i} = (T_{\text{b},i} + T_{\text{f},i+1})/2 \quad (100)$$

where

$T_{\text{b},i}$ is the temperature of the surface of layer (pane, film or shading) i , facing the cavity i , see clause 5.3, in ($^{\circ}\text{C}$);

$T_{\text{f},i+1}$ is the temperature of the surface of layer (pane, film or shading) $i+1$, facing the cavity i , see clause 5.3, in ($^{\circ}\text{C}$).

The characteristic height of the temperature profile is defined by:

$$H_{0,i} = \frac{\rho_i \cdot c_p \cdot S_i}{2 \cdot h_{\text{cv},i}} \cdot V_i \quad (101)$$

where

$H_{0,i}$ is the characteristic height (temperature penetration length), in (m);

ρ_i is the density of the air at temperature $T_{\text{gap},i}$, in (kg/m^3)

c_p is the specific heat capacity, in ($\text{J}/(\text{kg}\cdot\text{K})$) (i.c.: 1008)

S_i is the width of the cavity i , in (m);

V_i is the mean velocity of the air flow in the cavity i , see clause 7.4.4, in (m/s);

$h_{\text{cv},i}$ is the heat transfer coefficient for ventilated cavities, see eq. (96) in clause 7.4.2, in ($\text{W}/(\text{m}^2\text{K})$).

The leaving air temperature is given by:

$$T_{\text{gap},i,\text{out}} = T_{\text{av},i} - (T_{\text{av},i} - T_{\text{gap},i,\text{in}}) \cdot e^{-H_i/H_{0,i}} \quad (102)$$

where

$T_{\text{gap},i,\text{out}}$ is the temperature of the air at the outlet of the gap i , in ($^{\circ}\text{C}$)

$T_{av,i}$ is the average temperature of the surfaces of layers i and $i-1$, given by eq. (100), in (°C);
 $T_{gap,i,in}$ is the temperature of the incoming air in the cavity i ;
 $H_{0,i}$ is the characteristic height (temperature penetration length), given by eq. (101), in (m);
 H_i is the height of the space i , in (m).

The thermal equivalent (average) temperature of the air in the space i is defined by:

$$T_{gap,i} = \frac{1}{H_i} \int_0^H T_{gap,i}(h) \cdot dh = T_{av,i} - \frac{H_{0,i}}{H_i} (T_{gap,i,out} - T_{gap,i,in}) \quad (103)$$

where

$T_{gap,i}$ is the equivalent mean temperature of the air in the cavity i , in (°C);
 $T_{gap,i,out}$ is the temperature of the air at the outlet of the gap i , in (°C);
 $T_{gap,i,in}$ is the temperature of the incoming air in gap i , in (°C);
 $T_{av,i}$ is the average temperature of the surfaces of layers i and $i+1$, given by eq. (100), in (°C);
 $H_{0,i}$ is the characteristic height (temperature penetration length), given by eq. (101), in (m);
 H_i is the height of the space i , in (m).

7.4.4 Air flow and velocity

7.4.4.1 Forced ventilation

If the air flow within the air layer has a known value (for example due to mechanical ventilation), the equations given in 7.4.2 and 7.4.3 shall be applied as such, with the air velocity (m/s) given by:

$$V_i = \frac{\varphi_{v,i}}{s_i \cdot L_i} \quad (104)$$

where

V_i is the mean velocity of the air flow in the cavity i , in (m/s);
 s_i the width of the cavity i , in (m);
 L_i is the length of the cavity i , see Figure 21, in (m);
 $\varphi_{v,i}$ air flow rate in cavity i , in (m³/s); $\varphi_{v,i}$ is the air flow rate for the whole area, *not* normalised per m².

7.4.4.2 Wind induced ventilation

For external shading devices, the thermally induced ventilation is mixed with wind-induced ventilation. The heat exchange by ventilation between the shading and the next layer (pane) can be described on the basis of an appropriate value for the air flow or velocity. An appropriate value is to be determined on the basis of experiments or calculations (CFD modelling).

For conservative design calculations one may treat the cavity flow as forced convection (see clause 7.4.4.1), with the value for the air velocity v_i set to extreme low respectively extreme high values respectively, thereby giving two values for the total solar energy transmittance.

7.4.4.3 Thermally driven ventilation

The velocity of the air in the space caused by the stack effect depends on the driving pressure difference and the resistance to the air flow of the openings and the space itself (see Figure 23).

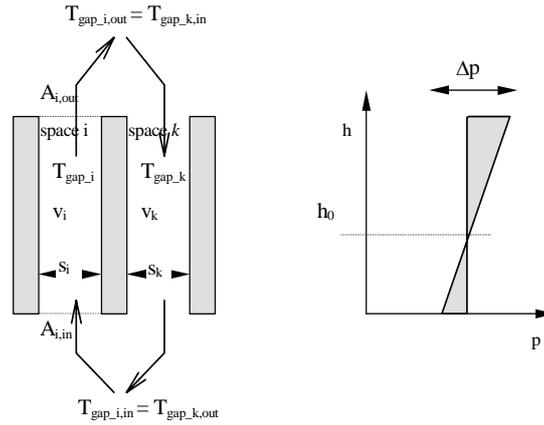


Figure 23 - Schematic presentation of the stack effect.

The height of the neutral zone h_0 depends on the flow resistances of the inlet and outlet openings

The air velocity is known by solving the set of equations given in this clause.

The pressure difference results from a temperature difference between the space j and the connected space k , which is the exterior air, the interior air or another space. The temperature profile in the spaces is represented by the thermal equivalent temperature (eq. 103). The driving pressure difference Δp_T may be written approximately as:

$$\Delta p_{T,i,k} = \rho_0 \cdot T_0 \cdot g \cdot H_i \cdot \cos \varphi_i \cdot \frac{(T_{\text{gap},i} - T_{\text{gap},k})}{T_{\text{gap},i} \cdot T_{\text{gap},k}} \quad (105)$$

where

$\Delta p_{T,i,k}$ is the driving pressure difference between space i and space k , in Pa;

H_i is the height of the space i (same as space k), in m;

$T_{\text{gap},i}$ is the equivalent (mean) temperature of the air in the space i , see eq (103), K;

$T_{\text{gap},k}$ is the equivalent temperature of the connected space, which may be another gap k or the indoor or outdoor environment, K;

φ_i is the tilt angle of the space i in degrees from vertical;

ρ_0 is the density of the air at temperature T_0 , in (kg/m³);

g is the gravity constant = 9.81 (m/s²);

T_0 is reference temperature, (e.g.) $T_0 = 283$ K.

The air flow in the space is described as a pipe flow. Therefore, the following effects have to be taken into account:

Acceleration of the air to the velocity V (Bernouilli's equation):

$$\Delta p_{B,i} = \frac{\rho_i}{2} V_i^2 \quad (106)$$

Steady laminar flow (Hagen-Poiseuille law):

$$\Delta p_{HP,i} = 12 \cdot \mu_i \cdot \frac{H_i}{S_i^2} V_i \quad (107)$$

Pressure loss in the inlet and outlet openings:

$$\Delta p_{Z,i} = \frac{\rho_i}{2} V_i^2 (Z_{\text{in},i} + Z_{\text{out},i}) \quad (108)$$

where

$\Delta p_{B,i}$ is the pressure loss B in space i , in Pa;

$\Delta p_{HP,i}$ is the pressure loss HP in space i , in Pa;

V_i is the mean velocity of the air flow in the cavity i , to be solved with eq. (109), in (m/s); (same for k);
 μ_i is the viscosity of the air at temperature $T_{\text{gap},j}$, in (Pa.s);
 ρ_i is the density of the air at temperature $T_{\text{gap},j}$, in (kg/m^3);
 H_i is the height of the space i , in (m);
 s_i the width of the cavity i , in (m);
 Z_i the pressure loss factors Z of cavity i , according to eq.(110)below;
 The same equations apply to space k , where $V_k = V_i \cdot s_i / s_k$.

If the space k is the exterior or interior, $V_k = 0$ is assumed, in which case the pressure loss terms $\Delta p_{B,k}$ and $\Delta p_{HP,k}$ are zero as well as $\Delta p_{Z,k}$, where

$\Delta p_{Z,i,k}$ is the pressure loss Z between space i and k , in Pa.

The total pressure loss shall be equal to the driving pressure difference and this results in the velocities V_i and V_k by solving the equation:

$$\Delta p_{T,i,k} = \Delta p_{B,i} + \Delta p_{HP,i} + \Delta p_{z,i} + \Delta p_{z,k} + \Delta p_{B,k} + \Delta p_{HP,k} \quad (109)$$

where

$\Delta p_{T,i,k}$ is the driving pressure difference between space i and space k , according to eq. 105, in Pa

$\Delta p_{B,i}$ is the pressure loss B in space i , according to equation (106), in Pa;

$\Delta p_{HP,i}$ is the pressure loss HP in space i , according to equation (107), in Pa;

$\Delta p_{Z,i}$ is the pressure loss Z at the inlet and outlet of space i , according to equation (108), in Pa;

$\Delta p_{z,k}$ the same as $\Delta p_{Z,i}$ but for space k

$\Delta p_{B,k}$ is the pressure loss B in space k , according to equation (106), in Pa;

$\Delta p_{HP,k}$ is the pressure loss HP in space k , according to equation (107), in Pa.

Pressure loss factors

The pressure loss factors Z for openings may be estimated from the ratio of the equivalent area of an opening A_{eq} to the cross section of the space A_s (see Figure 24) according to:

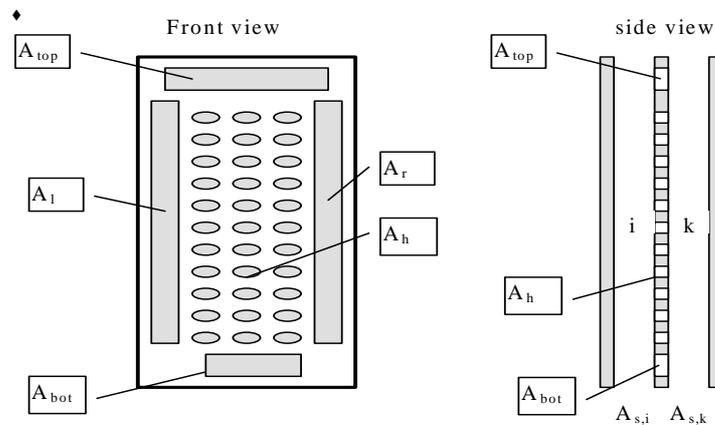


Figure 24 - Openings in a ventilated gap

$$Z_{\text{in}} = \left(\frac{A_s}{0,6 \cdot A_{\text{eq,in}}} - 1 \right)^2 \quad \text{and} \quad Z_{\text{out}} = \left(\frac{A_s}{0,6 \cdot A_{\text{eq,out}}} - 1 \right)^2 \quad (110)$$

where

$A_{s,i}$ is the cross section of the space i ; $A_{s,i} = s_i \times L_i$;

s_i is the width of the cavity i , in (m);

L_i is the length of the cavity i , in (m);

$A_{eq,in,i}$ is the equivalent inlet opening area of the cavity i , according to Equation (111 or 112), in m^2 ;
 $A_{eq,out,i}$ is the equivalent outlet opening area of the cavity i , according to equation (111 or 112), in m^2 .

If the temperature $T_{gap,i}$ (resp. $T_{gap,k}$) of the cavity i respectively k is higher than the temperature of the connected space k respectively i :

$$\begin{aligned}
 A_{eq,in} &= A_{bot} + \frac{1}{2} \cdot \frac{A_{top}}{A_{bot} + A_{top}} (A_l + A_r + A_h) \\
 A_{eq,out} &= A_{top} + \frac{1}{2} \cdot \frac{A_{bot}}{A_{bot} + A_{top}} (A_l + A_r + A_h)
 \end{aligned}
 \tag{111}$$

Otherwise:

$$\begin{aligned}
 A_{eq,out} &= A_{bot} + \frac{1}{2} \cdot \frac{A_{top}}{A_{bot} + A_{top}} (A_l + A_r + A_h) \\
 A_{eq,in} &= A_{top} + \frac{1}{2} \cdot \frac{A_{bot}}{A_{bot} + A_{top}} (A_l + A_r + A_h)
 \end{aligned}
 \tag{112}$$

where

A_s is the cross section of the space, in m^2 ;
 A_{bot} is the area of the bottom opening, in m^2 ;
 A_{top} is the area of the top opening, in m^2 ;
 A_h is the total area of the holes in the surface (homogeneously distributed holes), in m^2 ;
 A_l is the area of the left side opening, in m^2 ;
 A_r is the area of the right side opening, in m^2 ;

It is assumed that the side openings are distributed evenly from top to bottom.

All these areas are total flow areas for the window (i.e., not normalized).

7.4.5 Gas filled cavity with air circulation

In those cases of a closed cavity containing a gas mix and other component of the fenestration, e.g. an incorporated blind, the gas mix may flow from one side of the component (blind) to the other. In that case the equations given above remain valid, if 'air' is replaced by 'gas-mix', with the corresponding gas-mix properties.

7.4.6 Air permeability of slat types of shading devices

The air permeability of slat types of shading devices can be described with an appropriate value for the equivalent air permeability of the surface, A_h . An appropriate value is to be determined on the basis of experiments or calculations (CFD modelling).

For conservative design calculations the value for the equivalent air permeability of the surface, A_h , can be set to extreme low and extreme high values respectively, thereby giving two extremes for the total solar energy transmittance.