

WIS, THE EUROPEAN TOOL TO CALCULATE THERMAL AND SOLAR PROPERTIES OF WINDOWS AND WINDOW COMPONENTS

Dick (H.A.L.) van Dijk and Henk (H.P.) Oversloot
TNO Building and Construction Research, Delft, The Netherlands

ABSTRACT

WIS is a software tool, developed in a European research project, for the calculation of the thermal and solar properties of commercial and innovative window systems on the basis of known component properties and thermal and solar/optical interactions between the components.

WIS is available without charge and its further development and technical support is guided by the European network "WinDat", consisting of major research institutes and manufacturers of window components (glazings, solar shading, ...).

One of the features of the software tool is the combination of glazings and shading devices, with the option of free or forced air circulation between the components. This makes the tool particularly suited to calculate the thermal and solar performance of complex windows and active facades.

The paper describes the main features of WIS and the activities in WinDat. Specifically highlighted is the modelling of the thermal/solar properties of solar shading devices and their interaction with the other components in the window.

INTRODUCTION

WIS is a European software tool for the calculation of the thermal and solar properties of commercial and innovative window systems on the basis of known component properties and thermal and solar/optical interactions between the components.

One of the unique elements in the software tool is the combination of glazings and shading devices, with the option of free or forced air circulation between the components. This makes the tool particularly suited to calculate the thermal and solar performance of complex windows and active facades.

WIS has built in algorithms based on international (CEN, ISO) standards, for internationally uniform product comparison, but WIS also contains advanced calculation routines for those components or conditions where no standards are available yet or current standards do not apply. In this way WIS hopes to contribute to the further international

standardisation and harmonisation of product information.

The first version of the tool was available as the end product of a previous EU R&D Energy Programme: EU R&D project 'Advanced Windows Information System (WIS)', (1994-1996, coordination: TNO) (van Dijk and Bakker, 1995, van Dijk and Goulding, 1996).

Since 1996 this version was in use and highly appreciated by many users from different professions. But it lacked mass penetration, mainly due to a fee being asked per license (to cover distribution and support costs) and a poorly populated database containing only a limited number of examples of products.

The kind of component data needed are for instance spectral data sets of the optical properties of the available commercial glazings in Europe, optical properties of shading devices (venetian blinds, roller blinds, ..) and scattering glazings, thermal properties of edge spacers (for sealed double glazings) and thermal properties of window frame profiles on the market.

THEMATIC NETWORK WINDAT

Objectives

To overcome these limitations TNO initiated in 2001 a European Thematic Network WinDat.

WinDat ("Windows as Renewable Energy Sources for Europe - Window Energy Data Network", 2001-2004) is supported by DG for Energy and Transport of the European Commission (van Dijk, 2001, van Dijk and Hutchins, 2002).

The Networks membership comprises about 40 leading European research and educational organizations, industries, consulting engineers and designers, including a strong representation in relevant international standardization groups. (see also <http://www.windat.org>).

The main activities of the WINDAT Network are:

- support and guidance of the further development of WIS
- set up of WIS distribution without charge (e.g. via web site)
- validation the program's algorithms

- set formats for the standardized input of component data
- organize population of the component databases with the data from commercial products and data from research
- set up of benchmark tests (also available for similar tools)
- create links to building simulation tools (ESP, Radiance, etc.)
- preparation of training courses and sets of examples
- set up of a user forum

The ultimate aim of the WinDat consortium is that WIS will be collectively supported and used in research, industry, standardization, education and design throughout Europe to compare, select and promote innovative windows and window components for the optimum use of renewable energy (solar gains and daylight), highest energy savings (thermal insulation) and the best indoor comfort (solar shading, daylight quality).

Component databases

One of the early achievements, summer 2002, was the agreement with all major flat glass producers in Europe, on a European procedure and format for the collation of optical properties of non-scattering glazings. This European database is compatible with a similar existing database in USA (Optics5, 2003). Under this agreement series of data sets of commercially available glazings are currently being submitted as a first step towards populating the WIS database with comprehensive sets of certified component data. Simultaneously, similar formats are being developed for optical data from scattering glazings, plastics and solar shading products and thermal properties of frame profiles.

MODELLING SHADING DEVICES

WIS and ISO 15099

The way WIS treats the solar optical properties of “layer type” of shading devices has been the basis of a draft international standard ISO DIS 15099:2003, a detailed calculation method for the thermal and solar properties of windows including solar shading devices.

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

The algorithms in WIS on the heat transfer related to air flow in a cavity, and the air flow rate in case of free convection in a gap, for instance between a glass pane and a shading device, has inspired the development of equations for these phenomena in standard detailed calculation methods as laid down in prEN 13363-2 and ISO DIS 15099. The final version of the equations developed for ISO DIS 15099 have –

in turn- recently been adopted in a new version of WIS.

Shading devices are permeable for radiation and air

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 (see fig. 1). 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.

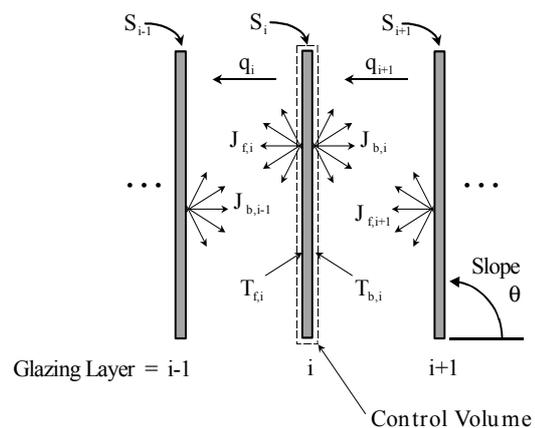


Figure 1 Energy balance per layer; each layer is a pane, suspended film or shading device. The shading device, however, may be permeable to air and solar and thermal radiation

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. 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.

Solar optical properties; effect of scattering

A particular characteristic of a shading device compared to ‘normal’ glazings or films is, that the incident solar radiation may change direction while being transmitted or reflected at the layer.

For the evaluation of thermal effects the following approximation is considered to be sufficiently accurate (see fig. 2):

Beam radiation transmitted or reflected by the solar shading device is considered to be split into two parts.

- a undisturbed part (specular transmission and reflection; "direct-direct");
- a disturbed part. The disturbed part is approximated as anisotropic diffuse (Lambertian; "direct-diffuse").

Diffuse radiation transmitted or reflected by the solar shading device is assumed to remain diffuse ("diffuse-diffuse").

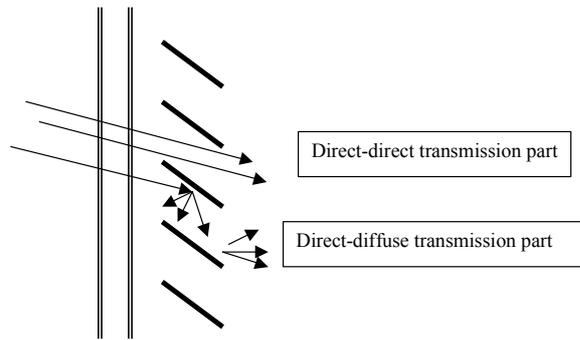


Figure 2 Illustration of split of transmission between a direct-direct and a direct-diffuse part

Venetian blinds and optical properties

A further approximation for venetian blinds is, that the reflection at the slats is diffuse and therefore can be calculated using the view factor approach.

An exact description of the way solar radiation travels through the system would require a full three-dimensional calculation using the full matrix of the transmission, absorption and forward and backward reflection for each angle of incidence at each component. For venetian blinds this would include the curvature of the slats and taking into account possible specularly of solar reflection at its surface. For the evaluation of the spatial distribution of daylighting this would be the necessary way to proceed (van Dijk, 2000, 2002).

It was proven by comparing the results with a detailed Monte Carlo ray tracing model (Molina, 1999) that, for calculating the energy properties, the two-split approximation is sufficiently accurate. Figure 3 shows the total solar energy transmittance (g-value) calculated by both approaches: for not too high solar incidence angles and reflection of the lamellas not highly specular the difference is smaller than 0.05.

Note: the M.C. model is currently being built in in WIS to provide a more detailed (nut time consuming...) alternative method.

g-value indication

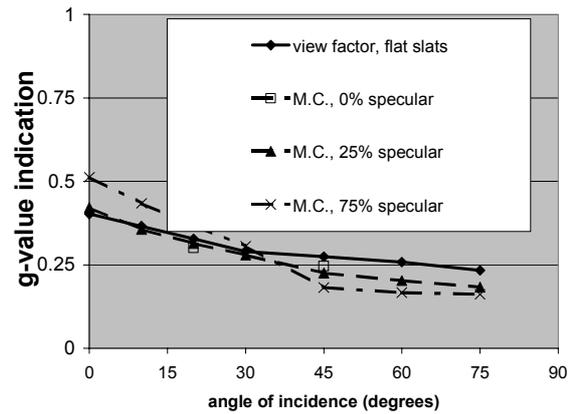


Figure 3 Comparison solar energy transmittance calculated with bi-directional (M.C.) and by view factor method

Venetian blinds are normally also semi-transparent for infrared (thermal) radiation. In order to obtain the IR transmittance and reflectance of the shading device for given (IR) slat properties, the same model is used as for the calculation of the "diffuse-diffuse" part of the transmission and reflection of solar radiation, replacing the slat's solar optical properties by its thermal radiation properties.

In the next chapter we will show more details on the sensitivity of the solar transmittance for incident solar angle.

Vented gaps (air flow and convective heat exchange)

In case of a vented gap, the convective heat exchange between the air flow and the adjacent surfaces is assumed to be:

$$h_{cv,i} = 2h_{c,i} + 4V_i \quad (1)$$

in which

$h_{cv,i}$ is the convective heat exchange coefficient between air and surface (W/m^2K)

$h_{c,i}$ is the convective heat exchange coefficient between surface and surface without ventilation, (W/m^2K)

4 is an empirical coefficient (J/m^3K)

V_i is the mean air velocity in the gap (m/s)

Note: $h_{c,i}$, the convective heat exchange coefficient between surface and surface without ventilation, is based on $Nu(Ra)$ relations as given in ISO 15099. These $Nu(Ra)$ equations are based on more recent research and therefore differ from similar equations given in EN 673 and the equivalent ISO 10291 for multiple glazings as such; this may lead to discrepancies in the order of 0.1 in U-value of the window (ISO 15099 leading to higher values).

For the temperature profile of the air flow we assume a plug flow. Consequently, it depends on the air velocity in the space and the heat transfer coefficient to both layers. The air temperature profile in space i is thus given by:

$$T_{\text{gap}_i}(h) = T_{\text{av},i} - (T_{\text{av},i} - T_{\text{gap}_i,\text{in}}) \cdot e^{-h/H_{0,i}} \quad (2)$$

where

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

$H_{0,i}$ is the characteristic height (temperature penetration length), see Equation 4, in m

$T_{\text{gap}_i,\text{in}}$ is the temperature of the incoming air in gap i , in °C

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

$$T_{\text{av},i} = (T_{b,i} + T_{f,i+1})/2 \quad (3)$$

where

$T_{b,i}$ is the temperature of the surface of layer (pane, film or shading) i , facing cavity i in °C

$T_{f,i+1}$ is the temperature of the surface of layer (pane, film or shading) $i+1$, facing cavity i , in °C.

The characteristic height of the temperature profile is defined by:

$$H_{0,i} = \frac{\rho_i \cdot c_p \cdot s_i}{2 \cdot h_{\text{cv},i}} \cdot V_i \quad (4)$$

where

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

ρ_i is the density of the air at temperature T_{gap_j} , in kg/m³

c_p is the specific heat capacity, in J/(kg.K)

s_i is the width of the cavity i , in m

$h_{\text{cv},i}$ see eq. (1)

The leaving air temperature is given by:

$$T_{\text{gap}_i,\text{out}} = T_{\text{av},i} - (T_{\text{av},i} - T_{\text{gap}_i,\text{in}}) \cdot e^{-H_i/H_{0,i}} \quad (5)$$

where

$T_{\text{gap}_i,\text{out}}$ is the temperature of the air at the outlet of gap i , in °C

H_i is the height of space i , in m.

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

$$T_{\text{gap}_i} = T_{\text{av},i} - \frac{H_{0,i}}{H_i} (T_{\text{gap}_i,\text{out}} - T_{\text{gap}_i,\text{in}}) \quad (6)$$

where

T_{gap_i} is the equivalent mean temperature of the air in the cavity i , in °C

Naturally vented gaps

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 fig.4).

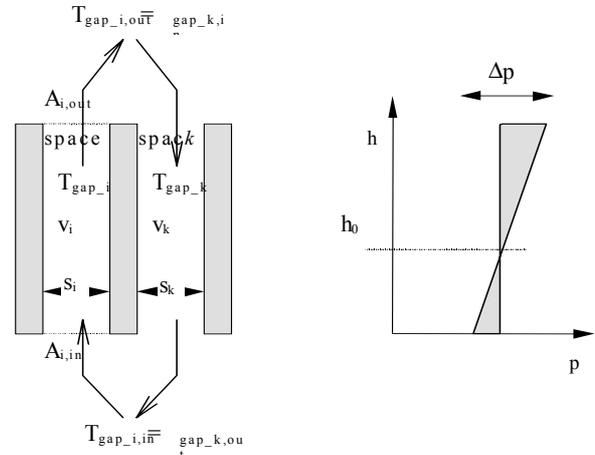


Figure 4 Naturally (buoyancy driven) air flow, in the illustrated case between two connected gaps; to the right: the neutral pressure plane

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. 6). The driving pressure difference Δp_T may be written approximately as:

$$\Delta p_{T,i,k} = \rho_0 \cdot T_0 \cdot g \cdot H_i \cdot \cos \varphi_i \cdot \frac{(T_{\text{gap}_i} - T_{\text{gap}_k})}{T_{\text{gap}_i} \cdot T_{\text{gap}_k}} \quad (7)$$

where

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

T_{gap_i} is the equivalent (mean) temperature of the air in the space i , K;

T_{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;

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 (Bernoulli's equation):

$$\Delta p_{B,i} = \frac{\rho_i}{2} V_i^2 \quad (8)$$

Steady laminar flow (Hagen-Poiseuille law):

$$\Delta p_{HP,i} = 12 \cdot \mu_i \cdot \frac{H_i}{S_i^2} V_i \quad (9)$$

Pressure loss in the inlet and outlet openings:

$$\Delta p_{Z,i} = \frac{\rho_i}{2} V_i^2 (Z_{in,i} + Z_{out,i}) \quad (10)$$

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. (11), in (m/s); (same for k);
- μ_i is the viscosity of the air at temperature $T_{gap,j}$, in (Pa.s);
- Z_i the pressure loss factors Z of cavity i , according to eq.(11)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:

$$\Delta p_{T,i,k} = \Delta p_{B,i} + \Delta p_{HP,i} + \Delta p_{Z,i} + \Delta p_{Z,k} + \Delta p_{B,k} + \Delta p_{HP,k} \quad (11)$$

where

$\Delta p_{T,i,k}$ is the driving pressure difference between space i and space k , 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 5) according to:

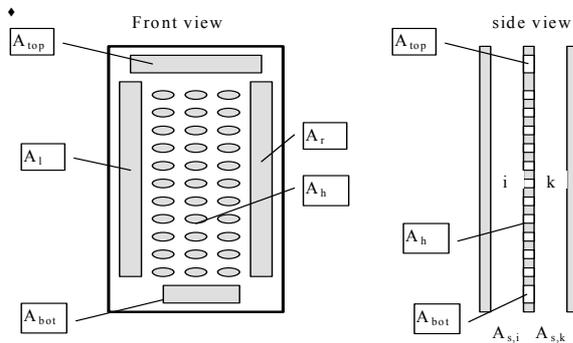


Figure 5 - Openings in a ventilated gap

$$Z_{in} = \left(\frac{A_s}{0,6 \cdot A_{eq,in}} - 1 \right)^2 \quad \text{and} \quad Z_{out} = \left(\frac{A_s}{0,6 \cdot A_{eq,out}} - 1 \right)^2 \quad (12)$$

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 (13 or 14), in m^2 ;
- $A_{eq,out,i}$ is the equivalent outlet opening area of the cavity i , according to equation (13 or 14), 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 :

$$A_{eq,in} = A_{bot} + \frac{1}{2} \cdot \frac{A_{top}}{A_{bot} + A_{top}} (A_l + A_r + A_h)$$

$$A_{eq,out} = A_{top} + \frac{1}{2} \cdot \frac{A_{bot}}{A_{bot} + A_{top}} (A_l + A_r + A_h) \quad (13)$$

Otherwise:

$$A_{eq,out} = A_{bot} + \frac{1}{2} \cdot \frac{A_{top}}{A_{bot} + A_{top}} (A_l + A_r + A_h)$$

$$A_{eq,in} = A_{top} + \frac{1}{2} \cdot \frac{A_{bot}}{A_{bot} + A_{top}} (A_l + A_r + A_h) \quad (14)$$

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).

SHADING DEVICES, SOME DETAILS HIGHLIGHTED

Sensitivity for angle of solar incidence

The angle of incidence has a strong effect on the total solar energy and light transmittance of a window

with blinds, much more than in case of commercial non-scattering glazings. The equations laid down now in ISO 15099 and used in WIS allow to calculate the solar and light transmittance as function of this angle. There is a clear need for more transparency and harmonisation in the chosen boundary conditions when declaring and comparing product information, and as input for building simulation tools.

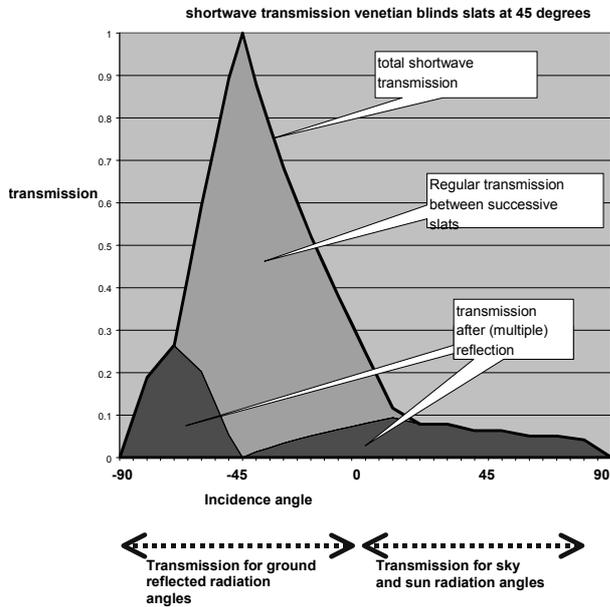


Figure 5 Illustration of short wave solar transmission in case of venetian blinds (slat position 45 degrees)

Fig. 5 shows as example the short wave solar transmittance of a double glazing with external white venetian blinds, with the slats tilted 45°. The system is highly transparent for e.g. ground reflected radiation. Table 1 presents the resulting g-value for different boundary conditions.

Table 1

Example of total solar energy transmittance (g-value) as function of solar incidence angle

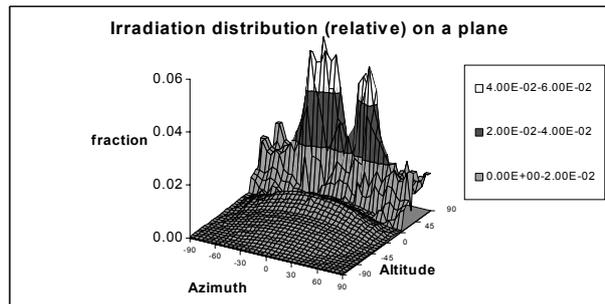
| solar incidence angle | g-value |
|-----------------------|-----------|
| 0 (normal) | 0.111 |
| 45° (altitude) | 0.045 |
| Isotropic diffuse | 0.196 (!) |
| Weighted mean: | 0.083 |
| 45° : diffuse = 3 : 1 | |

The last value is based on the g-value defined in The Netherlands: the solar transmittance is a weighted mean value, which roughly corresponds to 75% of radiation under 45°, plus 25% diffuse radiation.

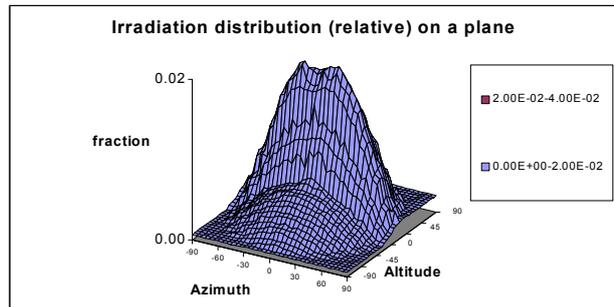
Note that in ISO/CEN standards (EN 410, ISO 9050) and product information the g-value is normally only defined for normal incidence angle and practical situations are normally assumed to lead to 10 to 15%

lower values. This may be suitable for glazings, but certainly not for combinations with shading devices.

A way to find the most suitable g-value for a given climate, period and orientation (and tilt, to be complete), is to take the hourly values in a weather file, convert the solar radiation data into data for vertical and tilted planes (using the Perez model, splitting radiation into beam, circumsolar, isotropic diffuse, near-horizon and ground reflected), attribute intensity of radiation to the elements of a grid of altitude and azimuth angles from the plane's point of view (using Tregenza's proposal of 145 positions per hemisphere) and sum over all hours of the considered period. Fig. 6a and fig.6b show two examples.



a: Nice (F), July, South vertical ($q_{incid} = 98 \text{ kWh/m}^2$)



b: de Bilt (NL), Jan., North vert. ($q_{incid} = 8 \text{ kWh/m}^2$)

Figure 5 Illustration of distribution of incident solar radiation over azimuth and altitude angles, seen from a plane

To be complete: the g-value is also determined by the spectral distribution of the solar radiation. The spectral distribution is, among others, a function of cloudiness and purity of the air. Unfortunately, there is a difference in the spectra currently prescribed in Europe (EN 410) and ISO (ISO 9050).

Double envelope facade

For the prediction of the solar energy transmittance of a prestigious double glazed building in The Netherlands (the ING House, Amsterdam), CFD calculations were performed to verify the natural air flow rate, induced by solar heat absorbed in the blind and the glazing, as well as the resulting convective heat transfer from the blind to the air flow. The model (TNO made, WISH3D) includes absorbed solar radiation and thermal radiation exchange. In order to

increase the confidence in the results, the CFD calculations were backed up with an ad hoc experiment using a full size 5 m height mock up of the double envelope's cavity, placed in the laboratory hall and with the lamellas electrically heated to emulate absorbed solar heat. Concerning the buoyancy driven air flow through the cavity there was good agreement between the model in WIS (as described above), the CFD calculations and the experiment. Concerning the convective heat exchange the experiment confirmed the CFD calculations, while WIS showed some overestimation of the heat transfer at the glazing surface which is compensated by some underestimation of the heat transfer at the lamella surfaces.

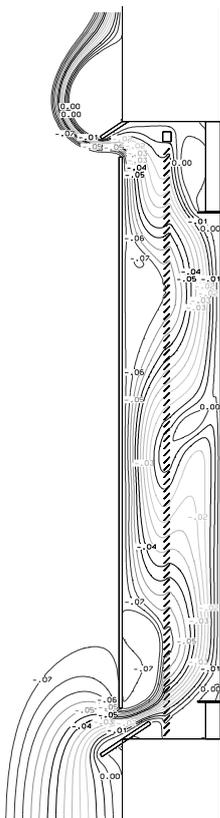


Fig. 7 Streamlines resulting from a CFD calculation on the cavity of a double envelope facade (ING House Amsterdam) with buoyancy driven air flow around an incorporated venetian blind

In general, the convective heat transfer is quite sensitive for the actual level of and difference between the involved surface temperatures. In particular because eq. (1) is a mix of local, $Nu(Ra)$ driven, free convection and buoyancy driven main air flow (velocity term). The effect on the g-value is however not as high as on the thermal transmittance (U-value); the actual U-value may vary, depending on the design and situation, between 0 and 20% or more with ambient conditions (temperature, solar heat).

Within WinDat, and in cooperation with IEA SHC Task 27 (Köhl, 2001) benchmark tests are under development which include a set of typical situations to explore this in more detail.

FUTURE DEVELOPMENTS

The WIS software tool was developed already some years ago (1996) in a EU research project and widely used since then. Currently the improvement, verification, database format and population and Europe-wide dissemination of the WIS tool is the subject of the EU Thematic Network WinDat. Results expected from WinDat in the course of 2003-2004 are for instance: version of WIS with some new features and agreed formats for component data, benchmark tests and results from validation exercises and extensive user feed back.

CONCLUSION

WIS is a software tool, developed in a European research project, for the calculation of the thermal and solar properties of commercial and innovative window systems on the basis of known component properties and thermal and solar/optical interactions between the components.

WIS is available without charge and its further development and technical support is guided by the European network "WinDat", consisting of major research institutes and manufacturers of window components (glazings, solar shading, ...).

One of the features of the software tool is the combination of glazings and shading devices, with the option of free or forced air circulation between the components. This makes the tool particularly suited to calculate the thermal and solar performance of complex windows and active facades.

In this paper we described the main features of WIS and the activities in WinDat. Specifically highlighted was the modelling of the thermal/solar properties of solar shading devices and their interaction with the other components in the window.

The WinDat consortium intends to make WIS a common tool for use throughout Europe, to achieve transparency and easy access to product information and comparison and input for design calculations and simulations. Consequently, it tries to keep a close link with both research and international standardisation activities.

More results are expected from WinDat and IEA SHC Task 27 in the course of 2003-2004.

ACKNOWLEDGMENT

All partners in the EU WIS project (1994-1996) and the EU Thematic Network WinDat (2001-2004) are acknowledged for their contributions in developing the software, suggesting algorithms, dialogues with/in ISO and CEN working groups on development and harmonisation of calculation methods for thermal and solar properties of windows, validation exercises, development of benchmark tests and last but not

least: developing common formats for product databases (glazing, shading, frames and edges) and helping to populate the tool with data from commercial products and data from research.

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