IEA SHC Task 34 / ECBCS Annex 43
Subtask E: Double Skin Facade

Double Skin Facade - Modeler Report

Empirical Test cases

VA114

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February 08, 2008 (third draft)
June 26, 2007 (second draft)
April 27, 2007 (first draft)

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<u>Remark:</u>
In April 2007 a first draft of the Modeller Report concerning the Empirical tests [6] was made: it contained a description of the model, its assumptions and the first results of the IEA-34/43 DSF Empirical tests.

The VA114 simulation program passed in earlier times the BESTEST [1], [2], [3]. Within this IEA-34/43 project it was already subjected to the IEA-34/43 DSF Comparative tests [4]. Results of these tests can be found in [5].

In June 2007, a second draft came ready. Two descriptions were added: a description of the VA114-submodel for air flow by wind fluctuations and a description of VA114's solar processor. A completed questionnaire for the program VA114 was added too. Reruns were done and results were reported.

Now, February 2008, a third draft (the final draft) is ready. Based on Steady State calculations and Steady State measurements the subtask concluded the presence of thermal bridges (cold bridges). The magnitude of these thermal bridges was determined. These thermal bridges have be taken into account. The U-value of the internal glazing changed slightly too. Reruns (the final runs) were done. Results are reported in this draft.

Heat exchange within a Zone and between Zones

1. Introduction

The Building simulation program VA114 is developed and distributed by VABI Software bv. The current version is 2.25.

The program calculates the Demand, the Supply, the Distribution and the Generation of heat and cold for a building with its energy supply system. Moreover the internal comfort temperature and overheating are calculated.

VA114 is a multi-zone program (up to 30).

The time step applied in VA114 is 1 hour.

The boundary conditions, that are possible in VA114 are:
- bounded to ambient
- bounded to a neighbour zone
- bounded to a mirror zone
- bounded to the underground

The current program VA114 models:
- heat exchange within a zone
- heat exchange between zones by conduction
- heat exchange between zones by airflow (ventilation)
- solar gain and solar exchange between zones
- solar shading
- and other processes

The simulation program VA114 passed the BESTEST [1],[2],[3]. In 2005 the simulation program was subjected to the new IEA-34/43 tests of subtask B (Multi-zone Non air – tests MZ320, MZ340, MZ350, MZ355 and MZ360).

Within IEA-34/43 subtask E (Double Skin Façade) last year (2006) the program was subjected to the Comparative tests [4]. Tests were still under development and were repeated a few times. The last time was in June 2007. Results can be found in [5].

In April 2007, within the same subtask, the program was subjected to the Empirical tests [6]. Available were test results from the test facility in Aalborg, Denmark. In the first draft of the Modeler report all background information and the results of the tests (first round) were given.

In June 2007, a second draft of the Modeler report came ready. Two descriptions were: a description of the VA114-submodel for air flow by wind fluctuations (appendix AA) and a description of VA114's solar processor (appendix D). A completed questionnaire for the program VA114 was added too (Appendix E). After some iterations the reruns were done and results were reported [9].

Now, February 2008, a third draft (the final draft) is ready. Based on Steady State calculations and Steady State measurements the subtask concluded the presence of thermal bridges (cold bridges). The magnitude of these thermal bridges was determined. These thermal bridges have be taken into account. The U-value of the internal glazing changed slightly too. Reruns (the final runs) were done. Results are reported in this report.

Remark:
VABI Software bv is developing the simulation program VA114. A new version of VA114 was distributed to its users (about 200) in February 2006. Before the distribution of this new version it was tested extensively: by running the Bestest cases (1995), by running the Dutch EDR-tests and by running the new IEA-34/43-MZ-tests.

2. Model description

The current program VA114 models:

- heat exchange within a zone
- heat exchange between zones by conduction
- heat exchange between zones by airflow (ventilation)
- solar gain and solar exchange between zones
- solar shading
- and other processes

In more detail:

- heat exchange within a zone

The zone air is described by one node. Between this zone air node and the internal surfaces heat exchange takes place by convection. The convection coefficient is user given and can be specific for each surface.
Heat exchange between the surfaces happens by long wave radiation. This heat exchange is dependent on the view factors and emittance factor of the internal surfaces.
Remark: there is an option in the model the value of the convection coefficient can switch between two values.

- heat exchange between zones by conduction

Internal and external walls are simulated by a number of nodes. Each with a heat capacity and with heat resistances in between.

- heat exchange between zones by airflow (ventilation)

Air exchange takes place between ambient and the zone and between neighbouring zones. This air exchange can be user given or calculated according to a network node model.
In Appendix A detailed information is given about the modelling aspects of this process.

- solar gain and solar exchange between zones

Solar radiation enters a zone by windows. This solar radiation is absorbed in the zone or can leave the zone through windows, to ambient or to a neighbouring zone.
In Appendix B detailed information is given about the modelling aspects of this process. Incident solar radiation is calculated by VA114's solar processor (see Appendix D).

- solar shading

Solar shading happens by surrounding buildings, by external façade parts, by own buildings parts and by setback of the window.
In Appendix C detailed information is given about the modelling aspects of this process.

- and other processes

Like: internal heat production (by persons, equipment and lighting), mechanical ventilation, ….

3. Modeling Assumptions

In this chapter the modeling assumptions are discussed. First in general and then specific per test case. See the corresponding paragraphs of the Test case specification [6]

Comments/assumptions with respect to the General information

DSF test cases
The DSF test cases are subdivided into 5 groups:

- DSF100: All openings are closed
- DSF200: Openings are open to the outside
- DSF300: Openings are open to the inside
- DSF400: Bottom opening is open to the outside and the top opening is open to the inside (pre-heating mode)
- DSF500: Top opening is open to the outside and the bottom opening is open to the inside (chimney/exhaust mode).

Geography, site location
Outdoor test facility the "Cube" at Aalborg University, Aalborg, Denmark:

- latitude 57,01 degree North
- longitude 10,00 degree East
- Altitude: 19 m above sea level

Weather data
The time on the tape is "standard local time". Total solar radiation on the horizontal and diffuse solar radiation on the horizontal are given; direct normal solar radiation is calculated from the 2 given components.
Wind velocity on the tape is the velocity in the open field at a height of 10 m.

Geometry
Four zones are specified:

- zone 1, the DSF
- zone 2, the zone behind the DSF
- zone 3, the left back zone
- zone 4, the right back zone

The inner dimensions were used to get the right volume. The depth of the zones 3 and 4 is 3,00 m. The wall in between zone 2 and 3 is not adiabatical; so is the wall in between zone 3 and 4.

Remark: with respect to the comparative tests cases the DSF is 20 mm deeper (internal window is moved that distance backwards)

The external and the internal window have an area of 19,37 m^2 (6 * 3,229 m^2): 16,16 m^2 is glazing (83,4%), 3,21 m^2 is frame.

Window properties

The external window has the following properties:

U-value = 5,36 W/(m^2.K) (glazing = 5,70 and frame = 3,63)
g-value = 0,667 (glazing = 0,80 and frame = 0,00)
C_f-value= 0,017 (glazing = 0,020 and frame = 0,00)

Angular Modifier (AM) of this single glazing:

```
Angle=    0.    15.    30.   40.    45.    50.    60.    70.    80.    90.
AM=    1.032  1.029  1.024  1.012  1.000  0.985  0.921  0.776  0.480  0.000
```

For diffuse solar radiation an incidence angle of 58^o is applied.

Remark: above g-value is for perpendicular incident radiation (incident angle is 0^o); AM is a multiplier for g-value at 45^o incident angle. So as input g-45 has to be used:

g-45 = 0,667 /1,032 = 0,646 (glazing = 0,775 and frame = 0,00)

The internal window has the following properties:

U-value = 1,53 W/(m^{2}K) (glazing = 1,12 and frame = 3,63)
g-value = 0,525 (glazing = 0,63 and frame = 0,00)
C_f-value=0,057 (glazing = 0,068 and frame = 0,00)

Angular Modifier (AM) of this double glazing:

```
Angle=    0.    15.    30.   40.    45.    50.    60.    70.    80.    90.
AM=    1.054  1.051  1.041  1.021  1.000  0.973  0.866  0.661  0.338  0.000
```

For diffuse solar radiation an incidence angle of 58^o is applied.

Remark: above g-value is for perpendicular incident radiation (incident angle is 0^o); AM is a multiplier for g-value at 45^o incident angle. So as input g-45 has to be used:

g-45 = 0,525 /1,054 = 0,498 (glazing = 0,598 and frame = 0,00)

The emissivity of the glazing is 0,84 on both the side to external and the side to internal.

Remark: C_f-value is determined by simulation and interpolation – at what C_f-value is for the given g-value the transmission as prescribed.

Remark: the standard AM's available in the VA114-input were used (for single glazing and for double glazing). Both AM's are given above.

Solar gain

It is assumed the solar gain is for 100% sensible (0% latent) and for 100% radiative (convective part Czon= 0%). There is one exception: in zone 2 the radiative part is 90 % (and so the convective part Czon= 10 %); this to take into account the effect of the lightweight air bags (light materials convert absorbed solar almost immediately into convective heat).

Properties of the constructions

The properties are as specified. However now also thermal bridges are taken into account (by increasing the thermal conductivity of the insulation layer). Table 1 gives the U-value of the several constructions (except window frame and glazing) without and with thermal bridges.

Table 1: U-value of the constructions

Construction	U-value No thermal bridges (in W/(m2.K))	U-value With thermal bridges (in W/(m2.K))
Wall 1	0,049	0,101
Wall 2	0,083	0,170
Wall 3	0,083	0,170
Roof/Ceiling	0,083	0,170
Floor (ground resistance excluded)	0,151 (0,195)	0,257 (0,417)

The constructions have an infrared emittance (emissivity) of 0,88. For the solar absorptance a distinction is made between external (0,40 - this value is estimated; a realistic value for a white surface) and internal (0,34 – from specs).

Heat loss through the floor

The heat loss through the floor (in W/m^2): the ground resistance to the heat transmission is prescribed - 1,5 $m^2.K/W$ (according to the DS 418).
For the given floor construction this results in an overall U-value of 0,15 $W/(m^2.K)$; so a heat loss of 1,5 W/m^2 (temperature difference is 20 – 10 = 10 K)

Remark: this value is about the same as the heat loss calculated based on ISO-13370

According to ISO-13370 (slab on ground)
The floor has the prescribed construction and is assumed to be above a 0,50 m layer of soil. The properties of the soil are not specified. Taken is:

- thermal conductivity = 1,75 W/(m.K)
- Specific mass = 1500 kg/m^3
- Specific heat = 1500 J/(kg.K)

Assumption for the heat loss:
Internal zone temperature = 20 °C - constant during the year
External temperature during the year = 9,1 °C with minimum 0,6 °C and maximum 16,8 °C.

Calculated heat loss through the floor according to ISO-13370 (slab on ground):

$$Q_{floor} = 1,76 + 0,86 \cos (arg)$$

With

Arg = argument, that is a function of time of the year.

Soil properties have some influence on this heat loss [5].

Remark: with thermal bridges included the U-value of the floor is 0,26 $W/(m^2.K)$

Heat loss from zone 2 to the back zones 3 and 4

The temperature in zone 3 and zone 4 are known from the measurement. The simulation takes the properties of the construction and a fixed temperature in zones 3 and 4 (as a mean temperature over the simulation period) into account

Heat loss by infiltration
By blow test the air tightness of the “Cube” was measured for both cases (DSF100_e – windows closed and DSF200_e – windows open).
Based on that measured air tightness the properties of cracks in the several walls were determined (under the assumption that for the DSF100_e case the leakage is uniformly distributed over all 4 facades; cracks at 0,10 m and at 5,50 m height)

Convective Surface Coefficients
The internal convective surface coefficients are constant and assumed to be 3,0 W/(m^2.K); the external convective surface coefficients are constant and assumed to be 18,0 W/(m^2.K).

Radiative Surface Coefficients
The radiative surface coefficients are calculated based on mean temperature, view factors and infrared emittance.
External sky radiation is calculated based on clouds cover, vapour pressure (location Arnhem – the Netherlands)

Pre-conditioning period
Weather files are available for a period of 2-3 weeks. VA114 works with a pre-conditioning period of 42 days. Normally 42 days before the starting date is taken. Now this is not possible, therefore 42 times the first day is taken.

Temperature control in the zones
The zones 2, 3 and 4 are equipped with a 100% convective heating and cooling device. The capacity of these devices are assumed to be infinite.

The control temperature is the air temperature.

The set point temperature for heating and cooling is the same (bang-bang), so no dead-band.

Each zone has its specific set point.

Comments/assumptions with respect to test case DSF100_e

Heat loss through the floor
Ground temperature was put at 10,0 ^oC.

Set points of heating/cooling device
The set points of the heating/cooling devices are:
- zone 1: no set points – free floating
- zone 2: 21,8 ^oC
- zone 3: 18,3 ^oC
- zone 4: 12,3 ^oC

Air tight ness
Measured relation: $dP = 217{,}59 * (Ach)^{1,3624}$; For uniformity - used relation: $dP = 228 * (Ach)^{1,40}$

Comments/assumptions with respect to test case DSF200

Heat loss through the floor
Ground temperature was put at 10,0 ^{o}C.

Set points of heating/cooling device
The set points of the heating/cooling devices are:

- zone 1: no set points – free floating
- zone 2: 21,8 ^{o}C
- zone 3: 18,5 ^{o}C
- zone 4: 14,7 ^{o}C

Air tight ness
Measured relation: $dP = 203{,}14 * (Ach)^{1{,}3998}$; For uniformity - used relation: $dP = 203 * (Ach)^{1{,}40}$

Window openings
The size of the window openings is determined by:

3 x free opening area (0,20 m^2) + 2 x side area of opening (0,075 m^2) = 0,75 m^2

Data shown is for the comparative cases and is for both top and bottom openings.

For the empirical cases the size of the top and bottom openings are smaller and different:

Top: 0,41 m^2
Top: 0,49 m^2

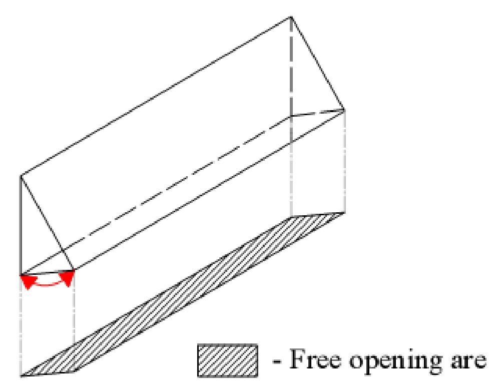


Figure 3. Free opening area

The discharge coefficient differs from the specs: VA114 uses 0,61 for both supply and exhaust openings, the specs set that coefficient to 0,65 for the supply openings and 0,35 for the exhaust openings.

Wind pressure coefficients differ from the specs: the VA114-table is applied (source AIVC) . Moreover VA114 assumes coefficients for top and bottom openings are the same (see chapter 5); the specs prescribe different coefficients for top and bottom

The internal convective surface coefficients in zone 1 (DSF has air flow through it) are unchanged: 3,0 W/(m^2.K).

Wind speed profile

The measured wind speed profile corresponds with:

$$Vh/Vh10 = 0,288 * \ln (h/0,31)$$

VA114 works with the relation of Davenport. For flat, open terrain it says:

$$Vh/Vh10 = 0,922 * (h/6,0)^{0.16}$$

These relations look very different, but at roof height (6,0 m) the specified relation gives Vh/Vh10 = 0, 853 whereas Davenport gives Vh/Vh10 = 0,922. So VA114 works with a 8 % higher wind speed. In the table below the difference is given as function of height.

Table 2: Ratio Vh/Vh10 (Windspeed at height h resp. at h= 10 m)

Height (m)	Specs	VA114
1	0,34	0,69
2	0,54	0,77
3	0,65	0,83
5	0,80	0,90
7	0,90	0,95
10	1,00	1,00
20	1,20	1,12

4. Modelling Options

Applied modelling options.

Infrared heat exchange (see chapter 2)
Infrared heat exchange within a zone works with view factors between the internal surfaces and with emittances of that internal surfaces. The view factors are calculated with a detailed Ray-tracing method, which is applicable for all shapes of zones

Heat exchange between zone by airflow - *ventilation (see chapter 2)*
Air exchange takes place between ambient and the zone and between neighbouring zones. This air exchange is calculated according to a network node model (model vent2). Air flow by thermal buoyancy, wind pressure and wind fluctuations. Calculation is based on properties of openings (cracks, open windows, …), actual temperatures, wind velocity and wind direction.

Solar distribution over the internal surfaces (see chapter 2)
Direct radiation and diffuse radiation are treated separately.
For the direct radiation it is calculated which internal surfaces are hit; such a surface absorbs a part of that direct radiation and reflects the rest diffusely.
The direct solar distribution is calculated with a detailed Ray-tracing method, which is applicable for all shapes of zones
The distribution of the diffuse radiation (through windows and the reflected direct radiation by internal surfaces) is calculated by the view factors (see above) and by the reflections (= 1,0 – absorptance) of the internal surfaces.

Solar shading (see chapter 2)
External façade parts, own building parts and set back of window cause both shading of the direct solar radiation and shading of the diffuse solar radiation. The direct shading is calculated by a detailed Ray-tracing method, which is again applicable for all shapes of zones.
Surrounding buildings can be submitted (input) to the program as external façade parts too. In that way both shading of the direct solar radiation and shading of the diffuse solar radiation is calculated.
For the diffuse shading a detailed Ray-tracing method is applied.

5. Modeling Difficulties

Window modelling (all DSF-cases)

The window can be modelled in several ways:

- as one construction (glazing and frame combined - method fg0)
- as two constructions (glazing and frame separately); 3 ways are distinguished:
  - frame one part, each of the 12 glazing parts separately (method fg1)
  - frame one part, glazing one part – both height and width of glazing smaller than window dimensions (method fg2)
  - frame one part, glazing one part – height of glazing same as window height, width of glazing smaller than window width (method fg3).

Each method has its advantages and disadvantages:

- method fg0 is easy to model, but window surface temperature (= mix of glazing and frame temperature) differs from the glazing temperature (a required output result)
- method fg1, fg2, fg3 require more detailed input, but give the right glazing temperatures
- method fg3 has the window openings at the right height; important in modelling thermal buoyancy.
- …..

Method fg3 was selected

Figure 1: : frame (f) and glazing (g) separated

```
 ----------------------------
|     |                |      |
|     |                |      |
|     |                |      |
|     |                |      |
|frame|    Glazing     | frame|
|     |                |      |
|     |                |      |
|     |                |      |
 -----------------------------
```

Modelling of internal window (all DSF-cases)

The internal window model used by VA114 was improved since the former tests: the real optical properties of the glazing part (the real transmission and the real absorption in the panes) are taken into account :

- transmission of solar radiation = Trsm
- absorption in the glazing panes = Abs,i
- reflection of solar radiation = 1 – Trsm – Sum(Abs,i)
- Angular Modifier (AM) = 1,0

The transmission Trsm and the absorptions Abs,i are derived from the g-value, the C_f-value and the U-value.

Modelling of window openings (DSF200-cases)

In VA114 per window 2 openings can be defined, each with their own dimensions and position within the glazing area.

Figure 2: : Window can have 2 openings

```
 ----------------------------
|   ------                   |
|  |      |                  |
|   ------                   |
|                            |
|                ----        |
|               |    |       |
|                ----        |
 -----------------------------
```

In test case DSF200 the bottom openings have not the same size as the top openings:
bottom 0,49 m^2 and top 0,41 m^2

In figure 2 the glazing dimensions and the position of both openings are given.

Figure 2: Glazing dimensions and position of both openings

```
  -----.-----2,965-----.------
 |     | ============= |      |
 |     | | 1,37*0,30 | |      | Height 5,060 - 5,360
 |     | ============= |      |
 |     |               |      |    ^
 |     |               |      |    | difference 4,990
 |Frame|  Glazing      |Frame |    |
 |     |               |      |    v
5,450  |               |      |
 |     | ============= |      |
 |     | | 1,63*0,30 | |      | Height 0,080 - 0,038
 |     | ============= |      |
  -----.---------------.------
 <- - - - - - 3,555 - - - - - >
```

Each of the two openings is modelled by two "cracks":
Length of cracks = width of opening
Height of crack1 = 0,28 * height of opening
Height of crack2 = 0,72 * height of opening
C-value of cracks = 0,40 * height of opening

Discharge coefficient used in the determination of C-value is 0,61 (both for top and bottom openings) in stead of the prescribed 0,65 for supply openings and 0,35 for exhaust openings.

Window openings are fully open and not controlled. All restrictions (window is not allowed to open) are excluded, so the window is open 24 hours a day.

Modelling of airflow

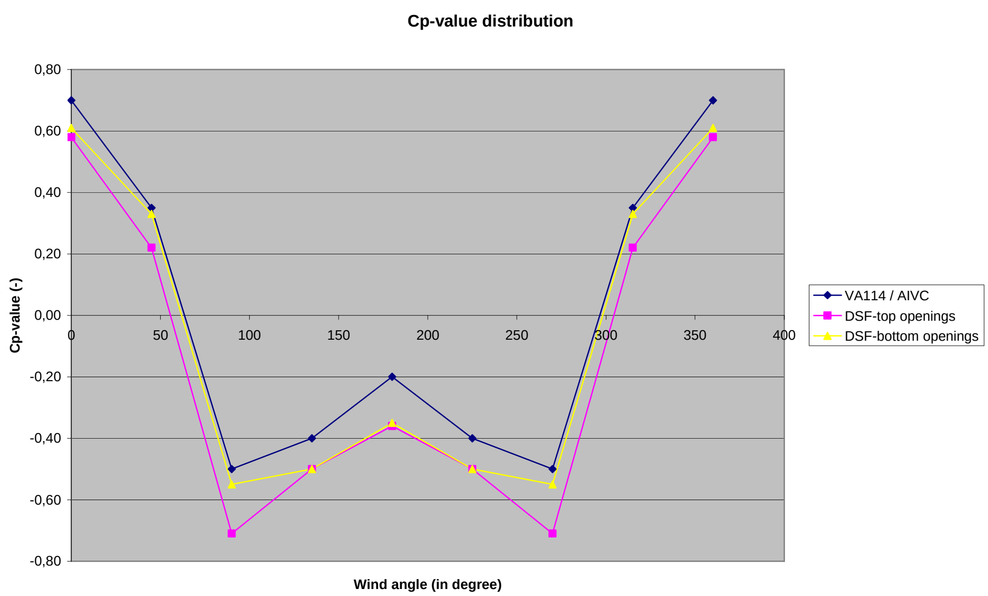
Air flow is calculated based on actual wind speed and wind direction, the actual ambient temperature and the zone temperature of the former time step (Tzone (hour-1))

Calculation of air flow is only possible in case cracks are present in all zones. There are cracks in each zone; properties are determined from air tightness data..

Wind pressure coefficients

In the DSF-test specifications the Cp-values of the top openings are different from those of the bottom openings. VA114 have one Cp-value on a façade, so Cp-values for top and bottom openings are the same.
VA114 makes use of the AIVC-table; values in that table are different from the DSF-table (See figure 3). Cp-values are available for each 45 degrees; rather rough. Interpolation between these values was done.

Figure 3: Wind pressure coefficients according to specs and according to VA114-table



Downward and upward flow separate in the output

How to distinguish? Driving forces are buoyancy and wind. Wind by pressure drop and by wind fluctuations. In the VA114-model the wind pressure difference = 0,0: openings are on the same façade (so wind pressure coefficients are independent on the height).

Observed air flows:

- Air flow in occurs at the bottom openings (through both "cracks") and air flow out at the top openings (through both "cracks") – see figure 4a.
- In some cases in- and outflow occurs both at the bottom and top openings (one "crack" in, second "crack" out) - see figure 4b.
- It also happens air flow in occurs at the top openings and air flow out at the bottom openings – see figure 4c.

Figure 4a: In- and outflow, upward flow

```
   -------------
  |             |
 /  ← 630       |
  | ← 600       |
  |             |
  |     ^       |
  |     |  1230 |
  |             |
  |             |
 /  → 600       |
  | → 630 kg/h  |
   -------------
```

Figure 4b: In- and outflow, upward and downward flow

```
   -------------          -------------
  |             |        |             |
 /  ← 400       |       /  → 400       |
  | → 200       |        | ← 200       |
  |             |        |             |
  |     | ^     |        |     | ^     |
  |200? v | 400?|        |400? v | 200?|
  |             |        |             |
  |             |        |             |
 /  ← 200       |       /  → 200       |
  | → 400 kg/h  |        | ← 400 kg/h  |
   -------------          -------------
```

Figure 4c: In- and outflow, downward flow

```
   -------------
  |             |
 /  → 210       |
  | → 200       |
  |             |
  |     |       |
  |     v   410 |
  |             |
  |             |
 /  ← 200       |
  | ← 210 kg/h  |
   -------------
```

In situation 4a there is a resulting upward flow (+) and in situation 4c a resulting downward flow (-). In both situations the resulting flow is equal to the amount of fresh ambient air that is entering. In situation 4b the resulting flow is upward (+200 kg/h) in the left figure and down ward in the right figure (-200 kg/h); but both different from the amount of fresh air that is entering (600 kg/h).

In the results the fresh air amount should be given, but giving that amount with a '+' or '-' sign to indicate upward or downward flow results in a jump from + to – in the air flow plot.

So it is not easy to give upward and downward flow separately in the output.

Remark: in the DSF the real air flows can/will be higher than the fresh air amount because of recirculation in the DSF.

6. Software errors discovered and/or Comparison between different versions of the same software.

The following software errors were discovered and corrected.

The internal window model

It was found the internal window model was too simple:

- transmission = g-value
- absorption in the panes = 0,0
- reflection of the window = 1,0 – g-value
- Angular Modifier = 1,0

The internal window model used by VA114 was improved: the real optical properties of the glazing part (the real transmission and the real absorption in the panes) are taken into account :

- transmission of solar radiation = Trsm
- absorption in the glazing panes = Abs,i
- reflection of solar radiation = 1 – Trsm – Sum(Abs,i)
- Angular Modifier (AM) = 1,0

The transmission Trsm and the absorptions Abs,i are derived from the g-value, the C_f-value and the U-value.

The sub model for air flow by wind fluctuations

In Appendix AA this model is described.

In the original version the wind coefficient C_1 was 0,01 and the wind velocity was the wind velocity at roof height. The way of sheltering had no influence on the velocity in the window opening.

After studying literature it was found the C_1 is dependent on the way of sheltering (exposed C_1= 0,004 , semi-exposed C_1= 0,002 , sheltered C_1 =0,001) and the wind velocity should be the wind at a local weather station. The model was revised for those points.

In figure 5 a comparison is made between the original model and the revised model for October 8th, a windy day (see figure 6); the temperature difference between DSF-zone and ambient was within a few degrees (see figure 7). In figure 5 also the measured air flow is given.

Conclusions:
From figure 5 the following conclusions can be drawn:

1. The revised model gives an lower air flow than the original model.

2. The empirical data shows a strong wind dependency, which is not found from the VA114 sub model for air flow by wind fluctuations. This point to the difference in Cp-value between top and bottom opening, that is not taken into account by VA114.

It seems to be necessary to extend the VA114 model with different Cp-values for different positions on a façade.

Figure 5: Air flow by the original and the revised air flow model; measured air flow

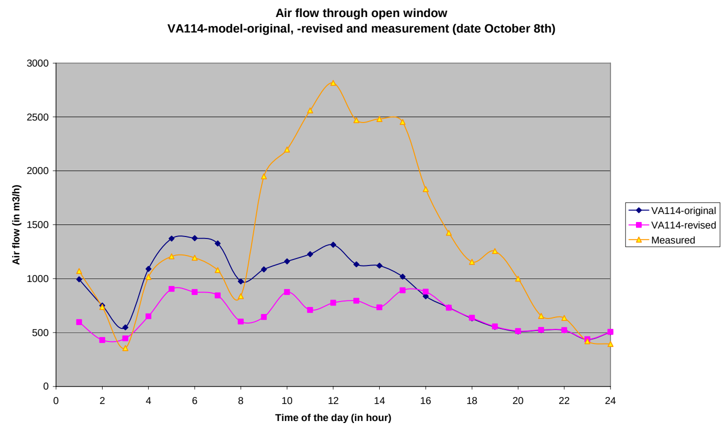


Figure 6: Wind velocity on October 8th, a windy day

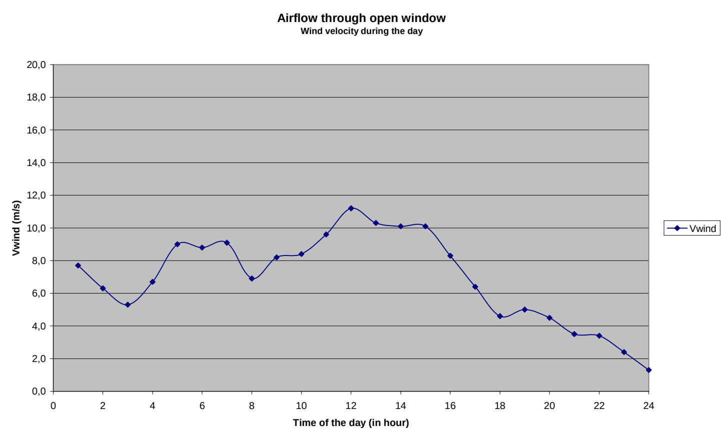
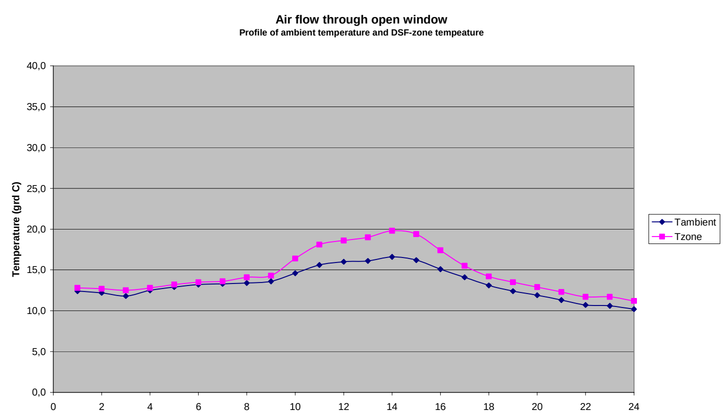


Figure 7: Temperature difference between DSF-zone and ambient – October 8th



7. Results

DSF100_e

The results of test case DSF100_e are given in file "Output Results DSF100_e-20080207.xls": 19 days with hourly results for the specified output parameters.

Totals during the 19-day's period:

Heating	154 kWh
Cooling	-59 kWh

Peak power used:

Heating	0,81 kW
Cooling	-2,94 kW

Net solar gain:

Incident on the DSF	473 kWh
Solar transmitted to zone 1	342 kWh
Solar transmitted to zone 2	157 kWh
Absorption by internal window	xxx kWh (is calculated, but not in output available)

Extreme temperatures:

Maximum zone 1	29,9 ^{o}C
Minimum zone 1	3,3 ^{o}C
Mean zone 1	13,5 ^{o}C

DSF200_e

The results of test case DSF200_e are given in file "Output Results DSF200_e-20080207.xls": 15 days with hourly results for the specified output parameters.

Totals during the 15-day's period:

Heating	60 kWh
Cooling	- 128 kWh

Peak power used:

Heating	0,53 kW
Cooling	-2,61 kW

Net solar gain:

Incident on the DSF	766 kWh
Solar transmitted to zone 1	549 kWh
Solar transmitted to zone 2	238 kWh
Absorption by internal window	xxx kWh

Extreme temperatures:

Maximum zone 1	22,9 ^{o}C
Minimum zone 1	6,2 ^{o}C
Mean zone 1	14,1 ^{o}C

Discussion :

Results are presented for the specifications and assumptions mentionned in this Modeler Report. There are still some question marks :

- The air bags in zone 2 are modelled by a radiative part of solar is 90% (Czon= 10% ; i.e. 10% of the solar radiation goes direct as convective heat to the zone air node) instead of 100% (Czon= 0%) ; this is a default value for VA114, but this assumption requires some more background.
- Air tightness was assumed to be uniformly distributed over the 4 facades of the Cube.
- VA114 works with constant convective heat transfer coefficients (internal 3,0 W/(m^2.K) and external 18,0 W/(m^2.K)), so independent of air movement, air flow and wind
- …………….

Comparison with measured data and with results of the other programs and evaluation of that comparison should lead to an answer on those points.

8. Other

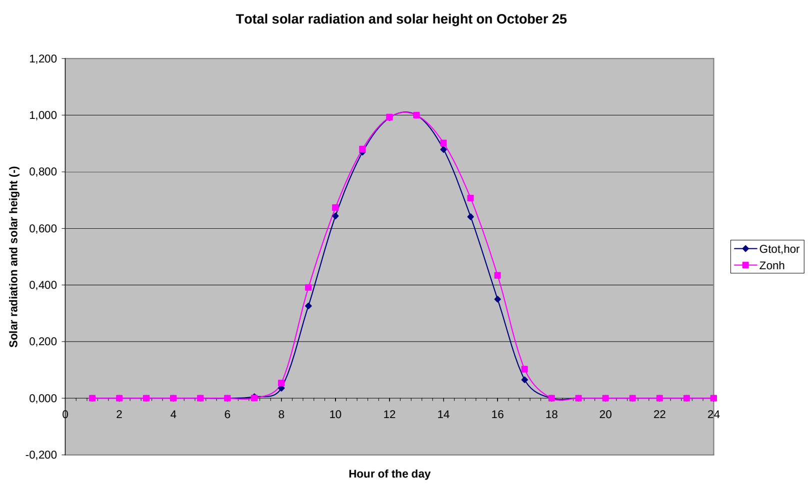
Solar on a clear sky

Solar data was checked for a clear sky: the solar intensity on the horizontal and the solar height should have their maximum at the same time (see figure 8.1).

The day selected was October 25, 2006.

As can be seen: the profiles are in very good agreement / are synchronical.

Figure 8.1: Solar intensity on the horizontal and solar height on a clear day - normalized
Calculations for the location "The Cube", Aalborg University



Final remark:

VA114 has an option to simulate the DSF not as separate zone, but as a single, ventilated component. Ventilation can be done in all thinkable ways. These simulations are not done yet, but can/will be done in future.

9. Conclusions and Recommendations

VABI Software bv does developments on the Building simulation program VA114. The program was subjected to the IEA34/43 DSF-Empirical-tests [6].

In this modeller report information about the program, about the tests and about the results are given.

Results are presented for the specifications and assumptions mentionned in this Modeler Report.

Remark

At the Glasgow – meeting (October 2007) the 'final' results were discussed for the first time. This lead to some extra exercises:

- Determination of the properties of the glazing with WIS
- The Steady State test

and some changes :

- U-value of the glazing of the internal window became 1,12 W/(m^2.K) instead of 1,20
- The presence of cold bridges

The results in this report should be considered as final results.

10. References

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"International Energy Agency Building Energy Simulation Test (BESTEST) and Diagnostic Method", IEA: SHC Task 12 / ECBCS Annex 21, February 1995.

[2] Soethout, L. L.
"BESTEST Kwalificatietesten uitgevoerd aan het gebouwsimulatieprogramma VA114, versienummer 1.35". TNO-rapport 98-BBI-R0830, mei 1998.

[3] Wijsman, A.J.Th.M.; Plokker, W.
"Eerste thermische gebouwsimulatieprogramma's ondergingen de keurmerktest".
TVVL Magazine, augustus 1999.

[4] Kalyanova, O. and Heiselberg, P.
"Comparative Test Case Specification – Test cases DSF100_2, DSF200_3, DSF200_4 and DSF400_3", IEA: SHC Task 34 / ECBCS Annex 43, April 2007.

[5] Wijsman, A. J. Th. M.
"Double Skin Façade – Modeler Report; Comparative Test cases", Vabi Software bv, April 2007.

[6] Kalyanova, O. and Heiselberg, P.
"Empirical Test Case Specification – Test cases DSF100_e and DSF200_e.", IEA: SHC Task 34 / ECBCS Annex 43, April 2007.

[7] Wijsman, A. J. Th. M.
"Double Skin Façade – Modeler Report; Empirical Test cases", Vabi Software bv, April 2007.

[8] Wijsman, A. J. Th. M.
"Double Skin Façade – Modeler Report; Comparative Test cases", Vabi Software bv, June 2007.

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"Double Skin Façade – Modeler Report; Empirical Test cases", Vabi Software bv, June 2007.

Appendix A: Heat exchange by airflow

Model description

Air exchange takes place between ambient and the zone and between neighbouring zones. Air exchange occurs through cracks and other openings in walls. Processes that are responsible for these airflows are:

- thermal buoyancy
- wind pressure and wind fluctuations
- mechanical imbalance over a zone

In figure A.1 this is given schematically

```
             M-In          M-Out         M-In
               |             ^             |
           ----|-------------|------------|------
          |    |        |    |    |       |      |
        <-|-   v        |         |       v    - | ->
          |             |         |              |
Wind      |             |         |              |
=== >     |             |         |              |
          |            <.-    <- - - -           |
          |             |         |              |
      - - | - >    - - -.->      -.>            <|-
v         |             |         |              |       vv
---------------------------------------------------------------
```

Figure A.1: Airflows in a building

In subroutine "VENT" the airflows are determined. Three models are available:

- subroutine "VENT1":
  In- and exfiltration flows are calculated based on an empirical relation for the air exchange rate. Interzonal flows are user given. In case of mechanical imbalance these in- and exfiltration flows and interzonal flows are adjusted to obtain balance.
- subroutine "VENT2":
  In- and exfiltration flows and interzonal flows are calculated with a nodal network. Thermal buoyancy, wind pressure, wind fluctuations and mechanical imbalance are taken into account.
- subroutine "VENT3":
  Airflows are calculated by interpolation between data from a database (depending on wind velocity and wind direction, ambient temperature and zone temperatures).

Some more information about the models will be given now. All models use as wind velocity the wind velocity at roof height.

Wind velocity at roof height
Available is the wind velocity from weather tape. That wind velocity is measured at a height of 10 m in a flat, open terrain. The wind velocity used in the models is the wind velocity at roof height. With the local circumstances (flat open terrain / woods, hilly terrain, villages, suburbs / town centre) and the relations of DAVENPORT the wind velocity at roof height is determined:

```
IWVELD = 1  A.    Flat, open terrain
                  Vwindh = Vwind6 * (Height/  6.)**0.16

IWVELD = 2  B.    Woods, hilly terrain, villages, suburbs
                  Vwindh = Vwind6 * (Height/ 46.)**0.28

IWVELD = 3  C.    Town centre
                  Vwindh = Vwind6 * (Height/104.)**0.40
```

In these relations is Vwind6 the wind velocity at a height of 6 m in flat, open terrain. With relation A:

```
                  Vwind6 = Vwind10 * (6./10)**0.16
                         = 0.922 * Vwind10
```

- **subroutine "VENT1"**

In- and exfiltration flows are calculated based on an empirical relation for the air exchange rate. Interzonal flows are user given. In case of mechanical imbalance these in- and exfiltration flows and interzonal flows are adjusted to maintain balance. The so-called SIMPLE model.

Relation for the infiltration rate Fv (in times per hour):

```
      Fv = Fva + Fvb*Vwind + Fvc*Vwind**2
```

Fva, Fvb and Fvc are given by user input. Vwind is wind velocity at roof height.

In- and exfiltration flows follow from multiplying the infiltration rate with the volume of the zone. In principle the infiltration flow is equal to the exfiltration flow

The interzonal airflows are given by user input. In principle the interzonal air flow from zone I to zone J is equal to the interzonal air flow from zone J to zone I.

In case of mechanical imbalance above mentioned airflows are adjusted based on the air balance for that zone

- **subroutine "VENT2"**

In- and exfiltration flows and interzonal flows are calculated with a nodal network. Thermal buoyancy, wind pressure, wind fluctuations and mechanical imbalance are taken into account.
Method uses zone temperatures at the end of the last time step and ambient temperature, wind velocity and wind direction of the present time step. The so-called DETAILED model

In general:
The airflow through a crack is given by

$$\text{Flow} = L \cdot C \cdot DP^{1/N}$$

width

```
L  =  crack length
C  =  air leakage coefficient of crack.
N  =  1/power coefficient
DP =  pressure difference across crack
```

A crack is characterized by its C and N. Common value for N = 1,5

Required input parameters:

- crack length L
- characteristics (C and N) of crack
- height at which crack is positioned

Crack height is important for calculation of thermal buoyancy. For calculation of airflows because of wind pressure differences are required:

- wind pressure coeffients CD
- wind velocity at roof height
- wind direction

In general:

Wind pressure = CD * Pthrust

with

CD	= wind pressure coefficient
Pthrust	= thrust = 0.5 * Rho * (Vwind)**2
Rho	= specific mass of ambient air
Vwind	= wind velocity at roof height

The wind pressure coefficients are available in table A.1 – source AIVC.

With the local circumstances (exposed, semi-exposed, sheltered) , the building height (< 3 storeys, 4-6 storeys, > 6 storeys), building shape (ratio length/width), wind direction and orientation of the façade in which the crack is present the CD-value is determined

Remark: a window opening is modelled by 2 cracks. After calculation of the airflows through that window the flows are corrected for wind fluctuations. By these fluctuations the in- and outflow through this window opening increase.

Calculation method

From the air balances for the several zones (sum of entering air flows = sum of leaving air flows) the pressure in each zone can be determined.
The relation between flow and pressure drop across a crack is not lineair, which makes the solution not so easy. Therefore the relation between flow and pressure drop

$$Flow = L \cdot C \cdot DP^{1/N}$$

is made linear

$$Flow = CLP \cdot DP$$

with

$$CLP = L \cdot C \cdot DP^{(1/N-1)}$$

The calculation process is iteratively:

- make a first estimation of the pressures in the zones
- calculate the coefficients CLP
- calculate the pressures in the zones: the air balances over the zones give N-equations (the number of zones) with N-unknowns (the pressures in each zone). By matrix solving all pressures are known.
- calculate the coefficients CLP again
- and so on

The airflow through each crack can now be calculated based on the known pressures.

Table A.1: Wind pressure coefficients CD

Igeval	IWbw	IWdim	IWbst	IWvlk	1	2	3	4	5	6	7	8	9
1	1	1	1	1	.70	.53	.35	-.08	-.50	-.45	-.40	-.30	-.20
2	1	1	1	2	.70	.53	.35	-.08	-.50	-.45	-.40	-.30	-.20
3	1	1	1	3	-.60	-.60	-.60	-.60	-.60	-.60	-.60	-.60	-.60
4	1	1	1	4	-.40	-.45	-.50	-.55	-.60	-.55	-.50	-.45	-.40
5	1	1	1	5	-.10	-.25	-.40	-.50	-.60	-.50	-.40	-.25	-.10
6	1	1	2	1	.40	.25	.10	-.10	-.30	-.33	-.35	-.28	-.20
7	1	1	2	2	.40	.25	.10	-.10	-.30	-.33	-.35	-.28	-.20
8	1	1	2	3	-.60	-.55	-.50	-.45	-.40	-.45	-.50	-.55	-.60
9	1	1	2	4	-.35	-.40	-.45	-.50	-.55	-.50	-.45	-.40	-.35
10	1	1	2	5	-.10	-.30	-.50	-.55	-.60	-.55	-.50	-.30	-.10
11	1	1	3	1	.20	.13	.05	-.10	-.25	-.28	-.30	-.28	-.25
12	1	1	3	2	.20	.13	.05	-.10	-.25	-.28	-.30	-.28	-.25
13	1	1	3	3	-.50	-.50	-.50	-.45	-.40	-.45	-.50	-.50	-.50
14	1	1	3	4	-.30	-.35	-.40	-.45	-.50	-.45	-.40	-.35	-.30
15	1	1	3	5	-.08	-.19	-.30	-.40	-.50	-.40	-.30	-.19	-.08
16	1	2	1	1	.50	.38	.25	-.13	-.50	-.65	-.80	-.75	-.70
17	1	2	1	2	.60	.40	.20	-.35	-.90	-.75	-.60	-.48	-.35
18	1	2	1	3	-.70	-.70	-.70	-.75	-.80	-.75	-.70	-.70	-.70
19	1	2	1	4	-.60	-.63	-.65	-.68	-.70	-.68	-.65	-.63	-.60
20	1	2	1	5	-.18	-.32	-.45	-.53	-.60	-.53	-.45	-.32	-.18
210	1	2	2	1	.28	.18	.07	-.15	-.35	-.47	-.59	-.55	-.50
220	1	2	2	2	.39	.29	.18	-.22	-.60	-.53	-.46	-.37	-.28
230	1	2	2	3	-.60	-.59	-.58	-.60	-.61	-.60	-.58	-.59	-.60
240	1	2	2	4	-.53	-.55	-.56	-.56	-.56	-.56	-.56	-.55	-.53
250	1	2	2	5	-.18	-.31	-.43	-.43	-.42	-.43	-.43	-.31	-.18
26	1	2	3	1	.06	-.03	-.12	-.16	-.20	-.29	-.38	-.34	-.30
27	1	2	3	2	.18	.17	.15	-.08	-.30	-.31	-.32	-.26	-.20
28	1	2	3	3	-.49	-.48	-.46	-.44	-.41	-.44	-.46	-.48	-.49
29	1	2	3	4	-.45	-.46	-.46	-.44	-.41	-.44	-.46	-.46	-.45
30	1	2	3	5	-.18	-.29	-.40	-.32	-.23	-.32	-.40	-.29	-.18

```
- IWbouw   = 1 : low buildings (\< 3 storeys)
             2 : middle high buildings ( 4 - 6 storeys)
             3 : high buildings (> 6 storeys)
- IWdim    = 1 : length/width    1 : 1
             2 :                 2 : 1
- IWbeschut= 1 : exposed
             2 : semi-exposed
             3 : sheltered
- IWvlak   = 1 : at the long side
             2 : at the short side
             3 : roof angle < 10 degree
             4 : 10 degree < roof angle < 30
             5 : roof angle > 30 degree
- IWricht  = 1 :   0.0 degree
             2 :  22.5 degree
             3 :  45.0 degree
             . :  .... degree
            17 : 360.0 degree
```

Remark: coefficients for IWbouw=2 and 3 (middle high and high buildings) are not available at the moment.. It is assumed they are equal to the coefficient for low buildings IWbouw=1

Source:

Air Infiltration and Ventilation Centre Handbook: 'Air infiltration Calculation Techniques - an Application Guide' (Liddament, 1986).

Open windows

Modelling can again be done in the simple way (air flow by open window is user given) or in the detailed way (air flow by open window is calculated).

The model user should specify each window to open in each zone. In figure A.2 this is given schematically

```
 ----------------------------------------------------------
|                                                          |
|    --------------------------------------------          |
|   |               L9              Window        |        |
|   |     -----------                             |
    |    | Part 2    |                            |
    |    | to open   L8                           |
    |    |           |                            |
    |     ----L7-----                             |
    |                                             |
    |                                             L2
    |                                             |
    |                                             |
    |     -----------                             |
    |    | Part 1    |                            |
    |    | to open   L5                           |
    |    |           |                            |        |
|   |     ----L4-----                             |        |
|   |               L6                            |        |
|    --------------------L1-----------------------         |
|                                                 L3   Wall |
 ----------------------------------------------------------
```

Figure A.2: Geometry of window parts to open

It should be specified what type of window opening it is:

- open it by moving in horizontal direction
- open it by moving in vertical direction
- …………

For each type of window opening in the model a translation is made to above shown geometry.

Each of the two openings is modelled as two cracks. Each crack has the following specs:

- crack length L
- characteristics (C and N) of crack
- height at which crack is positioned

And other …….

Control of window opening

Control of the window at day time operation and at night time operation can be selected independently.

General restrictions can be selected why windows are not allowed to be opened (danger for breaking in during weekend and night time, ambient noise during office hours). Also weather restrictions (too cold outdoors, too windy outdoors, ……) can be specified.

In case there are no restrictions windows open if indoor temperature Tzone comes above a given level (given by user input) and they close if temperature becomes below that temperature.

A window can have 5 opening positions between 0 % open (window is closed) and 100 % open (window at maximum position).

In time the position can be fixed (say for instance position 2) or variable (between position 1 and 5).

Variable window opening:

- if Tzone > Topen then window goes 1 position more open
- if Tzone < Topen then window goes 1 position more close.

Possible is for instance a fixed opening position at night time (people are not present) and a variable position at day time (people are present).

To prevent draught:
In case air velocity indoors comes above a certain level (given by user input) the window will go one position more close

Remark: Air flow by wind fluctuations through window openings is not modelled by other programs. Therefore in Appendix AA a description of the VA114-submodel is given.

Appendix AA: Air flow by wind fluctuations

Introduction

In IEA34/43 subtask E (DSF = Double Skin Facade) tests on Building Performance Simulations programs are conducted. One process that is tested is the ventilation of the DSF, i.e. the air flow through the DSF.

VA114's ventilation model takes 3 processes into account:

- air flow by thermal buoyancy
- air flow by wind pressure and by wind fluctuations
- air flow by mechanical imbalance over a zone

In appendix A all processes are described in short. Other participating programs take these processes also into account except air flow by wind fluctuations.

On request a short description of the sub-model for air flow by wind fluctuations is given in this memo.

Remark: VA114 works with one Cp-value for the entire façade, so in case there are no cracks or openings in one of the other walls the air flow by wind pressure will be 0,0.

The model for air flow by wind fluctuations

Wind on a single sided window opening, that is part of a further air tight zone, will cause an air flow through one half of the window opening the zone in and an air flow through the other half of the window opening the zone out. The mean velocity of the air is given by:

$$V_{oprm} = SQRT\ (C_1 * V_{wind}^2 + C_3) \qquad (1)$$

With

V_{oprm} = mean velocity of the air through the window opening to inside
V_{wind} = wind velocity at a local weather station

The coefficient C1 is depending on the sheltering:

- C_1 = 0,004 for exposed situations
- C_1 = 0,002 for semi-exposed situations
- C_1 = 0,001 for sheltered situations

The coefficient C_3 = 0,01; that means that in case there is no wind there is basic mean velocity of V_{oprm} = 0,1 m/s.

So at a wind of 0 m/s the V_{oprm} = 0,1 m/s; at a wind of 10 m/s the V_{oprm} = 0,33 m/s for a sheltered situation and 0,64 m/s for an exposed situation.

During a gust of wind locally the wind will be higher: $V_{wind, max}$. And so the V_{oprm}:

$$V_{oprm,max} = SQRT (C_1*V_{wind,max}^2 + C_3) \qquad (2)$$

Moreover it is assumed:

$$V_{wind, max} = 2,0 * V_{wind} \qquad (3)$$

With the mean velocity V_{oprm} in the window opening the inflow and outflow can be calculated and in the same way the maximum inflow and outflow. Air flows by wind fluctuations.

In practice the window is not the only opening in the zone, so there will be a flow (an inflow or an outflow) through the window opening because of buoyancy, wind pressure and/or mechanical imbalance.

The air flow by wind fluctuations and the air flow by buoyancy, wind pressure and/or mechanical imbalance interact with each other. In case the latter is large with respect to the first the effect of the first (air flow by wind fluctuations) is negligible.

The model takes both air flows into account and calculates the resulting air flows. How that is done will not be discussed here.

Remark: The model is rather empirical and was set up by TNO from measurements in a rather (wind) shielded situation [1].

$$V_{oprm} = SQRT (C_1*V_{wind}^2 + C_2*H*dT + C_3) \qquad (4)$$

With

V_{oprm} = mean velocity of the air through the window opening to inside
V_{wind} = wind velocity at a local weather station
H = height of window opening
dT = temperature difference between inside and outside
C_1 = 0,001
C_2 = 0,0035
C_3 = 0,01

In VA114 the second term (buoyancy) is separately taken into account, so left out in formula.

The calculated air flow rates (by formula 4) act as 'guaranteed' minimum value for urban situations. These air flow rates will often be exceeded in more wind exposed situations. For those situations the wind coefficient C_1= 0,001 will be higher. On the analogy of Awbi [2], table 3.4, page 67, it was decided to take for exposed situations C_1=0,004 and for semi-exposed situations C_1=0,002.

Resume

This appendix describes the model of air flow by wind fluctuations. The model is rather simple and should be seen as a first step to take this effect into account.

[1] Phaff, J.C. , de Gids, W.F. et al
The ventilation of buildings. Investigation of the consequences of opening one window on the internal climate of the room, TNO report C448, March 1980.

[2] Awbi, H.B.
Ventilation of buildings. Air infiltration and natural ventilation (chapter 3), E & FN Spon, ISBN 0-419-15690-9.

Appendix B: Solar gain and solar exchange between zones

Model description

In subroutine "ZONINT" the solar gain and solar exchange between zones is simulated. In figure B.1 this is given very schematically.

```
          \                \              \
\   .---==========-.------=======----.---======---.
  \ |        \     |          \      |      \|    |
    ||         \   |            \|   |      -    ||
    ||\          \ ||           -   ||           ||
    ||  \|         ||               ||           ||
    |   -          ||\              ||            |
\   |              ||  \            ||            |
  \ |              ||    \|         ||            |
    ||             ||    -          ||           ||
    ||\            ||               ||           ||
    ||  \|         ||               ||           ||
    |   -          |                 |            |
    |              |                 |            |
    |              |                 |            |
    .--------------.-----------------.------------.
```

Figure B.1: Solar enters a zone by external windows and by internal windows. Windows can be present in the facades and in the roof.

It is calculated what fraction of the solar gain of a zone

- is used for the evaporation by plants
- comes sensible available to the air node
- comes sensible available to the walls; the distribution over all surfaces within the zone is calculated.

Direct and diffuse solar radiation are treated separately.

Steps in the calculation process:

. *calculation of the solar gain of a zone*

External windows:

```
SOMZON = Σ A(IV,IVLK)*TRANS(IV,IVLK)*
           (Amdir*Gdir(IV,IVLK)+Amdif*Gdif(IV,IVLK))
```

with

```
SOMZON      = solar gain
A           = area of the window
TRANS       = transmission of the window (incident angle 45°)
Amdir       = Angular Modifier-direct radiation (=1.000 at 45°)
Gdir        = intensity direct solar radiation on the window
Amdif       = Angular Modifier-diffuse radiation (at 58°)
Gdif        = intensity diffuse solar radiation on the window
```

Internal Windows:
The solar radiation, that enters the zone by internal windows is added to the solar gain SOMZON.

. *calculation of the latent and the sensible part of the solar gain*

Latent part (evaporation by plants)

```
SOMZONV     = VZON(IV) * SOMZON
```

Sensible part

```
SOMZONS     = (1.0 - VZON(IV)) * SOMZON
```

The fraction VZON is an input of the model.

. *calculation of the convective part and the radiative part*

Convective part (to the air node)

```
QZONL(IV) = CZON(IV)      * SOMZONS
```

Radiative part (to the wall surfaces)

```
QZONW(IV) = (1-CZON(IV)) * SOMZONS
```

The fraction CZON is an input of the model.

. *Calculation of the internal distribution of the radiative part.*

Many models are available here, from very simple ones (100% goes to the floor) to very detailed ones.
For the calculation of the exchange between zones a detailed model, that calculates the actual solar distribution (so each time step) is applied.

Detailed model for the internal solar distribution

The distribution of the solar radiation is separately done for direct and for diffuse radiation and is dependent on the solar position, the geometry of the zone, the absorption / reflection of the internal surfaces bounding that zone.

Each window is treated separately.

The solar entering the zone by a window has two components:
- a direct component
- a diffuse component

Remark: a fraction FDIFRM of the direct radiation is converted into diffuse when it passes the window. The fraction FDIFRM is an input of the model (at this moment FDIFRM=0.0).
Remark: the circumsolair diffuse radiation component is treated as direct solar radiation

The internal distribution is calculated in subroutine ZABSVLK: the fraction of the radiative part of the solar gain that is absorbed by each surface. The part absorbed by the surface of a window is assumed to pass that window (to outdoors or to a neighbouring zone) for 100 %.

The direct component

Subroutine PZONI2 calculates, based on the solar position, what internal surface(s) receive direct radiation, that enters the zone by a specific window. A fraction (= absorption coefficient) of this direct radiation is absorbed, the rest (1-absorption) is diffuse reflected.

Remark: in case the internal surface is an internal window PZONI2 calculates also what internal surface(s) of the neighbouring zone recieve this direct radiation.

Remark: PZONI2 uses a Ray-tracing method; shading by external facade parts, by own building parts and by window setback is integrated in this method.

Remark: for simpler cases (rectangular zones; no internal window) subroutine PZONI0 (100 % of the direct radiation hits the floor) and subroutine PZONI1 (a projection method, that calculates where the direct solar radiation hits the internal surfaces) are available.

The diffuse component

The calculation of the distribution of the diffuse radiation (diffuse entered by the windows + the diffuse reflected direct radiation) happens by exchange factors. These exchange factors FUFACA(IV,I,J) are derived from the view factors and the absorption coefficients of all internal surfaces.

Remark: the absorption coefficient of the surface of an internal window is assumed to be equal to the g_{value} of that window; so (1-g_{value}) is reflected by that window surface.

Remark: in case of internal windows the exchange between zones is calculated iteratively.

The result of this calculation is the solar absorbed by each internal surface.

Final Remark: as can be seen from figure 1 the following situations can occur:

- a beam of rays hits a part of an internal window
- a beam of rays hits more than one internal window
- several beams of rays hit the same internal window.

The model is able to handle these situations.

Appendix C: Solar shading

Model description

In subroutine "ZONEXT" the solar radiation on external surfaces is simulated. Based on the orientation of each surface and the known solar radiation on each orientation. Both the unshaded direct component (Gdir(IV,IVLK)) and the unshaded diffuse components (Gdif(IV,IVLK)) are known.

For solar shading a distinction is made between direct and diffuse solar shading

Direct solar shading

Direct solar shading happens by surrounding buildings (subroutine 'schaduw1'), by external facade parts, by own building parts and by setback of the window (subroutine 'schaduw2').

Shading factors:

Pschv1 (IV,IVLK)	surrounding buildings
Pschv2 (IV,IVLK)	external facade parts, own building parts, setback window

Remark: Factor = 0.0 is not shaded, factor = 1.0 is fully shaded
Remark: only windows have shading, shading of opaque walls is (until further notice) not taken into account

These factors are combined to one factor

Psch0(IV,IVLK) = 1. - (1.- Pschv1(IV,IVLK)) * (1. - Pschv2(IV,IVLK))

Diffuse solar shading

Diffuse solar shading by surrounding buildings is not taken into account; diffuse solar shading by external facade parts, by own building parts and by setback of the window is (subroutine 'schadw2d').

Shading factors:

Pschv1d (IV,IVLK)	surrounding buildings (is not taken into account, i.e. = 0.0)
Pschv2d (IV,IVLK)	external facade parts, own building parts, setback window

Remark: Factor = 0.0 is not shaded, factor = 1.0 is fully shaded
Remark: only windows have shading, shading of opaque walls is (until further notice) not taken into account

These factors are combined to one factor

Psch1(IV,IVLK) = 1. - (1.- Pschv1d(IV,IVLK)) * (1. - Pschv2d(IV,IVLK))

Solar radiation, shading included

The shaded solar radiation on external surfaces is given by:

Direct solar radiation	Gdir(IV,IVLK) = (1.0-Psch0(IV,IVLK)) * Gdir(IV,IVLK)
Diffuse solar radiation	Gdif(IV,IVLK) = (1.0-Psch1(IV,IVLK)) * Gdif(IV,IVLK)

Remark:
The circumsolar diffuse radiation component is treated as direct solar radiation.

More details about the mentioned models (subroutine Schaduw1, Schaduw2 and Schadw2d) is given below.

Direct solar shading by surrounding buildings
Direct solar shading by surrounding buildings is simulated in subroutine 'schaduw1'.

<u>The method</u>
For a number of points on an external surface (see figure C.1.) the skyline is determined:
SKYH(IGR,IV,IPUNT)
This is done once and for each external surface.

```
5.----------------.4
 |                |
 |       .1       |
 |                |
2.----------------.3
```

Figure C.1: External surface with 5 points to determine shading

If the solar height at the given solar azimuth is below the skyline of a point then there is shading in that point (Psch = 1.0), if it is above there is no shading (Psch = 0.0).

The shading factor for that surface is the average shading factor of the 5 points.

Direct solar shading by external façade parts, own building parts and by setback of window
Direct solar shading by external facade parts, by own building parts and by setback of the window is simulated in subroutine 'schaduw2'.

In figure C.2a and b the situation with obstructions is shown

```
 . . . . . . . . . . . . . . . . .
.                                .
.           Surface IVLK         .
.                                .
.           4.    1.-----------------------------.4  4.
.           /|    /              .              /    /!
.          / |   /         Obstruction 1       /    / !
.         /  |  .-----------------------------.    /  !
.        /   !  2                .            3   /   !
.       /    !                   .               /    !
.     3.     !                   .             3.     !
.      !     !                   .              !     !
.      !     !                   .              !     !
.      !Obs 2!                   .              !Obs 3!
.      !     !                   .              !     !
.      !     .1                  .              |     .1
.      !    /                    .              !    /
.      !   /                     .              !   /
. . . .!. /. . . . . . . . . . . .              !  /
       ! /                                      ! /
       !/                                       !/
      2.                                       2.
```

Figure C.2a: External obstructions (facade parts) – side view

```
 --------------------------------------
|                            .          |
|       IV = 1               .  IV = 2  |
|                            .          |
|       Surface IVLK         .          |
 -------==.==.==.==.==--------. . . . . . |
     \                      |           |
      \                     |           |
       \                    |  IV = 3   |
        \                   |           |
         \                  |           |
Obstruction  \               -----------
```

Figure C.2b: External obstructions (facade parts) – top view

<u>The method</u>
The projections of all obstructions and all surfaces of the building on a plane perpendicular to the solar rays are determined. The overlap between the projection of an obstruction and the projection of a surface gives information about the shading:
- ‘no overlap’ means ‘no shading’
- ‘overlap’ means ‘shading’; the size of the overlap is a measure for the shading (0.0-1.0)

<u>Remark:</u> another new method uses Ray-tracing to determine the shading factor; at the moment it is only in use for windows and is integrated with the calculation method for the internal solar distribution. For this method the window is divided into 10x10 points.

Diffuse solar shading
Diffuse solar shading by external facade parts, by own building parts and by setback of the window is simulated in subroutine ‘schadw2d’.

To the diffuse solar radiation belong the isotropic component, the component from the horizon and the ground reflection component. The circumsolar component is treated as direct solar radiation.

In figure 2a and b the situation with obstructions is shown

The method
The shading by an obstruction on a surface is determined by the view factor between that surface and that obstruction.

The shading by setback of the window follows from the sum of the view factors between that surface and the edges around that surface: Fschzyv(IV,IVLK)

The shading by own building parts follows from the sum of the view factors between that surface and the own building parts: Fschegd(IV,IVLK)

The shading by other facade parts (obstructions) follows from the sum of the view factors between that surface and the several obstructions: Fschbel(IV,IVLK)

Total shading::
```
Fschdif = Fschzyv(IV,IVLK) + Fschegd(IV,IVLK) + Fschbel(IV,IVLK)
```

Appendix D: Solar processor of VA114

Introduction

In IEA34/43 subtask B1 (MZ = Multi Zone-non air) and subtask E (DSF = Double Skin Façade) tests on Building Performance Simulations programs are conducted, where the solar radiation impinging on the façade is the most important driving force. From first comparisons it seemed VA114 predicts a somewhat higher incident solar radiation on the façade starting from the same solar source on the horizontal surface. In this appendix the solar processor of VA114 is described in short to give the other task participants inside in that model. An earlier version of this appendix was distributed and reactions were gathered. A summary of these reactions is given. It did not lead directly to the cause, but the comments and suggestions given will be checked. That will be done in due time, but not as part of this IEA34/43 Task.

The description of VA114's solar processor

Solar position

Solar position is given by solar height (h) and solar azimuth (az). Both are calculated half way the hour.

Used formulas:

- hour angle OHM
  OHM = 2 * π / 24 * (12,5 – ST)

  with solar time ST
  ST = KL – DTIME
  In this formula
  KL = hour of the day
  DTIME = time shift in hours
  The time shift DTIME is given by
  DTIME = EQT/60 – (DLONGD/15 – ITIMEZ)
  with
  EQT = equation of time (in minutes); EQT depends on day of the year
  DLONGD = longitude of site (in degrees; East = positive)
  ITIMEZ = time zone (East = positive)

- Solar height H and solar azimuth AZ
  Sinus of solar height (sinh) and cosinus of solar azimuth (cosaz) are both calculated based on solar declination, latitude of site and hour angle OHM.

Splitting in Direct and Diffuse radiation

For IEA-34/43 MZ (subtask Multi-Zone Non air) the GH (Global radiation on the horizontal) and GBN (Normal Beam radiation) is given on tape. With sinus of solar height (sinh) follows for the GBH (Horizontal Beam radiation):

GBH = GBN * sinh

and for the GDH (Horizontal Diffuse radiation)

GDH = GH – GBH

For IEA-34/43 DSF (subtask Double Skin Façade) the GH (Global radiation on the horizontal) and GDH (Horizontal Diffuse radiation) is given on tape. For the GBH (Horizontal Beam radiation) follows:

GBH = GH – GDH

and with sinus of solar height (sinh) the GBN (Normal Beam radiation):

GBN = GBH / sinh

Remark:
GBN should be lower than a maximum value GBN,max that is based on the outer atmospheric normal radiation G0N and the air mass AIRM. Correction:

IF (GBN > (GBN,max +55,6)) THEN GBN = GBN,max

The corrected GBN results in a corrected GBH and with GDH = GH – GBH in a corrected GDH.

Splitting Diffuse on the horizontal in 3 components

The diffuse on the horizontal surface is split into 3 components based on Perez [1]:

- Isotropic component D1
  D1 = GDH * (1,0 – F1ACC)
- Circumsolar component D2
  D2 = GDH * (F1ACC / CZET)
- Component from the horizon D3
  D3 = GDH * F2ACC

With

F1ACC = new circumsolar brightness coefficient
F2ACC = horizon brightness coefficient
CZET = cosinus of zenith angle

Remark:
F1ACC and F2ACC should be both between 0,0 and 1,0; circumsolar (D1) has as maximum value of 500 W/m^2.
If not values F1ACC, F2ACC or D1 are given the limit value and components are recalculated.

Calculation of total solar radiation on a tilted surface

By geometric formulas the contribution of the direct component, the 3 diffuse components and the ground reflected component to the total radiation on the tilted surface are calculated.

The used formulas:

- Direct solar radiation:
  GBT = GBN*COS(Teta)
  With
  GBN = Normal Beam radiation
  Teta = angle of incidence of solar radiation on the tilted surface

- Diffuse isotropic radiation:
  GD1 = D1 * 0,5 * (1,0 + COS(Beta))
  With
  D1 = diffuse isotropic component on horizontal
  Beta = tilt of surface

- Diffuse circumsolar radiation:
  GD2 = D2*COS(Teta)
  With
  D2 = diffuse circumsolar component
  Teta = angle of incidence of solar radiation on the tilted surface

- Diffuse radiation component from horizon:
  GD3 = D3 * SIN(Beta)
  With
  D3 = diffuse component from the horizon
  Beta = tilt of surface

- Ground reflection:
  GRT = GH * RHO * 0,5 * (1,0 - COS(Beta))
  With
  GH = total radiation on the horizontal
  RHO = ground reflectivity
  Beta = tilt of surface

Total radiation on tilted surface:

GT = GBT + GD1 + GD2 + GD3 + GRT

<u>Remark</u>

VA114's solar processor is described. The big lines are given. If necessary more details can be provided, such as details about calculation of:

- equation of time EQT
- solar height and solar azimuth
- outer atmospheric normal radiation G0N
- Perez factors F1ACC and F2ACC; zenith angle ZET
- Angle of incidence of solar radiation impinging on the tilted surface
- ……..

Reactions and suggestions from participants

Valuable reactions were received from Joel Neymark (USA) and Paul Strachan (GB).

Joel Neymark

He read about the Perez 1987, 1988 anisotropic sky model in Duffie and Beckman (*Solar Engineering of Thermal Processes*, 1991) that there are a number of disagreements that could occur with respect to how the model details are implemented ...
e.g.

- for calculating circumsolar diffuse a maximum for cos(zenith angle) of cos(85) is shown (*remark VABI: VA114 takes that into account*).
- the implementation of the brightness coefficients could easily be different among modelers (for those using a Perez model).

Duffie and Beckman note that this Perez model generally predicts slightly higher total radiation on a tilted surface, so in the MZ work the VA114 results are consistent with that. Duffie and Beckman recommend Perez for surfaces with azimuth angle far away from 0 [which is common for many building vertical surfaces]

Paul Strachan

Most of the calculations looked OK to him.

One difference is that VA114 is using Perez 1987. Paul's program ESPr was updated to the Perez 1990 model (probably also used by TRNSYS-TUD and Energy+). His experience: it does make some difference, but not a huge amount.

Paul (ESPr) supplied detailed results on direct and diffuse radiation for the comparative tests concerning solar radiation on the façade. For the period April 17 - April 30 a comparison between ESPr and VA114 was made [2]:

- concerning the solar sum over the period:
    - Direct - VA114 is 1,4% higher than ESPr
    - Diffuse - VA114 is 4,2% higher than EPSr
    - Total - VA114 is 2,8% higher than EPSr
- daily plots show VA114 is somewhat higher in the peaks!!!

Paul suggested another possibility for comparisons: compare with the detailed solar processing analysis that used the EMPA data set.
It was published as:

> Loutzenhiser P G, Manz H, Felsmann C and Strachan P A, Frank T and Maxwell G M Empirical Validation of Models to Compute Solar Irradiance on Inclined Surfaces for Building Energy Simulation, Solar Energy, 81(2), Feb 2007, pp 254-267.

All the measured data and the predictions are included on the IEA34/43 FTP site.
Measured were direct normal as well as global horizontal and diffuse horizontal.

Other comparisons by Vabi Software BV

The solar results of the comparative and empirical DSF-tests were studied intensively. There were a lot of observations, concerning all programs [3]. But our conclusion about the VA114 solar processor is:

> On total radiation and direct radiation VA114 is close to the other programs. On diffuse radiation two groups of programs can be distinguished, a higher group and a lower group; VA114 belongs to the higher group and is the highest in that group.

So the differences are much smaller than was found from the earlier comparisons

Remark: information about what model assumptions other solar processors are using is not available at the moment. The individual Modeler's reports should provide that information. Not all Modeler's reports are available at the moment

Resume

In this appendix VA114's solar processor is described in big lines. Valuable reactions / suggestions were received from task participants. It did not lead directly to the cause of the differences, but the suggestions given will checked. That will be done in due time, but not as part of this IEA34/43 Task. Until now it was concluded the differences between VA114 and the other programs are much smaller than was found from the first, earlier comparisons

Literature

[1] Perez et all
"A new simplified version of the Perez diffuse irradiation model for tilted surfaces", Solar Energy Voume 30, No. 3, pp. 221-231, 1987.

[2] Wijsman, A
"Solar radiation VA114 versus ESPr", Excel sheet, June 12th, 2007

[3] Wijsman, A
"Solar radiation predicted by the several programs", May 31st, 2007

Appendix E: Questionnaire completed for the program VA114

GENERAL

1	**Program name and version number**	**VA114 – version 2.25**
2	**Name of organization performed the simulations**	**VABI Software bv**
3	**Name of person performed simulations and contact information**	**A. Wijsman** **Email: a.wijsman@vabi.nl**

4 Program status

☐ Freeware
X Commercial
☐ Other, please specify

5 Time convention for weather data: first interval in the weather input lasts 00:00-01:00, climate is assumed constant over the sampling interval

X Yes
☐ No, please specify

CALCULATION OF BOUNDARY CONDITIONS

6 Please specify the solar model for calculation of incident solar radiation
See appendix D to this Modeller report

7 Transmission of the direct solar radiation into zone 1

☐ Calculated with the constant solar heat gain coefficient (g-value)
☐ Calculated with the g-value as a function of incidence (function of incidence is fixed within code)
☐ Calculated with the g-value as a function of incidence (function of incidence is user defined)
X Other, please specify: Calculated with Transmission (as a function of incidence – user defined) and Absorption in the pane;

8 Transmission of the direct solar radiation into zone 2

☐ Treated as diffuse solar radiation and calculated with the constant g-value
☐ Calculated with the g-value as a function of incidence (function of incidence is fixed within code)
☐ Calculated with the g-value as a function of incidence (function of incidence is user defined)
X Other, please specify: Calculated with Transmission and Absorption in the panes; properties at angle of incidence of 45 degree

9 Transmission of the diffuse solar radiation into zone 1

☐ Calculated with the solar heat gain coefficient at the solar incidence 60^o
X Other, please specify: Calculated with Transmission (at solar incidence of 58^o) and Absorption in the pane.

10 Distribution of solar radiation to the surfaces in the zone 1

☐ Distributed equally to all surfaces
☐ Calculated according surface area weighting
☐ Calculated according to solar path and view factors
X Other, please specify: Different treatment for Direct and Diffuse solar radiation. Distribution of Direct solar is calculated by solar path; partly absorbed and partly diffuse reflected at surfaces that are hit. Distribution of Diffuse solar and Diffuse reflected Direct solar is calculated by absorption factors (based on view factors and absorption coefficients of the surfaces that are hit)

11 Distribution of solar radiation to the surfaces in the zone 2

☐ Distributed equally to all surfaces
☐ Calculated according surface area weighting
☐ Calculated according to solar path and view factors
X Other, please specify: same as distribution in zone 1

MODEL DEFINITIONS

12 Air temperature in the zone 1 is calculated as:

X One node temperature
☐ Few zones are stacked on the top of each other and the air temperature in each of zones is calculated, please specify number of stacked zones
☐ Other, please specify

13 Air temperature in the zone 2 is calculated as:

X One node temperature
☐ Few zones are stacked on the top of each other and the air temperature in each of zones is calculated, please specify number of stacked zones
☐ Other, please specify

HEAT EXCHANGE WITH EXTERIOR

14 External heat transfer coefficients

X Split radiative/convective
☐ Combined radiative/ convective
☐ Other, please specify

15 External heat transfer coefficients are calculated with identical assumptions for all surfaces (window frame, window glazing, walls etc.)

☐ Yes
X No, please specify : External heat transfer coefficients are not calculated (see external convection and external radiative heat exchange)

16 External convection

☐ Constant coefficients fixed within code
X User-specified constant coefficients
☐ Calculated within code as a function of orientation
☐ Calculated within code as a function of wind speed
☐ Calculated within code as a function of wind speed and direction
☐ Other, please specify

17 External radiative heat exchange

☐ Assumed to be ambient temperature
X Assumed to be sky temperature
☐ Other, please specify

HEAT TRANSFER WITHIN ZONES

18 Internal heat transfer coefficients

X Split radiative/convection
☐ Combined radiative/ convective
☐ Other, please specify

19 Internal heat transfer coefficients are calculated with identical assumptions in all zones and for all surfaces (window frame, window glazing, walls etc.)

☐ Yes
☐ No, please specify : Ixternal heat transfer coefficients are not calculated (see internal convection and internal radiative heat exchange)

20 Internal convection

☐ Constant coefficients fixed within code
X User-specified constant coefficients
☐ Calculated within code as a function of orientation (vertical/horizontal)
☐ Calculated within code as a function of temperature difference
☐ Calculated within code as a function of air velocity in the zone
☐ Calculated within code as a function of surface finishes
☐ Other, please specify

21 Longwave radiation exchange within zone

☐ Constant linearized coefficients
☐ Linearized coefficients based on view factors
X Linearized coefficients based on view factors and surface emissivities
☐ Nonlinear treatment of radiation heat exchange
☐ Other, please specify

WINDOW

22 Window

X Window frame and glazing are modelled as separate elements of construction; properties are user defined
☐ Window frame and glazing are modelled as separate elements of construction, but the total U-value is calculated within the code
☐ Window frame and glazing are modelled as separate elements of construction, but the total U-value and g-value are calculated within the code
☐ Other, please specify

23 Glazing temperature

☐ Calculated for 1 nodal point on the basis of fixed resistance
X Calculated dynamically, using the same scheme as for opaque elements
☐ Other, please specify

AIRFLOW MODEL

24 Discharge coefficient

X Fixed within the code
☐ User-specified fixed value
☐ Calculated by code, please specify what are the parameters involved in code calculations

☐ Other, please specify

25 Pressure difference coefficients

☐ Fixed within the code, identical for all openings sharing the same surface
X User-specified, identical for all openings sharing the same surface
☐ User-specified for every opening
☐ Other, please specify

26 Calculated mass flow rate in the model is a function of

X Buoyancy force
X Wind pressure
X Wind fluctuations
☐ Other, please specify