Ministry of Economic Affairs Project

Ventilated double facades

Determination of the energy performances of ventilated double facades by the use of simulation integrating the control aspects – Modelling aspects and assessment of the applicability of several simulation software

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1   INTRODUCTION

In the design phase of a building equipped with a ventilated double facade, it is essential to be able to predict the energy performances of the facade in the building and this for different design possibilities of the facade. The possibility of modelling the facade (and the building) with simulation programs can play an important role from that point of view and allows to compare different possible design concepts.

The prediction of the energy performances of a ventilated double facade is a complex matter. The thermal process and the airflow process interact. These processes depend on the geometric, thermo-physical, optical and aerodynamic properties of the various components of the ventilated double facade.

The aim of this document is to explain how the thermal and solar performances of ventilated double facades and of buildings equipped with this kind of facades can be predicted by simulation. The control aspects are also considered.

2   OBJECTIVES

During the first phase of this project (2001-2002), an overview of some existing simulation software that could be used to simulate the energy behaviour of ventilated double facades has been given [1]. Only the modelling of the ventilated double facade has been considered (no modelling at the building level). The simulation results have been compared to measurements carried out in outdoor test cells. The comparison showed a good agreement between all simulation programs and measurements in case of a mechanically ventilated facade.

The objectives in the second phase of the project (2003-2004) are the following:
- to widen the scope of the first phase of the project by considering not only the modelling of the ventilated double facade alone, but also the modelling of the whole building equipped with the facade, the HVAC systems and the control aspects. Further simulation programs (only software which are available on the market) are analysed. Studying the interaction between the facade, the building and the installations is important for a good assessment of the performances of ventilated double facades. Until now, practically no research study has assessed the impact of the control systems and the integration of ventilated double facade with the HVAC systems,
- to analyse the capability to simulate control systems and control strategies,
- to assess the various simulation programs on basis of their modelling possibilities, user-friendliness, advantages, disadvantages, etc.,
- to explain how a ventilated double facade can be modelled with the various software. Sometimes, 'tips' are needed. This is the reason why the knowledge of experts in simulation has been collected.

3 CONSIDERED SIMULATION SOFTWARE

3.1 SOFTWARE AVAILABLE ON THE MARKET

Most of the time, models of ventilated double facades are developed by researchers and are not available on the market. Saelens D. gives an overview of multiple-skin facades models that have been developed during the last years [5]. Most of them have been developed for mechanically ventilated types. Only few models for naturally ventilated facades are available. Only simulation programs and models that are available on the market and that can be used by design offices, consultants, architects… are considered in this study. Of course, not all existing software have been analysed. Models developed by researchers, which are not available on the market, will not be assessed.

3.2 BUILDING AND COMPONENT SIMULATION SOFTWARE

One can distinguish two kinds of simulation software:
- Component simulation software, which are able to simulate a facade component in order to predict its thermal, energetic and visual behaviour and performances on the basis of the material properties of the component,
- Building simulation software, which are able to simulate a whole building (facade included) in order to predict the thermal dynamic behaviour of the building, the indoor temperatures, the energy consumptions, etc.

Both types of simulation software are important in the scope of this project. The 'component simulation software' allows determining the thermal and solar performances of the ventilated double facade alone. As the ventilated facade is usually connected to the HVAC system and/or managed by control systems, the facade model must also be implemented in building energy simulation programs in order to assess the effect of the facade performances on the building performances (building energy consumption, interior temperature, etc.).

Table 1 gives an overview of the simulation software considered in this study.

Software	Facade component	Building
WIS	✓	
BISCO/TRISCO/VOLTRA	✓	
CAPSOL	✓	✓
TRNSYS	✓	✓
ESP-r	✓	✓
TAS	✓	✓

Table 1: Simulation software considered in this study

4 CAPABILITY TO SIMULATE BUILDINGS EQUIPPED WITH VENTILATED DOUBLE FACADES

4.1 REQUIREMENTS

This section presents all the functionalities that an 'ideal' simulation software should have in order to correctly simulate buildings equipped with any kind of ventilated double facades. The physics must be accurately represented by the models.

This 'ideal' software should be able to (see Figure 1):

- correctly model the <u>outdoor climate</u>
- correctly model the ventilated <u>facade</u>: glass skins, shading device, frame, mechanical or natural ventilation, etc.
- correctly model the <u>building</u>, the connection between the facade and the building, the <u>HVAC systems</u>, etc.
- correctly model the <u>control systems</u> and the <u>control strategies,</u> which influence the working and the performances of the building and its systems.

Of course, such 'ideal' software doesn't exist. Each software has its own limitations. The criteria that a software should fulfil in order to make a correct model are given in the following sections.

The choice of the most appropriate software depends on the main objective of the simulation. For example, if the objective is to estimate the yearly energy consumption of a building equipped with a naturally ventilated double facade, then a powerful software must be used with detailed models of the facade, the building, the HVAC systems, the control systems, etc. But more simplified software can be used if one aims to determine the maximum indoor temperatures in the building during summertime for example.
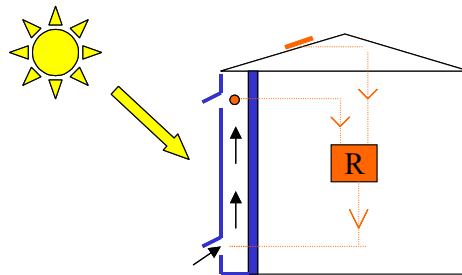
Figure 1: Outdoor climate, facade, building and control systems

4.2 OUTDOOR CLIMATE

In order to predict the yearly performances of a building, it is important that the program simulates the outdoor climate on a real way. The items given in Table 2 must be taken into account.

Wind speed and wind direction are two important data in order to correctly predict the ventilation in case of a naturally ventilated double facade. But it is clear that these two data are very difficult to obtain just around the facade. The wind is very variable in the space and also in the time.

In order to determine the solar performances of a facade system, detailed data on the incident solar radiation (on a vertical, normal and/or horizontal surface) must be obtained. The solar radiation is decomposed into three components: direct, diffuse and reflected (by the ground).

The latter component should be known in order to accurately determine the solar transmittance through venetian blinds near the ground level.

Temperature	Outdoor air temperature
	Sky temperature
	Surroundings temperature
Humidity	
Wind	Speed
	Direction
Incident solar radiation	On a vertical surface / Horizontal / Normal
	Direct + Diffuse + Reflected (by the ground)
	Spectral data
	Incidence angle (azimuth & …)

Table 2: Simulation of the outdoor climate

4.3   SIMULATION OF FACADE COMPONENT

One of the difficulties of simulating a ventilated double facade is explained, among other things, by the complex heat exchange process around the shading device due to the absorption of the solar radiation (by the shading device) and to the cavity ventilation.

Therefore, it is important to correctly model the shading device on one hand and the heat transfer around the shading device and the glass panes (convective and radiative heat transfer) in the cavity on the other hand. A further difficulty in case of a naturally ventilated facade is the prediction of the airflow rate in the cavity due to the buoyancy and wind effects.

Table 3 gives a description of some functionalities that a simulation software should have in order to assess on a correct way the thermal and solar performances of ventilated double facades (this list is not exhaustive). Some modelling aspects are described and discussed more in detail below.

Modelling of the shading device and heat transfer
In the case of a VDF, different types of shading devices can be installed: venetian blind, roller blind, louvres, etc.

Only few simulation programs are able to model shading devices with fixed or adjustable slats (louvres or venetian blinds), which are widely used in VDF in Belgium.

The heat transfer around this type of shading device is particularly difficult to model:

- *Short wavelength radiation (solar radiation):* the incident solar radiation is multireflected on the slats of the venetian blind.
- *Airflow around the shading device:* inter-cavity airflow can occur (air from the exterior cavity can flow through the shading device towards the interior cavity or vice-versa).
- The *heat absorbed by the shading device* is extracted by the air flowing into the cavity; the heat exchange by convection is a complex matter (see also below). There is also a heat radiation exchange between the shading device and the glazing panes.

Convective heat transfer in the cavity
The convective heat transfer depends on the nature of the airflow (laminar/turbulent), the airflow rate and the temperature difference between the surface and the fluid.

The flow in naturally and mechanically ventilated cavities is fundamentally different. Saelens (2002) gives in Ref.[5] existing relations obtained from experimental research and numerical simulations to estimate the convective heat transfer coefficient. Distinction is made between natural, forced and mixed convection regimes. It was shown that obtaining a reliable expression for the heat transfer coefficient is difficult. Different convection regimes can exist depending on the operation of the VDF (closed/open, forced/natural flow).

In mechanically ventilated cavities, the airflow rate is fixed. Empirical equations exist and can estimate the convective heat transfer.

In case of natural convection, the situation is more complex as the airflow rate is unknown. The airflow rate and the temperature profiles are mutually dependent. The airflow rate is caused by the two following effects:

- *stack effect (buoyancy effect)*: caused by the temperature difference between the air that comes in and the air that comes out the cavity of the ventilated double facade,
- *wind effect*: caused by the wind pressure differences between the air inlets and outlets. The wind pressure on a specific point of the building envelope depends on the wind velocity and the wind pressure coefficient of that particular point. Both parameters are difficult to estimate. The local wind velocity depends mostly on the surroundings (on a large scale). The wind pressure coefficients depend on the wind direction, the surroundings (on a small scale) and the geometry of the building itself.

The combined effect of wind and temperature difference creates a total pressure difference between the inlet and outlet of the facade, which determines the airflow rate in the cavity. As shown in Figure 2, when wind velocities are limited, the *stack-effect* is dominant. When wind velocities are high, the *wind-effect* is dominant. Between these two regimes, there is a transition regime where both effects may assist each other or may counteract.
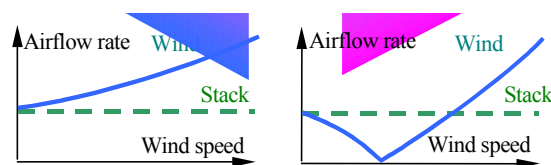

Figure 2: Combined stack and wind effects:
a) wind and buoyancy have cumulative effects;
b) wind and buoyancy have opposite effects.

As already mentioned, in the naturally ventilated facades, the airflow rate and the temperature profiles are mutually dependent and hence the thermal system must be solved iteratively. In order to take the combined effect of heat and mass flow into account, two possibilities exist [5][10][8]:

- Computational fluid dynamics (CFD) simulation
- Air flow network coupled with energy balance

CFD-simulations have the potential to achieve more accurate results (details about the nature of the flow field) but its implementation in practice is quite difficult. In case where one aims to obtain results for a complete year, this kind of simulations requires a lot of effort and time and must be carried out in so many configurations that the required computational time would be enormous. Due to the high complexity of CFD simulations, a validation of the CFD model is required and is not often available. The CFD results are highly dependent on the inputs (wind, Cp, etc.), which are very variable.

The second possibility is easier to implement and is compatible with simulation of long periods. Some simulation programs are able to couple the thermal and the airflow models (like in this the case in e.g. TRNFLOW, which is a combination of the thermal model TRNSYS and the ventilation model COMIS). Thermal and ventilation models can be coupled in several ways :

- The *full integration* approach: both ventilation model equations and thermal model equations are solved simultaneously, by incorporating both sets of equations into a single equation system (e.g. ESP-r).
- The *onions* approach: airflow rates are passed from the ventilation model to the thermal model, which calculates new air temperatures and pass them to the ventilation model, which calculates new airflow rates… until convergence is reached. The procedure is then repeated for the next time step.
- The *ping-pong* approach: airflow rates calculated in the ventilation model at time t are used as input by the thermal model to calculate new temperatures at time t. These temperatures are then used by the ventilation model to calculate new airflow rates at time t+1. This approach has as main disadvantage that it can generate substantial errors and should be used with care.
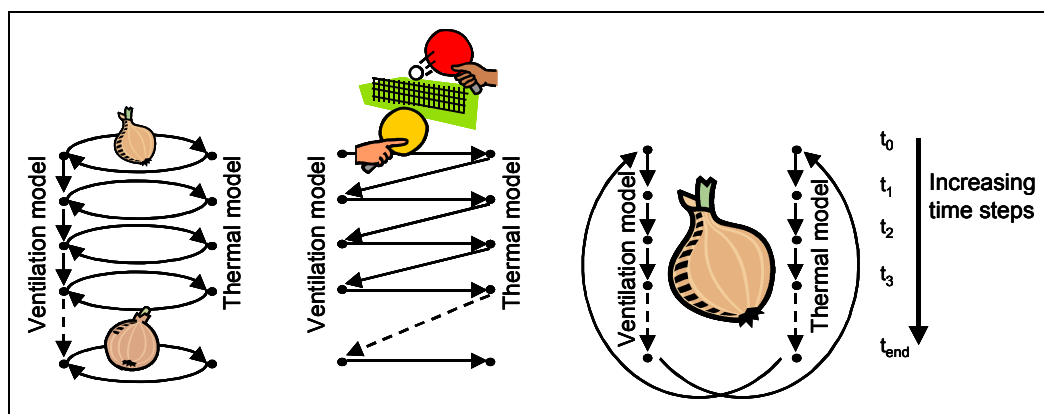
Figure 3: Onions, ping-pong and global onion approaches

- The *global onion* approach: the thermal model is run for the whole period. The resulting temperatures are introduced to the ventilation model, which calculates ventilation rates for the all period. These airflow rates are introduced in the thermal model to calculate new temperatures, and so on… up to convergence of both models. This method presents a major limitation: it is not possible to implement a ventilation control strategy that is not fixed in advance (e.g. time-controlled, controlled according to the outdoor climate…). Indeed, the opening of a window according to the inside temperature for instance will not affect the inside temperatures because they are considered as input data for the ventilation model.

FACADE LAYERS		Comments
Glass layers		
- optical properties	Spectral ? Angular dependent? Optical properties different for direct, diffuse and reflected (incident) solar radiation?	
- thermal properties	Function of the temperature?	
Shading device		
- type of shading device	Modelling of any type of shading device? (roller blind, venetian blind with orientable slats, etc.) Overhang ?	
- optical properties	Spectral? Angular dependent?	
- position of the shading device in the cavity	Attached to the internal or external glass skins ? Placed in centre of the cavity ?	
- control	Can the shading device be controlled ?	Pull down or roll up the blind according to the sunshine level, temperature, etc
Frame		
- modelling	Possible?	
- thermal properties	Can ventilation air pass through the frame? Thermal properties function of the airflow rate passing through the frame? Possibility to set an inlet temperature (air entering the ventilated cavity) different to the exterior or interior temperature?	For certain applications, it is important that the frame of the ventilated double facade can be modelled. The heat transmission through the frame can represent a non-negligible part of the total heat transmission losses through the complete facade. Air entering the ventilated cavity can be heated and cooled down due to contact with the bounding surfaces and heating due to solar radiation. The inlet temperature in the cavity influences both the transmission losses and the enthalpy change of the air flowing through the cavity.
Cavity subdivision		
- Vertical	Vertical subdivision?	The number of zones into which the facade must be divided is not straightforward. This vertical subdivision is needed to take into account the temperature profile in the cavity.
- Horizontal	Horizontal subdivision ?	Fictive vertical walls can be simulated ? (in some programs it is needed to model fictive vertical walls to represent the shading device rolled up)

HEAT TRANSFER		
Convective heat transfer in the cavity		
- Forced convection	Convective heat transfer coefficient: - must it be given (fixed value)? Possibility to modify the value of the coefficient during the simulation (in function of some inputs)? - is calculated from some parameters? (flow regime, airflow rate, temperature difference, etc)	
- Natural convection	Possibility to model natural ventilation in the cavity? (naturally ventilated facades)	See also "Air flow modelling" (see below)
Radiative heat transfer		
- in the cavity	Radiation and convection treated separately? Radiation heat transfer coefficient is a function of the temperature ?	
- exterior radiation heat transfer	Calculated from sky temperature and environment temperature?	
- view factor	Correct determination of the view factor between facing panes ?	
Short wave radiation		
- all panes	inter-reflections between the glass panes and the shading device?	
- venetian blind	inter-reflections between the slats of the venetian blind?	
AIR FLOW MODELING		
- Coupling airflow modelling and thermal modelling	- Combination of a thermal and an airflow network in the same software? - Possibility to combine the software to air flow models? (other software)	
- Natural ventilation	Buyancy effect? (stack effect) Wind effect? Airflow between the cavity and the interior of the building through the window openings?	

FACADE & BUILDING		
Coupling facade and building	Possibility to connect the facade model with the building and its installations?	

Table 3: Simulation of the facade component

4.4 SIMULATION OF CONTROL SYSTEMS AND CONTROL STRATEGIES

Most current building performance simulation software do not have a flexible way of dealing with control systems and control strategies.

The current situation is that there exists software that are very advanced in control modelling, but limited in building performance simulation concepts.

On the other hand, building performance simulation software is usually relatively basic in terms of control modelling and simulation capabilities [14].

Coupling the two approaches (building simulation software and control modelling software) would potentially enable integrated performance assessment by predicting the overall effect of control strategies. Communication mechanisms exist, which allow to marry the two approaches [13][14].

Adequate dynamic control systems and strategies are needed to reach the expected performance of ventilated double facades. Several studies have shown that only an optimal control of the facade (shading device up or down, slat angle of the venetian blinds or louvres, airflow regimes, opening of dampers, etc) enables this system to truly act as active energy savers and to bring comfort.

According to Park [15], the lack of such a dynamic control is because of the following challenges:

"First, an adequate control needs an underlying mathematical model to predict the response of a system. But, the nature of the dynamics of these systems involves complex irregular 3D geometry where turbulent air flows and each solid and non-solid component is linked to other components by radiative and convective heat exchange, and thus it is not easy to accurately predict the response of the system in computations.

Second, it is difficult to apply modern analytical optimal control theory such as Pontryagin's Minimum Principle because of high nonlinearity of the physical mathematical representation of the system, complicated by the change of the airflow regime and thus of the mathematical representation. In addition, the occupant's intervention further complicates the application of the optimal control theory.

Third, the systems are expected to reflect the multifaceted user preference such as energy conservation, visual comfort and thermal comfort.

The determination of optimal control actions synthesizing these three major system utilities is a complex tradeoff influenced by heating, cooling, and lighting loads, exterior and interior glazing temperature, outdoor and indoor air temperature, solar radiation, sky condition, personal preference, etc. The above-mentioned set of state variables and parameters woven with the multifaceted quantitative and qualitative cost elements explain the difficulty to determine optimal control actions."

In this document, the capability of the considered software of simulating control systems and control strategies is analysed. In case of some software, 'tips' are needed for simulating controls. The optimisation of the control strategies is out of the scope of this document.

5 ASSESSMENT OF SEVERAL SOFTWARE

5.1 WIS SOFTWARE

WIS 3.0 is a uniform, multi-purpose, European-based software tool designed to assist in determining the thermal and solar characteristics of window systems (glazing, frames, solar shading devices, etc.) and window components. The tool contains databases with component properties and routines for calculation of the thermal/optical interactions of components in a window. 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 both. This makes the tool particularly suited to calculate the thermal and solar performance of complex windows and active facades.

The WIS algorithms are based on international (CEN, ISO) standards, but WIS also contains advanced calculation routines for components or conditions where current standards do not apply.

WIS 1.0 (the first version of WIS), previously developed as a licensed tool under a European Commission-funded research project, has been upgraded to WIS 3.0 during the last three years within the European WINDAT Network, which includes 40 leading research and educational organizations, industries, consulting engineers and designers, including a strong representation in relevant international standardization bodies.

This tool is collectively supported and used in research, industry, standardisation, education and design throughout Europe to compare, select and promote innovative windows and window components to maximise energy savings and improve indoor comfort.

WIS 3.0 tool is now freely available, and is designed as a user-friendly tool, prepared for a wide variety of users including: consulting engineers, manufacturers, Building designers, researchers, those involved in standardisation, building regulation and education.

Control systems and building modelling are not considered in this tool.

For more information, support, and free download of the tool: http://www.windat.org.

Section 8.1 gives a detailed description of the software in the context of the modelling of ventilated double facades.

WINDAT and WIS were financially supported by the European Commission Directorate General for Energy and Transport.

5.2 BISCO/TRISCO/VOLTRA SOFTWARE

The company Physibel has developed a series of software aimed at modeling heat transfer of building details using the energy balance technique.

Where all other simulation programs calculate the ventilated double façade (VDF) as parallel glass and shading layers which does not directly take into account the thermal bridging effect of sub-components with a clear 2D or 3D heat flow, BISCO, TRISCO and VOLTRA have the potential to calculate for both temperature distribution and heat loss, the interaction between the glass and shading layers in combination with the thermal bridging effect of the subcomponents around the VDF (e.g. the supporting mullions and transoms, connection with inlet and outlet openings and even the false ceiling).

Control systems and building modelling are not considered in this tool.

For more information about BISCO, TRISCO, VOLTRA: http://www.physibel.be/[1]

Section 8.2 gives a detailed description of the software in the context of the modelling of ventilated double facades.

5.3   CAPSOL SOFTWARE

CAPSOL is a programme that calculates multi-zone transient heat transfer.
In CAPSOL, the building and its environment are considered as a set of zones, between which heat flows occur due to conduction, convection, radiation and ventilation. The behaviour of the system is defined by the boundary conditions, i.e. known temperatures, heat fluxes (such as solar radiation and internal heat gains) and controls (such as heating, cooling, mechanical ventilation and sun shading). The program contains a solar processor; building sun obstacles and wall sun obstacles can be defined to simulate e.g. other buildings and overhangs.
During the dynamic calculation, a system of energy balance equations is built and solved each calculation time step, using the Crank-Nicolson finite difference method.

For more information about CAPSOL: http://www.physibel.be/

Section 8.3 explains in detail how CAPSOL can be used to simulate a building equipped with a ventilated double façade.

5.4   TRNSYS SOFTWARE

TRNSYS (TRaNsient SYstem Simulation Program) simulates the dynamic thermal behaviour of buildings and systems. It has a modular system approach, which makes it very flexible.
It includes a graphical interface, a simulation engine, and a library of components that range from various building models and standard HVAC equipments to renewable energy and emerging technologies. TRNSYS also includes a method for creating new components that do not exist in the standard package. Extensive libraries of non-standard components for TRNSYS are available commercially from TRNSYS distributors.
This simulation package has been used for more than 25 years for HVAC analysis and sizing, electric power simulation, solar design, building thermal performance, analysis of control schemes, etc.
Coupled with COMIS, it allows multizone airflow analyses. This can be done "manually" or with the commercial tool TRNFLOW.

For more information about TRNSYS, see the websites: http://sel.me.wisc.edu/TRNSYS/ and http://www.transsolar.com/.
For more information about COMIS, see the website: http://epb1.lbl.gov/COMIS/
For more information about TRNFLOW, see the website http://www.transsolar.com/.

Section 8.4 explains in detail how TRNSYS can be used to simulate a building equipped with a ventilated double façade.

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[1] Two examples of ventilated double façades are given under http://www.physibel.be/ > VOLTRA > Animation examples

5.5   ESP SOFTWARE

ESP-r is an Open Source program, developed by the Energy Systems Research Unit at the University of Strathclyde with inputs from many other organisations. It has been developed over a 28 year period, with funding from the UK's Engineering and Physical Sciences Research Council and the R&D Framework Programmes of the European Commission.

ESP-r is a transient energy simulation program based on the finite volume technique. It is capable of modelling the energy and fluid flows within combined building and plant systems when constrained by control actions and subject to dynamically varying boundary conditions. By default, the Crank-Nicolson formulation for mixed explicit/implicit finite differences is used (although the user can change this from fully explicit to fully implicit solutions). The user can specify simulation timesteps up to a maximum of hourly and there are options for timestep control to increase resolution where needed.

It is available by download from ESRU's website (http://www.esru.strath.ac.uk). Other information (tutorials, exercises, documentation, upgrade notes etc) can also be found on the website.

Section 8.5 explains in detail how ESP-r can be used to simulate a building equipped with a ventilated double façade.

5.6   TAS SOFTWARE

TAS is a suite of software products, which simulate the dynamic thermal performance of buildings and their systems.

- The main module is **Tas Building Designer** (A-Tas), which performs dynamic building simulation with integrated natural and forced airflow. It has 3D graphics based geometry input that includes a CAD link.

- **Tas Systems** is a HVAC systems/controls simulator, which may be directly coupled with the building simulator. It performs automatic airflow and plant sizing and total energy demand.

- The third module, **Tas Ambiens**, is a robust and simple to use 2D CFD package which produces a cross section of micro climate variation in a space.

A-Tas is a software tool which simulates the thermal performance of buildings. The main applications of the program are in assessment of environmental performance, natural ventilation analysis, prediction of energy consumption, plant sizing, analysis of energy conservation options and energy targeting.

For more information about TAS: http://ourworld.compuserve.com/homepages/edsl

See section 8.6 for detailed information about the modelling of ventilated double facades.

6   CONCLUSIONS

The modelling of ventilated double facades is complex because of the high degree of interaction between the many heat and mass transfer (air flow) processes. The selection of the appropriate correlations for the convective heat transfer in the cavity of the ventilated double façade is a quite difficult matter. In mechanically ventilated facades, the airflow rate is fixed and empirical equations exist and can estimate the convective heat transfer. The case of naturally ventilated facades is more complex as the airflow rate is variable, depending on the wind and stack effects. In particular, the determination of the airflow caused by the wind effect requires the knowledge of the wind velocity and the wind pressure coefficient, which are difficult to estimate. In order to take the combined effect of the heat and mass flow into account, two possibilities exist : computational fluid dynamics (CFD) or the coupling between an air flow network and a thermal network. The accurate modelling of some types of shading device (Venetian blinds for example) placed in the cavity of the VDF is far from evident.

The choice of the most appropriate software for simulating a VDF depends on the objective of the simulation : design of a new concept of VDF ? Dimensioning of the HVAC systems which are connected to the VDF ? Determination of the maximum cooling or heating loads during a whole year ? Determination of the maximum indoor temperatures in the building during summertime ? Determination of the yearly energy consumption ? Condensation risk ? Testing of various control alternatives ? etc.

Some modelling aspects where there is uncertainty (e.g. choice of the appropriate convection correlations, discharge coefficients, wind pressure coefficients) may have a significant impact on the predictions. Hence it is advised that a cautious approach be adopted according to the aim of the simulation. For example, in the case of an energy consumption problem, it is safer to use a factor giving higher wind speeds; in the case of an air quality or overheating problem, a factor giving a low estimate of wind speeds should be selected.

In spite of these modelling difficulties, the role of simulation is important and simulation represents the only one method to estimate the yearly energy consumption of a building equipped with a ventilated double façade and to assess for example the impact of different control systems and control strategies on the building performances.

In this document, the capability of several simulation programs to simulate a VDF or a building equipped with a VDF has been analysed.
The software TRNSYS, ESP-r and TAS are powerful transient energy simulation programs and are able to simulate a ventilated double façade, the building, the HVAC systems and the control systems and strategies in a certain extent. These programs can make the coupling between thermal and airflow models. Nevertheless, all these programs face similar obstacles regarding the level of resolution necessary to model some major thermodynamic flowpaths in ventilated double facades. Time and experience are required in order to use properly these quite complex software. The software CAPSOL shows less functionalities than the three previous ones but this software can be recommended for specific points of interest due to its facility of use.
The software WIS combines a user-friendly interface with the most advanced calculations of the thermal and solar properties of window and façades. The WIS algorithms are based on

international (CEN, ISO) standards, but WIS also contains advanced calculation routines for components or conditions where current standards do not apply. Control systems and building modelling are not considered in this tool. Finally, BISCO, TRISCO and VOLTRA belong to a series of software aimed at modelling the heat transfer of building details using the energy balance technique. These programs are well adapted to calculate the interaction between the glass skins and the shading layer in combination with the thermal bridging effect of the subcomponents around the VDF (e.g. the supporting mullions and transoms, connection with inlet and outlet openings, etc).

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[15]   Park Cheol-Soo et al.; Occupant responsive optimal control of smart facade systems, Eighth International IBPSA Conference, Netherlands, 2003.

[16]   TRNSYS – A Transient System Simulation Program – Reference manual, 2000

[17]   Heijmans N., Wouters P.; Impact of the uncertainties on wind pressures on the prediction of thermal comfort performances, HYBVENT technical report, 2002

1: WIS SOFTWARE

8.1   WIS SOFTWARE

8.1.1   General software information

Introduction

WIS 3.0 is a uniform, multi-purpose, European-based software tool designed to assist in determining the thermal and solar characteristics of window systems (glazing, frames, solar shading devices, etc.) and window components. The tool contains databases with component properties and routines for calculation of the thermal/optical interactions of components in a window. 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 both. This makes the tool particularly suited to calculate the thermal and solar performance of complex windows and active facades.

The WIS algorithms are based on international (CEN, ISO) standards, but WIS also contains advanced calculation routines for components or conditions where current standards do not apply.

WIS 1.0 (the first version of WIS), previously developed as a licensed tool under a European Commission-funded research project, has been upgraded to WIS 3.0 during the last three years within the European WINDAT Network, which includes 40 leading research and educational organizations, industries, consulting engineers and designers, including a strong representation in relevant international standardization bodies.

This tool is collectively supported and used in research, industry, standardisation, education and design throughout Europe to compare, select and promote innovative windows and window components to maximise energy savings and improve indoor comfort.

WIS 3.0 tool is now freely available, and is designed as a user-friendly tool, prepared for a wide variety of users including: consulting engineers, manufacturers, building designers, researchers, those involved in standardisation, building regulation and education.

WIS description

WIS combines the most advanced calculation routines with a user-friendly interface that runs under Windows 98, Windows 2000, Windows NT and Windows XP. Figure 4 gives an impression of the WIS structure. Windows are composed of a transparent system, a frame and spacer. All can be selected from an elaborate database with component data. Transparent systems are made up of layers. Each layer is chosen from a database with specular glass layers, scattering layers (such as blinds and diffusing glass) and gas fills. Air exchange between layers and the environment or between mutual layers can be modeled by free or forced convection.

Important new features compared to version 1 are:
- The component databases are filled with a large number of components (hundreds of glazings, dozens of shadings and frames and spacers)
- The calculation routines are adapted to the newest CEN and ISO standards
- New data can easily be imported when it comes available and glazing data can also be imported from other sources (older WIS database or the International Glazing Database)
- The linear thermal transmittance of frames and spacers can be determined with 3 different methods
- The optical properties of scattering layers can also be determined with a built-in ray tracing module as an addition to the existing view factor method
- As an addition to venetian blinds WIS can also model pleated blinds, roller blinds and screens and other diffusing devices
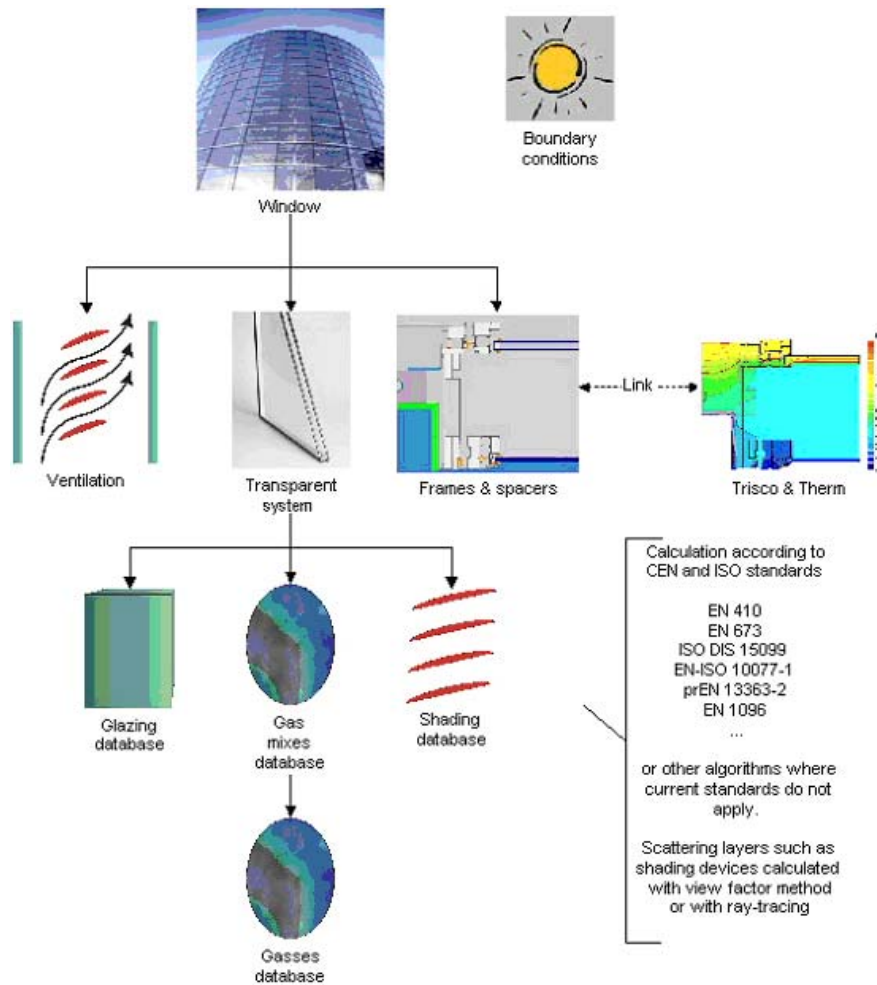
Figure 4 : WIS structure

8.1.2 Outdoor climate

The following information has to be given (see Figure 5) :

- outdoor and indoor air temperature in °C
- outdoor and indoor radiant temperatures in °C
- direct solar radiation in W/m²
- convective surface coefficient outdoor in W/m²K
- convective surface coefficient indoor in W/m²K

For the calculation of the solar factor g and the light transmittance τ_v the relative spectral distribution of the global solar radiation has to be specified.
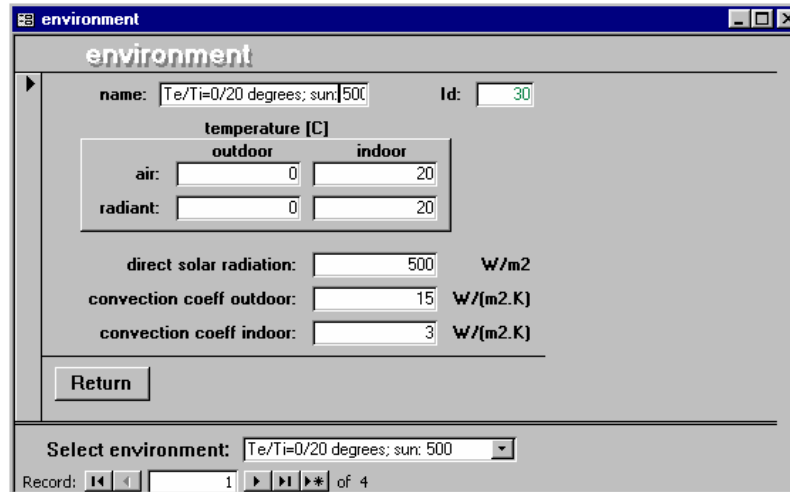
Figure 5 : environment

8.1.3 Simulation of a ventilated double facade

8.1.3.1 General methodology

Transparent systems are made up of layers. The properties of the whole façade (U-value, direct solar transmittance, solar factor, UV-transmittance, etc.) are calculated from the properties of its components and from the thermal and optical interaction between them.

For example, if one wants to determine the properties of a ventilated double facade of type 'climate façade', the constitutive components of the façade must be specified (see Figure 6) :
- Double glazing unit
- Ventilated air gap 100 mm width
- Shading device
- Ventilated air gap 100 mm width
- Single glazing

The double glazing unit is composed by a glass pane (6 mm width), an air gap (12 mm width) and a second glass pane (6 mm width).

The thermal and optical properties of each component (glass pane, shading device, etc) must be individually specified (see after).
The air gap can be naturally or mechanically ventilated (see after).

All layers are supposed to be parallel between them.
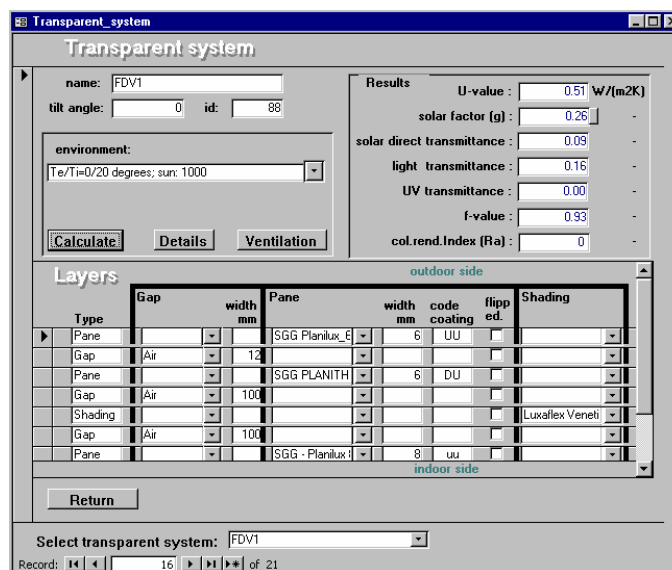
Figure 6: transparent system

8.1.3.2   Façade layers

Glass layer

WIS offers the full spectral data for glass panes in an extended database with products from different manufacturers. The pane data that is officially submitted to the WINDAT network and reviewed according to the WINDAT guidelines is marked by the letter 'E' and protected (see Figure 7) .
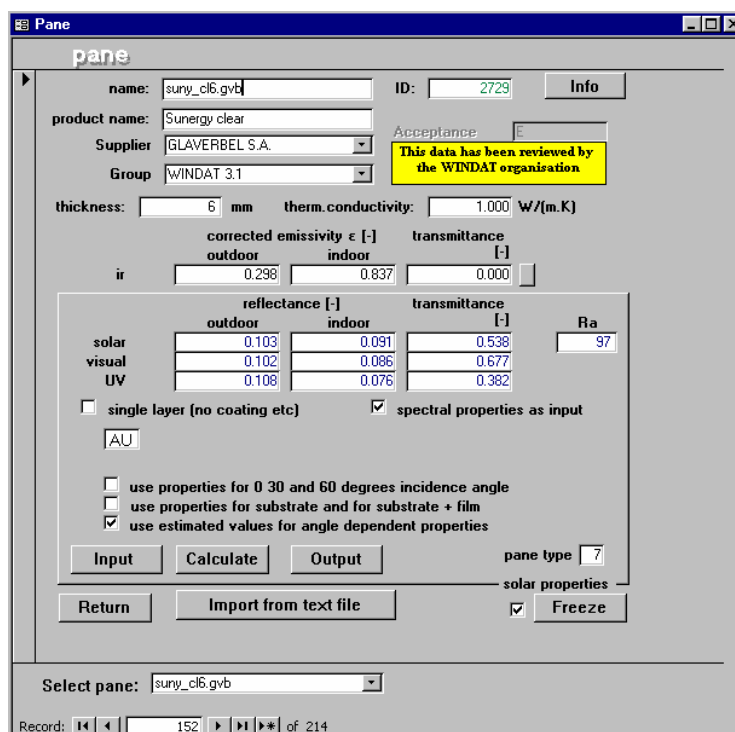

Figure 7: Glass selection screen

The user can furthermore import his or her own spectral data e.g from measurements or from the International Glazing Database. WIS calculates a number of optical properties such as the solar, visual and UV reflectance and

transmittance values, according to the European standard EN410. Angle dependant properties can also calculated according to appropriate algorithms, see Figure 8.
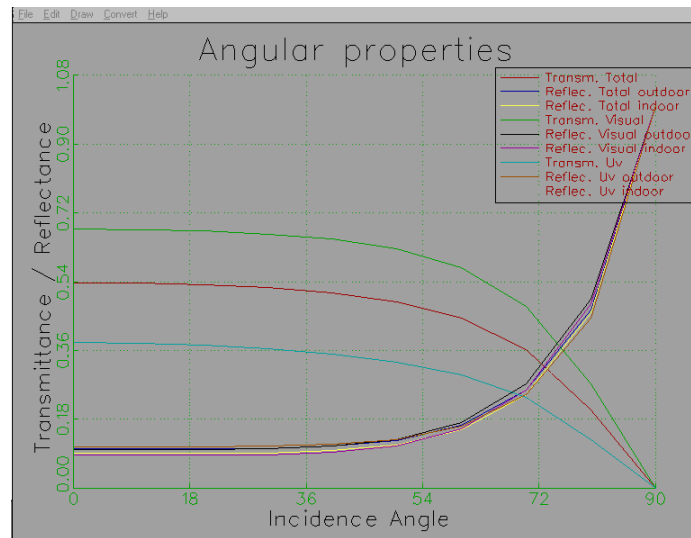
Figure 8: Angular properties of selected glass
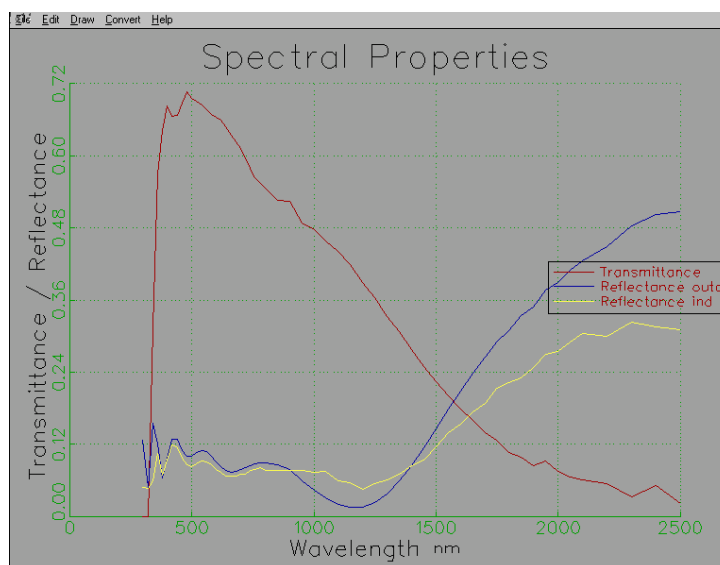
Figure 9: Spectral properties of selected glass

In order to model a double glazing unit, each glass pane and the gas fill must specified.

WIS includes a database with the physical properties of a number of gasses often used in double glazed units, such as air, argon, krypton, etc. The user can create any mixture by mixing 2 or more different gasses. WIS will automatically calculate the physical properties of the mixture needed to determine the insulation value (U-value) of the window, see Figure 10. The gas properties of the standard gasses are given according to EN673. The properties of gas mixtures are volume weighted, also according to EN673.
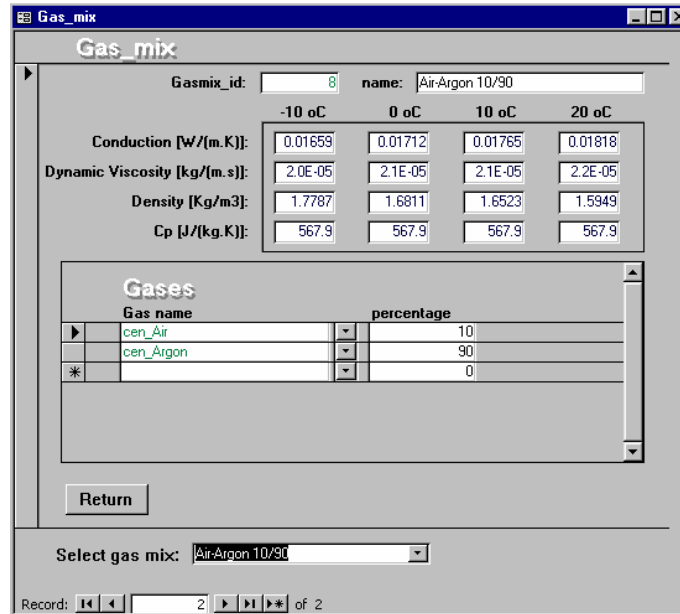
Figure 10: 'Gas mix' screen

Shading device

The shading device is considered as a scattering layer. Scattering layers form a special category in WIS. In the new version of WIS four different types of scattering layers are distinguished:
1. Slat type blinds (such as venetian blinds)
2. Pleated blinds
3. Roller blinds and screens
4. Other scattering devices such as diffusing glass

The database contains the measured spectral properties of various products (mainly shading devices) and the user can import his or her own data (e.g. from measurements) into the database. The properties that are used are the normal incidence beam to beam reflectance and transmittance and the normal to hemispherical beam to diffuse transmittance.

For venetian blinds and pleated blinds WIS calculates the blind properties from the material properties, including all inter-reflections between the blinds. The blinds may be partly transparent.
The properties of pleated blinds are always calculated with the built-in ray-tracing module. For venetian blinds WIS offers the choice between ray-tracing calculations or the view factor method. Although much faster, the view factor method assumes that all slat reflections and slat transmissions are diffuse, which can be an incorrect assumption for blinds that are specularly reflecting. The ray-tracing option is a much better choice for blinds that are highly specular.
Another new feature (only with the ray-tracing method) is to calculate the properties of curved slat type blinds. This type of blinds is very popular because of their light re-directing properties. For the user modeling the slat curvature is simply done by setting the curvature value (known as crown height) to the appropriate value and WIS will do the rest, see Figure 11.
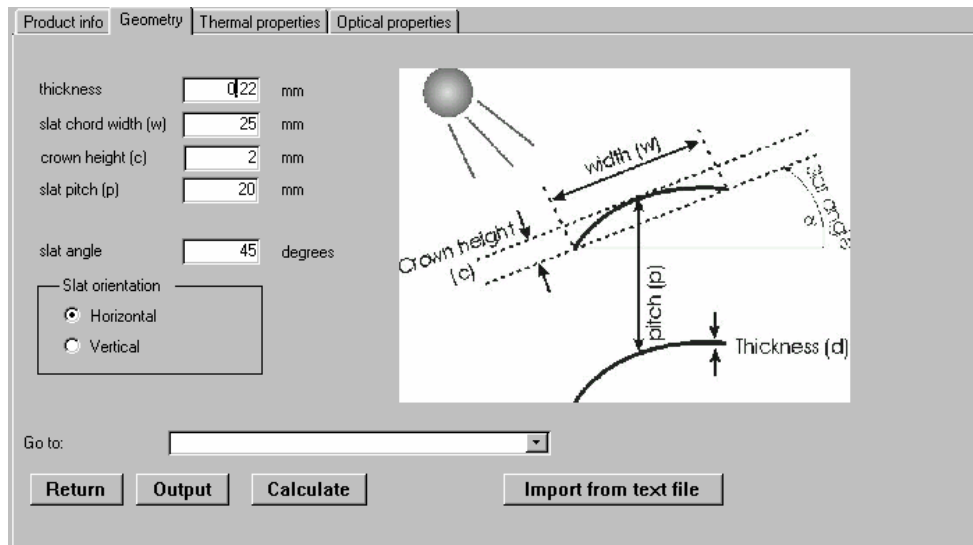
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Figure 11: Geometrical definition of curved slat type blinds

Frame

WIS contains a database of frames with their width and U-value as the principal properties, according to EN ISO 10077-1. New entries of frames with these properties can be easily added.
For a detailed analysis of frames, WIS provides the link to steady state numerical calculation tools (THERM and KOBRA).
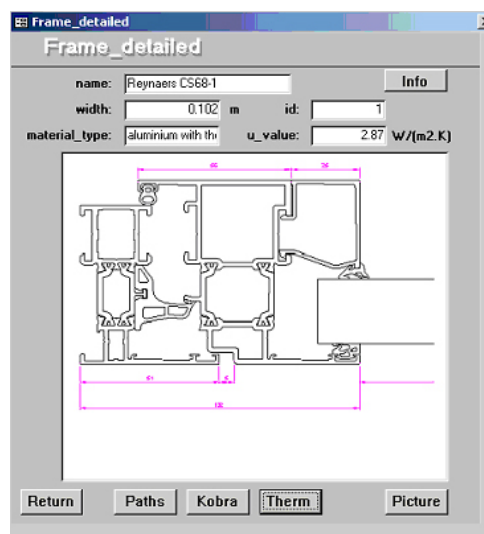

Figure 12 :'frames' screen

Spacers properties of some typical spacers are also stored in the WIS database.

Transparent system

The panes, gas filling and shading devices of a window system are put together into a transparent system. In WIS all 'solid' layers (panes and scattering layers) are assumed to be separated by a gas (mix) layer. A laminate is assumed to be one solid layer. The optical and thermal properties of the transparent system are calculated according to EN410 and EN673 when no shading layer is included. When a shading layer or another scattering layer is included or when air exchange is included all calculations should be performed in expert mode. In this mode WIS uses some powerful algorithms, which are not (yet) standardized. Systems with inside air circulation (ventilated systems) and shading layers will then be calculated according to ISO DIS 15099 and (where
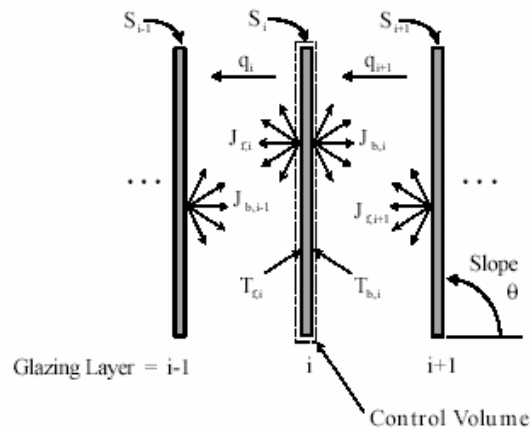
applicable) to prEN 13363-2. Following (and contributing to) the latest drafts of these standards, the current calculations in WIS "are as close as possible to the physical reality and as close as possible to the standards". With these special features, the WIS tool is particularly suited to calculate the thermal and solar performance of complex windows and active facades.

Ventilated double façade

The heat transfer in the cavity is governed by the equations given in the international standard ISO 15099:2003, a detailed calculation method for the thermal and solar properties of windows including solar shading devices.

Convective heat transfer in the cavity

For a ventilated cavity, the equations related to the convection heat transfer are those given in ISO 15099:2003. The surface-to-air heat transfer coefficient by conduction/convection for vented cavities is given by the following equation :

$$h_{cv,i} = 2h_{cdv,i} + 4V_i$$

where

$h_{cv,i}$ is the surface-to-air heat transfer coefficient by conduction/convection for vented cavities [W/m²K]

$h_{cdv,i}$ is the surface-to-surface heat transfer coefficient by conduction/convection for non-vented cavities [W/m²K]

V_i is the mean air velocity in the gap [m/s]

Figure 13 : ISO 15099 - Model of mean air- and outlet temperature

The convective heat transfer coefficient $h_{cdv,i}$ is given by detailed equations in function of the Nusselt number N_u. This N_u is calculated using correlations based on experimental measurements of heat transfer across inclined air layers.

Short wave radiation : transfer through the cavity

The transmitted (or reflected) part of the incident solar radiation through the façade is determined on basis of the spectral properties (transmittance, reflectance and absorptance) of each layer of the façade and the thermal and optical interaction between the different layers.

Figure 14 : Energy balance on layer i

In case of a shading device, the incident solar radiation may change direction while being transmitted or reflected at the layer. In WIS (and according to ISO 15099), 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);
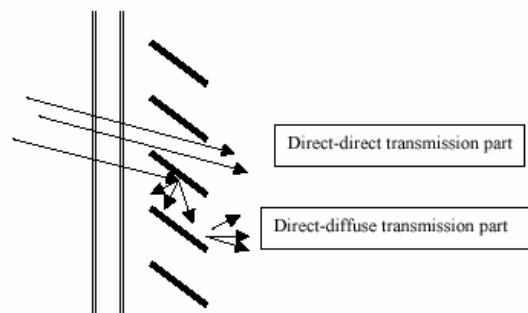- a disturbed part, which is approximated as anisotropic diffuse (Lambertian) (with the view factor method)

Figure 15: Direct and diffuse transmittance for a shading device (Venetian blind)

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

WIS gives the calculation of the transfer of the short wave radiation not only for normal incidence but also for all incidence angles.

Long wave radiation : transfer through the cavity

The long wave radiation transfer is calculated (detailed equations of heat transfer) on basis of the temperatures and of the emissivities and long wave transmittance of the panes.
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. This phenomenon is covered in WIS.

8.1.3.3 *Ventilation in the cavity of the double facade*

WIS offers two possibilities for the ventilation of the air cavity : forced ventilation (known airflow rate) and free ventilation (see Figure 16). In both cases, the following information must be given :

- geometry of the air cavity : width (m) and height (m)
- origin and destination of the air that is flowing through the cavity : air from outdoors (at the outdoor air temperature specified in the 'environment' screen – see Figure 5) or from indoors (at the indoor air temperature specified in the 'environment' screen – see Figure 5) can enter the cavity. Air leaving the cavity can go to indoors or outdoors.
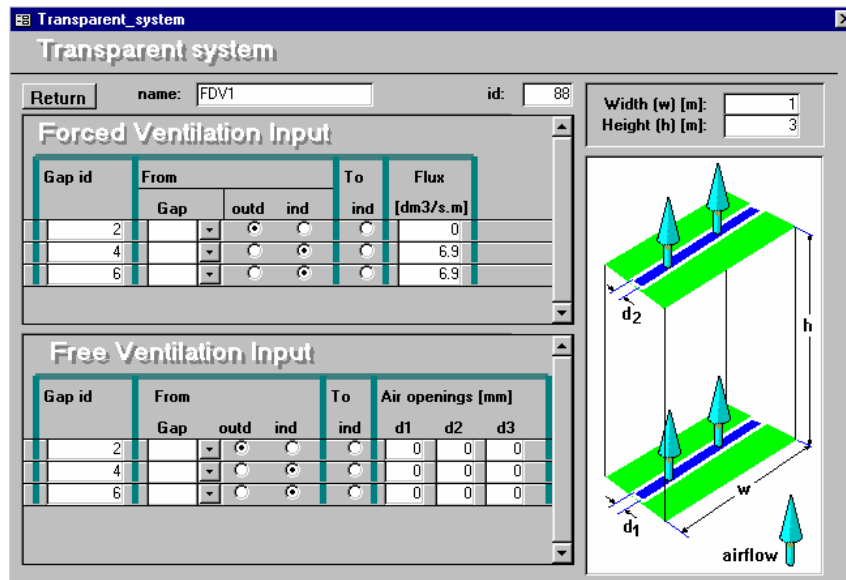
Figure 16: Ventilation models in WIS

Forced convection

In this case, the air flow rate (and thus the mean velocity of the air in the cavity) is known. The temperature profile and the heat flow are calculated by a simple model ('plug flow'). Due to the air flow through the cavity, the air temperature in the cavity varies with height (see Figure 17).
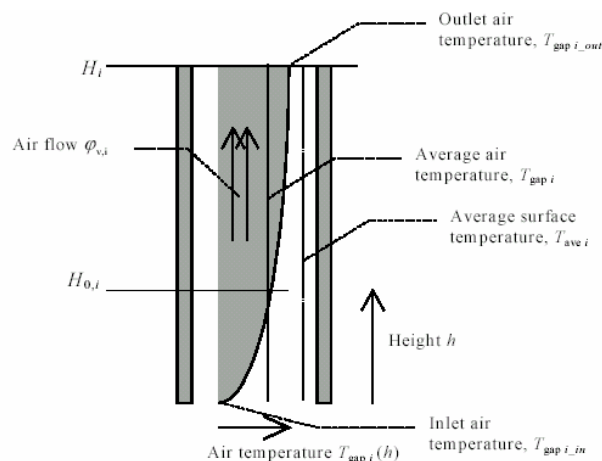
Figure 17 : air flow in the cavity of a facade

The temperature profile depends on the air velocity in the cavity and the heat transfer coefficient to both layers. The temperature of the air in the cavity at a certain height depends on the following parameters :

- the temperature of the incoming air in the cavity
- the temperature of the layers adjacent to the cavity
- the characteristic height of the temperature profile (depending on the mean velocity in the cavity, the heat transfer coefficient, the width of the cavity, the density and the specific heat capacity of the air)

The thermal equivalent (average) temperature of the air in the ventilated cavity is calculated on basis of the temperature profile. In this way, the bi-dimensional heat transfer is reduced to a one-dimensional process. This is the procedure described in the ISO 15099 standard.

Natural convection

WIS offers the possibility to model natural convection caused by the stack effect (thermally-driven ventilation). Wind-induced ventilation is not considered in WIS.
The velocity of the air in the space caused by the stack effect depends on the driving pressure difference and the resistance to the airflow of the openings and the space itself.
The air velocity in the cavity of the façade is calculated by solving a set of equations (this is described in the ISO 15099 standard).
The calculation of the pressure loss in the inlet and outlet openings requires the determination of the pressure loss factors for openings (inlet and outlet). These pressure loss factors are calculated on basis of the area of the bottom opening of the cavity, of the top opening, of the left side opening and of the right side opening (see Figure 18).
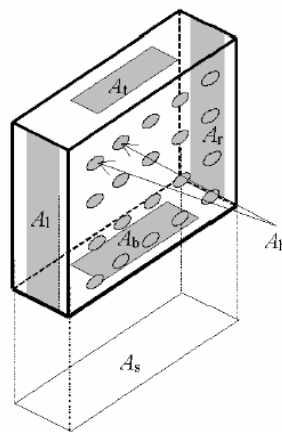
Figure 18 : schematic representation of openings

In order to determine these openings, the user must specify the air openings d1, d2 and d3 in mm (see Figure 16).

8.1.4   Simulation of control systems and control strategies

The WIS software is not able to simulate any control strategy or control system. Each working condition must be simulated independently.

2: BISCO/TRISCO/VOLTRA SOFTWARE

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8.2 BISCO/TRISCO/VOLTRA SOFTWARE

8.2.1 General software information

Physibel has developed a series of software aimed at modeling heat transfer of building details using the energy balance technique.

Where all other simulation programs calculate the ventilated double façade (VDF) as parallel glass and shading layers which does not directly take into account the thermal bridging effect of sub-components with a clear 2D or 3D heat flow, BISCO, TRISCO and VOLTRA have the potential to calculate for both temperature distribution and heat loss, the interaction between the glass and shading layers in combination with the thermal bridging effect of the subcomponents around the VDF (e.g. the supporting mullions and transoms, connection with inlet and outlet openings and even the false ceiling).

8.2.1.1 Bisco

BISCO allows to calculate two-dimensional steady state heat transfer in objects with any shape. The geometry required to perform the calculation is a picture in bitmap format (e.g. a drawing on paper can be scanned, a drawing on screen can be captured, ...). The only complementary input consists of an association between the colors in the bitmap picture and the material properties or the boundary conditions. The grid generation is fully automatic.
BISCO allows to calculate important thermal quantities as defined by European standards: temperature factor, linear thermal transmittance, thermal transmittance of a window frame, etc.

8.2.1.2 Trisco

TRISCO allows the very same kind of calculations as BISCO but with three-dimensional objects. The geometry is here described with a list of rectangular blocks that the user has to encode manually. Two-dimensional BISCO files can be imported and altered to take the third dimension into account.

8.2.1.3 Voltra

VOLTRA is an extension for time-dependent boundary conditions of the steady-state program TRISCO. The object modeling is completely identical as in TRISCO except that thermal inertia of materials is taken into account. TRISCO data files can be imported in VOLTRA. The time-dependent boundary conditions are described with functions, either built-in functions based on variable parameters, or external user-defined functions based on function values given at a fixed time interval.

All those programs can be used with the RADCON module. The RADCON module allows a more realistic simulation of the separate heat transfer by radiation and convection in enclosures and between material objects and the environment.

Since VOLTRA is the most complete software of the series and also the most useful to model ventilated double façade, only this one will be described (Version 4.0 was used in this study).

8.2.2 Theory

This paragraph describes how the program takes different theoretical aspects into account.

8.2.2.1 Convective heat exchange in the cavity

The user is free to use any convective heat transfer between the air inside the cavity and the surrounding materials. For example the convective heat transfer relations of parallel surfaces as described in ISO 15099 can be used. Coefficients are chosen once at the beginning of the simulation and can not vary during the simulation as a function of the air flow.

8.2.2.2 Short-wave (solar) radiation

The user can define a radiation [W/m²] between a boundary and all materials in contact with this boundary. The intensity can vary as a function of time.
Opaque and transparent materials are treated the same way, which means that solar radiation cannot pass through a material.

In order to simulate the effect of short-wave solar radiation through the double facade, first the absorption fraction of the different glass layers and shading devices need to be calculated. This can be done from the knowledge of the solar glazing characteristics of the different layers by use of a program as WIS. The absorption fraction multiplied with the incident solar radiation will result in the solar absorption of every component. It is possible to add heat sources between different planes representing the absorbed heat in the materials. The absorbed short wave energy of the sun (represented by the different heat sources) will make the temperature of the radiated elements (i.e. heated elements) to rise.

8.2.2.3 Longwave radiation

Thanks to the RADCON module, radiation flux can be treated separately. The user can define the emissivity (ε) of each material. The program calculates automatically all view factors. Linear or non-linear radiative heat transfer can be used.

For external longwave radiation, the user can specify a sky radiation temperature as a function of time. Taking into account the interaction with the radiation coming from the ground or another building is possible by explicitly modelling it with all boundary conditions.

8.2.2.4 Air flow in the double facade

Air flow between different zones can be defined as a function of time, which allows to model forced ventilation of double façade. Natural ventilation, depending on temperature, wind speed, etc. can not be taken into account.

VOLTRA considers each zone with a uniform temperature. The cavity of the VDF can be split in different zones so that each one has a different temperature. About ten volumes are sufficient to correctly model the evolution of the air temperature inside a double façade of 3 m high.

8.2.2.5 Control

VOLTRA is not aimed at simulating control strategy of a DVF. Ventilation fluxes are indeed defined a priori (before simulation) and cannot depend on another specific parameter.

8.2.3 Procedure for setting up a model

In this paragraph, we will present the building up of a model, step by step. Examples of ventilated double facades will illustrate the procedure.

The input in VOLTRA is organized in several windows. Normally the following windows are open when the command *File > New* or *File > Open...* is invoked:
The **Image window**, with a graphical representation of the model. In this window the object can be interactively rotated and zoomed in.
The **Grid window**, with the distances between the successive grid planes in three dimensions.
The **Blocks window**, with a list of all building blocks of the geometry. All coordinates refer to the grid in the Grid window.
The **Colours window**, with the thermal data of all materials and surface boundary conditions. Each block in the Blocks window refers to a colour in the Colours window.

These are the main windows but others will be introduced when needed. Each window can be activated by using the *Edit* menu.

8.2.3.1 Grid

The default model consists of a three-dimensional cube of 1m. First define the **grid unit** (or scale) of the mesh sizes in the Grid window by choosing *Grid > Grid Unit…*. It is usually more convenient to choose a grid unit equal to 1m or 1cm.

Enter the **number of meshes** for the three dimensions. Each dimension is represented by a column in the Grid window, headed by X, Y and Z. Initially all new mesh widths are equal to 1. One can edit the individual mesh widths to different values. The position of the meshes is reflected in the Image window by a surrounding box.

Figure 19 gives an example of grid definition that will be used to build up a ventilated double façade model.

No.	X	Y	Z
0-1	25.000	50.000	25.000
1-2	5.000	15.000	5.000
2-3	5.000	5.000	5.000
3-4	10.000	10.000	10.000
4-5	5.000	15.000	5.000
5-6	51.028	10.000	50.000
6-7	797.943	5.000	250.000
7-8	51.028	80.000	250.000
8-9	5.000	5.000	250.000
9-10	10.000	80.000	250.000
10-11	5.000	5.000	250.000
11-12	5.000	10.000	250.000
12-13	25.000	5.000	250.000
13-14		15.000	250.000
14-15		50.000	250.000
15-16			250.000
16-17			50.000
17-18			5.000
18-19			10.000
19-20			5.000
20-21			5.000
21-22			25.000
Sum	1000.000	360.000	2700.000

Figure 19: Definition of the grid

All coordinates in the Blocks window, which will be discussed below, are given with reference to grid numbers, as defined in the Grid window.
While or after entering the geometry of the object, grid meshes can be subdivided or merged using grid functions.

8.2.3.2 Geometry

Both the object geometry and the boundary condition locations are defined by using rectangular blocks defined in the *Blocks window*. A block defining the object geometry corresponds to a material part of the object considered. A block defining a boundary condition location has to be defined in such a way, that the surfaces between that block and adjacent material blocks correspond to surfaces on which the boundary condition has to be applied.

The blocks are ordered in a sequential list. You can insert a new block before or after the current block (wherein the cursor cell is), delete the current block, copy the current block or move the current block into another position in the list.

Each block has a colour number (between 0 and 255), which is a reference to a colour in the Colours window and 6 coordinates, which are grid numbers as defined in the Grid window.
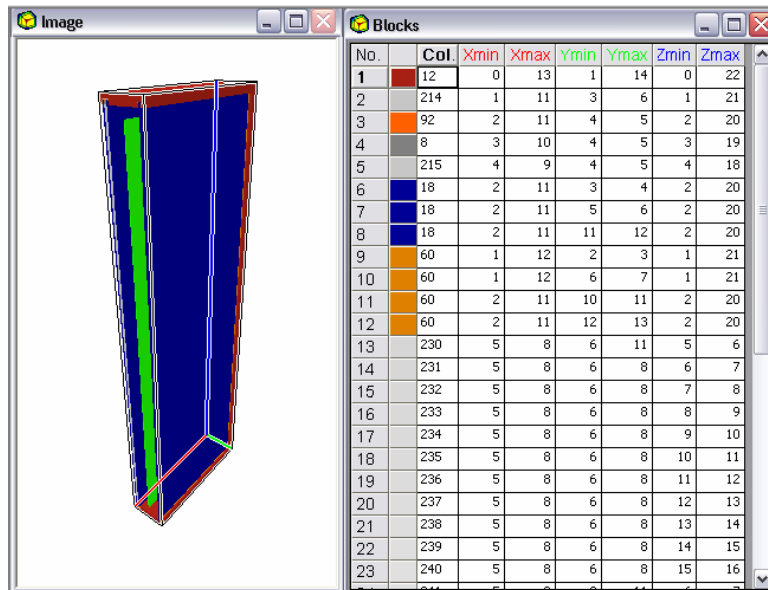
Figure 20 : Encoding the geometry with Blocks

Only rectangular blocks can be defined. The order of succession in the blocks list is important. There is a **superposition rule**: blocks further in the list (with higher block number) override previous blocks (with lower number) where they overlap. An intelligent definition of blocks can reduce the required number of blocks to model a given object.

Complex shape
This way of encoding the geometry of the model is convenient for simple geometries. But for more complex model it can be tedious. Figure 21 shows an example of aluminum window frame encoded in order to calculate a U value.

An alternative way of entering the geometry has been used for this example. It consists of the following steps:
- Generate a 256 colours bitmap file representing a two-dimensional view of the model, with a more convenient software as AutoCAD (a simple hand-drew picture scanned as bitmap file can also be used). Each colour corresponds to a different material or boundary condition.
- Use BISCO program to create a first two-dimensional model, starting from this bitmap file.
- Import the BISCO model in TRISCO.
- Import the TRISCO model in VOLTRA and alter it to take the third dimension into account.
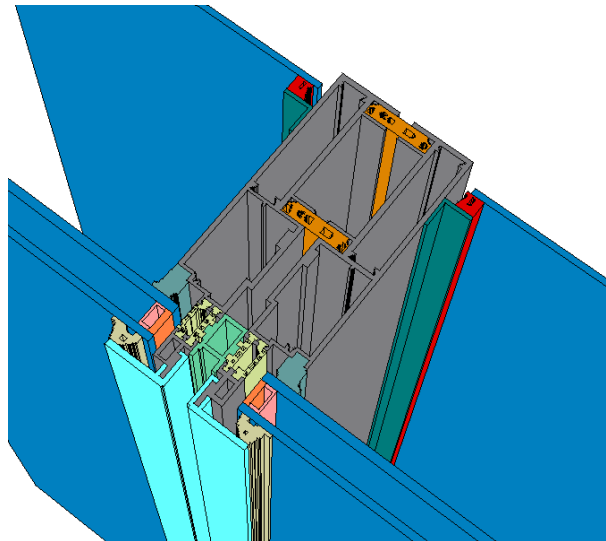
Figure 21 : Zoom on a complex frame detail

8.2.3.3 Material properties

The definition of a block requires an index to a colour (i.e. a number between 0 and 255 in the first column, see Figure 22). Each colour corresponds to a specific material or boundary condition depending on the type of colour. Different blocks can refer to the same colour defined in the *Colours window*.

Figure 22 : The colours window

The type **MATERIAL** means that all blocks with the referenced colour are defined as a material with given thermal conductivity, density, emissivity coefficient and thermal capacity. The characteristics of most usual materials can be loaded from a database.

Thermal conductivity (λ) and thermal capacity (C) can be function of the temperature.

Glazing
As mentioned in section 8.2.2.2 (short wave radiation) glazing is modeled as an opaque material. In order to simulate the effect of short-wave solar radiation through the double facade, first the absorption fraction of the different glass layers and shading devices need to be calculated. This can be done from the knowledge of the solar glazing characteristics of the different layers by use of a program as WIS. The absorption fraction multiplied with the incident solar radiation will result in the solar absorption of every component. It is possible to add heat sources between different planes representing the absorbed heat in the materials.

Shading device
The shading device is modeled as a material. Note that it can not be removed during calculation in transient condition. Two different models must be created so that the performance of the double façade with and without shading device can be assessed.

Frame

As mentioned in the introduction, one of the main interesting features of this program is that it can take all detail of the façade and their interaction into account. An accurate calculation of heat loss and surface temperature are the most interesting output of the program.

8.2.3.4 *Boundary condition and air cavities*

The blocks that are not material can be defined as one of the following type:

- BC_SIMPL   To simulate **simplified combined convection and radiation** between the object surfaces and the environment, using a global heat transfer coefficient and an environment temperature. This coefficient can be chosen by the user. The air temperature can be time dependant.

In our example, the climate inside the building is of the type BC_SIMPL.

- BC_FREE   To consider **enclosures** (i.e. normally fully surrounded by material surfaces) with an **unknown air temperature** ("free" air temperature) and with a **known heat source** .

The cavity of the double façade is modeled as a set of BC_FREE cavities.

-   BC_SKY   To consider **environments** with a **known air temperature** and with a **known radiation temperature**   of   the   environment   of   the   object   (the   "sky"). The simulation will consider both the radiation between surfaces of the object themselves and between the surfaces of the object and the environment (the "sky").

This type is the most accurate to model outside conditions.

8.2.3.5 *Ventilation in cavity*

Ventilation flow paths can be defined by entering one or more ventilation flows between two boundary conditions in the **Ventilation Flows window**, opened with *Edit > Ventilation Flows*.

Per input line a ventilation source and ventilation destination must be entered. Both are identified by colour numbers to the corresponding boundary conditions.

As mentioned in section 8.2.2.4, VOLTRA considers each zone with a uniform temperature. The cavity of the VDF can be split in different BC_FREE volumes so that each one has a different temperature. About ten volumes are sufficient to model the evolution of the air temperature inside a double façade of 3 m high with enough accuracy. When a shading device is used, each cavity must be split in 2 independent BC_FREE cavities. Figure 23 shows an example of ventilation flow definition in a cavity with a shading device in the middle of it.
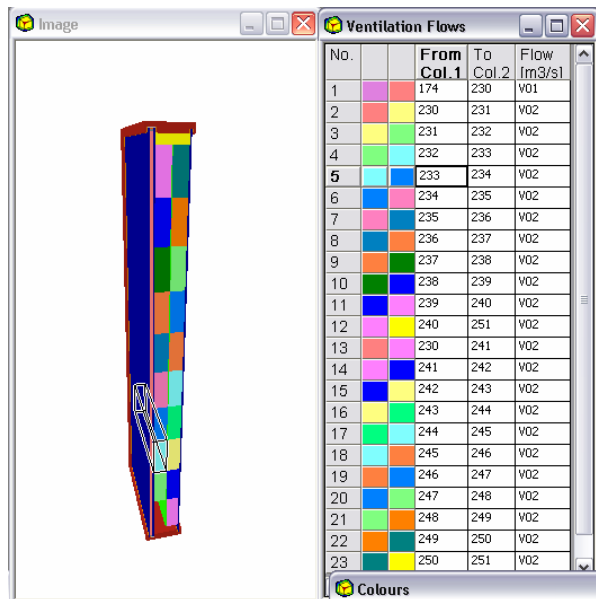
Figure 23 : Encoding ventilation flows

The ventilation flow refers to a function in the *Functions window* which can be time dependant.

8.2.3.6 Function

All parameters that are not constant refer to a function in the *Function window*.

Boundary conditions and ventilations flow can be time dependant which can be useful to simulate a whole day of temperature, solar radiation and ventilation fluctuation. But temperature dependant functions are not allowed for boundary conditions or ventilation flow, which makes it impossible to simulate control strategies. Indeed, all ventilation flow must be defined in a separate data file before the beginning of the simulation.

VOLTRA propose basic build-in functions as sinusoidal or step functions that can be helpful to simulate daily fluctuation. But the user can also make reference to external functions in txt format. This possibility allows to simulate real measured conditions.

8.2.3.7 Output

When transient conditions are used, VOLTRA calculates temperature of all nodes, every time step. However the program doesn't keep all those information in memory. By default, only the final temperature and heat flux are displayed at the end of the simulation.
The user must define, in the *output node* window, the particular point for which the evolution of the temperature must be kept in memory. The same principle applies for the surface through which the evolution of heat flux must be kept in memory by use of the *output blocks* window.
It is also possible to make a movie in avi format by saving an image such as Figure 24 at regular time step.
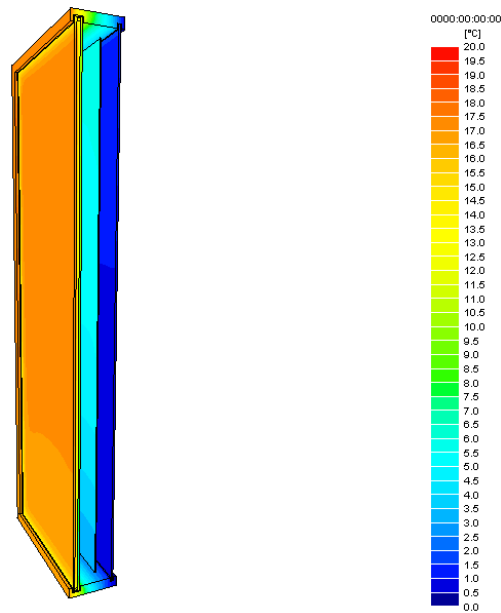
Figure 24 : cross section of a double facade showing temperatures

8.2.4 Conclusion

BISCO, TRISCO and VOLTRA have the potential to calculate for both temperature distribution and heat loss, the interaction between the glass and shading layers in combination with the thermal bridging effect of the subcomponents around the VDF. They allow to calculate important thermal quantities as defined by European standards: temperature factor, linear thermal transmittance, thermal transmittance of a window frame, etc.

But those software's are not aimed at simulating control strategy of a DVF. Ventilation fluxes are indeed defined a priori (before simulation) and cannot depend on another specific parameter.

3: CAPSOL SOFTWARE

8.3 CAPSOL SOFTWARE

8.3.1 General software information

CAPSOL[2] is a programme that calculates multi-zone transient heat transfer.

In CAPSOL, the building and its environment are considered as a set of zones, between which heat flows occur due to conduction, convection, radiation and ventilation. The behaviour of the system is defined by the boundary conditions, i.e. known temperatures, heat fluxes (such as solar radiation and internal heat gains) and controls (such as heating, cooling, ventilation and sun shading). The program contains a solar processor; building sun obstacles and wall sun obstacles can be defined to simulate e.g. other buildings and overhangs.

During the dynamic calculation, a system of energy balance equations is built and solved each calculation time step, using the Crank-Nicolson finite difference method.

For more information about CAPSOL: http://www.physibel.be/

8.3.2 Outdoor climate

The outdoor climate is defined by:
- one temperature function (type "T"),
- two horizontal radiation functions, to be selected out of three possible functions: global horizontal radiation ("G"), diffuse horizontal radiation ("D") and direct beam horizontal radiation ("B"),
- an infrared sky radiation function ("I"), if necessary.

Other climate characteristics as humidity, wind speed and wind direction are not considered by CAPSOL.

8.3.3 Simulation of a ventilated double facade

8.3.3.1 General methodology

The general methodology is to consider the VDF as a set of zones, as shown on Figure 25. Indeed, to take the thermal stratification into account, it will be necessary to divide the cavity in a few zones, as CAPSOL considers isothermal zones. If a shading device is present in the cavity, the number or zones required for the cavity will be two times higher.
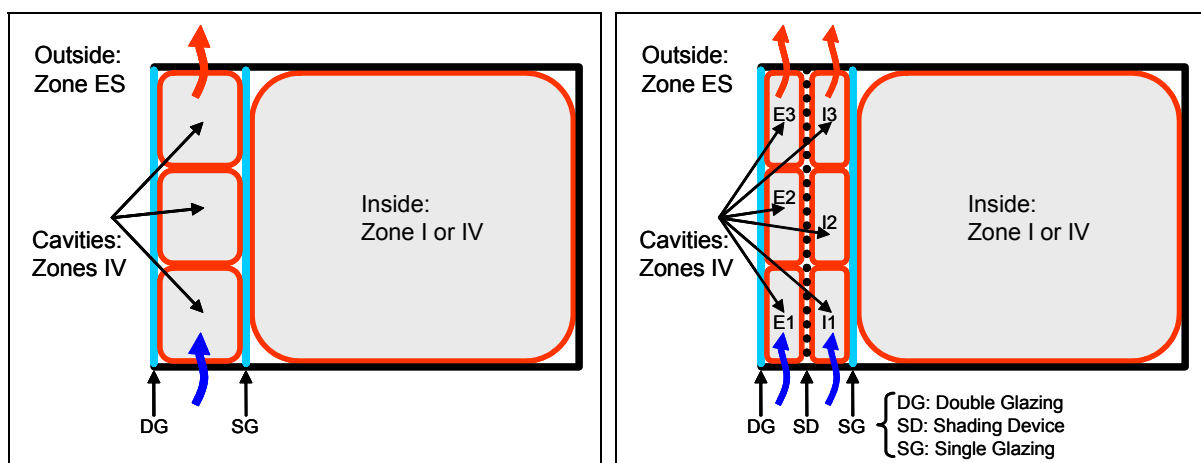
Figure 25: Simulation of a VDF
without shading device (left) – with shading device (right)

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[2] This document is based on CAPSOL v4.0w, released in 2002.

The control strategy of a VDF may act on the ventilation (by modifying the airflow in case of a mechanical ventilation system or by modifying the position of the air inlets and outlets in case of natural ventilation system) and on the characteristics of the shading device (by modifying its position into the cavity (up/down) or e.g. the positions of the slats of Venetian blinds)

CAPSOL offers possibilities to simulate control strategies.
− **Shading device** may be simulated by the controls integrated in CAPSOL. Some tricks will be required to simulate the situation where the shading device is up and to link the shading device to the solar conditions; they are discussed below.
− **Ventilation related aspects** might be more difficult to implement, according to the type of VDF. It is important to keep in mind that CAPSOL is a <u>thermal</u> model. This means that it can calculate temperatures of zones and walls, but it was not designed to calculate airflow between zones, according to their temperatures. However, a *multilateral ventilation control* has been integrated in the last versions of CAPSOL (v3.4 and higher). This control can be used to increase the ventilation rates between zones, in function of a temperature difference. This possibility is less accurate than a calculation according to a ventilation model (as COMIS), but can be used to avoid complex coupling of simulation models and to allow control strategies. It will be discussed in §8.3.5.2.

8.3.3.2   Facade layers

Glass layer

For the double glazing and the single glazing that compose the VDF, there is nothing special to mention; they are defined as usually. However, it is not always easy to get all input data for such glazing. It could be helpful to use the WIS software to get the relevant data.

Example of definition of a single glazing
 Table 4 gives an example of data usually given by the glazing manufacturer.

Single glazing "XY"	
Width	4 mm
Solar direct transmittance	83 %
Solar reflectance external side	8 %
Solar reflectance internal side	8 %
Solar absorption	9 %
Solar factor	0.85
U-value	5.8 W/m².K

Table 4: Example of single glazing characteristics
provided by the manufacturer

This set of data does not cover all the needs of CAPSOL. Missing data are:
− the thermal conductivity, which can be found in NBN B 62-002: $\lambda = 1$ W/m.K,
− the density, which can be found in NBN B 62-002: $\rho = 2500$ kg/m³,
− the specific heat, which can be found in NBN B 62-002: $c = 750$ J/kg.K,
− the infrared emission factor of both sides. The emissivity of a typical clear glazing without coating is $\varepsilon = 0.837$. For glazing with coating, typical values can be found in WIS.
− the angular dependence of the solar reflection factor on the external side. Typical values are given in the CAPSOL manual ($p = 0$ for 0°, 15° and 30°, $p = 1$ for 45°, $p = 14$ for 60°, $p = 46$ for 75°, $p = 100$ for 90°); other set of data can be derived from the WIS software if necessary. The angular dependence does only apply for wall sides in contact with outside.
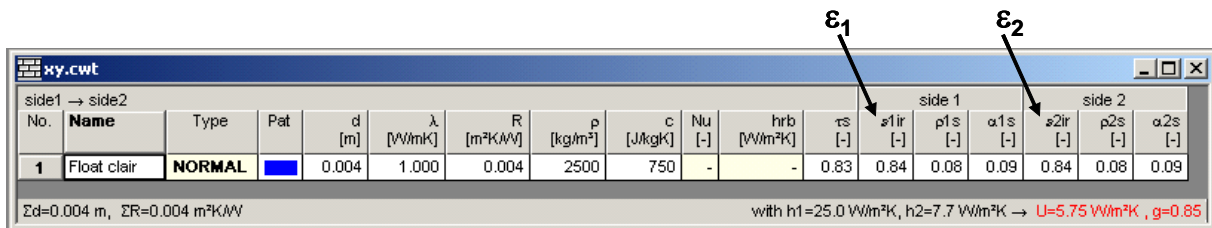
Figure 26: Definition of a single glazing in CAPSOL v4.0w
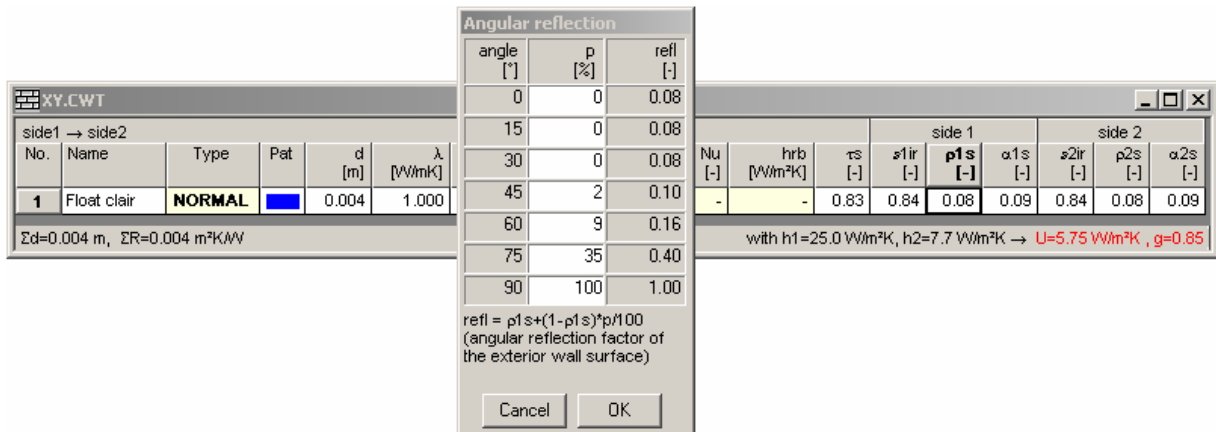
Figure 27: Definition of angular reflection in CAPSOL v4.0w

Example of definition of a double glazing
Table 5 gives an example of data usually given by the glazing manufacturer.

Double glazing "YZ"	
Width	6-12-6 mm
Coating position	2
Solar direct transmittance	14 %
Solar reflectance external side	22 %
Solar absorption external pane	62 %
Solar absorption internal pane	2 %
Solar factor	0.22
U-value	2.6 W/m².K
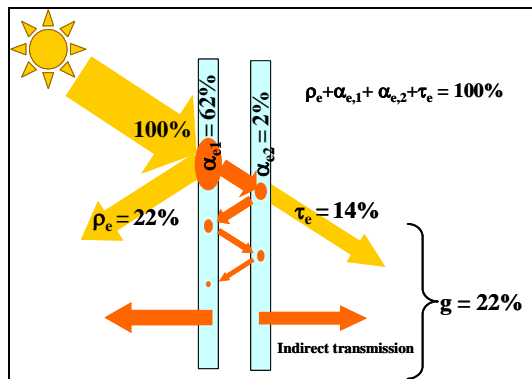
Table 5: Example of double glazing characteristics
provided by the manufacturer

This is too less information compared to what CAPSOL or other simulation softwares require. A procedure to find the missing data is described below; this procedure is not specific to CAPSOL and may be used for other simulation softwares.

1. The first step is to consider a standard double glazing with the same geometry (6-12-6), without coating. The U-value of such a glazing is typically 2.8 W/m².K, and its g-value 0.71.

Figure 28: First step – considering a standard double glazing

2. The second step is to use the equation given in EN 410[3] in order to find the missing solar characteristics.

$$\tau = \frac{\tau_1 . \tau_2}{1 - \rho_1' . \rho_2}, \; \rho = \rho_1 + \frac{\tau_1^2 . \rho_2}{1 - \rho_1' . \rho_2}, \; \rho' = \rho_2' + \frac{\tau_2^2 . \rho_1'}{1 - \rho_1' . \rho_2}, \; \alpha_e = \alpha_1 + \frac{\alpha_1' . \tau_1 . \rho_2}{1 - \rho_1' . \rho_2}, \; \alpha_e' = \frac{\alpha_2 . \tau_1}{1 - \rho_1' . \rho_2},$$

$$g = \left(\frac{(\alpha + \alpha')}{h_e} + \frac{\alpha'}{(1/U - 1/h_i - 1/h_e)} \right) . U . \tau$$

where τ is the direct solar transmission of the double glazing,

τ_1 and τ_2 are the direct solar transmission of the external and internal panes (noted τ_s in CAPSOL),

ρ is the solar reflectance of the double glazing

ρ_1 is the solar reflectance from outdoor of the external pane (noted $\rho 1s$ in CAPSOL),

ρ'_1 is the solar reflectance from indoor of the external pane (noted $\rho 2s$ in CAPSOL),

ρ_2 is the solar reflectance from outdoor of the internal pane (noted $\rho 1s$ in CAPSOL),

ρ'_2 is the solar reflectance from indoor of the internal pane (noted $\rho 2s$ in CAPSOL),

α_e is the direct solar absorption of the external pane of the double glazing,

α'_e is the direct solar absorption of the internal pane of the double glazing,

α_1 is the solar absorption from outdoor of the external pane (noted $\alpha 1s$ in CAPSOL),

α'_1 is the solar absorption from indoor of the external pane (noted $\alpha 2s$ in CAPSOL),

α_2 is the solar absorption from outdoor of the internal pane (noted $\alpha 1s$ in CAPSOL),

g the solar factor,

U the U-value,

h_e and h_i are the external and internal global heat transfer coefficient.

By introducing the known value of the internal pane in these equations, it is be possible to find a set of possible data for the internal pane so that the characteristics of the double glazing are met.

Figure 29: Step 2 –Using EN 410 to find missing solar characteristics

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[3] EN 410:1998 Glass in Buildings – Determination of luminous and solar characteristics of glazing

3. The third step is to use WIS in order to find the data that are still missing (ε_1, Nu, h_{rb}).

$$h_{rb} = h_r \cdot \left(\frac{1}{\varepsilon_1'} + \frac{1}{\varepsilon_2} - 1 \right)$$

where h_{rb} is the black radiation heat transfer coefficient required in CAPSOL,

h_r is the radiation heat transfer coefficient between the panes given in WIS,

ε_1' is the emissivity of the internal surface of the external pane,

ε_2 is the emissivity of the external surface of the internal pane,

Nu is the Nusselt number of the cavity.

Figure 30: Step 3 – Using WIS to find ε_1', Nu, h_{rb}

Shading devices

An example of a shading device composed by a screen (or roller blind) is given below.

Screen "WX"	
Width	4 mm
Solar direct transmittance	7.5 %
Solar reflectance external side	26.0 %
Solar reflectance internal side	34.8 %
Solar absorption ext → int	66.5 %
Solar absorption int → ext	57.7 %

Table 6: Example of screen characteristics
provided by the manufacturer

The thermal resistance of such as screen is negligible. The density is typically ±500 g/m² and the thickness 1 mm; however, in order to simulate the situation without screen, very small values will be introduced for the density ρ and the specific heat c. The emissivity is usually not given by the manufacturer; $\varepsilon = 0.8$ will be chosen as default value.

Figure 31: Definition of a shading device in CAPSOL w4.0w

However, the shading devices usually applied in climatic facades is composed of "Venetian blinds", sometimes orientable.   The characteristics of such a shading device could be calculated in WIS and equivalent characteristics can be introduced in CAPSOL. However, differences might be expected, due to the fact that, in CAPSOL, all walls are considered more or less as *specular panes* (as glazing), whereas WIS simulates shading devices as *scattering layers*. The difference is that there is no diffusion in the first ones (see Figure 32).
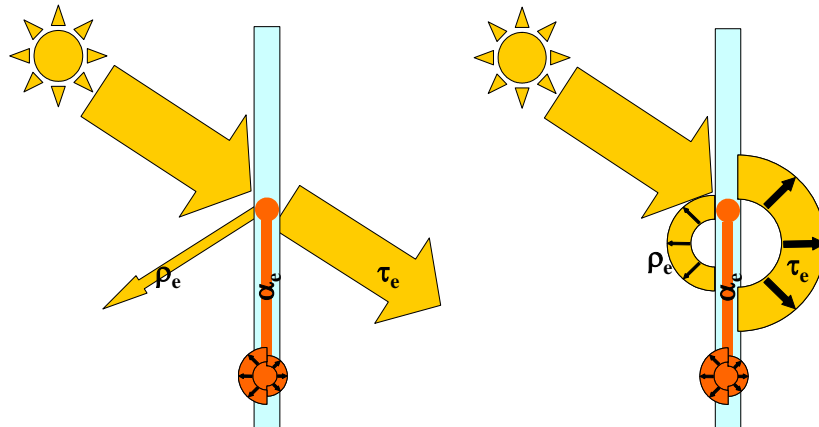
Report on simulations of the energy performances

Figure 32: Specular panes (left) versus scattering layer (right)

This will be illustrated by comparing CAPSOL simulations with WIS calculations[4], for the specific case of the VDF described in Table 7. The cavity width is 200 mm. The VDF is 3 m high and is divided in 3, as shown in Figure 25. The convective heat transfer coefficients h_c in the cavity depend of course on the airflow and the glazing surface temperatures in the cavity. The values given by WIS for case 6 have been used, as well as the values for h_e and h_i.

Analysed VDF				
Element	Double glazing		Shading device	Single glazing
	Pane 1	Pane 2		
Width	6 mm	6 mm	1 mm	8 mm
Solar direct transmittance	79 %	58 %	10 %	75 %
Solar reflectance, side 1 / 2	7 % / 7 %	24 % / 7 %	51 % / 51 %	7 % / 7 %
Emissivity, side 1 / 2	0.84 / 0.84	0.04 / 0.84	0.85 / 0.85	0.84 / 0.84
U-value (cavity: 12 mm air)	1.6 W/m².K			
Solar factor g	0.6			

Table 7: Characteristics of the analysed VDF

Six sets of boundary conditions were simulated; the heat losses/gains through the VDF are given in Table 9 for each of them.

Case	ΔT°	Sun	Ventilation	WIS scattering	WIS specular	CAPSOL
1	0°C	0 W	0 m³/h	0 W	0 W	0 W
2	0°C	200 W	0 m³/h	1173 W	948 W	896 W
3	20°C	0 W	0 m³/h	-57 W	-57 W	-62 W
4	20°C	200 W	0 m³/h	1074 W	858 W	837 W
5	20°C	0 W	50 m³/h	-25 W	-25 W	-25 W
6	20°C	200 W	50 m³/h	638 W	506 W	495 W
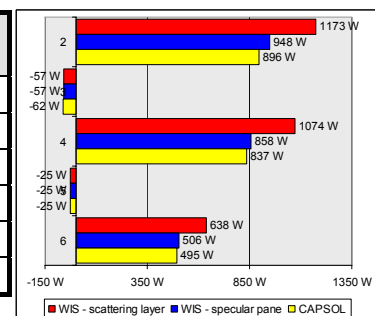
Table 8: Boundary conditions and heat losses (−) / gains (+)
WIS – scattering = (direct → diffuse)
WIS – specular = shading device as a pane (direct → direct)

The remaining difference is due to the fact that the black radiation heat transfer coefficients in the cavity are set to h_{rb} = 5.15 W/m².K, which is a value for an average temperature of both faces of the cavity equal to ±12°C. If a value derived from the WIS calculations for case 6 is used (h_{rb} = 7.82 W/m².K), CAPSOL gives the same result than WIS – specular for this case.

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[4] The simulations were carried out with WIS 2.0.1.

Evaluation of the impact of the dummy shading device

As said previously, in order to simulate the situation when the shading device is up, it is necessary to divide the cavity in two sets of zones (Ex and Ix) which are separate by a "dummy" shading device. This dummy shading device should have the lowest possible influence on the heat exchanges in the cavity. The definition of such a dummy shading device is given below.

No.	Name	Type	Pat	d [m]	λ [W/mK]	R [m²K/W]	ρ [kg/m³]	c [J/kgK]	Nu [-]	hrb [W/m²K]	τs [-]	ε1ir [-]	ρ1s [-]	α1s [-]	ε2ir [-]	ρ2s [-]	α2s [-]
1	No shading	NORMAL		0.001	999.999	0.000	0.1	0.1	-	-	1	1.00	0.00	0.00	1.00	0.00	0.00

NoShading.CWT — side1 → side2 — Σd=0.001 m, ΣR=0.000 m²K/W — with h1=25.0 W/m²K, h2=7.7 W/m²K → U=5.89 W/m²K , g=1.00

Figure 33: Dummy shading device
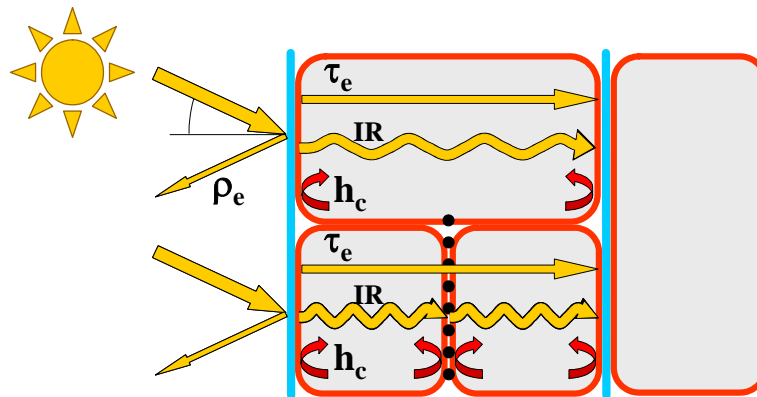
Figure 34: DVF simulated with 1 series of zones (without dummy shading device)
and 2 series of zones (with dummy shading device)

Figure 34 shows the differences between the cavity simulated with 1 series of zones (without dummy shading device) and 2 series of zones (with dummy shading device).

- The directly transmitted solar radiation is not influenced by the dummy shading device, as its solar transmission factor τ_e is set to 1.
- The dummy shading device is opaque to IR; it is not possible to define an IR transmission of 1 for a wall in CAPSOL (as it is for instance possible in WIS). To minimise this interference, the emissivity of both faces of the dummy shading device are set to 1. The IR will heat up the dummy shading device, but this heat will be reemitted as maximum as possible to both external and internal glazing. However, this will lead to a reduction of the IR exchange in the cavity.
- In CAPSOL, the convective heat transfer coefficients of the wall surfaces have to be fixed in advance and can not be changed during the simulation. In order to correctly simulate the actual shading device, heat transfer coefficients have to be introduced to its both surfaces. This increases the total thermal resistance of the VDF, which therefore decrease the convective heat transfer through it.

In order to evaluate the impact of the dummy shading device, the VDF described above (see Table 7) has been simulated without the shading device and with 1 series of zones (VDF1) and 2 series of zones (VDF2). For this analysis, the convective heat transfer coefficients h_c was fixed to 1.7 W/m².K and 2.1 W/m².K for respectively the external and internal cavities in case of VDF2 and to 1.9 W/m².K in case of VDF.

The heat losses/gains through the VDF are given in Table 9 for the same six sets of boundary conditions.

Case	T°$_{out}$ / T°$_{in}$	Sun	Ventilation	VDF 1	VDF 2
1	20°C / 20°C	0 W	0 m³/h	0 W	0 W
2	20°C / 20°C	200 W	0 m³/h	+310 W	+302 W
3	0°C / 20°C	0 W	0 m³/h	-71 W	-59 W
4	0°C / 20°C	200 W	0 m³/h	+239 W	+242 W
5	0°C / 20°C	0 W	50 m³/h	-47 W	-30 W
6	0°C / 20°C	200 W	50 m³/h	+237 W	+240 W
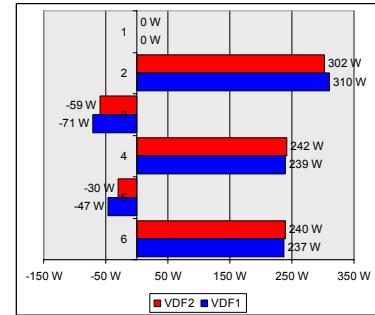
Table 9: Boundary conditions and heat losses (–) / gains (+) – CAPSOL
VDF 1 = 1 series of zones (without dummy shading device)
VDF 2 = 2 series of zones (with dummy shading device)

As can be seen in Table 9, in cases 3 and 5, the losses are reduced respectively by 20% and 56% (for the analysed configuration). However, it must be noticed that the heat losses are quite low (-59 W and -30 W). These results have been "validated" with WIS calculations.

Case	T°$_{out}$ / T°$_{in}$	Sun	Ventilation	VDF 1	VDF 2
1	19.99°C / 20°C	0 W	0 m³/h	0 W	0 W
2	19.99°C / 20°C	200 W	0 m³/h	+314 W	+307 W
3	0°C / 20°C	0 W	0 m³/h	–72 W	–60W
4	0°C / 20°C	200 W	0 m³/h	+242W	+246W
5	0°C / 20°C	0 W	50 m³/h	–42W	–28W
6	0°C / 20°C	200 W	50 m³/h	+238W	+239W
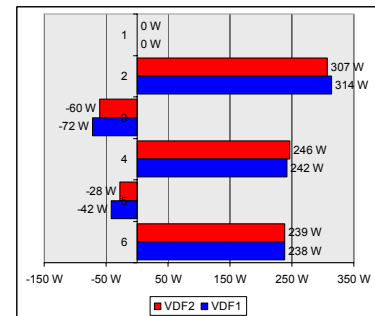
Table 10: Boundary conditions and heat losses/gains - WIS, ε = 1

As we have said previously, it is not possible in CAPSOL to introduce a wall that has an IR transmission of 1. In WIS, this is possible, see below.

Case	T°$_{out}$ / T°$_{in}$	Sun	Ventilation	VDF 1	VDF 2
1	19.99°C / 20°C	0 W	0 m³/h	0 W	0 W
2	19.99°C / 20°C	200 W	0 m³/h	+314 W	+315 W
3	0°C / 20°C	0 W	0 m³/h	–72 W	–69W
4	0°C / 20°C	200 W	0 m³/h	+242W	+245W
5	0°C / 20°C	0 W	50 m³/h	–42W	–44W
6	0°C / 20°C	200 W	50 m³/h	+238W	+238W
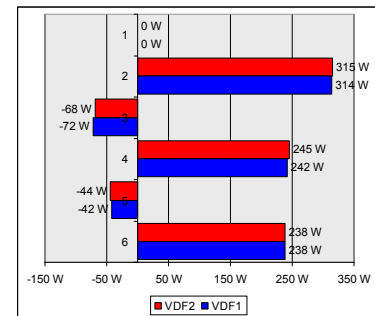
Table 11: Boundary conditions and heat losses/gains - WIS, τ$_{IR}$ = 1

As we have seen in Table 9, when there is no sun and no ventilation (as could be the case during the night) the convective heat transfer is reduced by ±20%. Therefore, it might be desirable to reduce the U-value of the double glazing by 20%. With this modified double glazing, the results are:

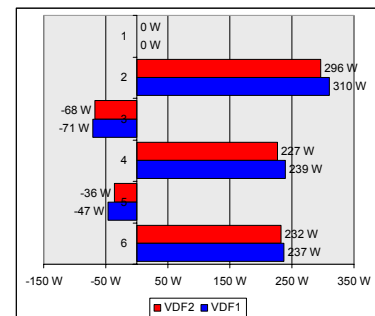| Case	T°$_{out}$ / T°$_{in}$	Sun	Ventilation	VDF 1	VDF 2
1	20°C / 20°C	0 W	0 m³/h	0 W	0 W
2	20°C / 20°C	200 W	0 m³/h	+313 W	+296 W
3	0°C / 20°C	0 W	0 m³/h	–72 W	–68 W
4	0°C / 20°C	200 W	0 m³/h	+242 W	+227 W
5	0°C / 20°C	0 W	50 m³/h	–45 W	–36 W
6	0°C / 20°C	200 W	50 m³/h	+238 W	+232 W

Table 12: Modified double glazing

In order to verify that the proposed procedure to simulate the shading device has no important impact on the results, the same VDF was simulated with and without the shading device. The VDF with the shading device is simulated with 2 series of zones (VDF 2), and the VDF without the shading device with 1 series of zones (VDF 1). As can be seen on Figure 35, when the shading device is not activated, the heat gains or losses through the VDF are identical. It is also important that the temperatures of the air that leaves the cavities of VDF 1 and VDF 2 are similar, as this temperature could be used to calculate the energy saved by a heat recovery unit. With the modified double glazing, this is almost the case of the temperature of the internal cavity of VDF 2.
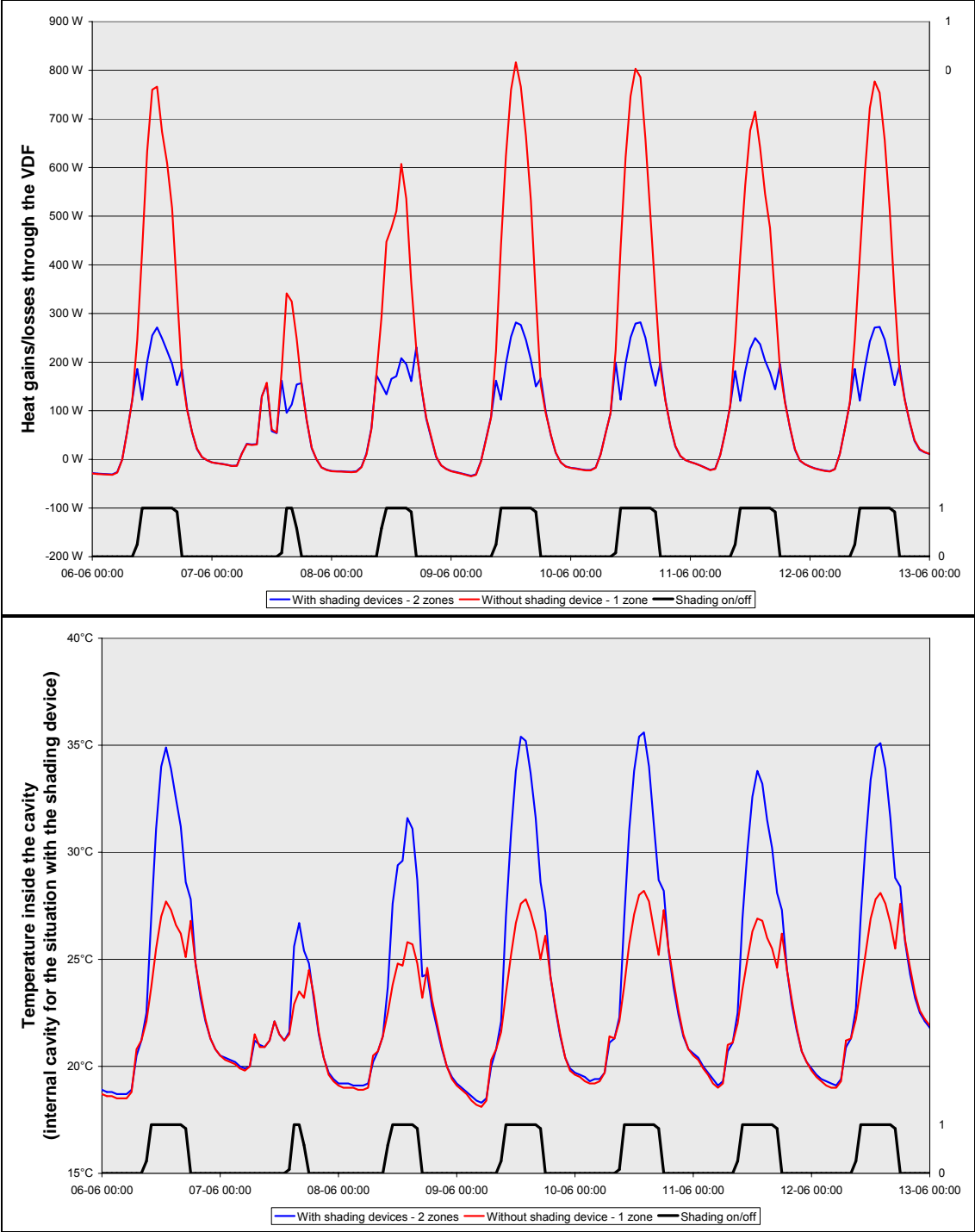
Figure 35: Simulation of the VDF with and without a shading device

Frame

This aspect has not been analysed here. The frame could be simulated by introducing walls surroundings the cavities of the VDF.

Double facade

As said previously, the VDF will be simulated as a set of zones and walls.

Convective heat transfer in the cavity.

The convective heat transfer coefficients inside the cavity h_c can not be changed during the simulation, in spite of the fact that they will depend on the actual airflow. The best value has to be determined in advance (for instance, by using the WIS software).

Short and long wave radiation: transfer through the cavity.

The short wave radiation (sun) transfer through the cavity is illustrated in Figure 36. The solar radiation striking the external glazing is partially reflected (ρ_e), directly transmitted (τ_e) and absorbed (α_e).

(1) Repartition according to "sun reception percentages"
(2) Repartition according to "wall surface vieuw factores"
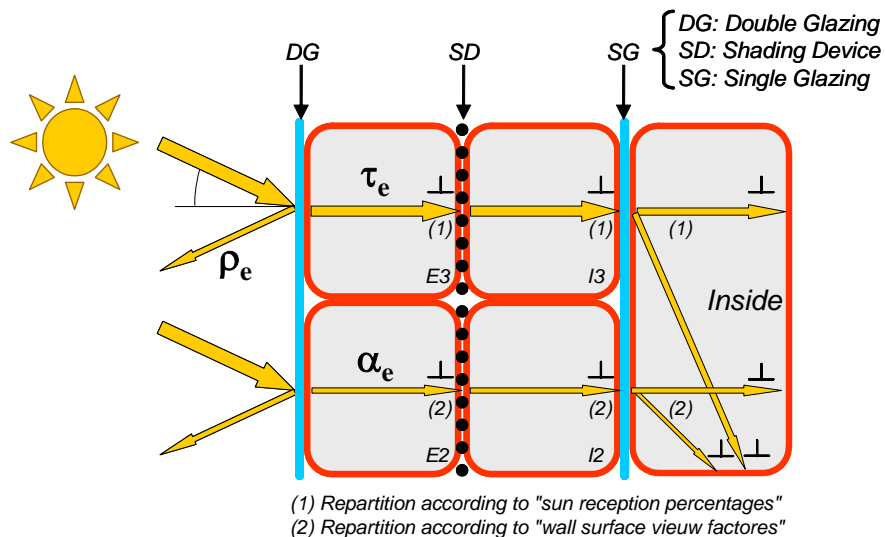
Figure 36: Short and long wave radiations transfer through the cavity in CAPSOL

- **Reflection (ρ_e).** The reflection characteristics of the **external** surface can be defined depending on the angle of incidence (as shown in Figure 27).
- **Transmission (τ_e).** The part of the solar radiation that is directly transmitted through a wall is distributed to the walls adjacent to the next zone according to their respective "sun reception percentages" (see also Figure 43) and is supposed to be perpendicular to these walls (in other words, the angular dependence of the reflection is not considered anymore, even if defined by the user). In case of a VDF, 100% of the solar radiation transmitted through the external glazing will strike the shading device and 100% of the radiation transmitted through the shading device will strike the internal glazing[5]. The distribution of the radiation transmitted through the internal glazing can be distributed over the internal walls of the zone, according to the geometry of the room. The "sun reception percentages" can not be changed during the simulation.
- **Absorption (α_e).** In case of zones of type IV, the part of the absorbed radiation that is remitted is distributed to the walls adjacent to the next zone according to their respective "wall surface view factors" (see also Figure 44) and is supposed to be perpendicular to these walls. In the case of a VDF, the view factors have to be defined so that the internal glazing only "see" the shading device, and vice et versa. The black radiation heat transfer coefficients h_{rb} inside the zones can not be changed during the simulation, in spite of the fact that they will depend on the temperature. The default value proposed by CAPSOL is 5.15 W/m².K.

---

[5] If no dummy horizontal wall are defined between E1 and E2 and between I1 and I2 (see 8.3.6.2).

8.3.3.3 Ventilation in the cavity of the double facade

How is ventilation introduced in CAPSOL?

In CAPSOL, the ventilation path is fixed in advanced by filling a matrix "zone ventilation", as the one shown in Figure 37.

In this example, the air that enters into the cavity of the VDF is supposed to be equally distributed on both sides of the shading device (zones E1 and I1), and is supposed not to mix afterwards. These assumptions could be changed if more information about the actual flow path was available. However, it must be reminded that the flow path defined here is fixed and can not be changed during the simulation according to e.g. the flow rate or the temperature.

If the flow path changes during the simulation, it will be necessary to define dummy zones of type IT (simplified zones with known temperature). An example can be found in [17].

From:	To: Σ [%]	1 OUTSIDE	2 E3	3 I3	4 E2	5 I2	6 E1	7 I1	8 ROOM
1 OUTSIDE		-	V00	V00	V00	V00	V00	V00	V01
2 E3	100.0	100.0	-	0.0	0.0	0.0	0.0	0.0	0.0
3 I3	100.0	100.0	0.0	-	0.0	0.0	0.0	0.0	0.0
4 E2	100.0	0.0	100.0	0.0	-	0.0	0.0	0.0	0.0
5 I2	100.0	0.0	0.0	100.0	0.0	-	0.0	0.0	0.0
6 E1	100.0	0.0	0.0	0.0	100.0	0.0	-	0.0	0.0
7 I1	100.0	0.0	0.0	0.0	0.0	100.0	0.0	-	0.0
8 ROOM	100.0	0.0	0.0	0.0	0.0	0.0	50.0	50.0	-

Figure 37: Definition of ventilation in CAPSOL v4.0w

Forced convection.

As we will see in § 8.3.5.2, forced ventilation can be modelled with the standard control procedures implemented in CAPSOL.

Natural convection.

As we will see in § 8.3.5.2, natural ventilation will probably require to couple CAPSOL with a ventilation model.

8.3.4 Simulation of the building and HVAC systems

The building can be simulated by a set of zones, walls, internal gains functions…
The heating system and the air conditioning system can be simulated with the help of controls.
A heat recovery can be simulated with a series of zones and walls.

8.3.5 Simulation of control systems and control strategies

8.3.5.1 Modeling the control strategy of the shading device

The control of the shading device will be implemented with the help of the standard CAPSOL control procedure. However, every control in CAPSOL is related to a temperature sensor whereas in reality, the shading device is usually submitted to the outdoor luminance level (which can be related to the solar radiation[6]). PHYSIBEL has therefore proposed a method to simulate a solar radiation sensor. The sensor is introduced as a wall with a thermal resistance of R = 1 m².K/W, a low density, a low specific heat, an absorption coefficient of 1, the orientation and the slope of the actual sensor. This wall is placed between the external zone and a dummy IT zone with a constant temperature of 0°C; the respective surface heat transfer coefficients are $h_e = 0$ W/m².K and $h_i = \infty$ W/m².K. In this case, the external surface temperature of the wall is equal to the solar flux [W/m^2] on that wall. This procedure is described in detail in the CAPSOL Pilot Book.

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[6] In average on a vertical surface oriented to South, 1 W corresponds to ±105 lux (based on yearly measurements at BBRI test site).

In § 8.3.3.2, it was proposed to change the characteristics of the double glazing, in order to reduce the error caused by the dummy shading device. If this solution is adopted, six controls will be required for a VDF divided in three cavities.

Figure 38: Implementing the control of the shading device in CAPSOL v4.0w

8.3.5.2   Modeling the control strategy of the ventilation

General considerations about coupling thermal and ventilation models
In order to correctly simulate the ventilation, a thermal model should be coupled to a ventilation model (like it is the case in e.g. TRNFLOW, which is a combination of the thermal model TRNSYS and the ventilation model COMIS). Thermal and ventilation models can be coupled in several ways.

- The **full integration** approach: both ventilation model equations and thermal model equations are solved simultaneously, by incorporating both sets of equations into a single equation system (e.g. ESP-r).
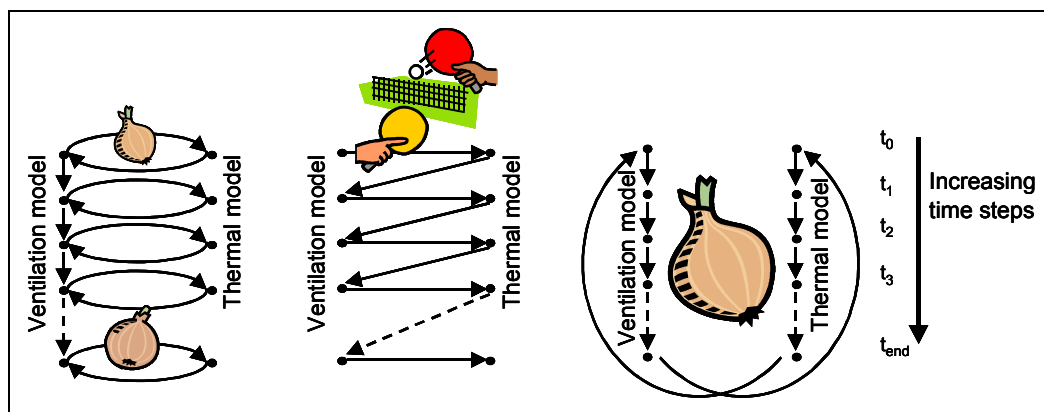
Figure 39: Onions, ping-pong and global onion approaches

- The **onions** approach: airflow rates are passed from the ventilation model to the thermal model, which calculates new air temperatures and pass them to the ventilation model, which calculates new airflow rates… until convergence is reached. The procedure is then repeated for the next time step.
- The **ping-pong** approach: airflow rates calculated in the ventilation model at time t are used as input by the thermal model to calculate new temperatures at time t. These temperatures are then used by the ventilation

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Ventilated double facades

model to calculate new airflow rates at time t+1. This approach has as main disadvantage that it can generate substantial errors and should be used with care.

- The *global onion* approach: the thermal model is run for the whole period. The resulting temperatures are introduced to the ventilation model, which calculates ventilation rates for the all period. These airflow rates are introduced in the thermal model to calculate new temperatures, and so on… up to convergence of both models. This method presents a major limitation: it is not possible to implement a ventilation control strategy that is not fixed in advance (e.g. time-controlled, controlled according to the outdoor climate…). Indeed, the opening of a window according to the inside temperature for instance will not affect the inside temperatures because they are considered as input data for the ventilation model.

Coupling CAPSOL with a ventilation model

As said previously, CAPSOL is a thermal mode and should be coupled with a ventilation model (like e.g. COMIS). The only way to couple CAPSOL with a ventilation model is the *global onion* approach. This implies that control strategy based on temperature or airflow rate can not be implemented.

A *multilateral ventilation control* has been integrated in the last versions of the software, but the possibilities offered by this option are rather limited. The use of multilateral ventilation controls to simulate a ventilation strategy is well described in the CAPSOL Pilot Book – Case J. The principle is to use a series of controls in order to reproduce as good as possible the airflow rate that would be calculated by a ventilation model. This *principle of superposition* can strictly only be used if the phenomena is linear, which is not the case. However, if enough controls are used, the difference might be acceptable (as shown in the example given in the CAPSOL Pilot Book – Case J). In summary, the CAPSOL multilateral ventilation control may simulate very simple control strategies, as far as the ventilation can be approximated by a series of controls. This will be the case for instance if there is only one inlet and one outlet and if the air is driven by stack-effect only, or by mechanical ventilation only.

Consequently, if someone wants to simulate a VDF with CAPSOL, it will have to choice to use the multilateral ventilation control, which is less accurate and may not take into consideration some important parameters, or to couple CAPSOL with a ventilation model, which will not let him simulate control strategies not based on parameters known in advance. The choice will have to be made according to the type of VDF to be simulated.

For instance, in the case of climatic facades, the air flow pattern is simple (only one inlet and one outlet) and is not influenced by the wind. The best choice will be to use the CAPSOL multilateral ventilation controls.
These conditions are not met in the case of double-skin facades; in such cases, the best choice will probably be to couple CAPSOL with a ventilation model.
Remarks:

- The CAPSOL Pilot Book – Case J also describes how to couple CAPSOL with a ventilation model (in this case, the ventilation model is developed in MS Excel).
- Even if the multilateral ventilation controls are used, it might be necessary to first simulate the VDF in a ventilation model, in order to calibrate the required ventilation controls (especially in case of natural ventilation).
- It seems not possible to combine the wind-effect with the stack-effect with the multilateral ventilation controls, as the combination of these two effects is complex and in any cases not linear.

8.3.6 Other aspects

8.3.6.1 Number of zones that compose the VDF

According to the problem analysed, it might be desirable to increasing the number of zones that compose the VDF. However, this will increase the time for introducing the data in CAPSOL.
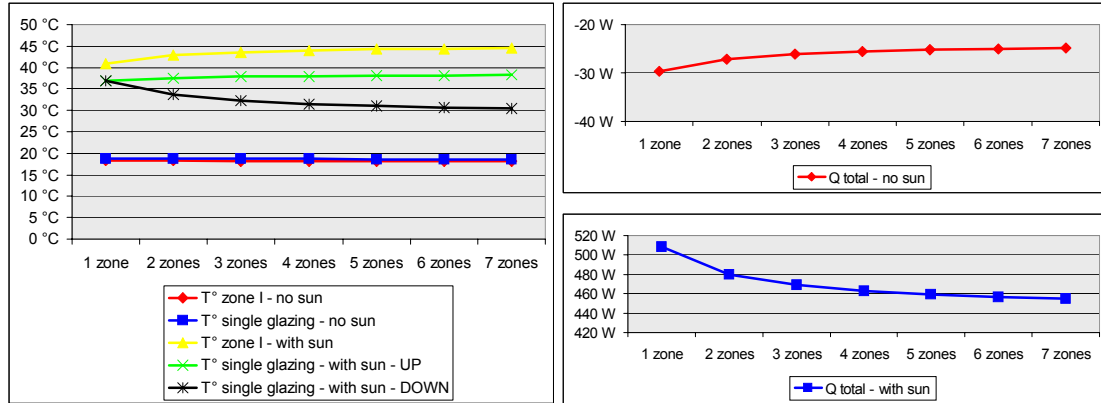

Figure 40: Example of the impact of the number of zones that compose a VDF.

In the case of the VDF analysed in Figure 40, it can be seen that there is no major difference if the VDF is simulated with 7 (couples of) zones or 3 or 4 zones.

8.3.6.2 Adding dummy walls between the zones that compose the cavities of the VDF

As can be seen on Figure 36, there are no walls simulated between the zones that compose the cavities of the VDF. The consequences of this choice is that the part of the solar radiation striking the upper part of the external glazing can not be directly transmitted to the lower part of the internal glazing, as in real VDF. This could be changed by introducing dummy walls between the zones that compose the cavities. The distribution of the radiation transmitted through the glazing and the view factors should be adapted, but remain fixed for the whole simulation period. The dummy wall should have a very low thermal resistance and a solar transmission of 1.

(1) Repartition according to "sun reception percentages"
(2) Repartition according to "wall surface vieuw factores"
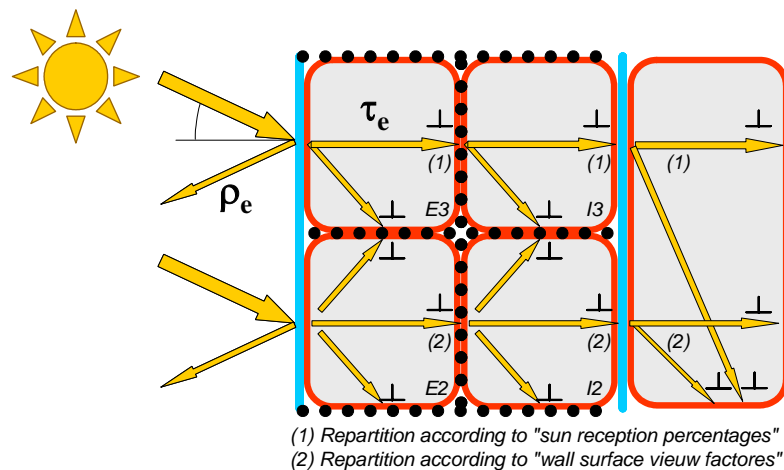
Figure 41: Solar processing trough zones of a VDF – option 2

A case has been run with such a configuration, for a narrow cavity (20 cm). There were no major differences between this case and the original one. Bigger differences might be expected for larger cavities.

8.3.7 Building up a model

In this paragraph, we will present the building up of a simple model of a VDF, step by step. This simple model does not include horizontal dummy walls.

8.3.7.1 Step 1: definition of functions

Seven types of "functions" can be used to define the outdoor climate, the internal gains and the set-up for the controls:
1. T: Temperatures,
2. I: Infrared radiation,
3. P: Power,
4. G: Global horizontal radiation,
5. D: Diffuse horizontal radiation,
6. B: Direct beam horizontal radiation,
7. V: Ventilation air changes.

These functions can be values in a file, but 5 types of "built-in" functions are also available (as constant, steps, sinusoid…).

- **Outdoor climate**

As said previously, the outdoor climate is usually defined by one temperature function (T) and two horizontal radiation functions (e.g. G and D).

- **Internal gains**

Internal gains are simulated by power functions. These powers are dissipated in zones.

8.3.7.2 Step 2: definition of zones

The outdoor environment is represented by a zone of type ES (External solar zone with known temperature) with a function of type T for the outdoor temperature. The cavity is divided in e.g. six zones (as shown on Figure 25 (right)) of type IV (radiative and convective heat exchange are calculated separately). The room is a zone of type IV with a function of type P for the internal gains.

Zone	Name	Type	V [m³]	ρc [J/m³K]	θ-w [°C]	Qfree-w [W]	n-w [1/h]	θ-s [°C]	Qfree-s [W]	n-s [1/h]	Ventilation zone	θ [°C]	Ir [W/m²]	Qfree [W]
1	OUTSIDE	ES	-	1200	0	-	-	0	-	-	-	T99	100	-
2	E3	IV	0.26	1200	0	0	0	0	0	0	E2	-	-	P00
3	I3	IV	0.26	1200	0	0	0	0	0	0	I2	-	-	P00
4	E2	IV	0.26	1200	0	0	0	0	0	0	E1	-	-	P00
5	I2	IV	0.26	1200	0	0	0	0	0	0	I1	-	-	P00
6	E1	IV	0.26	1200	0	0	0	0	0	0	ROOM	-	-	P00
7	I1	IV	0.26	1200	0	0	0	0	0	0	ROOM	-	-	P00
8	ROOM	IV	54.6	1200	0	0	0	0	0	0	OUTSIDE	-	-	P01

Figure 42: Definition of zones in CAPSOL v4.0w

8.3.7.3 Step 3: definition of ventilation

This point has been discussed in § 8.3.3.3.

8.3.7.4 Step 4: definition of walls

Figure 43 presents the definition of the walls that compose the VDF only. From that figure, it appears that:

−   For the wall surfaces in contact with an external zone, there is no separation of radiative and convective heat exchanges. Consequently, the global surface heat transfer coefficient h_g is used (e.g. $h_g = 23$ W/m².K). This parameter, which actually depends on the local wind speed, can not be changed during the simulation.

−   Similarly, the convective heat transfer coefficients inside the cavity h_c can not be changed during the simulation, in spite of the fact that they will depend on the actual airflow. The best value has to be determined in advance (for instance, by using the WIS software).

−   In conformity with what was said in § 8.3.3.2, 100% of the incoming solar radiation that enters the external side of the cavity (e.g. zone E3) strikes the shading devices (wall SD3). 100% of the solar radiation that pass to the internal side of the cavity (zone I3) strike the single glazing (wall SG3).

							Side 1			Side 2		
Wall	Name	Type	A [m²]	Ori [°]	Slope [°]	Zone1	hg1 [W/m²K]	hc1 [W/m²K]	sr1(tot) [%]	Zone2	hg2 [W/m²K]	hc2 [W/m²K]	sr2(tot) [%]
1	DG3	FDV-DG	2.6	-	-	OUTSIDE	23	-	-	E3	-	3	0(100)
2	SD3	FDV-SD	2.6	-	-	E3	-	3	100(100)	I3	-	3	0(100)
3	SG3	FDV-SG	2.6	-	-	I3	-	3	100(100)	ROOM	-	3	0(0)
4	DG2	FDV-DG	2.6	-	-	OUTSIDE	23	-	-	E2	-	3	0(100)
5	SD2	FDV-SD	2.6	-	-	E2	-	3	100(100)	I2	-	3	0(100)
6	SG2	FDV-SG	2.6	-	-	I2	-	3	100(100)	ROOM	-	3	0(0)
7	DG1	FDV-DG	2.6	-	-	OUTSIDE	23	-	-	E1	-	3	0(100)
8	SD1	FDV-DG	2.6	-	-	E1	-	3	100(100)	I1	-	3	0(100)
9	SG	FDV-SG	2.6	-	-	I1	-	3	100(100)	ROOM	-	3	0(0)

Figure 43: Definition of walls in CAPSOL w4.0w

8.3.7.5 Step 5: definition of wall types

This point has been already discussed in § 8.3.3.2.

8.3.7.6 Step 6: definition of points

Points must be defined for each controls (see next paragraph) e.g. to specify the location of a sensor, and for each location an output has to be reported.

8.3.7.7 Step 7: definition of controls

Three types of controls are available in CAPSOL: a power released in a certain point to simulate a heating or a cooling system, a ventilation and a sunshade action on a certain wall.

The shading device control has been discussed in § 8.3.5.1 and the multilateral ventilation controls in § 8.3.5.2.

8.3.7.8 Step 8: definition of surface view factors

As the cavity is divided in zone of type IV, the surface view factors have to be specified. In conformity with what was said in § 8.3.3.2, all the walls must be defined as convex.
In the zone "ROOM", the surface view factors of the glazing that compose the VDF must be set to zero, so that they can not see each other.
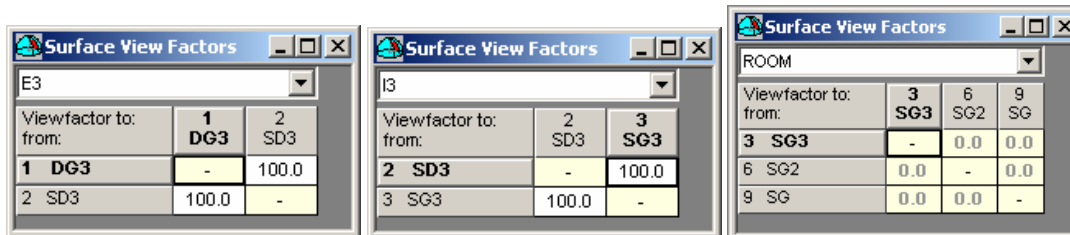
Figure 44: Definition of surface view factors
in CAPSOL w4.0w

8.3.7.9   Step 9: definition of sun obstacles

CAPSOL allows to define sun obstacles which apply to the whole building or to specific walls only. The first one can be used for instance to simulate the impact of other buildings, and the second one to simulate overhangs. It is recommended to add a building sun obstacle to simulate the horizon, as shown in Figure 45.
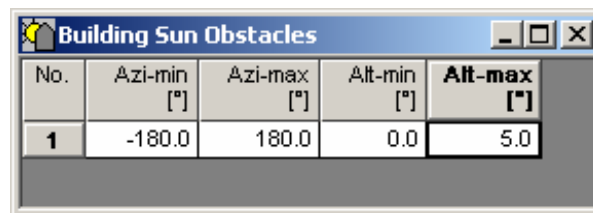

Figure 45: Definition of building sun obstacles
in CAPSOL w4.0w

8.3.7.10 Step 10: modifying calculation parameters

As said in § 8.3.3.2, the black radiation heat transfer coefficient is fixed and can not be changed during the simulation. The value can be fixed in the definition of the calculation parameters.
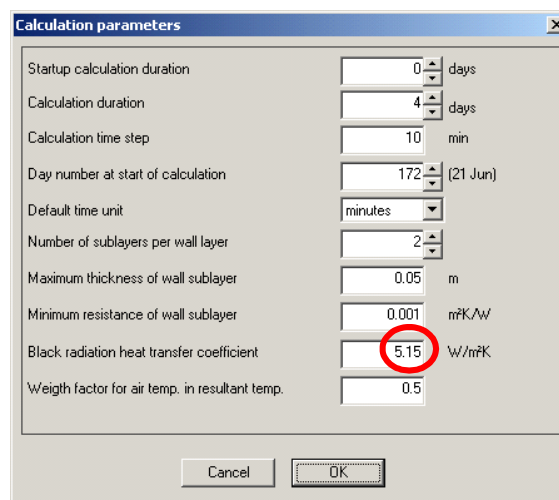
Figure 46: Definition of calculation parameters
in CAPSOL w4.0w

8.3.7.11 Step 11: Running!

There is nothing specific to VDF to specify into the other input screens, which are well described in the CAPSOL manual. The model is now ready to run!

8.3.8   Conclusions

- The aspects analysed in this study have shown that CAPSOL is able to simulate most of the VDF.
- The global philosophy is to consider the VDF as a set of zones, in order to take into account the thermal stratification in case of ventilation and the control strategy of the shading device.
- The introduction of a dummy shading device to simulate the situation where the shading device is up does not have a large impact on the results. This has been "validated" by comparing results of CAPSOL simulations with WIS calculations.
- CAPSOL does only consider an angular dependence for the solar reflection of wall surfaces in contact with outside (zone ES). The solar transmission is always supposed to be angular independent. As WIS considers the angular dependence of both reflection and transmission, for every surface of both glass panes (specular panes) and shading devices (scattering layers), this might lead to differences between results from CAPSOL simulations and WIS calculations (especially in the case of shading devices).
- As CAPSOL is a thermal model, the ventilation related should in principle require to couple CAPSOL with a ventilation model (as e.g. COMIS). However, the multilateral ventilation controls can be used to directly simulate ventilation strategies in CAPSOL, without coupling it with any ventilation model.
- The simulation of complex situation (as e.g. naturally ventilated double façades where the impact of the wind has to be considered or VDF with more than one air inlet and one outlet) will required to couple CAPSOL with a ventilation model. This can only be done with the so-called "global onion" approach, which prevent the simulation of ventilation strategies that are not based on parameters that are known in advance (as the time, the outdoor temperature, the solar conditions…). In this situation, the use of another building simulation model might be more appropriate.
- A serious advantage of CAPSOL is that it is quite easy to use it. Of course, the user must have backgrounds in building physics, but this is obviously the case for every building simulation tool. It must be mentioned that CAPSOL is well documented and its user interface is friendly and intuitive.

8.3.9   References

[18]   Heijmans N., Wouters P.; Impact of the uncertainties on wind pressures on the prediction of thermal comfort performances, HYBVENT technical report, 2002

4: TRNSYS SOFTWARE

Report on simulations of the energy performances

8.4 TRNSYS SOFTWARE

8.4.1 General software information

TRNSYS (TRaNsient SYstem Simulation Program), commercially available since 1975, simulates the dynamic thermal behaviour of buildings and their systems. It has been used for more than 25 years for HVAC analysis and sizing, electric power simulation, solar thermal systems design, building thermal performance analysis, modern renewable energy systems including PV and wind power simulation, etc.

TRNSYS has a modular system approach, which makes it very flexible. It includes a simulation engine and a library of components that range from various building models to standard HVAC equipment to renewable energy and emerging technologies. Extensive libraries of non-standard components for TRNSYS are available commercially from TRNSYS distributors.

That core software can be completed by other software to make its use easier or to enlarge its possibilities:
- a user friendly software to define the building to simulate: **PREBID**.
- a model to calculate air flows in the building or the HVAC equipments: **COMIS**.
- a graphical interface: **IISiBat**.

The version of the software, which has been used in this study, is TRNSYS version 15.

The core software: TRNSYS

TRNSYS relies on a modular approach to solve large systems of equations described by Fortran subroutines. Each Fortran subroutine contains a model for a system component. For example, subroutine "Type 56" contains a model of a multizone building and subroutine "Type 32" contains a model of a cooling coil.

Each component has inputs and outputs that represent the actual pipes, ducts, and control signals of their physical counterparts.
> *Example: the inlet flow rates and temperatures for the air and water are inputs to the Type 32 model, while the total and latent cooling rates are among the outputs of the model.*

TRNSYS allows users to completely describe and monitor all interactions between system components. For example, the user determines the connections between the output of the pump and other system components. The modularity of the program allows the user to have as many pumps, chillers, cooling coils, controllers and solar panels as necessary, in any desired configuration. Because the components are written in Fortran, a user can easily generate a TRNSYS model that does not exist in the standard package (any new technology that is created for example).

The user has to create an input file. It tells TRNSYS which parameters and initial values to use for each system component and how the various system components are linked together. The TRNSYS engine calls the system components based on the input file and iterates at each time step until the system of equations is solved.

A software to define the building: PREBID

To simulate the thermal behaviour of a building, TRNSYS, and more specifically "Type 56" model, needs a file describing the building. It looks like that:

Figure 47: part of a ".bui" file defining a building

Although this file can be written by hand, a software called PREBID is available to help users with that task.
To create a building with PREBID, the user specifies the thermal zones (physical attributes, occupation and use) and then describes the interactions between this zone, the ambient, and other zones in the building. The user can choose layers, wall types, and windows from libraries, or describe its own elements.
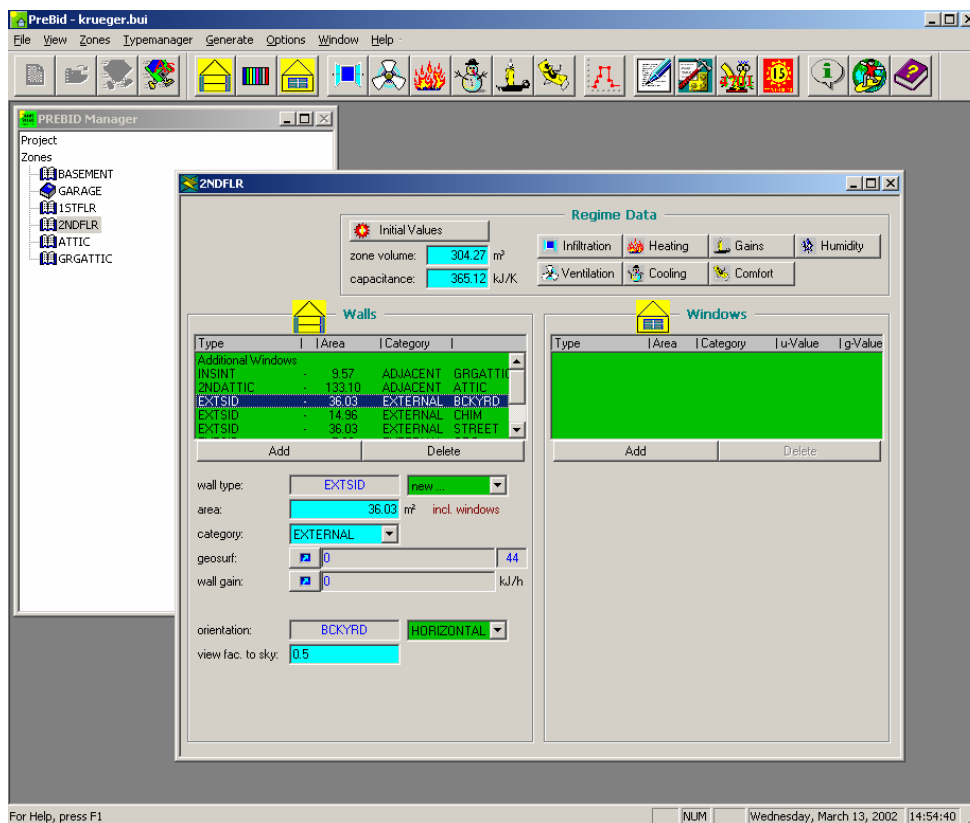

Figure 48: zone definition in PREBID

A model to calculate air flows in the building: COMIS

When simulating the thermal behaviour of a building, TRNSYS can manage air flows but does not calculate them. The user has to specify how much air comes in or out each zone.

The software COMIS, which can be coupled with TRNSYS, models the air flow distribution in buildings. The program can simulate several key components influencing air flow: cracks, ducts, duct fittings, fans, flow controllers, vertical large openings (windows and/or doors), kitchen hoods, passive stacks, and "user-defined components".

COMIS allows the user to define schedules describing changes in the indoor temperature distribution, fan operation, pollutant concentration in the zones, pollutant sources and sinks, opening of windows and doors, and the weather data. The flexible time step implemented in COMIS enables the modelling of events independent of the frequency with which the weather data are provided.

The COMIS air flow calculation is based on the assumption that indoor air flows reach steady-state at each time step.

To allow user friendly simulations of natural ventilation systems, e.g. passive night cooling, double facades or exhaust air shafts with a coupled heat and air flow model, TRNFLOW was created. The multizone air flow model COMIS has been completely integrated into the thermal building module of TRNSYS. The coupling of the two models has been realized within one module. Therefore the user has no longer to perform a laborious linkage of two modules in each individual simulation case. The linkage is done one for all, and can be used for any situation. The existing user interface of the building thermal model (PreBid) has been enhanced with new features to be used for the data input of the air flow model. Data redundancy in the two models is covered by the user interface. Thus, compared to the old version of the air and heat flow model coupling in TRNSYS/COMIS, with TrnFlow many possibilities for erroneous data input have been eliminated.
An air flow model input file (".cif") is generated with the two thermal model input files (".bld" and ".trn").

User tip: be careful with the order of the thermal zones.
Both the air flow and the thermal models number the air zones in the order they are introduced. User should though introduce in PREBID first all the thermal zones which are used in both models, than the other ones (e.g.: basement, attic,... in which no air flow is calculated).

Example:
One wants to calculate the temperature in three zones: an office, a corridor, and a basement. Air is entering in the office and going out through the corridor. There is no air flow in the basement.
1st case:
> *The zones are introduced in PREBID in that order*
> *1. Basement*
> *2. office*
> *3. corridor*
> *The thermal model numbers them in that order, but the air flow model numbers the zones as follow:*
> *1. Office*
> *2. corridor*
> *because it doesn't use the basement.*
> *There will be a recognition problem between the air flow input files (".cif") and the thermal input files (".bld" and ".trn").*
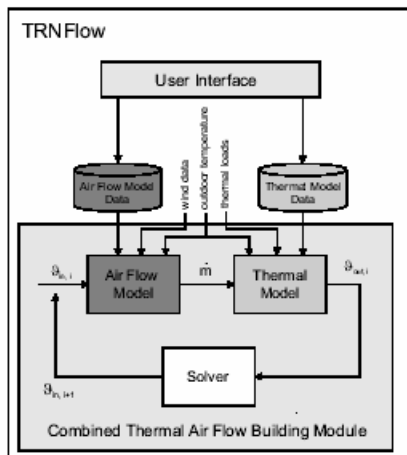*2nd case:*
> *The zones are introduced in PREBID in that order*
> *1. Office*
> *2. corridor*
> *3. basement*
> *The thermal model numbers them in that order, but the air flow model numbers the zones as follow:*
> *1. Office*
> *2. corridor*
> *There will be no recognition problem between the air flow and the thermal input.*

The Figure 49 shows the links between the thermal and the air flow model. For simplification, the information flow between the two models is represented by one room air temperature node and one air flow variable. In fact there are at least as many air temperature nodes as there are thermal zones in the building and each node has at least one air flow.

In the solution process, the air flow model starts with the input node temperatures θ_{in} and calculates the corresponding air flows $\dot{m}$ of each node. These flows are used in the thermal model, which calculates the output room temperatures θ_{out}. With an iterative solver algorithm the input temperatures set is found which matches the output temperatures set.

Figure 49: coupling between the airflow model and the thermal model (TRNFLOW)

The air flow model in COMIS / TRNFLOW is a multizone model. It idealizes the building as a network of nodes and air flow links between them (Figure 50). The nodes represent the thermal zones (which can be a room or many rooms with the same function and occupation) and the building surrounding. The links depict openings, doors, cracks, window joints and shafts as well as ventilation components like air inlets, outlets, ducts and fans. The room temperatures are calculated with TRNSYS ("Type 56") which is a non-geometrical dynamic thermal model. One air node per zone represents the thermal capacity of the zone air volume and capacities which are closely connected with the air node (furniture for example).
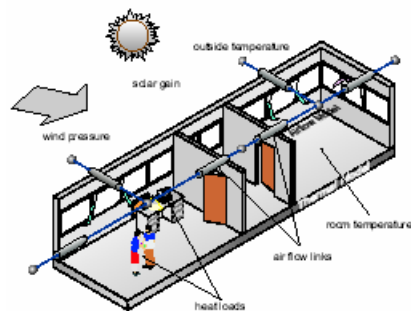
Figure 50: COMIS model used in TRNFLOW

A graphical interface to make the TRNSYS use easier: IISiBat

An example of the input file needed by TRNSYS is represented in Figure 51. It can be written by hand. But to create it more easily, the 'Centre Scientifique et Technique du Bâtiment' (CSTB in Sophia Antipolis, France) has developed a general front-end program, IISiBat which can be roughly translated from French as "Intelligent Interface for the Simulation of Buildings". It allows the TRNSYS user to graphically choose icons that represent components, and connect their inputs and outputs.

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Figure 51: TRNSYS input file

Figure 52 shows the IISiBat Assembly Window. This main window contains many descriptive icons with lines connecting them. Each icon represents a different system component (e.g. pump, solar collector, etc.). The user drags the necessary icons into the Assembly Window.
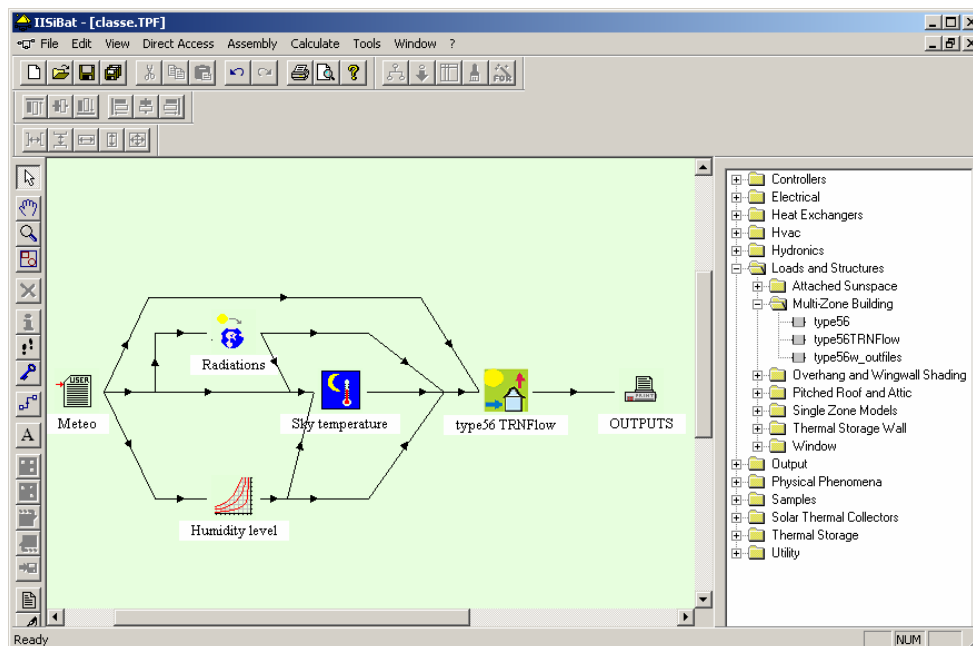

Figure 52: The IISiBat Assembly Window

The user creates links between the components that share information. The lines connecting the icons represent the pipes and wires that connect the physical components. While several connections are possible between two components, just one link is displayed. To view or change the input and output connections, the user clicks on the link itself to view a detailed window (see Figure 53). A bunch of Tools around the border of the Assembly Panel window allow the user to place icons onto the working area, connect the icons as necessary, run the simulation, access the editor, access the spreadsheet and plotting packages, and perform many other functions.
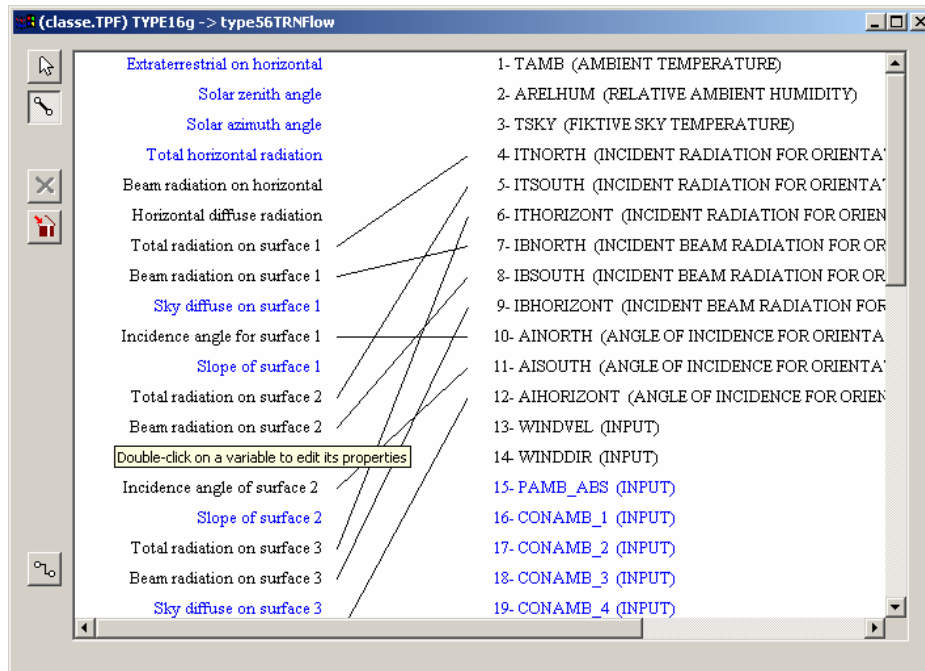
Figure 53: Connections between the outputs of one model and the inputs of another model in IISiBat

8.4.2 Outdoor climate and other context data

To run a simulation, TRNSYS needs the following parameters, for each time step:
- outdoor temperature
- relative ambient humidity level

    If the user doesn't have that value at his disposal, a component (type 33) can be used to calculate the relative ambient humidity from the absolute humidity level.
- fictive sky temperature

    That value is calculated by a component (type 69b) from beam and diffuse radiation on horizontal plane.
- for each orientation, total solar radiation, incident beam radiation, and angle of incidence
    Those values can be calculated by a component (type 16) from various radiation values (for example, from total and direct radiation on horizontal plane).
    Since the calculations made in transforming solar radiation on a horizontal surface depend on the time of day, it is important that the correct solar time be used. So, TRNSYS needs the building location on earth to run a simulation. It is defined via two parameters: latitude and shift with solar time. This parameter is used to account for the differences between solar time and local time.

So, the user can use various types of weather data files. Up to him to adapt the TRNSYS file (chose the right components, and make the good connections).

To simulate the airflow distribution in building with natural openings (doors, windows, etc.), COMIS (or TRNFLOW) needs, for each time step:
- Wind speed at meteo station reference height [m/s]
- Wind direction [deg] (0° wind from north, 90° wind from east…)

In order to predict the wind speed at the building site, it also needs the altitude of the building, its location on earth (defined by its latitude and longitude), the wind speed profile exponents at the reference meteo station as well as at the building site (where they can be angle dependant). Moreover, the wind pressure coefficients cp are required. A good estimation of all these data is important in order to be able to correctly predict the ventilation rate in a naturally ventilated double facade.

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8.4.3 Simulation of a ventilated double facade

8.4.3.1 General methodology

With TRNSYS, buildings with a ventilated double facade like the one seen in Figure 54 can be modelled in various ways:
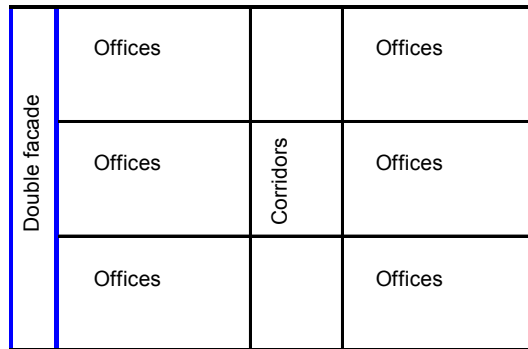

Figure 54: Building with a double facade to model

► **With a specific model for the ventilated double facade, linked to the building model**

The building is then modelled without the double facade (see Figure 55). That's the way D. Saelens used in [5]. He developed his own model as no double facade model exists in the available commercial model libraries.
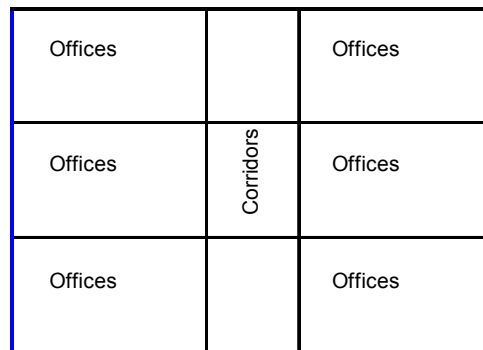
Figure 55: Building is modelled with no double facade.

The VDF is modelled by a specific type in TRNSYS. That type is linked to the building model (see Figure 56).
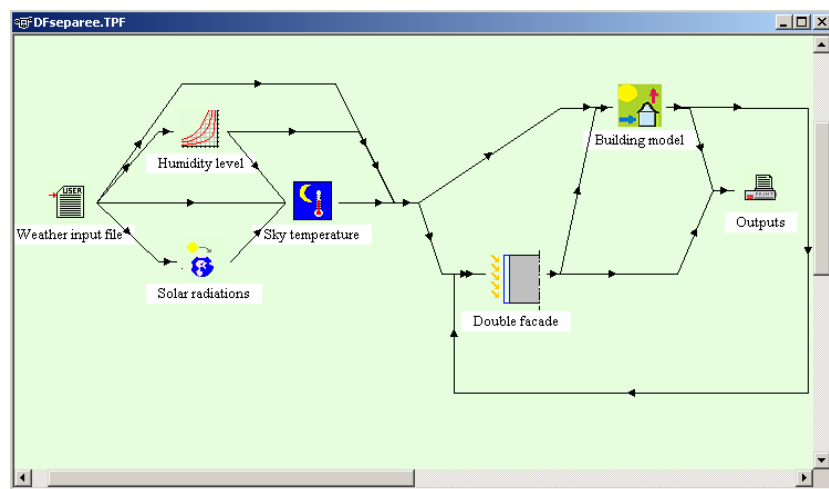
Figure 56: The double facade model is linked to the building model in IIsiBat.

► **As one or many thermal zones included in the building model**

The subdivision of the cavity of the DVF will depend on the shading device position and on the desired level of detail.

Examples:

If the shading device is against one of the two glass layers, the cavity can be modelled by a single zone (see Figure 57) or by 3 or more zones for a more detailed model (see Figure 58).
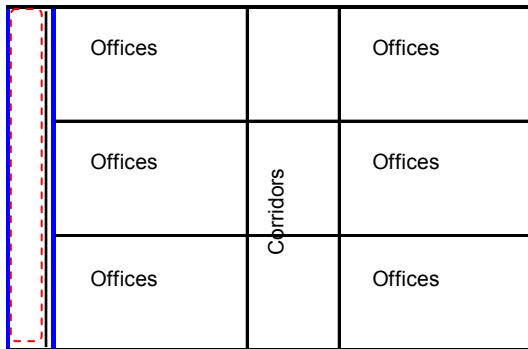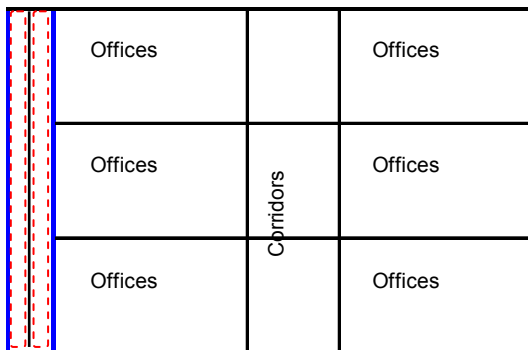

Figure 57: The VDF is modelled as one single zone
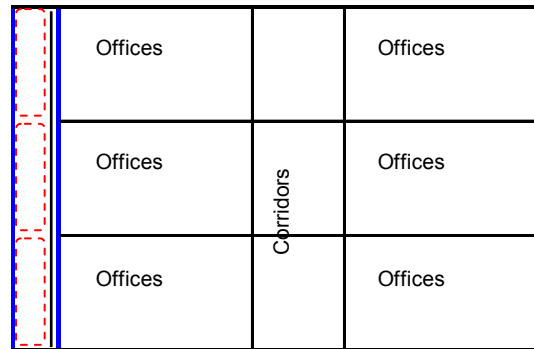
Figure 58: The VDF is modelled with three distinct zones

If the shading device is between the two glass layers, in the middle of the cavity of the double facade, the cavity can be modelled by a double zone (see Figure 59) or by 6 or more zones for a more detailed model (see Figure 60).

Figure 59: The VDF is modelled with two distinct zones between which is the shading device
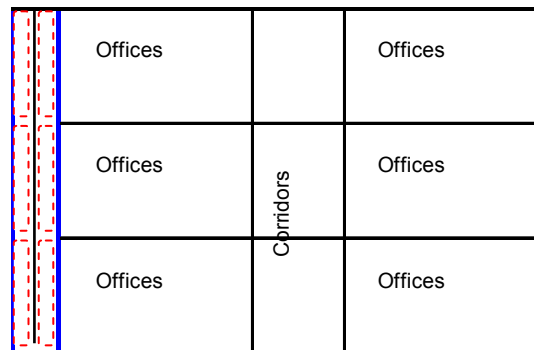
Figure 60: The VDF is modelled with six distinct zones

Note: The more the cavity is subdivided, the longer is the TRNSYS simulation.

Example:
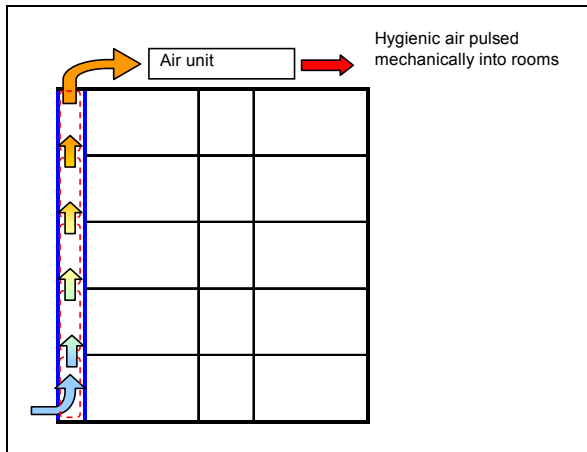
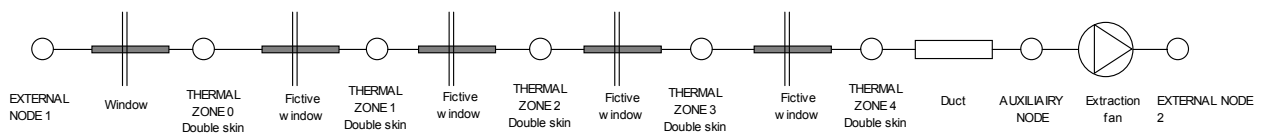► 1 zone for the cavity of the VDF: simulation time = 12 min 30 sec.
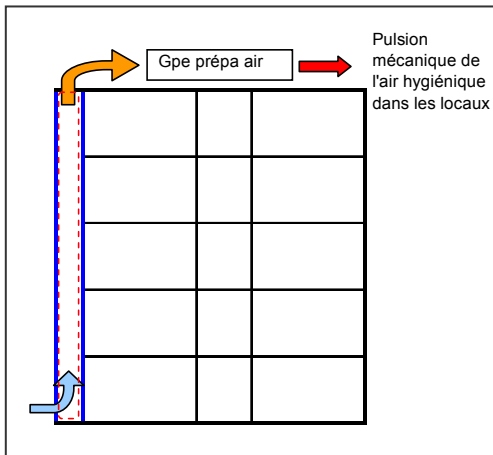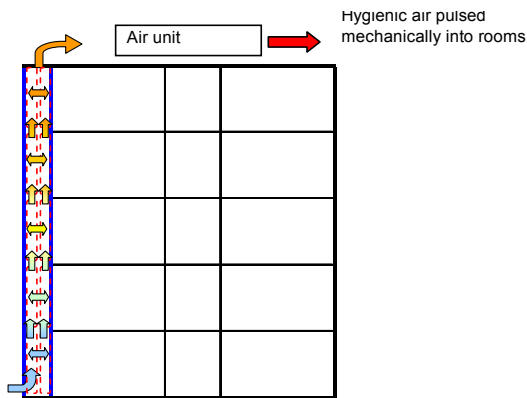

The air flow chart is quite simple:
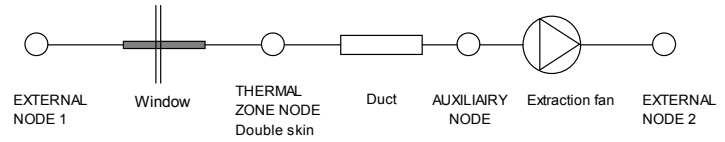
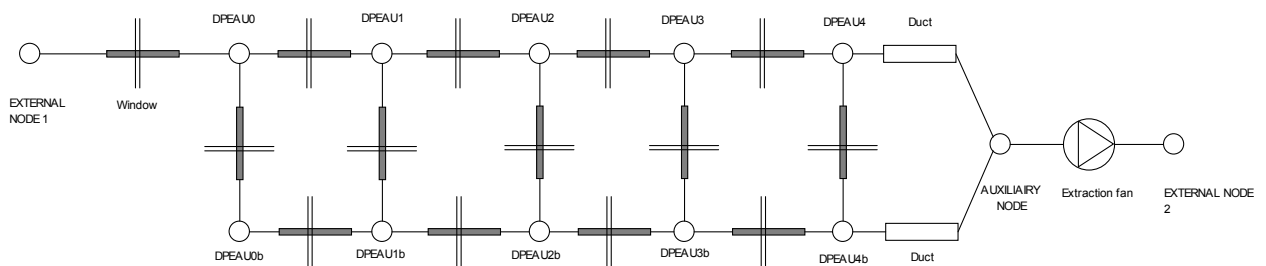► 5 zones for the cavity of the VDF: simulation time = 24 min

The air flow chart becomes more complex:

► 10 zones for the cavity of the VDF: simulation time = 5 hours and 24 min

The air flow chart is even more complicated:

To model the cavity subdivisions:

- *Horizontal subdivisions:*

  In the thermal model the subdivision should be modelled by a window with a solar transmission of 1. The thermal resistance should ideally be as close to 0 as possible. But with a too small thermal resistance, TRNSYS program doesn't reach convergence. For example, it is possible in the WINDOW program (which calculates the ASCII file including the optical glass data used by TRNSYS – see § 8.4.3.2) to model a glass thick of 3mm, with a solar transmission of 1. Its conductance value is 6,77 W/m².K (see *Figure 61*).

  The longwave radiations are stopped by the window in the thermal model, which does not exactly suit a fictive subdivision.
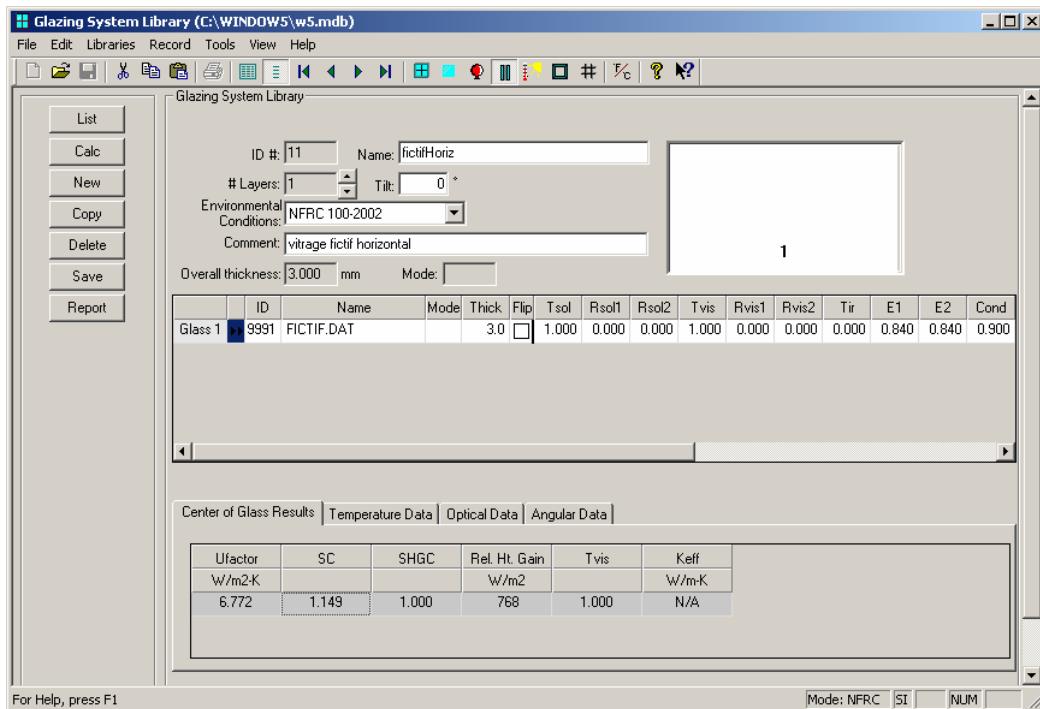
*Figure 61: definition in the WINDOW program of a glass
modelling a fictive subdivision in the VDF*

That "very transparent" window is coupled, in the air flow model, with a permanently open window (see *Figure 62*). As long as the cavity is ventilated, the heat transfer associated to the air transport between cavity zones is important, and the relative importance of conduction heat transfer is low. That reduces the weight of the heat conductivity value chosen for the window in the thermal model. This is less true if the cavity is not ventilated.
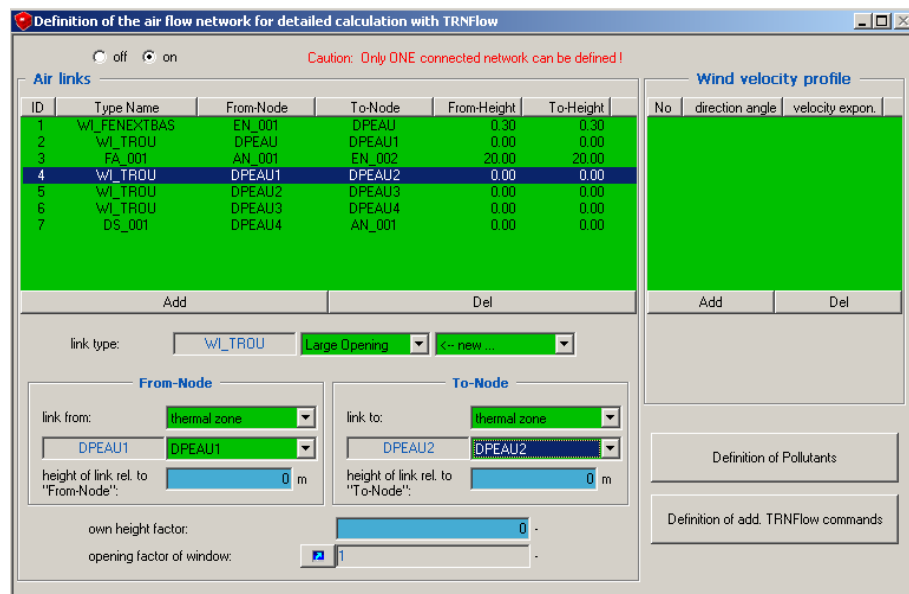

Figure 62: definition of a permanently open window in PREBID

Note: there are actually two models for the fictive subdivision:
- one closed window in the thermal model, which is used to calculate radiation and conduction heat transfers,
- and one open window in the air flow model, which is used to calculate heat transfer associated to air transport.

There is no incompatibility as the two models are coupled and do not check the geometry of the elements modelled.

- *Vertical subdivisions with sun protection:*

    The vertical fictive subdivision can be modelled on the similar way. To model the associated sun protection:
    - in the thermal model: an internal sun shading, which can be controlled on the way the user wants (see § 8.4.3.2), will be added to the window;
    - in the air flow model: the permanently opened window will now be closed when the sun shading is pulled down. Indeed, when the shading device is pulled down, there is almost no air transport between the zones. If there is still air transfer (through the fabric, or between slats), it can be modelled via the "flow through crack when window is closed" (see *Figure 63*).

    The control values and equations should be the same for the shading device and the closing/opening fictive window.

    In order to minimize to impact of the fictive vertical window on the thermal radiation (infrared) transfer, an emissivity value of 1 must be set for this fictive window (see section on CAPSOL software for more information on this topic).
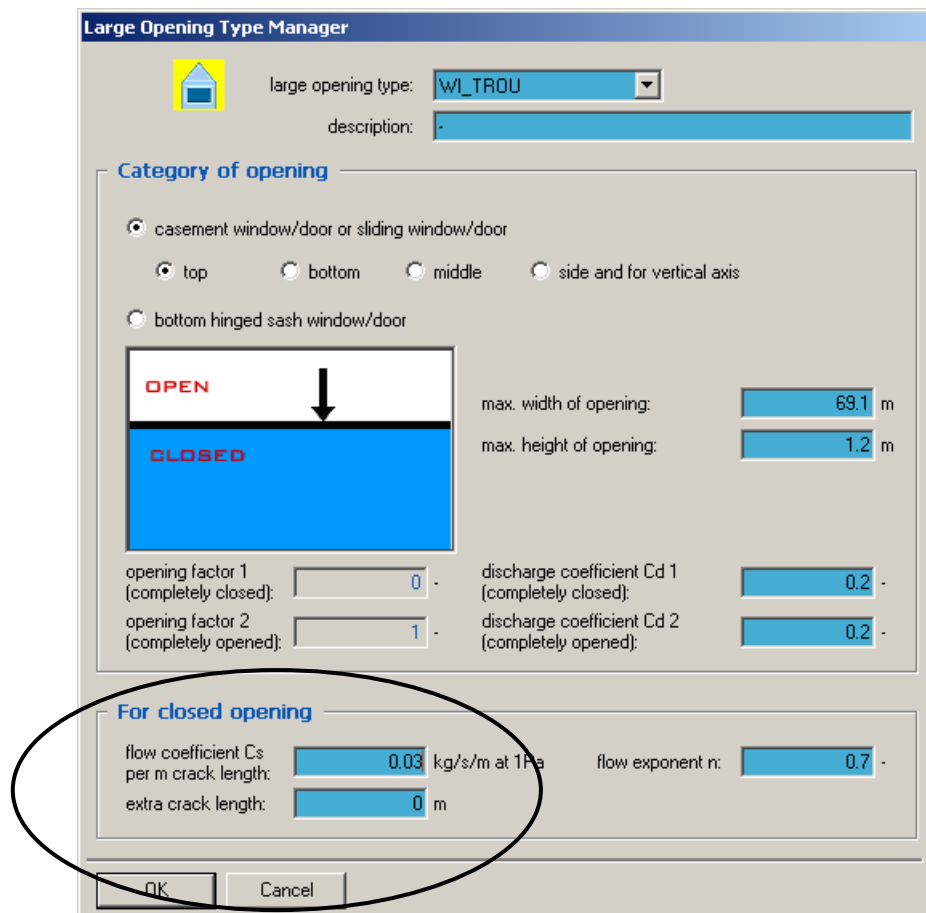

Figure 63: definition of air flow between two zones when the window is closed

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8.4.3.2 Facade layers

Glass layer

The window incorporated into the type 56 component, with up to 6 panes, is considered as a 2-nodes model in the heat balance calculation. The window is thermally considered as an external wall with no thermal mass (the heat capacity of the frame, the window panes and the gas fillings are neglected), partially transparent to solar, but opaque to long-wave internal gains. Long-wave absorption is considered to occur only at the surfaces.

For each glazing of the window, the resulting temperature is calculated considering transmission, absorption and reflection of incoming direct and diffuse radiation, diffuse short-wave radiation being reflected from the walls of the zone or an internal shading device, convective, conductive and long-wave radiative heat transfer between the individual panes and with the inner and outer environment. An edge correction for different glazing spacer types is considered [16].
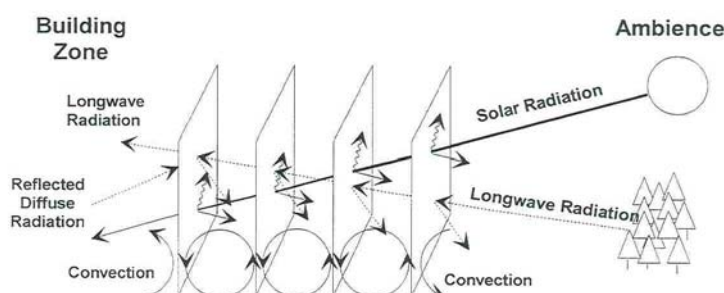

Figure 64: Glass model in Type 56 of TRNSYS

The window model incorporated into the type 56 component uses output data from the WINDOW 5 program developed by Lawrence Berkeley Laboratory, USA. Each glazing absorbs and reflects a part of the incoming solar radiation depending on the glazing material and the incidence angle. In the program WINDOW, the detailed calculation of reflection between the individual panes is performed hemispherically for diffuse radiation and in steps of 10° incidence angle for direct solar radiation. Together with the thermal properties of the gas fillings and the conductivity and emissivity of the glazings, the optical data for the window is written to an ASCII file by the WINDOW program. This output file has a standard format (see extract here under) which makes the results available for thermal analysis programs such as DOE 2.1 and TRNSYS. For TRNSYS, a window library file was created using the WINDOW program to have commonly-used glazing systems available for the user.

| WINDOW 5.0 TRNSYS 15 Data File: Multi Band Calculation										
Angle 0	10	20	30	40	50	60	70	80	90	Hemis
Tsol 0.727	0.726	0.723	0.716	0.702	0.669	0.599	0.455	0.215	0.000	0.623
Abs1 0.080	0.081	0.082	0.085	0.089	0.094	0.101	0.110	0.117	0.000	0.093
Abs2 0.064	0.065	0.066	0.068	0.070	0.071	0.071	0.065	0.049	0.000	0.067
Rfsol 0.129	0.129	0.129	0.131	0.140	0.166	0.230	0.370	0.619	1.000	0.208
Rbsol 0.129	0.129	0.129	0.131	0.140	0.166	0.230	0.370	0.619	1.000	0.208
Tvis 0.817	0.816	0.815	0.811	0.799	0.768	0.695	0.538	0.273	0.000	0.714
Rfvis 0.148	0.148	0.148	0.151	0.162	0.191	0.262	0.417	0.682	1.000	0.236
Rbvis 0.148	0.148	0.148	0.151	0.162	0.191	0.262	0.417	0.682	1.000	0.236
SHGC 0.777	0.776	0.774	0.769	0.756	0.725	0.656	0.509	0.261	0.000	0.676
SC: 0.86										

Figure 65: Extract from a WINDOW 5.0 file used by TRNSYS

Shading devices

Movable shading devices

In a VDF, the shading device can be placed in various positions:

- against the external glass facade
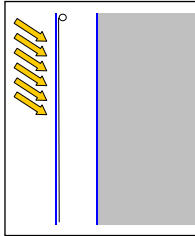
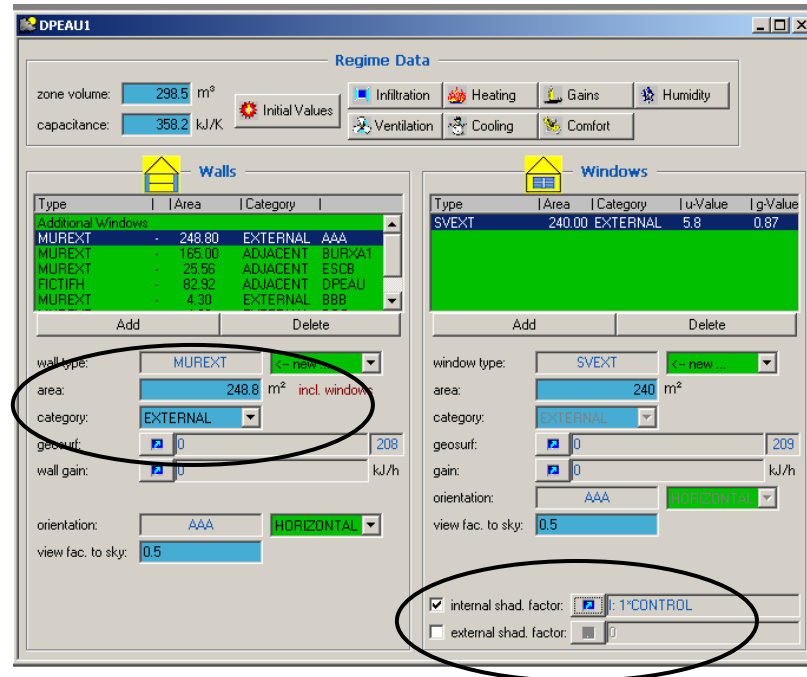It is modelled as an internal shading device associated to an external window (see Figure 66).
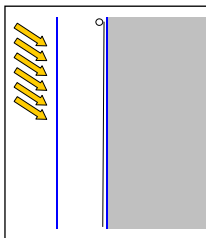

Figure 66: Internal shading device defined on an external wall

- against the internal glass facade

It is modelled as an internal shading device associated to an internal window (see Figure 67).

User tip: It is not possible to associate an external shading device with an internal wall. So, user has to be careful choosing the front and back face of the internal glass layer of the double facade. The front face must be in the cavity, the back face must be in the rooms behind the double facade.
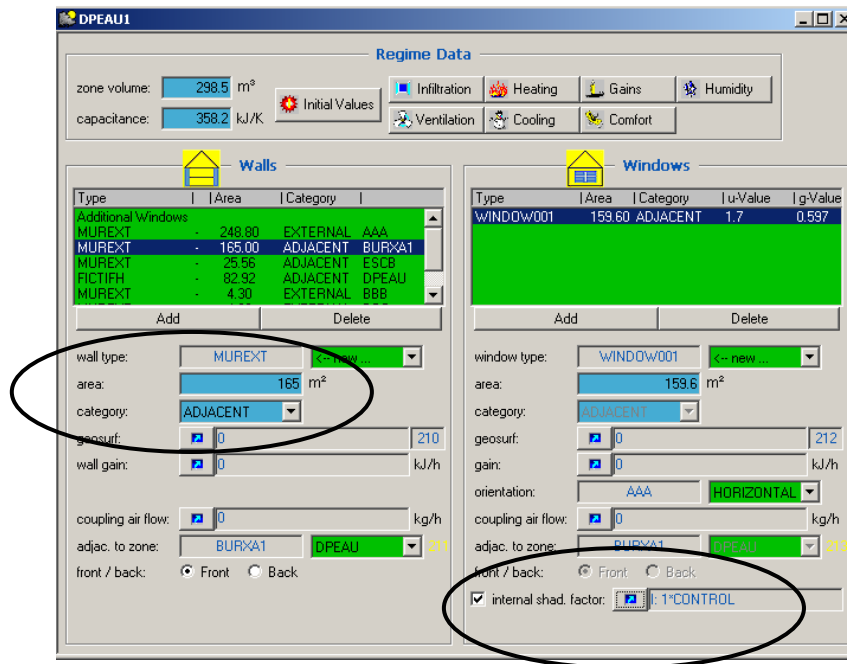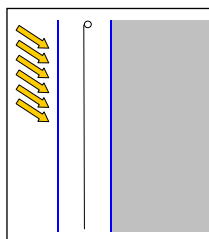
Figure 67: Internal shading device defined on an internal (and so adjacent) wall

- between the two glass facade, in the middle of the cavity

It is modelled as an internal shading device associated to a fictive internal window (see above) (see Figure 68).
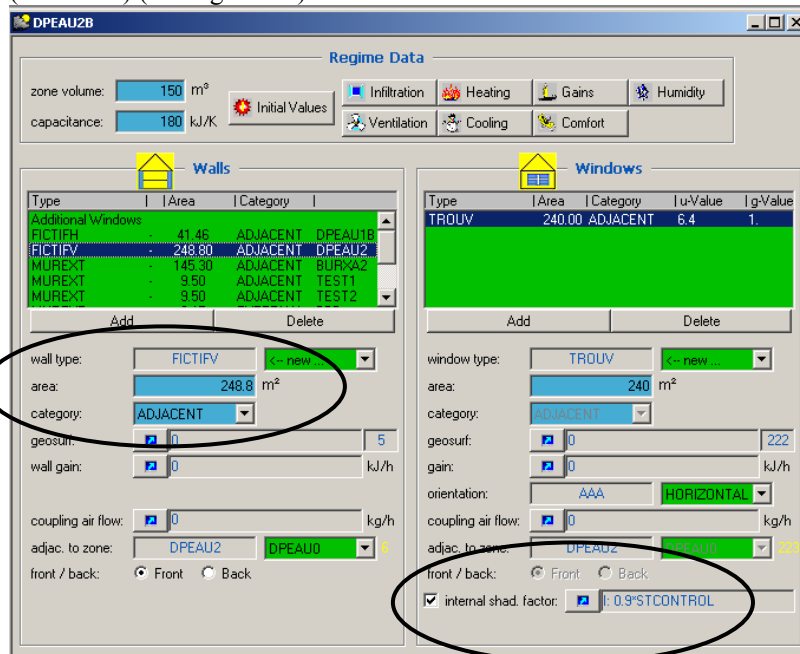

Figure 68: Internal shading device defined on an internal (and so adjacent) wall between two zones of the double facade: DPEAU2 and DPEAU2B

In any case, user can pull down or roll up the blind according to any value: sunshine level, inside temperature, wind speed, or anything else.

User must specifiy the shading factor. It is defined as the ratio of non transparent area of the shading device to the whole glazing area. So, its value is 1 for a perfectly opaque pulled down blind (no transmission at all), and 0 when there the shading device is rolled up. The shading device reduces the incoming solar radiation on the glazing area of the window by that factor.

It can be a constant value (e.g. if the shading device is always pulled down), or it can be calculated according to a schedule or an input number (e.g. sunshine level, inside temperature, wind speed) (see Figure 69).
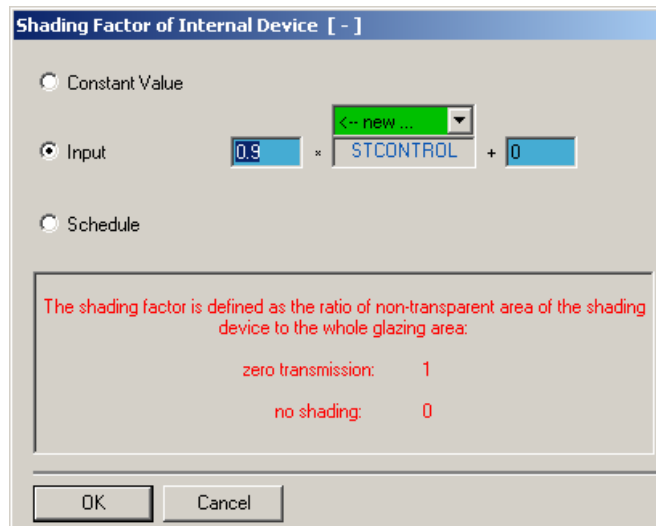

Figure 69: Various possibilities to define the shading factor of a shading device

That input can come from one or many controllers (Type 2) to insert in TRNSYS (see Figure 70). Completed with some equations, these controllers can take into account various values (e.g. sunshine level and inside temperature). Like real controllers, the TRNSYS controller models use operational hysteresis to promote stability. It avoids shading devices to keep going up and down all the time as soon as the control value varies a little bit.

Examples:

- A shading device can be pulled down when sun is shining as soon as inside temperature reaches 22°C, but not rolled up until temperature comes down above 21°C.

- A shading device can be pulled down as soon as the solar radiations reaches 250 W/m², but not rolled up until radiations come down above 200 W/m².
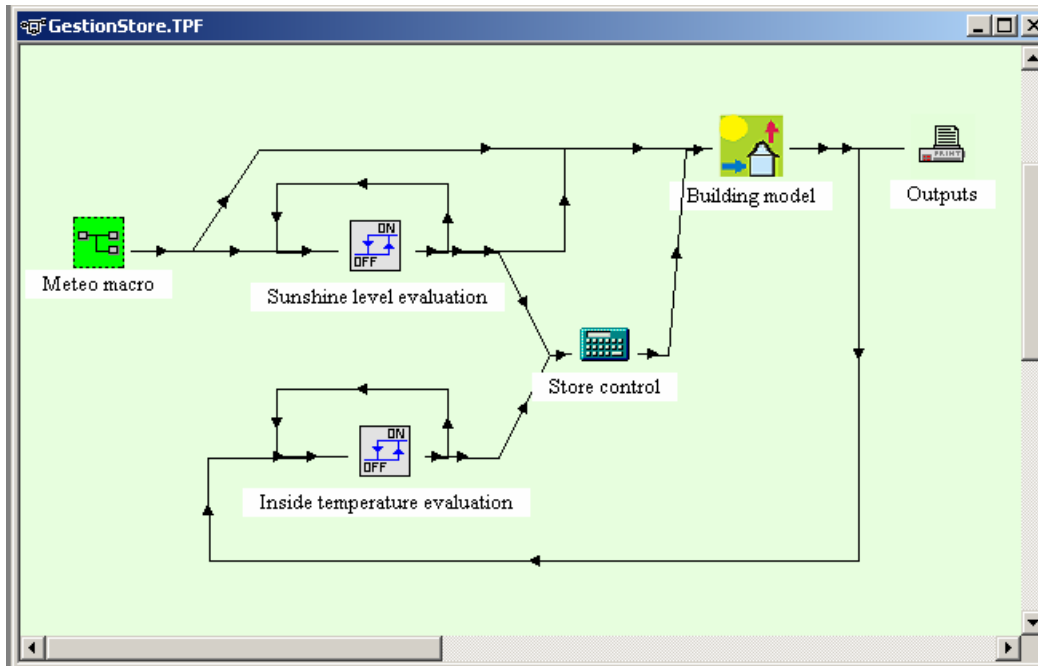
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Figure 70: running of a shading device in TRNSYS with two controllers (type 2)

Note: The shading devices defined in the "Type 56" component model easily a roller blind. But it is not so appropriate to model venetian blinds. Nevertheless, the user could associate various shading factors for a range of slats orientations. He should then, in a first step, use a more detailed software (WIS software for example) to calculate the values.

Permanent shading devices: overhangs and wingwalls

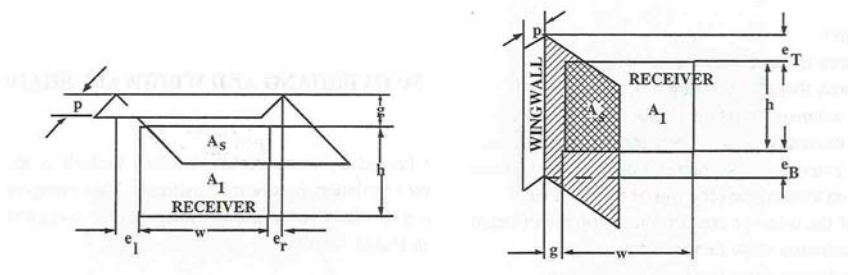Overhangs and wingwalls shading can be modelled with "type 34" component.

Figure 71: Overhangs and wingwalls modelled by type 34

That component has to be linked to the building component (Type 56).

> *User tip: to simplify the IISiBat model and fasten the TRNSYS calculation, you can run a separate simulation with only 2 components "type 34" (one with the overhang, one with no overhang) and calculate an hourly fictive shading factor. These various shading factors are stocked in a data file which will be used, in the building simulation.*

Frame

The user defines the surface of the frame (percentage of window surface) and its properties: U-value [KJ/h.m².K] and solar absorptance (same value for both sides).
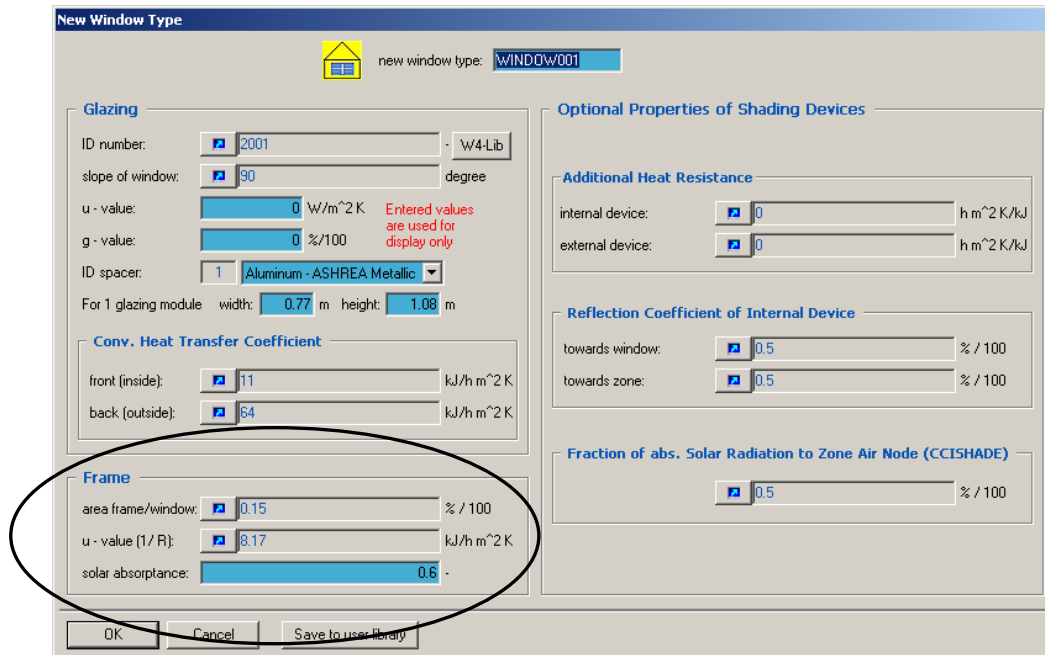
Figure 72: Window definition in PREBID: glass, frame and shading device

Ventilated double facade

Convective heat transfer in the cavity

The convective heat transfer coefficient h_c which is associated to the glass facades (wall or window) is not necessarily a constant. It can vary according to an input value, e.g. the flow level in the ventilated double facade (see Figure 73).

Figure 73: definition of convective heat transfer coefficient in PREBID

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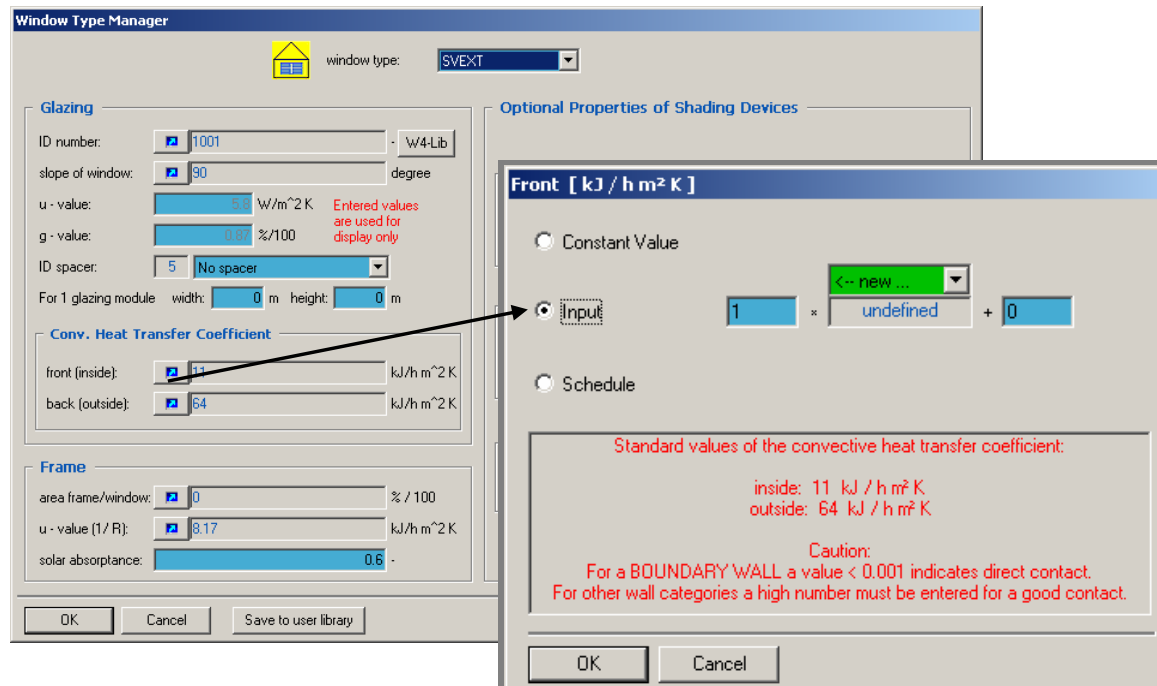The thermal model takes into account the heat transfer due to ventilation and infiltration (defined in the thermal model) as well as the heat transfer due to air flows calculated by the air flow model. These air flows will come essentially from adjacent zones defined in the cavity. Indeed, the boundaries between adjacent zones in the cavity are defined as window permanently or temporarily open.

If the internal shading device is against one of the glass layers, the model takes into account an additional convection due to a chimney effect of warm air heated by the absorption of solar radiation on the shading device. So the user has to define, together with the window definition, a parameter defining the degree of additional convection to the air node of the zone [16]. The coefficient CCISHADE defines the part of the absorbed radiation which goes directly to the air node by convection. If the internal shading device is located very close to the window pane without any flow in between it should be set to 0. Typical values for that coefficient range from 0,3 to 0,6.

If the shading device is located in the middle of the ventilated double facade, there is no additional convection and that CCISHADE coefficient should also be set to 0.

Short wave radiation and long wave radiation : transfer through the cavity

a) Through the first glass layer

The window is partially transparent to solar radiation (the solar transmission is chosen with the glass type), but opaque to long-wave internal gains. Long-wave absorption is considered to occur only at the surfaces of the glass.

The direct solar radiation entering a zone is distributed between walls according to absorptance weighted area ratios. However, if the user wishes it, he can modify that distribution mode and choose the exact part of solar radiation that will reach each wall. That is by giving a specific value (not default 0) to the parameter GEOSURF associated to any wall. It represents the fraction of the total entering direct solar radiation that strikes the surface.

For example, user can decide that all direct solar radiation entering in the double facade are distributed to the other glass facade, and that none is distributed to the fictive windows separating the various zones in the cavity (see Figure 74).

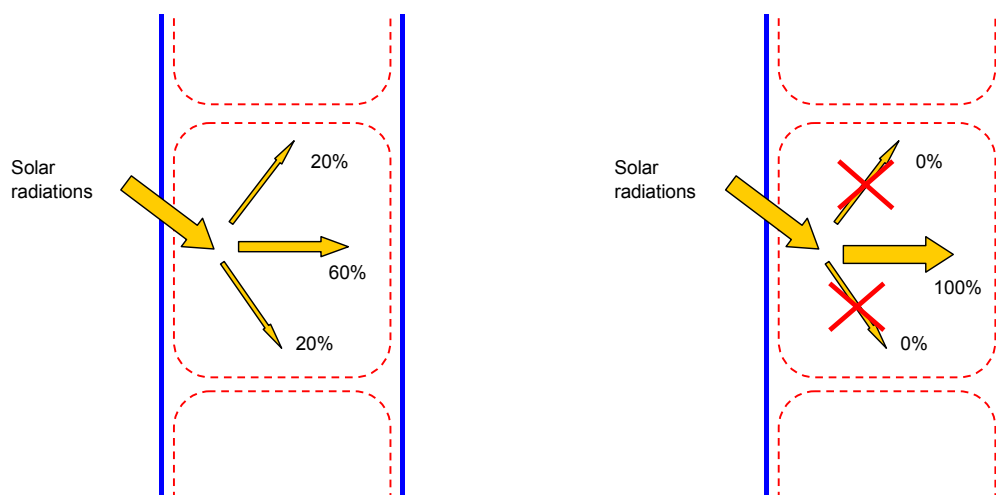*Figure 74: Distribution of solar radiations between zone surfaces.*
Left: GEOSURF=0 for all walls
Right: GEOSURF= 1 for internal glass facade and 0 for fictive subdivisions

Beside transmission and convection heat flux from the ambient, the glass surfaces temperatures are calculated according to solar and sky radiations, as well as net radiative heat transfer with all surfaces in view of the surface (see *Figure 75*).
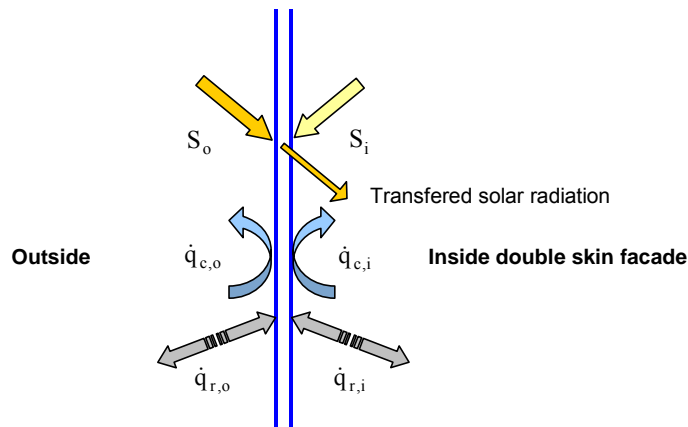
Figure 75: Heat fluxes in the external glass facade

S_o =   radiation heat flux absorbed at the outside surface: solar gains

$\dot{q}_{r,o}$ =   net radiative heat transfer with all surfaces in view of the outside surface

$\dot{q}_{c,o}$ =   convection heat flux to the outside surface from the boundary / ambient

S_i =   radiation heat flux absorbed at the inside surface: reflected solar radiation

$\dot{q}_{r,i}$ =   net radiative heat transfer with all other surfaces within the zone

$\dot{q}_{c,i}$ =   convection heat flux from the inside surface to the zone air

b) Through fictive windows (when cavity is subdivided)

Through the fictive windows which separate the various zones in the cavity, long wave radiations are stopped (see §8.4.3.2 about glass model) but short wave radiations can be completely transfered as long as the fictive glass chosen has 1 for solar transmission factor (see §8.4.3.1).

c) Through the shading device

The shading device reduces the incoming solar radiation entered through the first glass facade by the shading factor introduced.
For internal shading devices, the model takes into account multiple reflections between the internal shading device and the window panes. So the user has to define, together with the window definition, a reflection coefficient for solar radiation for both faces of the shading device [16] (see Figure 76).

Note: it is not the case for external shading devices, but these are never used with double facades as one of their advantage is precisely to protect the shading device between the two windows.

There is no detailed model for venetian blinds that would take into account inter-reflections between the slats.
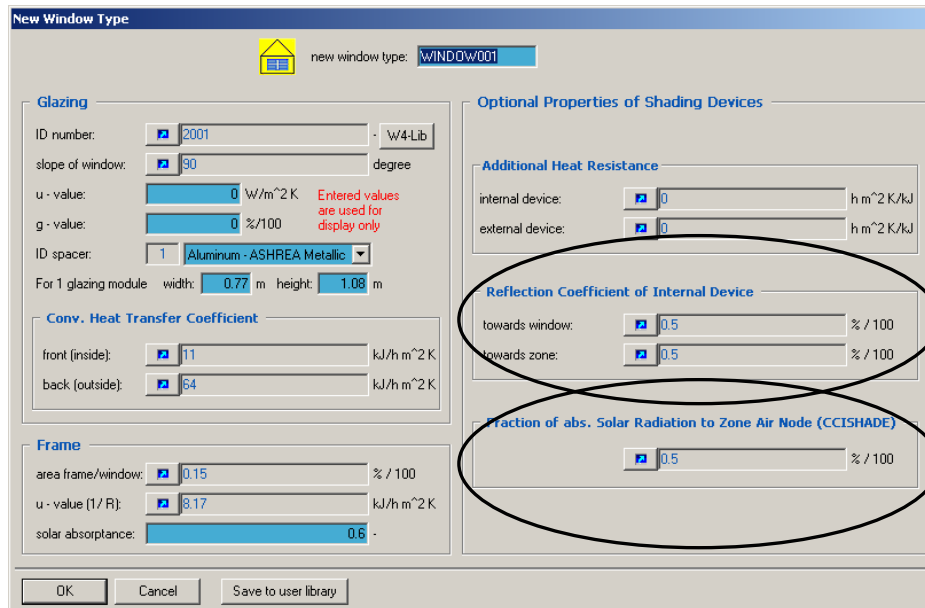
Figure 76: Window and shading devices definition in PREBID

User can define the part of the absorbed radiation that goes directly to the air node by convection (CCISHADE), and the refection coefficient of the shading device surfaces

d) Through the second glass layer

The window is partially transparent to solar radiation (the solar transmission is chosen with the glass type), but opaque to long-wave internal gains. Long-wave absorption is considered to occur only at the surfaces of the glass.

8.4.3.3 Ventilation in the cavity of the double facade

Forced convection.

To model forced convection, user does not need the air flow model. The air transfer between zones can be modelled through VENTILATION and COUPLING functions in the thermal model.

To model air entry in the double facade, the user will use VENTILATION function which can be associated to any thermal zone (see *Figure 77*).
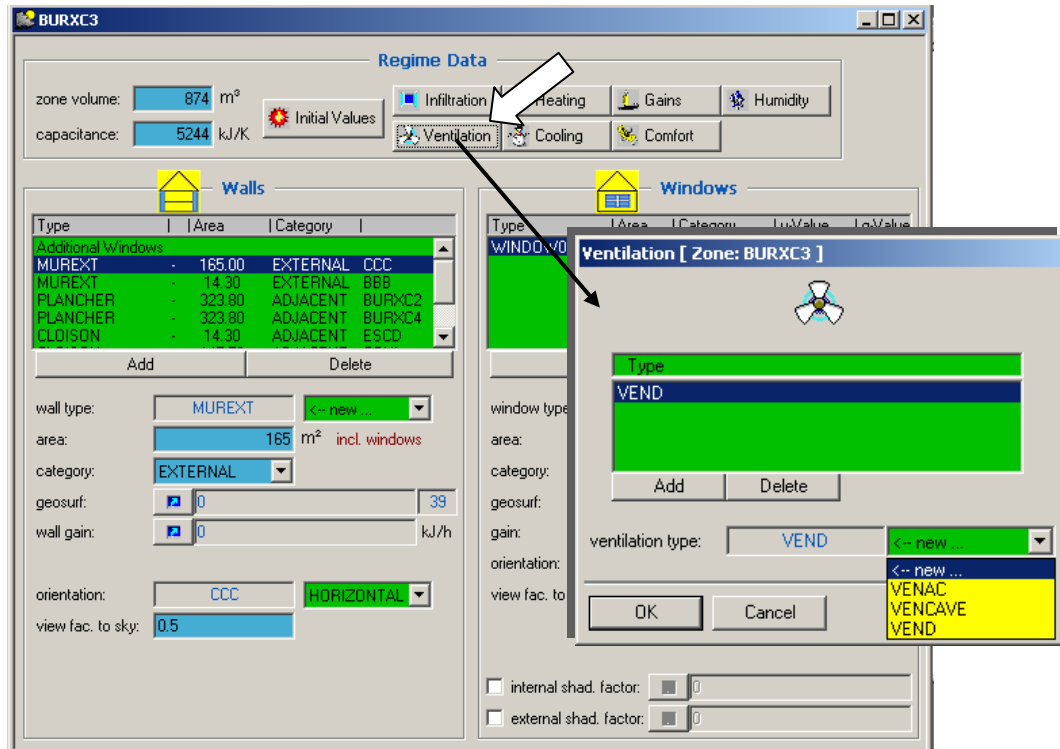
Figure 77: association of a ventilation to a thermal zone

He will define ventilation according to the double facade running (see *Figure 78*):

- <u>air change rate</u> which can be defined as a constant, an input, or a schedule. It can be controlled according to various values (e.g. working place temperature, cavity temperature, outside temperature, sunshine amount, previous day maximal temperature, time of the day…).

- <u>temperature and relative humidity of air flow.</u> User will select "outside" if the VDF is ventilated with outside air and "other" if the double facade is ventilated with air from other rooms. It can then be defined (see *Figure 79*) as a constant (if the air room is constant), a schedule (e.g. a temperature for working hours and another one for nights and week-ends) or an input (the room temperature calculated through the thermal model).
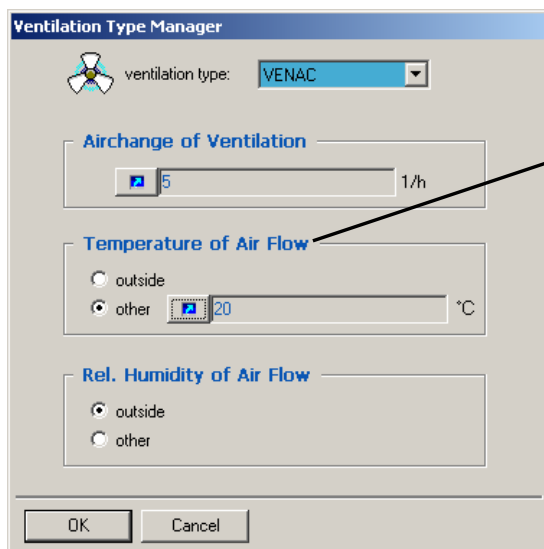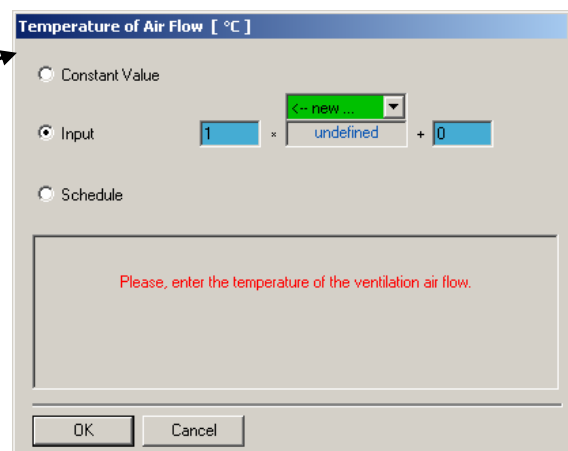

Figure 78: definition of the ventilation

Figure 79: definition of air flow temperature

To model air transfer between various zones in the subdivided cavity, the user will use COUPLING function which can be associated to any adjacent wall (common with two thermal zones) (see *Figure 80*)
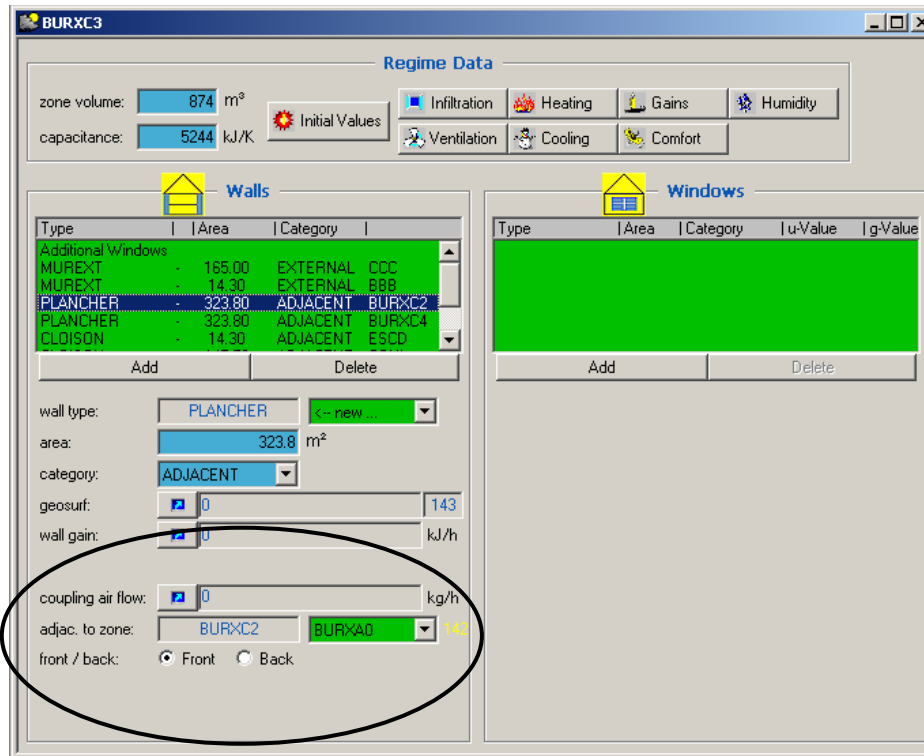
Figure 80: Coupling function associated with adjacent walls

The coupling statement allows the definition an air mass flow a zone receives from another zone, considered as a heat flow from the air node (see *Figure 82*). The statement does not automatically define the air flow back. The user has to introduce another coupling in another (or the same) adjacent zone.
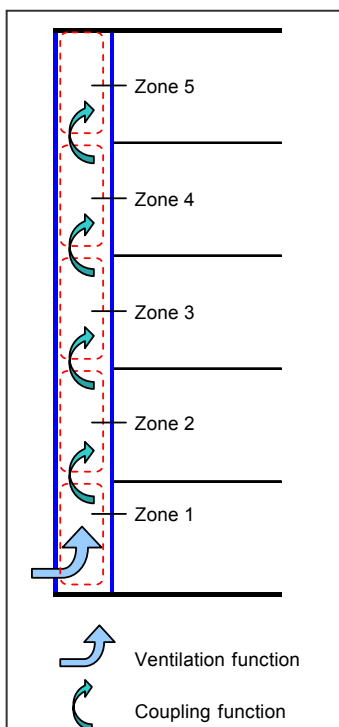
Coupling can be defined (see *Figure 81*). as a constant value, a schedule (e.g.: a normal ventilation rate during working hours and a reduced one during night and week-ends), or an input (e.g.: the air temperature in the double facade, or the sunshine amount).

Figure 81: definition of coupling air flow

Figure 82: coupling between zones of a double facade

The convective heat transfer coefficient h_c that is associated to the glass facades of the ventilated double facade can vary according to the air flow. This one becomes an input which controls the h_c value.

Natural convection.

To simulate natural convection in the cavity, the user needs the air flow model: COMIS coupled with TRNSYS or TRNFLOW. They allow the evaluation of air flow through various natural air openings: windows, doors, cracks, window joints and shafts.
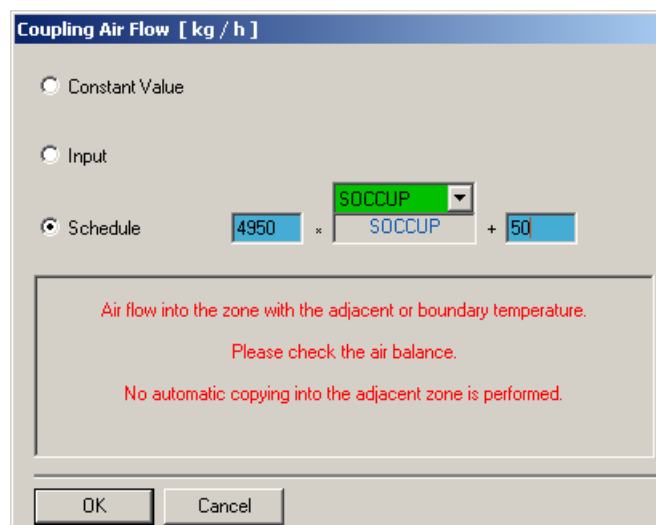
To evaluate the air flows in the building, COMIS / TRNFLOW takes into account two driving forces: wind pressure and buoyancy.

► Wind pressure

The wind pressure on a facade is defined as the difference between the local pressure on the surface and the static pressure in the undisturbed wind on the same height. It is calculated according to this equation:

$$\Delta p_w = C_p \frac{\rho}{2}(v_0)^2$$

where:

Δp_w = wind pressure [Pa]

C_p = wind pressure coefficient [-]

v_0 = reference wind velocity at building location and reference height [m/s]

ρ = air density [kg/m3]

For each external node defined, at least one averaged Cp-values has to be introduced. But a set of Cp-values for as many wind directions as desired can be defined (see *Figure 83*). At least one external node per facade is necessary, but dividing the facade in smaller elements will be more accurate (so far that accurate Cp-values are available, which is not evident!).

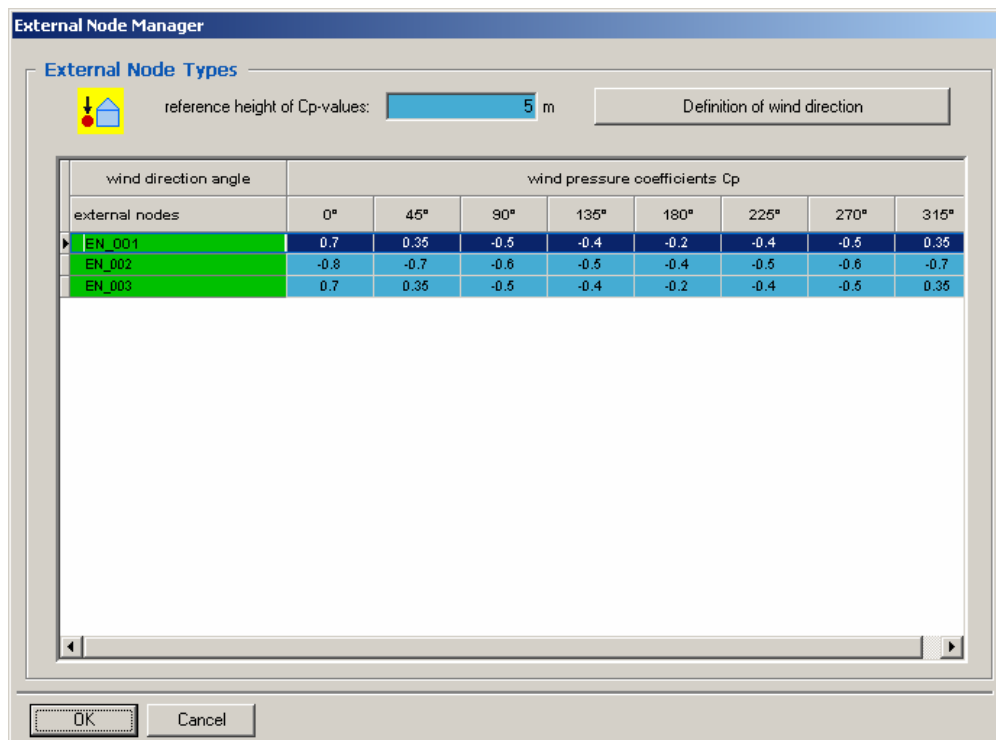| wind direction angle								
external nodes	0°	45°	90°	135°	180°	225°	270°	315°
EN_001	0.7	0.35	-0.5	-0.4	-0.2	-0.4	-0.5	0.35
EN_002	-0.8	-0.7	-0.6	-0.5	-0.4	-0.5	-0.6	-0.7
EN_003	0.7	0.35	-0.5	-0.4	-0.2	-0.4	-0.5	0.35

Figure 83 Introduction of Cp values in PREBID for TRNFLOW

Note: in some software (TAS for example), some default Cp values are available for various building configurations. That is not the case in TRNFLOW The user has to define all Cp values by himself, using tables, measurements, ...

The reference wind velocity v_0 is calculated according to the meteo wind velocity v_m given in a meteo data file. Indeed, location and pylon height of the meteo station usually don't correspond to building location and building reference height. The calculation takes into account the reference height and the height of the building, as well as the roughness of the terrain.

The roughness of the terrain is specified through a value α called "wind velocity profile exponent". It can be defined for various wind directions (see *Figure 84*).
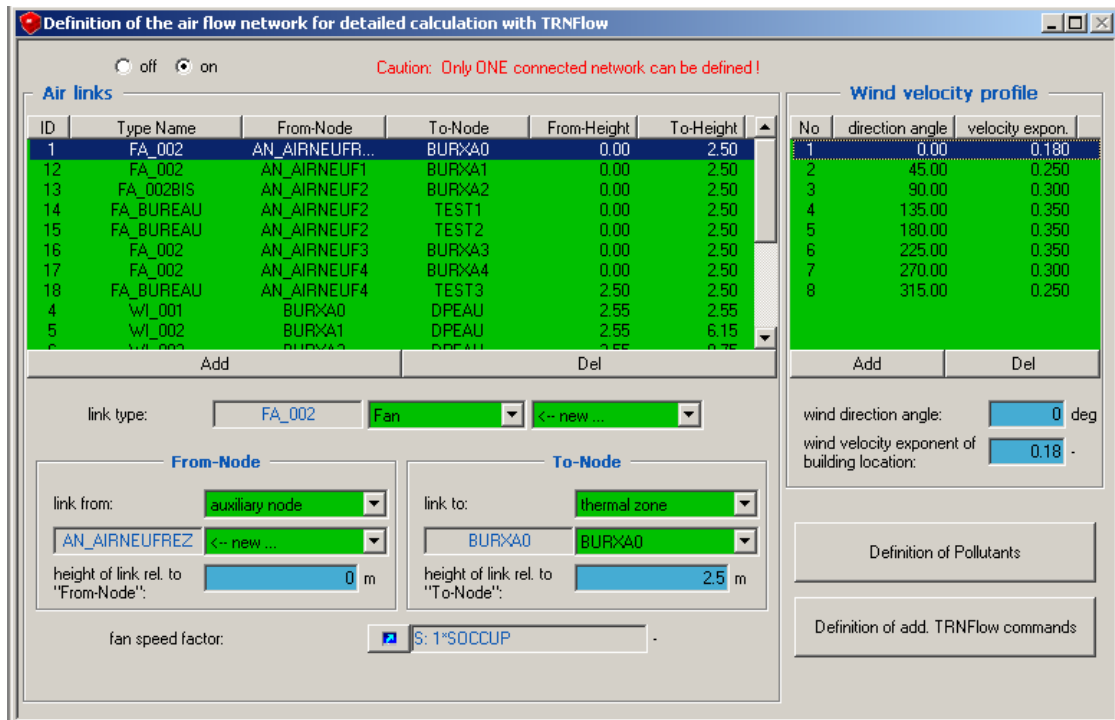
Figure 84 Introduction of wind velocity profile in PREBID for TRNFLOW (on the right part of the screen).

► **Buoyancy**

Not only wind effect, but also buoyancy resulting from temperature and air composition differences, is taken into account. Therefore the vertical position of the nodes and links must be given. In *Figure 85*, a link between an external node and a thermal zone is shown.
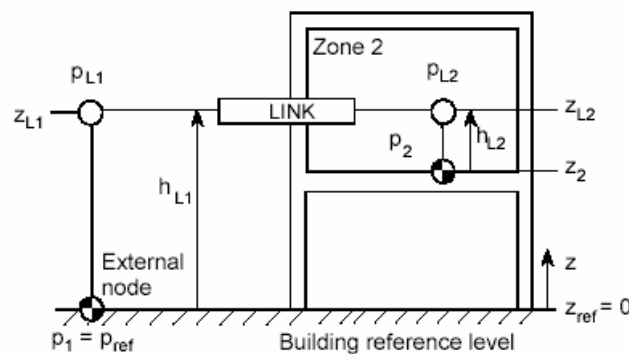
Figure 85 Definition of zone and link pressure

The user has to characterise the openings:
- the type of opening,

- The width and the height of the totally opened window/door,
- The discharge coefficient (C_d -value) of the completely closed and the completely opened opening. It is the ratio between the actual flow rate through the opening and the theoretical flow rate calculated with the Bernoulli equation. This value is depending on the shape of the opening edges, the geometry of the opening, and on the surrounding conditions on both sides of the opening. TRNFLOW is able to calculate the Cd-value for some window types in certain situations depending on the actual condition during the run. For the other situations C_d values can be found in literature,
- The crack characteristics of the closed opening.
- The "own height factor" (see *Figure 86*) which allows to define slanted windows. It is the cosine of the angle between the opening plane and the vertical plane. A value of one means the opening is in a vertical wall and a value of zero means the opening is in a horizontal ceiling or floor.

Figure 86 Definition of the opening characteristics

User also commands the openings through the "opening factor". It varies between 0 (which means the aperture is closed) and 1 (which means the door or window is fully opened). A value in between means the opening is partly opened.
It can be defined (see *Figure 87)* as a constant value (e.g. for a permanently opened aperture), as a schedule (e.g. for a window opened during working hours and closed during night and week-ends), or as an input. This allows the user to control the openings of the cavity according to one or various other values (e.g. building temperature, cavity temperature, outside temperature, sunshine amount, previous day maximal temperature, time of the day…).
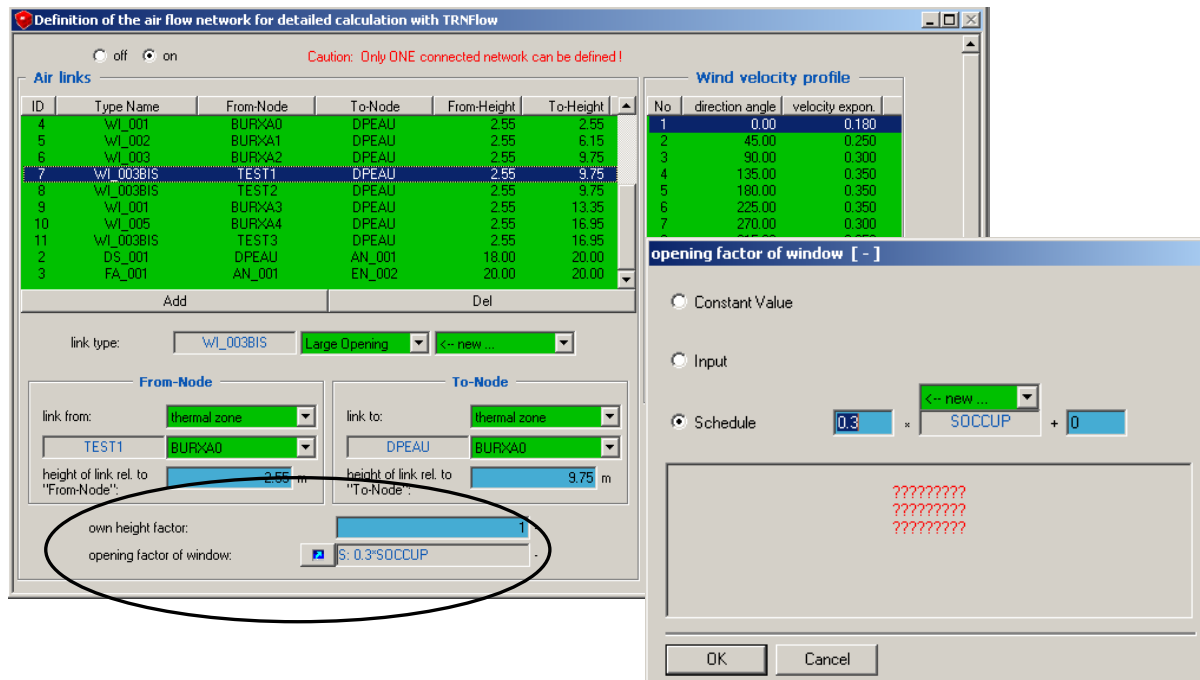
Figure 87 Definition of the opening factor, defining how the opening is managed

The convective heat transfer coefficient h_c which is associated to the glass facades of the double facade can vary according to the air flow. This one becomes an input which controls the h_c value.

8.4.4 Simulation of the building and HVAC systems

TRNSYS offers the possibility to model the ventilation, the heating and cooling of the building. With COMIS or TRNFLOW, the air duct system can also be modelled (air inlets, outlets, ducts and fans).

As the facade, divided or not in various zones, is a part of the building, it can be connected with its HVAC installations.

Here some examples of interaction between the building and the ventilated double facade:

► The double facade is ventilated with outside air. That air, which is partly heated when sun shines, is afterwards used to ventilate the rooms (see *Figure 88*).
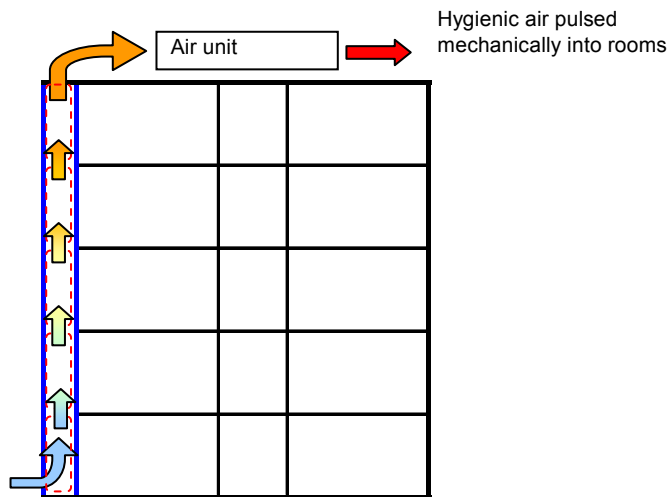
Figure 88 Hygienic air is preheated in the double facade
and pulsed mechanically into the rooms

► The double facade is ventilated with vitiated air extracted from the rooms. Before being thrown outside that air passes through a heat exchanger which pre-heats the hygienic air (see *Figure 89*).
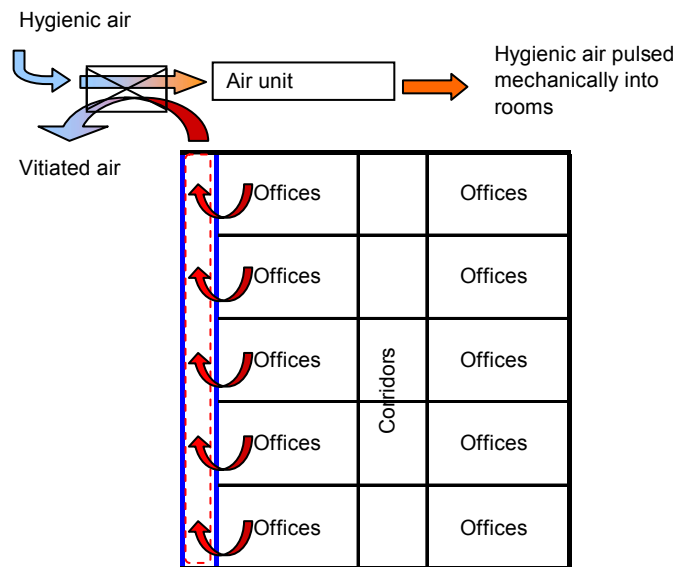
Figure 89 Vitiated air from rooms extracted through the double facade
preheats the hygienic air via a heat exchanger

As COMIS/TRNFLOW allows studying natural ventilation in the double facade, it also allows studying natural ventilation of the entire building. This is a common case as the double facade can ease natural ventilation of the building, acting as a stack. Indeed, TRNFLOW allows modelling openings between the double facade and the building.

Example:
► Rooms on one facade are ventilated directly with outside air through windows. The fresh air is transferred to the rooms opposite and then extracted through the double facade (see *Figure 90*).

Report on simulations of the energy performances
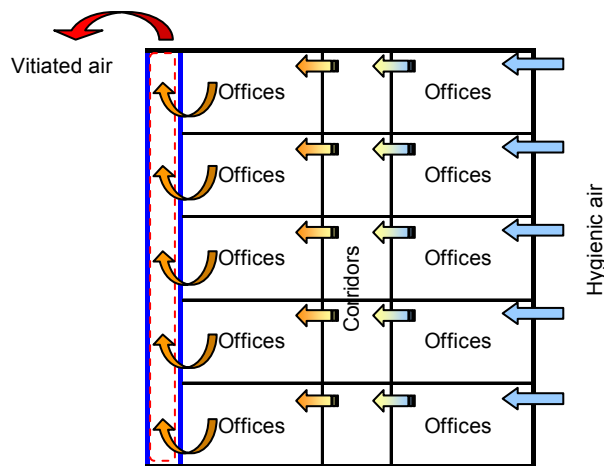
Figure 90 Natural ventilation of a building

8.4.5   Simulation of control systems and control strategies

Thanks to the modular system of TRNSYS, any control strategy can be modelled. User can control window openings, mechanical ventilation, fans, sun shadings, or any other building or system component according to any value: sunshine amount, outside or inside temperature, air flow, wind speed, wind direction,...

Moreover, with the possibility to use any equation, user can also control these components according to various values (e.g. the sunshine amount AND the air temperature inside the double facade).

Examples:
►   The sun protection can be controlled according to the sunshine amount and the temperature inside the double facade.
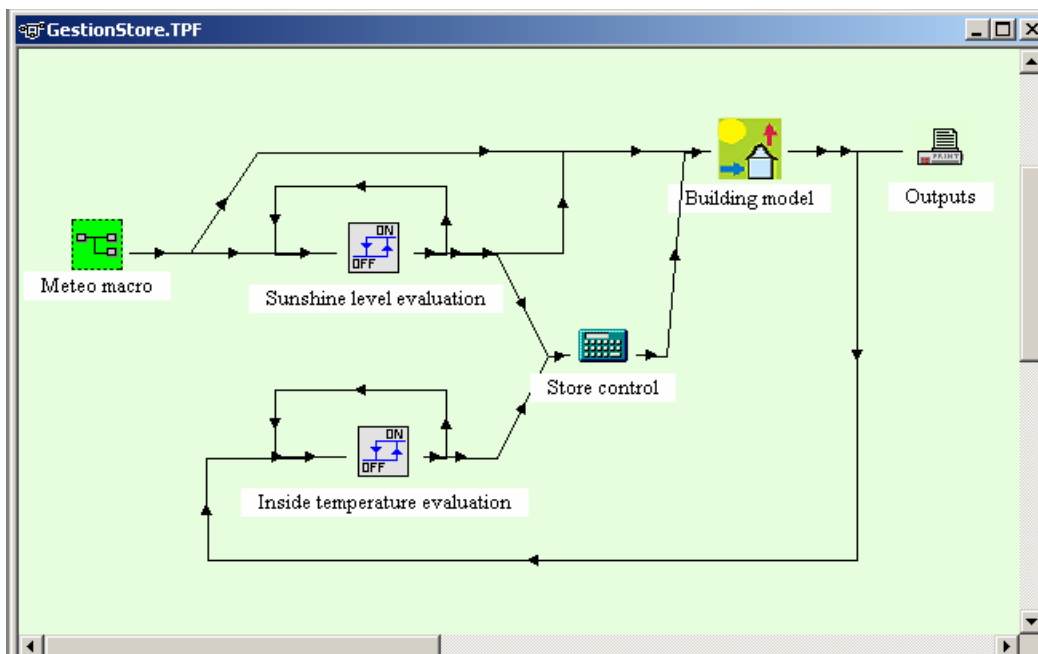
Figure 91 Natural ventilation of a building

8.4.6 Examples of simulations

8.4.6.1 *Comparison of various running modes of a ventilated double facade*

The building modelled comprises 5 levels of offices. The two main facades face north and south. The ventilated double facade faces south and is modelled by a single thermal zone. It has a single pane glass on the outside side and a low-e double pane glass on the inside side (U=1.7 W/m².K, g=0.6).

Note that it would be better to divide the whole cavity in several zones (as shown in the next section) but the aim of the following examples is just to show that it is possible to compare different strategies of ventilation.

Different strategies of ventilation are compared:

► **It is not ventilated**

The double facade is always closed and there is no interaction between it and the building.
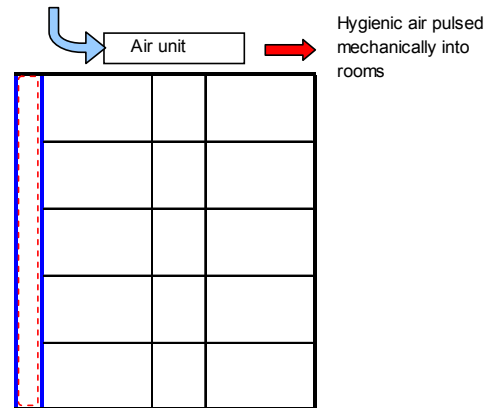
► **It is ventilated with outside air**

The bottom of the double facade is open. The air extracted at the top is partly preheated when sun is shining. It is used to ventilate the offices.
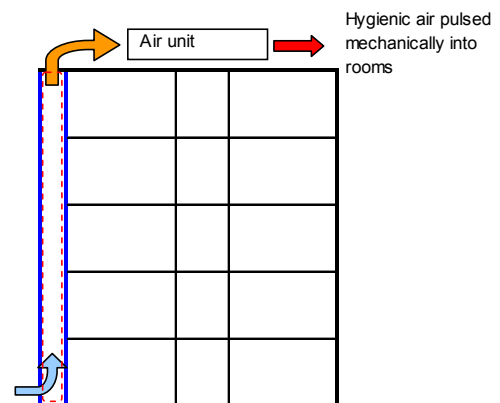
► **It is ventilated with air from offices**

The double facade is ventilated with air taken from the adjacent offices. The air extracted from the double skin facade is going to a heat exchanger, which preheats the hygienic air.

The heat exchanger is not modelled with the building in Prebid but in IIsiBat. It is a specific module (Type 91)
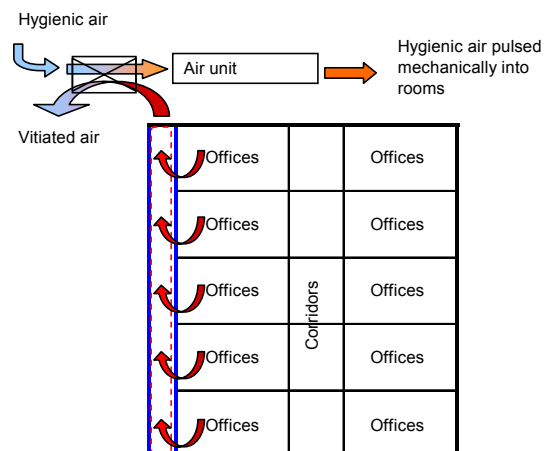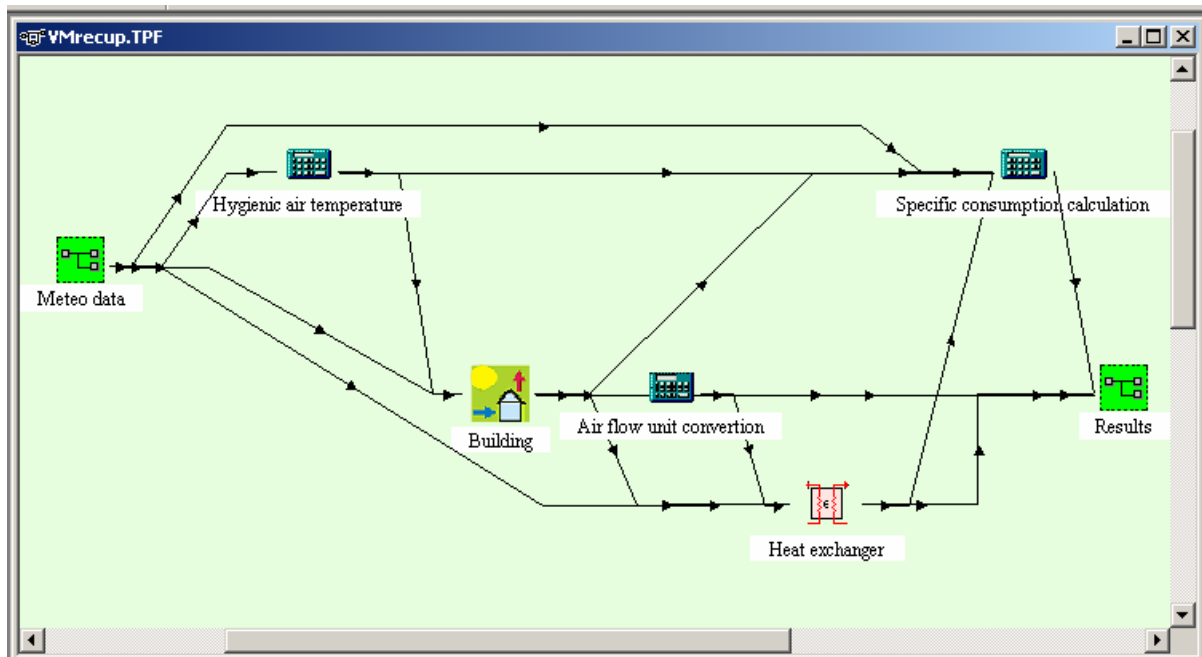
Figure 92: building with heat exchanger model in IIsiBat

These 3 ways of running a double skin facade have been compared to the same building with no double facade.

As showed on Figure 93, the temperature in the double facade varies with the outside temperature and the sunshine level. It is usually lower when the cavity is ventilated with outside air instead of closed or ventilated with offices air.
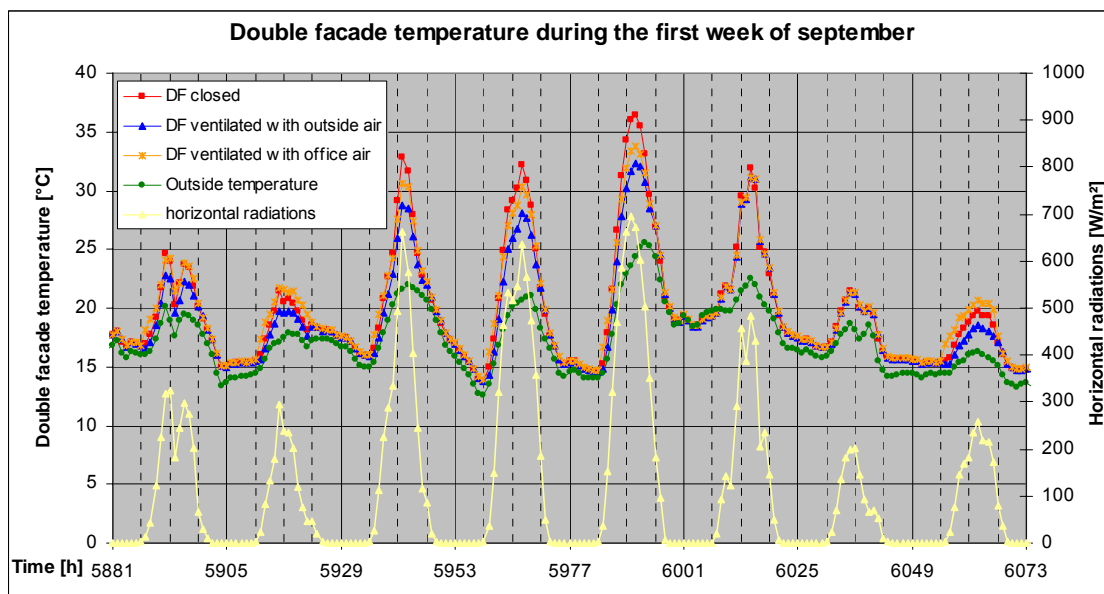
Figure 93: *Temperature in the double facade according to the way it is running*

8.4.6.2 Comparison of various numbers of zones to model a double facade

The building modelled comprises 5 levels of offices. The two main facades face north and south. The double facade faces south and has a single pane glass on the outside side and a low-e double pane glass on the inside side (U=1.7 W/m².K, g=0.6). It is ventilated with outside air when the building is occupied. The preheated air is used for hygienic ventilation of offices.

The cavity is successively modelled by 1, 5 and 10 zones (see figure 86).
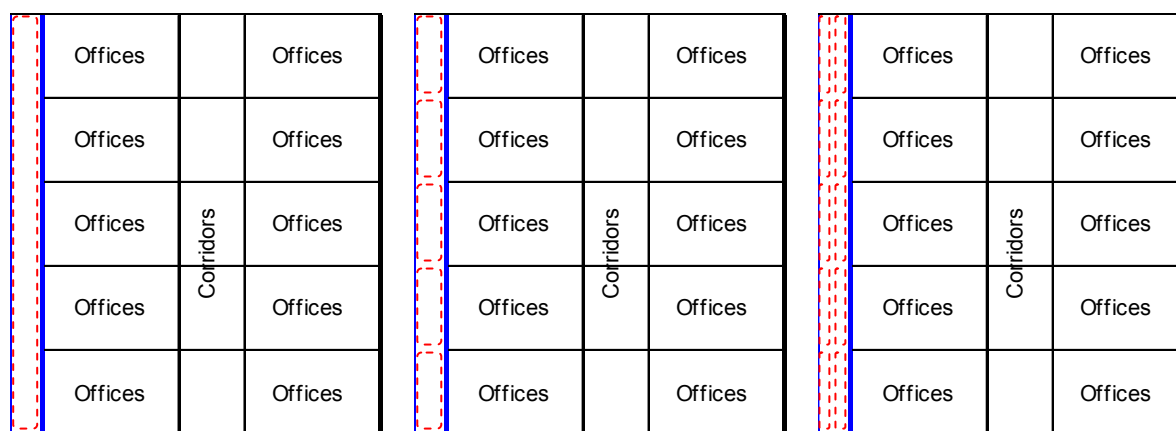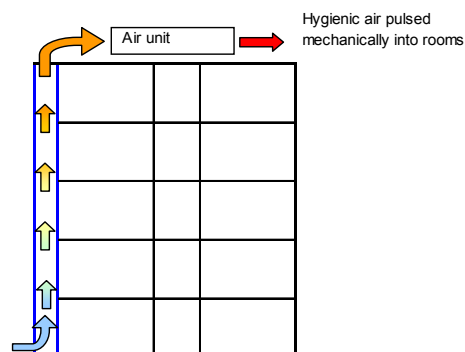
Figure 86: Cavity modelled successively by 1, 5 and 10 zones.

Different positions of the shading devices (placed in the cavity) (see *Figure 94*): against the external face, against the internal face, and in the middle of the cavity (only with the 10 zones model).
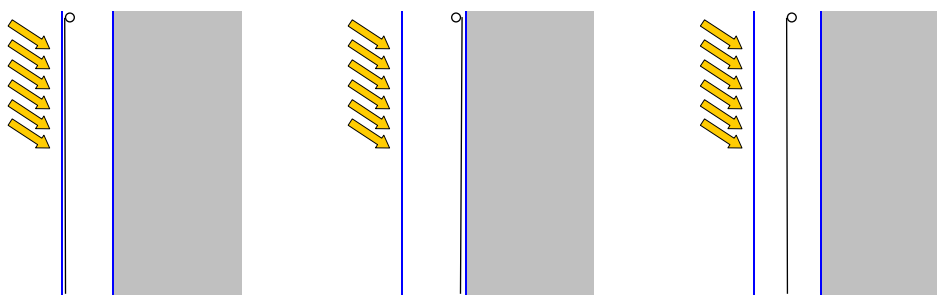
Figure 94: Various stores modelled: against the external facade, against the internal facade, and in the middle of the cavity

The position of the shading device (screen) is monitored according to the incident horizontal global solar radiation (down if I_{glob}>250 kJ/hm²).

Let's compare the evolution of the total thermal demand (demand for air preparation and room demand) for a central office located against the double facade with the blind location when the number of cavity zones varies (see *Figure 95*).
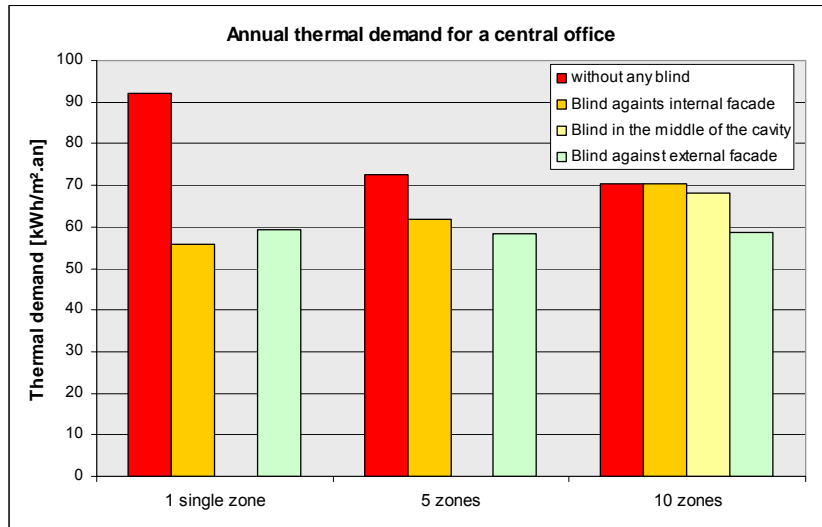
Figure 95: comparison of thermal demand for different positions of the shading devices, for various models.

Let's compare now the total thermal demand between the various models for each blind location.
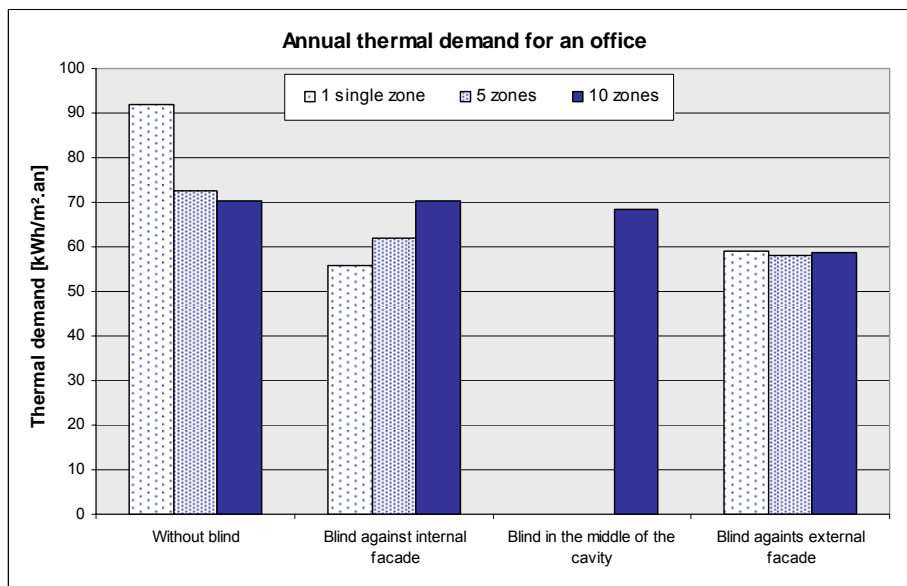
Figure 96: comparison of thermal demand for an office for various models.

When there is no blind, the model answer is quite similar for 5 and ten zones, but differs of around 25% from the answer with a "1 zone" model.
With an external blind, answers are similar for 1, 5 or 10 zones.
And with an internal blind, answers vary a lot, up to 25% according to the number of thermal zones in the cavity.

These figures show that the number of zones can lead to different results. A more detailed analysis must be performed to explain the impact of the vertical and horizontal subdivisions (impact of the modelling of the fictive vertical window, etc.)

Let's have a look at the temperatures in the double facade and in an office with a blind located against the external facade.
The air temperature of a central office is consistent between the "1 zone" and the "5 zones" models. It is a little bit lower with the "10 zones" model (up to 1,5 degree for the first week of September) (see *Figure 97*). This shows that a part of the solar radiations that should come into the office is stopped by the fictive vertical window.
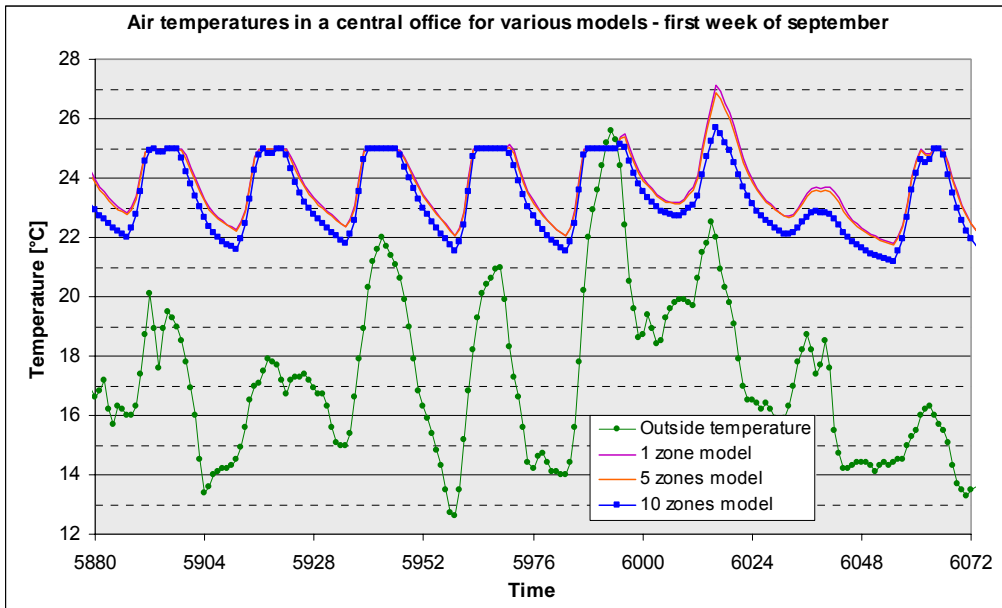
Figure 97: comparison of the air temperature in a central office for various models.

5: ESP-r SOFTWARE

8.5 ESP-r SOFTWARE

8.5.1 General software information

History

ESP-r is an Open Source program, developed by the Energy Systems Research Unit at the University of Strathclyde with inputs from many other organisations. It has been developed over a 28 year period, with funding from the UK's Engineering and Physical Sciences Research Council and the R&D Framework Programmes of the European Commission.

It is available by download from ESRU's website (http://www.esru.strath.ac.uk). Other information (tutorials, exercises, documentation, upgrade notes etc) can also be found on the website.

Overview

A key design aim of ESP-r is to provide a detailed dynamic integrated simulation of a building and its systems, as shown in Figure 98.
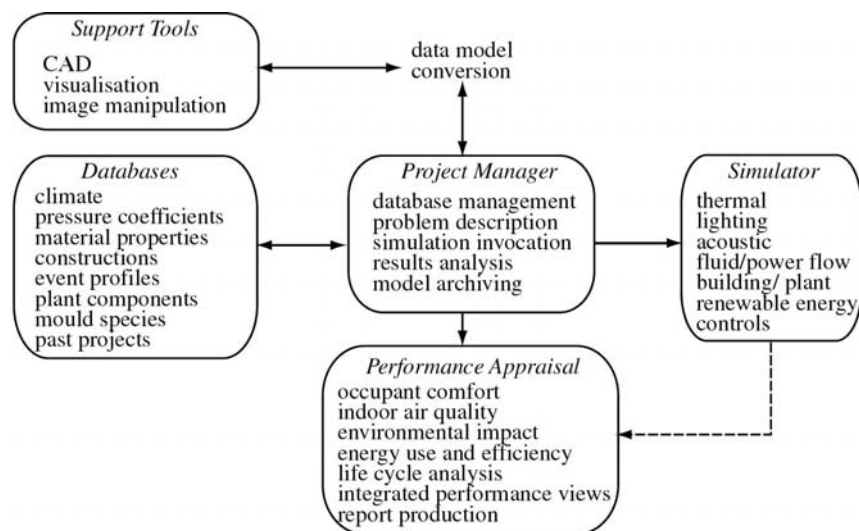
Figure 98: ESP-r system

Another important aspect of ESP-r's design – of importance in the modelling of double facades where integration of the thermal, lighting and ventilation performance is key – is that it is possible to model at different levels of resolution. For example, with respect to the airflow, it is possible:

a) to specify scheduled infiltration and ventilation rates into the various thermal zones;
b) to include an airflow network to calculate the inter-zonal bulk airflows (integrated with the thermal simulation);
c) to include a CFD domain to study intra-zonal airflow within one or more of the thermal zones.

It is generally recommended that a user starts with a relatively simple model and progressively adds additional resolution.

Program structure

In use, the user defines the model in the Project Manager. The resulting model is passed to the simulator which stores results in one or more results databases (depending on which domains are included in the model). Performance data in tabular or graphical form, as well as summary performance metrics, can then be studied in the results module.

Theory

ESP-r is a transient energy simulation program based on the finite volume technique. It is capable of modelling the energy and fluid flows within combined building and plant systems when constrained by control actions and

subject to dynamically varying boundary conditions. By default, the Crank-Nicolson formulation for mixed explicit/implicit finite differences is used (although the user can change this from fully explicit to fully implicit solutions). The user can specify simulation timesteps up to a maximum of hourly and there are options for timestep control to increase resolution where needed. Full details of the underlying theory can be found in Clarke (2002).

In general use, one or more zones within a building are defined in terms of geometry, construction and usage profiles. The zones are then interlocked to form a building, in whole or in part. An important feature of ESP-r is that the zones are defined as a full 3-D representation: this aids visualisation and allows more accurate radiation processing. Following the building description, the leakage distribution is optionally defined to enable integrated airflow simulation. The plant network can then be defined by connecting individual components and this network connected to the building. The complete model is then passed to the Simulator and subject to simulation processing against user-defined climate, user-defined simulation period and user-defined control. The development of the model is achieved interactively with the aid of pre-existing databases. The simulation and results recovery components can be undertaken either interactively or can be automated.

In the thermal, airflow and lighting domains, of interest here, all heat and mass transfer processes are treated and solved simultaneously at each timestep of the simulation, as indicated in Figure 99.
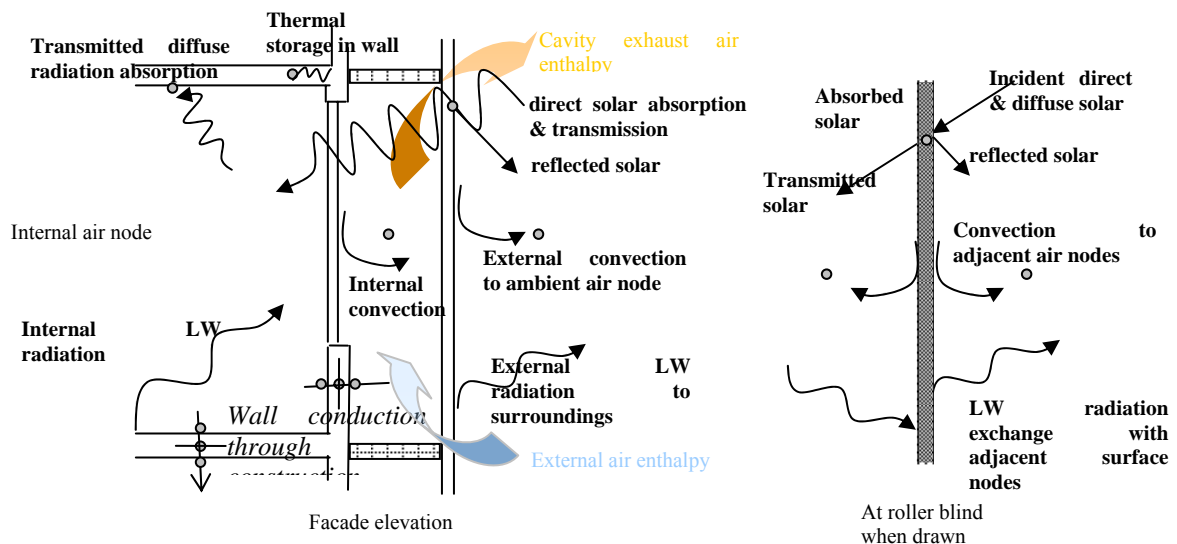
Figure 99: Flowpath diagram for dynamic thermal processes in a double-skin facade

The following sets out how the various heat and mass transfer processes and related systems of interest in double facade modelling are modelled. Some capabilities of ESP-r are therefore not covered (e.g. moisture transfer, plant systems, power flow). The terms "finite volumes" and "nodes" are synonymous.

Conduction: By default, nodes are assigned to each layer in a construction at the centre and boundary of the layer, giving *(2n+1)* nodes per construction, where *n* is the number of layers. Each layer is attributed with thickness and the material thermophysical properties of conductivity, density and specific heat. A finite difference method is used to solve the conductive heat transfer process, including thermal storage. Both opaque and transparent constructions are modelled in the same way, except that there is the additional possibility of nodal absorption of solar radiation in the case of transparent constructions. For opaque constructions, the solar radiation is absorbed at the surface node.

It is also possible to change the nodal distribution and to include 2-D and 3-D conduction paths at selected points in the model for calculation of thermal bridge effects, but this facility is rarely used in practice.

Convection: The internal surface convective transfer process is particularly important in double facades and much attention has been focussed on this in recent research. By default, the Alamdari and Hammond correlations for buoyancy-driven convection are assigned for each internal surface. However, users can select a large range of alternative correlations, which are likely to be more appropriate for flow in channels such as occur in double facades and for forced convection. For example, it is possible to select correlations developed specifically for channel flow such as Bar-cohen and Rohsenow, and Molina and Maestre equations. It is also possible to control which correlations are used.

External convection coefficients are calculated by default based on empirical relationship between wind speed, wind direction and surface orientation. They can also be specified by the user.

Short-wave (solar) radiation: Direct and diffuse radiation, taken from the hourly climate database, are treated separately. Sub-hour climate data can be used if available via the temporal database facility.

A separate module can be invoked from the Project Manager to undertake a shading and insolation analysis, with obstructions defined as appropriate (e.g. remote shading due to surrounding buildings or overhangs and fins on the façade). A grid is set up on external surfaces and calculations based on ray projections from the sun used to determine if the grid points are shaded, for each hour of the day for one day of each month. Shading fractions are then calculated and stored in a shading database for use during the simulation. An optional insolation analysis can also be undertaken extending the ray projections on unshaded grid points on transparent surfaces to determine which internal surfaces are insolated (again for each hour of the day for one day of each month) by direct radiation. The fractions of incoming direct radiation for each internal surface are then stored in the shading/insolation database for use during the simulation.

An optical database is available containing the transmittance and layer absorptances for different glazing systems, at incident angles of normal, 40º, 55º, 70º and 80º (linear interpolation is used between these values). New glazing systems can be added using automatic import from the Window 5 program of LBL, or from WIS (an automatic import option from WIS is currently being added). A transparent construction in the construction database (containing the thermophysical properties of the glazing) is associated with the appropriate entry in the optical database.

During simulation, the solar processor calculates the incident direct and diffuse radiation on all external surfaces at each time row. An anisotropic diffuse sky model is used, by default the Perez model, but users can select alternatives. Ground reflection depends on the user-specified ground albedo (by default 0.2). For opaque surfaces, the construction absorptance is used to determine the absorbed direct plus diffuse solar radiation at the finite volume representing the surface. For transparent surfaces, the optical data is used to determine the direct and diffuse solar radiation absorbed in each finite volume representing the transparent construction.

The transmitted radiation is then processed; firstly, the direct radiation which is distributed according to data in the shading/insolation database (or by user specified fractions if such a database does not exist, with diffuse distribution by default). The absorbed radiation is then calculated for each directly insolated internal surface depending on its absorptivity. In the case of transparent surfaces, the solar radiation is processed in the same way as for radiation entering from the outside (i.e. solar absorbed at each node in the construction with transmitted radiation either passed as direct radiation to the adjacent zone or lost to the outside of the building). Directional properties of the direct radiation are lost after the first zone. Radiation reflected is summed and added to the diffuse reflected component.

Transmitted diffuse radiation is handled in a similar way. The radiation entering the zone is distributed to other surfaces according to area and absorptivity (except for the surfaces in the same plane as the glazing through which the radiation entered). The reflected radiation, summed with the direct reflected component is then distributed in a similar way, according to the area and absorptivity of all surfaces in the zone. This procedure iterates until all radiation is accounted for.

It is also possible to create a file of bi-directional data. ESP-r can process this, dealing with separate knowledge of surface-to-solar altitude and surface-to-solar azimuth to calculate by 2-dimensional linear interpolation the appropriate transmittances and absorptances. This is useful for accurate modelling of non-homogeneous glazing systems (e.g. Venetian blind systems), but in practice the required input data is rarely available.

Longwave radiation: By default, for internal longwave exchange, explicit surface-pair linearised radiation coefficients are used, with viewfactors based on area weighting. The radiation coefficients at each timestep are a function of temperatures, viewfactors, surface areas and emissivities. Another module can be optionally invoked which calculates view factors more accurately – either by analytical solution in the case of simple rectangular zones, or by ray tracing for more complex geometries.

For external longwave radiation, ESP-r considers the external viewfactors to sky, other buildings and ground. Currently these viewfactors are constant for all external vertical surfaces. They are specified as part of the "model context" as a function of user-specified site. Sky temperature is based on the Berdahl and Martin algorithm (although the user can change this to various alternatives) with cloud cover estimated from direct and diffuse radiation and relative humidity. The temperature of other buildings is considered to be the same temperature as the external surface being considered. Ground surface temperature is calculated based on a simple nodal model using one of the existing profiles or a user-specified profile of monthly ground temperatures.

Internal gains: Users can specify a time schedule of casual gains for each zone, split by radiative/convective fractions, by sensible/latent fractions, and by source (lights, occupants and equipment).

Air flow: It is possible to schedule air change rates to zones with limited control possibilities based on temperature, but for double façade modelling it is more appropriate to use ESP-r's integrated inter-zone airflow network for bulk airflows through the double façade and associated building. In this scheme, the user specifies a leakage network consisting of a number of internal and external nodes connected by a variety of airflow 'components' such as openings, cracks, fans etc. The full network is solved at each timestep depending on control conditions of the various openings. Flows are calculated as a function of wind-induced pressure differences and buoyancy-induced pressure differences.

CFD: One or more zones in a building can be associated with a 3-D CFD domain. The space can be gridded (limited to cuboidal spaces at present, but with blockages added if necessary). CFD simulation can be done in conjunction with the remainder of the whole building simulation in order to calculate the detailed zone temperature and air flow distribution. This is usually done only at predefined points in the simulation, due to simulation time constraints. There are several possibilities for linking the CFD domain to the rest of the building simulation. The main linking mechanisms, at each timestep, are

- Thermal 1: The Simulator establishes surface temperatures and the CFD module invoked. Air-surface heat transfer is determined from the CFD module flow and temperature fields using wall functions. Surface-averaged film coefficients are then passed back to the Simulator for solution of air, surface and inter-constructional temperatures.
- Thermal 2: As above but the CFD module is used to calculate the zone average air-point temperature as well as the calculated convective fluxes, which are passed to and used by the Simulator. The CFD and building thermal domains iterate at the same timestep.
- Mass flow: a single airflow network node is replaced by a CFD domain. The network flow model establishes airflow and temperature boundary conditions which are passed to the CFD module. Predicted airflows are then passed to the network air flow solver. The CFD, building thermal and airflow network can all be integrated and solved iteratively at the same timestep.

Other features of ESP-r's CFD module are:
- Finite volume, 3-D Cartesian staggered grid.
- Solver: SIMPLEC pressure-correction method.
- Turbulence models: k-e model (fully turbulent flows) and zero-equation model (natural convection with infiltration, forced convection and mixed convection with displacement ventilation)
- Wall functions: Log-law; Yuan et al (buoyancy-driven flow over vertical walls) and replacement with empirical convective heat transfer correlations
- Ability to provide CFD determined convection co-efficient to the building simulator
- Ability to distinguish between natural, forced & mixed flow regimes and select appropriate near wall treatment, based upon a comparison of the Grashof and Reynolds numbers
- Ability to check when conditions are such that CFD is likely to be incapable of providing accurate results (e.g. weak turbulence conditions) and switch to using traditional correlations for heat transfer.

Heating and cooling plant: Specification of plant systems is not covered here. For most double façade studies, it is sufficient to use ESP-r's ideal heating/cooling control definition. Here maximum and minimum heating and cooling fluxes can be specified for each zone, together with sensor locations (air temperature, surface

temperature or intra-constructional temperature), actuator locations (e.g. heating/cooling injections to the zone air, zone surface or intra-constructional node), setpoints etc. Several control laws are available relating the sensed condition to the flux injections (ideal control, proportional control, fixed heat injections etc).

Lighting: The simplest method for modelling daylight/thermal interaction in ESP-r is the definition of casual gain control. ESP-r calculates illuminance levels at user-specified points based on the split-flux method. The lighting gains can then be controlled as a function of the illuminance level according to a range of light switching models (on/off, proportional, etc).

However, a more detailed analysis may be required for daylight-responsive buildings such as those with double facades. In this case, an accurate prediction of the time varying internal illuminance distribution against temporal events such as blind movement and sky luminance changes is required. Two modelling approaches have been developed in ESP-r with links to radiance.

The first approach is based on the direct linkage of the ESP-r and RADIANCE systems, with the former system providing the overall supervisory control at simulation time as shown in Figure 100. A separate RADIANCE desktop module is called from the Project Manager which takes ESP-r's geometry, attributes it with lighting properties such as surface reflectivities, and sets up the parameters for a lighting simulation.
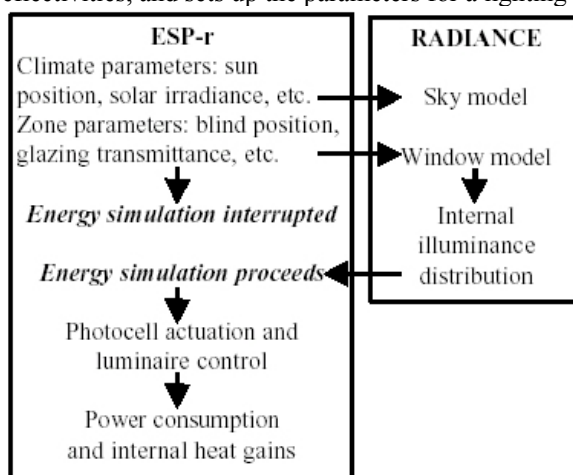
Figure 100: ESP-r-RADIANCE interactions at timestep level

At each simulation time-step, ESP-r's luminaire control algorithm initiates the daylight simulation, passing model parameters such as shading device position to RADIANCE. RADIANCE then carries out several tasks as follows: (1) transfer of data defining current climate and zone state; (2) generation of sky model; (3) calculation of internal illuminance for defined sensor locations; (4) transfer back of illuminance data to luminaire controller. The returned data are then used to determine, as a function of the active control algorithm, the luminaire status and hence the casual gain associated with lights at the current time-step.

A second approach, which reduces the computationally demanding nature of the direct coupling method, involves the re-use of already calculated data. This method makes use of daylight coefficients. These are calculated by RADIANCE at the start of the simulation for each sensor point and blind position. Then, at each simulation timestep, the complex internal illuminance distribution can be determined by simple multiplications and additions. The method is detailed in Janak and Macdonald (1999).

Control: The following control options are available (all of which can be scheduled, i.e., different controls can be applied at different times):

> **Heating and cooling fluxes**: see the paragraph on heating and cooling plant above.
> **Lighting**: heat gains from lighting can be controlled on the basis of calculated lux levels at user-defined locations. See the paragraph on lighting above.
> **Optical properties**: the optical properties can be replaced by an alternative set depending on some sensed condition (e.g. radiation levels, internal or external air temperature).

Thermophysical properties: the thermophysical properties of a construction can be replaced by an alternative set depending on some sensed condition (e.g. radiation levels, internal or external air temperature). This can be done in conjunction with changing the optical properties to represent, for example, insulated blinds and shutters opening and closing.

Airflow: Airflow connections can be controlled based on a large range of sensed conditions with either on/off control, proportional control or range-based control. Complex control strategies are possible with, for example, windows being closed if winds are above a certain speed and external air temperature below a certain setpoint and internal temperatures below a certain setpoint.

Convection coefficients: An adaptive convection controller has been implemented in ESP-r that assigns appropriate correlations depending on the type of flow (buoyancy-driven, mechanically-driven or mixed). Control is enabled to switch between correlations depending on whether the HVAC plant is on or off. Details of the methods implemented can be found in Beausoleil-Morrison (2000).

General Procedure for Setting up a Model

The main steps in setting up a model for double façade studies are set out here. Specific details are given in later sections.

1. Analyse the design problem in hand and decide on the performance features to be appraised by the simulation program ESP-r. In the case of double facades, these may include zone comfort levels, airflow rates, energy consumption, condensation risk, the consequences of alternative design options assessed, or testing various control alternatives. This is an important task since it will influence the time and expense incurred thereafter.

2. Decide on the minimum number of building zones which will yield the performance measures required. Avoid, in the first instance, any attempt to simulate large, complex building/plant systems. It is, of course, possible to undertake such an exercise, but only at the expense of significant time increase for data preparation and analysis. Very often, good design insight can be obtained from simulations directed at portions of the overall system. In ESP-r terminology, the final system for simulation, irrespective of size or composition, is termed the system configuration, and the high level model description is held in the configuration file.

3. A basic computer model must now be created via the Project Manager. The underlying procedure is as follows.
   a) Enter contextual information such as building location, year of analysis etc. The user is encouraged to maintain a log of the building model assumptions and can associate images with the model.
   b) Establish the databases. For double facades, the following databases should be checked, with additional entries added if necessary: climate, material properties, constructions, optical properties and pressure coefficients.
   c) Create the geometry of the thermal zones, either from dimension input or 3-D coordinate input. Input from CAD packages is possible but not generally recommended.
   d) Attribute the thermal zones and the links between them in terms of constructions and boundary conditions.
   e) Enter internal gains and design air change rates in the operations section. Each thermal zone has three mandatory files describing the geometry, the constructions and the operations.
   f) Enter the control information for the idealised heating and cooling plant, including definition of the location of sensors and actuators.

The Project Manager provides an interactive dialogue and validity checking of user inputs. It is also possible to display a QA report listing the essential features of the model.

4. At this stage, it is suggested that a short period simulation is done in order to check correct functioning of the model. Interactive simulation should be chosen and a short-period simulation undertaken, driven by the simulation module, with results (with user-selectable level of detail) stored in a results file. The results module should then be started to undertake a graphical check on predicted temperatures/fluxes etc.

5. Additional model detail can now be added. The following may be important in the case of double facades:
   a) A shading/insolation analysis to determine shading factors on all external surfaces arising from façade-mounted and remote shading blocks, and internal solar insolation distribution (taking into account any shading on the glazing) for each glazing.
   b) An internal inter-surface viewfactor calculation for accurate viewfactors for longwave radiation calculations.
   c) An airflow network to describe the leakage distribution for combined thermal/airflow modelling. The calculated airflows supersede those entered in the operations description. Control information for the airflow network can be added to allow opening/closing of windows, fan switching etc.

d) Casual gain control file in the case of controlled lighting systems based on the availability of daylight.
e) A convection coefficients file. By default, ESP-r assumes buoyancy-driven surface convection but many alternatives are available depending on the flow regime.
f) Blind control can be established in the definition of the construction details. It is possible to switch just optical properties (e.g. electrochromic glazing) or both thermophysical and optical properties (e.g. an insulated blind).
g) A CFD domain in which 3-D gridding and related parameters are specified in support of a stand-alone or combined CFD simulation.
h) Addition of short-timestep measured data can be added through the temporal database module: this could be climate data, measured temperatures, measured internal gains etc.
i) Addition of new technologies such as phase change materials and photovoltaic modules can be added through the "special material" definition.
j) Addition of a plant network, by specifying each component and its connections to other components and to the building model.

Each of these optional functions can be included via the Project Manager. The key consideration is to avoid complexity where possible, starting with a simple model and adding to the model resolution incrementally.

6. Simulations can now be run on the created model. It is recommended that the climate dataset is analysed first (using the climate module accessible from the Project Manager) to identify typical sequences and design days, in order to provide boundary conditions which best stress the performance attribute to be tested. The Results Module can then be used to analyse the performance data, either graphically, in tabular form (either internally or externally by data export) or in summary form. Additional information on energy balances and detailed flux breakdowns can help to understand cause and effect relationships implied by the energy flowpath magnitudes and directions.

7. Appropriate design modification can now be implemented via the Project Manager by editing the model. In this way constructions can be changed, operational schemes modified, shading devices added or removed, and so on.

8.5.2   Outdoor climate and other context data

The location of the building must be specified. The items required (in the "context" menu of the project manager) are in the Table 13 :

Latitude	Degrees (positive in northern hemisphere, negative in southern hemisphere)
Longitude difference from local meridian	Degrees (positive if east of meridian, negative if west)
Site exposure	Choose from menu – the choice will affect external viewfactors (sky/buildings/ground) for external longwave exchange calculations
Ground temperature	Average monthly temperatures (ºC)

Table 13: Building model context data

The climate parameters required are hourly averages. The first data for each day is the data for hour 1 (which could be a spot value or the hourly average from 00:30 to 01:30). Several climate datasets are provided with the ESP-r distribution for the UK and elsewhere. It is also possible to import measured data and data from the extensive climate datasets held on the US Department of Energy website (http://www.eere.energy.gov/buildings/energyplus/weatherdata.html) held in EPW format. Table 14 indicates the required data.

Global horizontal or direct normal solar radiation	A flag in the climate file indicates which is provided in the climate file. Units: W/m^2
Diffuse horizontal solar radiation	Units: W/m^2
External dry-bulb temperature	Units: ºC
Wind speed	Units: m/s. Usually measured at 10m above ground
Wind direction	Units: degrees clockwise from North
Relative humidity	Units: %

Table 14: Climate data requirements

If climate data is available at sub-hour frequencies (e.g. 5 minutely data), it is possible to import the data into the "temporal database" accessed in the Project Manager in the model context section.

8.5.3   Simulation of a ventilated double facade

8.5.3.1   General methodology

The modelling of double facades is particularly complex because of the high degree of interaction between the many heat and mass transfer processes. The following gives some general guidance on modelling the facades, but it should be remembered that some aspects where there is uncertainty (e.g. selection of appropriate convection correlations, discharge coefficients, and wind pressure coefficients) may have a significant impact on the predictions.

There are many possible configurations of double facades, with different widths and heights relative to the rooms in the building, forced and naturally ventilated, different shading and control options etc. The following shows how the thermal zones can be defined.

Regarding a **single-storey** type double-skin facade, a model should consist of at least one repeating section of the double facade and adjoining internal perimeter zone:

No shading

With shading
(two cavity zones required)
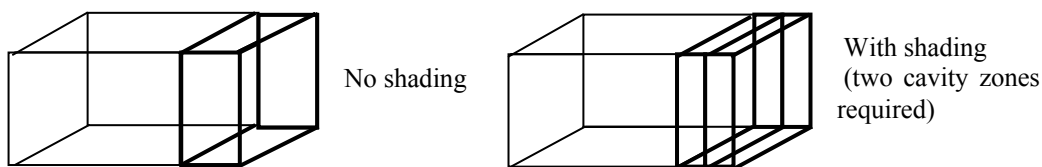
In a **corridor type** double-skin facade, the repeating section becomes either a floor of the building or part of it:

No shading

With shading
(two cavity zones required)
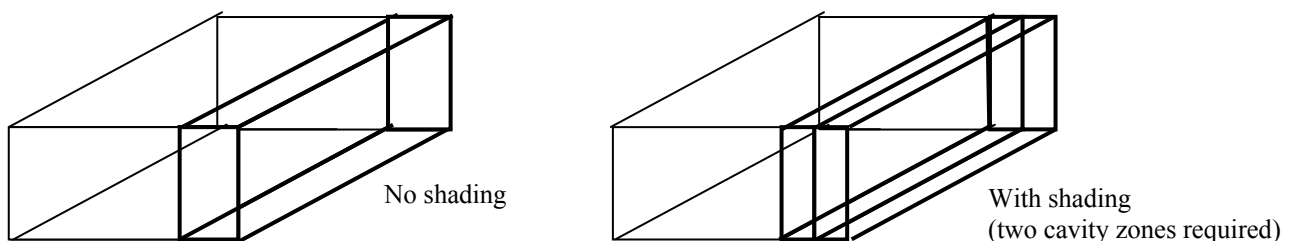
In a **multi-storey type** facade it is necessary to represent the full-height of the facade and perimeter storeys to account for the stack effect. Also wind effects become apparent over large heights.

No shading

With shading
(two cavity zones required per floor)
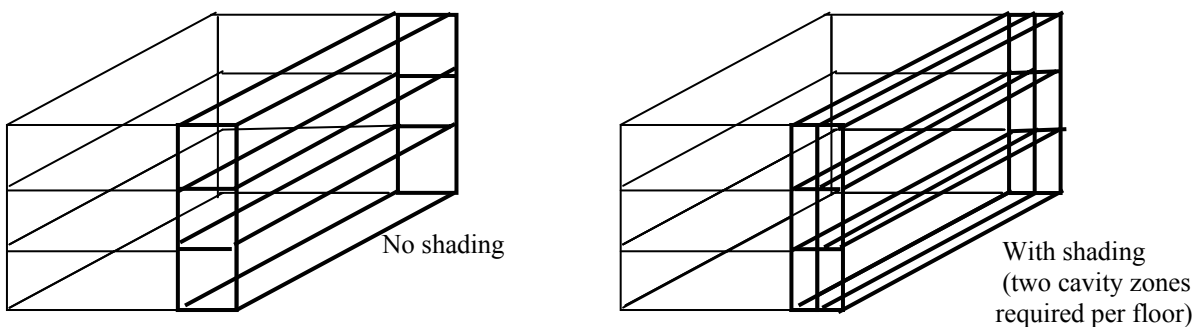
An example of zoning for the case where there is airflow through the double façade over several storeys can be seen in the Figure 101 (from Hensen et al 2002). The model formed in ESP-r is shown in the bottom right of this figure.
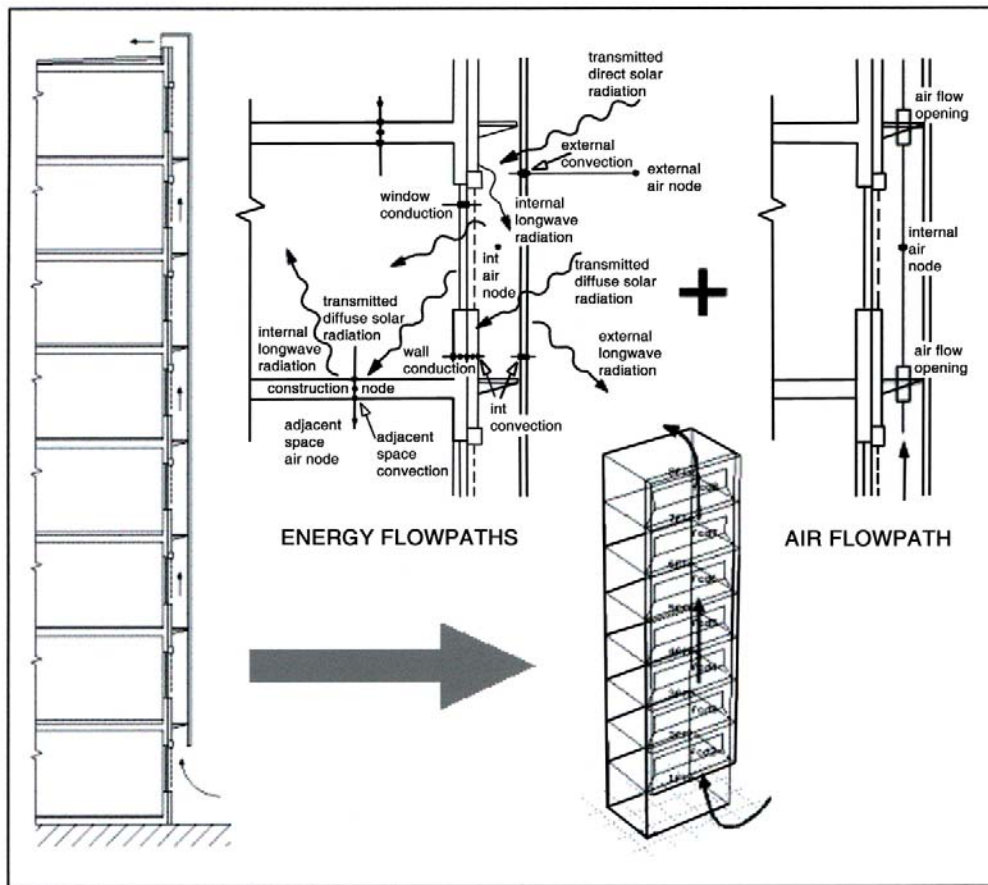
Figure 101: Example of zoning for double façade (from Hensen et al 2002).

8.5.3.2   Facade layers

Opaque constructions

As described above, the constructional materials (thermophysical properties) and constructions (materials and thickness) should be specified in the appropriate databases. Then each surface in the model is associated with a construction and a boundary condition. This is found in the "surface attribute" section of the Project Manager (see Figure 102).
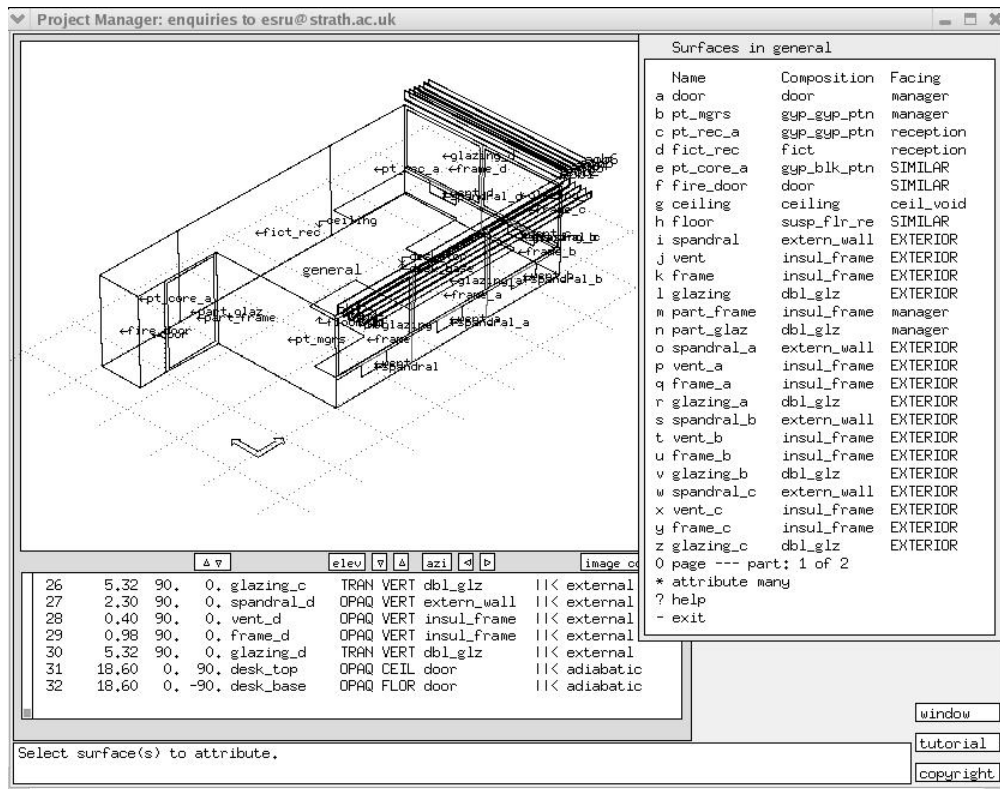
Figure 102 : Screen shot of surface attribution in ESP-r's Project Manager

Transparent constructions

The glazing constructions are represented in ESP-r similarly to any other construction, but declared as transparent with associated optical properties. So, for example, if the inner glazing is double-glazed, the appropriate double glazing would be defined as a 3-layer system (glass-air-glass) in the construction database with the thermophysical properties (conductivity, density and specific heat) of glass obtained from the materials database. The optical properties required by ESP-r are the system transmission and the absorption of the individual layers. These are held at 5 angles of incidence (0º - normal to glass, 40º, 55º, 70º, and 80º).

The optical data can be obtained from Window5 or WIS or from manufacturer's catalogues.

Fictitious constructions

These are necessary to represent the fictitious boundaries between stacked zones and, for the case of two cavity zones where blinds are placed in the centre of the double façade, between these cavity zones when the blinds are opened. A construction should be created made of a thin "fictitious" material with high conductivity, negligible thermal mass and high emissivity. It should be associated with optical properties of 100% transmittance and zero absorptance. The existence of fictitious bounding surfaces will have an impact on the longwave exchange when the blinds are up, but the errors introduced are small, particularly when accurate viewfactors are calculated.

Shading devices

Fixed shading from façade overhangs and fins and from surrounding buildings should be modelled as obstruction blocks (in the section of the Project Manager dealing with geometry specification). Shading from these obstruction blocks is calculated in the shading/insolation analysis.

For movable shading associated with the double façade, the modelling will depend on the location of the shading. It is very important to accurately depict the spatial sense of the roller blind in the double-skin facade cavity. (Venetian blinds are dealt with in a later section.) It may be that the blinds are attached to the internal or external skins, and this can easily be accounted for with a single zone representing the cavity. Typically however, the blinds are located in the centre of the cavity. In that case it is necessary to split the cavity into two

zones, with the vertical division forming the blind surface (Figure 103). Trying to represent mid-blinds by associating them with either the internal or external glazing can result in large errors (Dickson 2004).
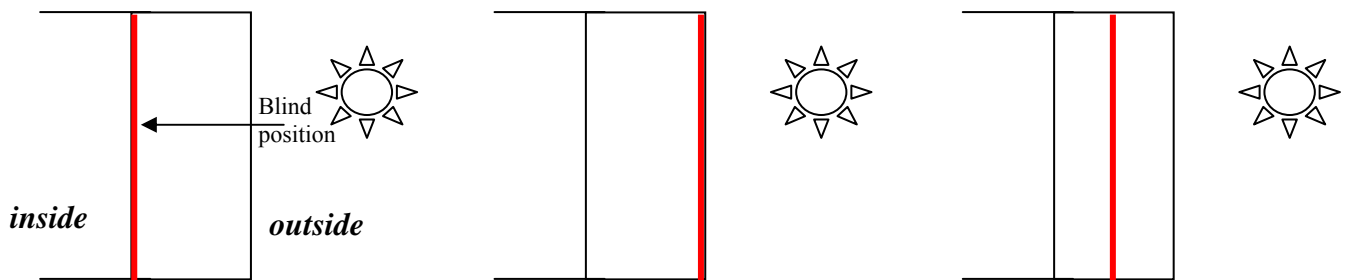
Figure 103: One-storey elevation, showing different modelling methods for blind position within cavity space (placement: inner, outer, midway)

For the case of the blinds associated with either the internal or external glazing, the blinds can be included as part of the glazing construction, with optical properties defined for the normal state of the blinds (see control section below for how to control blind operation).

For the case of the blind in the cavity, the blind should be defined as an independent transparent construction with the appropriate thermophysical and optical properties defined in the database entries.

Frame

If framing losses are likely to be significant, the frames should be included as a separate surface in the model with the effective conductivity and capacity assigned according to the framing material. It is usual to lump the framing together as a single surface associated with each zone to avoid complexity, although where visualization is important the individual framing bars can be included in the model.

Ventilated double façade

Once the basic geometry and constructions of the double façade have been defined, additional modelling resolution can be added through optional selections available in ESP-r's Project Manager: shading and insolation, convection and viewfactor calculations etc. (Figure 104).
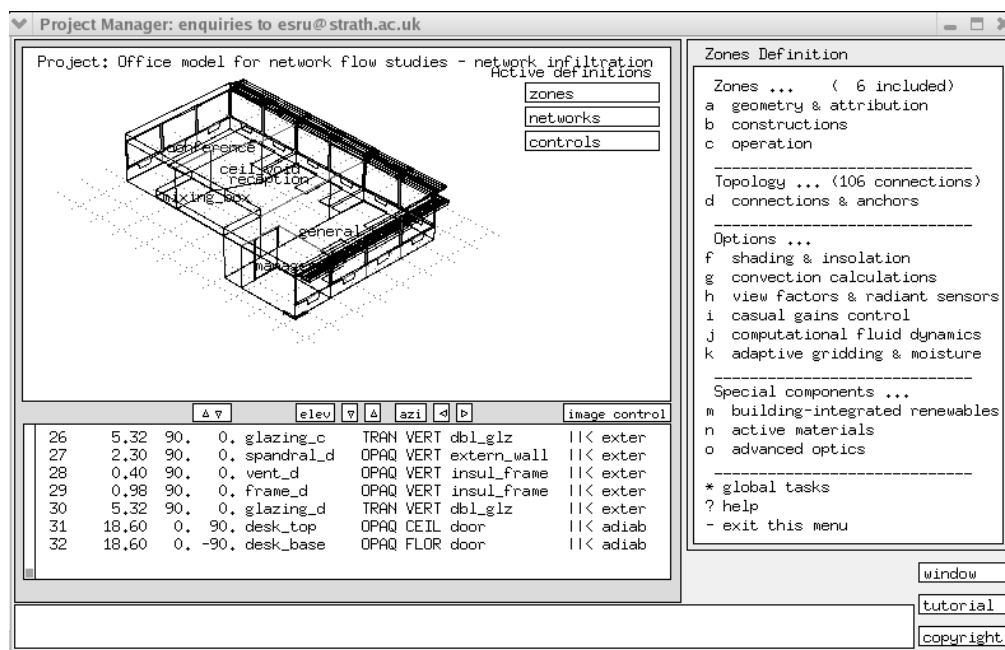
Figure 104 : Screen shot of menu choice for increased resolution

Convective heat transfer in the cavity

In ESP-r, the default internal convective coefficients are based on Alamdari and Hammond. Convective heat transfer is particularly important in double facades and there are several options available. The options relevant to double façade modelling are discussed in Dickson 2004 and Leal et al (2004).
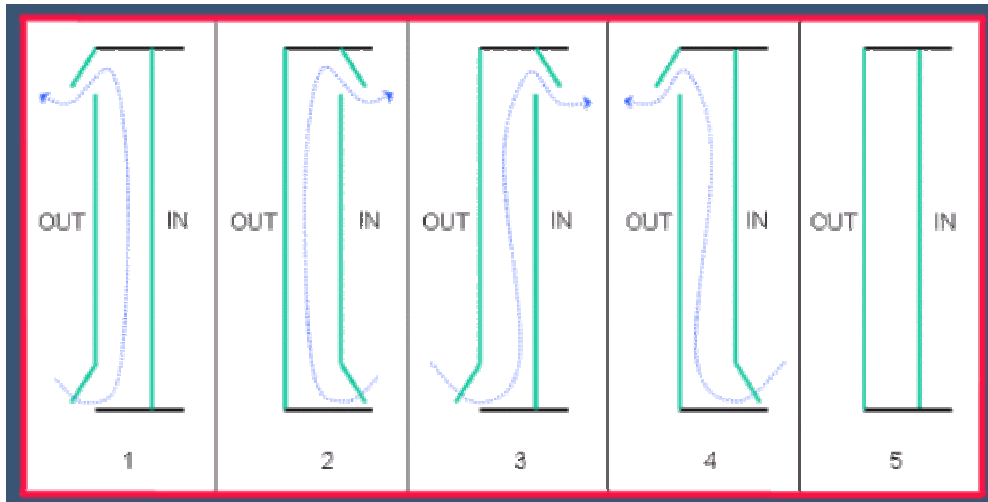
Figure 105: BBRI ventilation classification diagram

(http://www.bbri.be/activefacades/images/schema/ventilation-modes-ADE-001.jpg)

When the cavity is ventilated (as in modes 1 to 4 of Figure 105), the Bar-Cohen & Rohsenow correlation is recommended to predict the convective heat transfer over the range of cavity aspect ratios, although recent work in the Solvent project by Leal (2004) suggests this may not always be appropriate. When the cavity is closed (as in mode 5 of Figure 105), the standard Alamdari and Hammond correlations are recommended as a worst case estimate until suitable correlations are made available. Note that further work in this area is currently underway.

When the cavity is mechanically ventilated, the convection regime will be better represented by a forced convection correlation.

Short wave radiation : transfer through the cavity

By default, all short-wave radiation entering a thermal zone is spread diffusely according to an area/absorptivity weighting. Because solar radiation is a key energy flowpath to consider in double facades, it is strongly recommended that the insolation distribution is calculated via the ESP-r solar tracking facility prior to simulation, in order more accurately calculate the distribution of the direct radiation. (If there is any fixed shading, this should be preceded by a shading analysis.) At present, the solar radiation distribution can only be calculated for solar radiation entering through a glazing from the outside. For onward transmission to other zones, the solar distribution can be assumed to be entirely diffuse (or the direct component can be assigned to prescribed surfaces, such as the floor).

Long wave radiation : transfer through the cavity

As the cavity is treated as a thermal zone, the radiative heat transfer between all surfaces is calculated. By default, the viewfactors are based on an area weighting and this is normally sufficient where surface temperatures do not vary markedly. However, in a cavity, there may be significant surface temperature variations and therefore it is recommended that ESP-r's viewfactor calculations are invoked before simulation.

8.5.3.3   Ventilation in the cavity of the double facade

For cases of forced ventilation when flow rates are constant (possibly scheduled), the simplest way of specifying the airflow is through the operations file by inputting a known air change rate. However, the options for control

are then limited to time scheduling and to range based temperature control. In most cases an airflow network would be more appropriate. This is specified as detailed below for natural ventilation. For mechanical ventilation, the fan can be represented by a constant volume flow component in the airflow network (or, for detailed studies, as a polynomial function of pressure drop against mass flow rate).

In ESP-r, an airflow network consists of a number of internal and external nodes connected by flow components. Airflow modelling is fully integrated with the thermal side to permit the study of the combined effect of air flow and heat transfer. The internal nodes can be linked to building zones: temperatures are then passed from the thermal zone solver to the mass flow network, and flow rates are passed from the mass flow solver to the thermal zones, but more nodes can be added and linked to internal or external surfaces.

Within the Project Manager, the airflow network option can be selected. The user then has to describe the model in terms of network nodes, flow components and connections which link one node to another node by a specified component.

To illustrate the specification of the network, the following simple example is given in Figure 106.
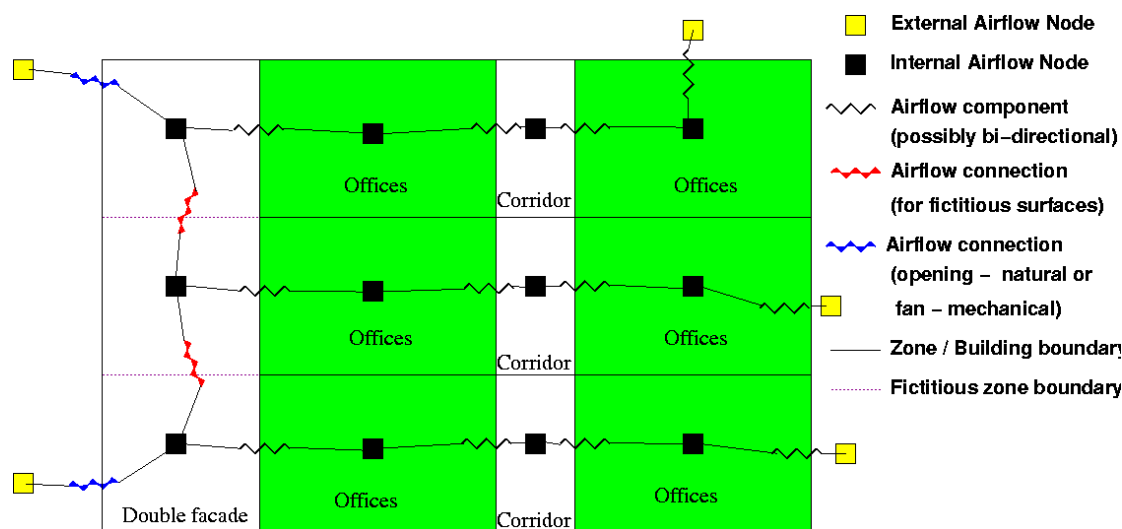
Figure 106: Airflow network for a three storey building with double façade

Wind pressure coefficients
The surface pressure distribution is wind-induced. As usual for airflow network modelling, the boundary conditions are specified in terms of dimensionless pressure coefficients. In the case of ESP-r, the pressure coefficients database contains sets of these coefficients, each set comprising 16 compass values at 22.5º intervals. Positive coefficients represent windward exposure, negative coefficients represent leeward exposure. Available pressure coefficients are from the AIVC database. It is possible to add further sets if available from wind tunnel tests. Pressure coefficients can also be calculated using the relationships developed in the program CPCALC (Grosso 1992), based on wind tunnel tests, which have been integrated into ESP-r. These coefficients require the user to specify building dimensions, plan area density, a position of the opening on the façade, surrounding building heights and other parameters. It must be noted that there are significant uncertainties in defining appropriate pressure coefficients as they are influenced by many factors, notably the local obstructions and terrain.

Wind speed profile
The wind speed in the climate file is usually at a reference height of 10m. To be able to determine wind-induced boundary pressures, it is necessary to map this wind velocity onto the surface as a function of the height and local terrain roughness. The user can select various wind profiles within ESP-r, with the logarithmic wind profile the most widely used. Given the uncertainty, it is advised that a cautious approach be adopted. For example, in the case of an *energy consumption and infiltration problem* it is safer to use a factor giving higher wind speeds; in the case of an *air quality or overheating and ventilation problem*, a factor giving a low estimate of wind speeds should be selected.

Nodes
There are four node types available in ESP-r, but only the following two are of relevance to double façade modelling:

- Internal; unknown pressure.
- Boundary; wind pressure.

Internal nodes corresponding to the thermal zones can be generated automatically. Additional internal nodes and external nodes must then be individually specified. In the case of external nodes, a pointer to the appropriate wind pressure coefficient set is required, as well as surface orientation (this can be obtained automatically when associating the external node with a particular surface).

Node heights are also required for buoyancy calculations. Figure 107 indicates the height data required for nodes and connections.
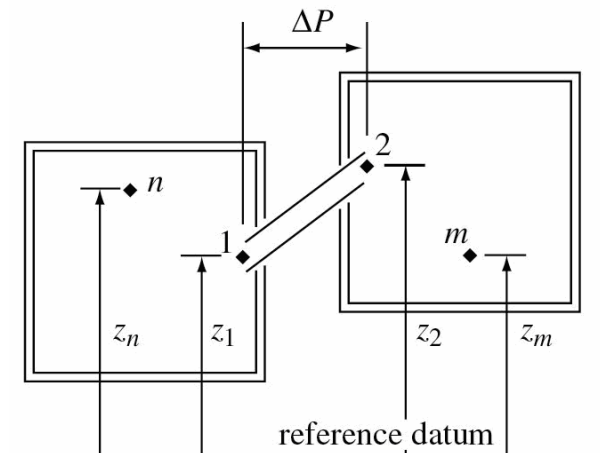
Figure 107: Height data for nodes and connections

Components
Flow components are essentially relationships for the mass flow rate as a function of pressure drop. Available components are representative of doors, ducts, fans, windows, cracks etc.   All of these are for uni-directional flow (at a particular time in the simulation), except for a door component for which bi-directional flow is possible. In the case of double façade modelling the most common components are openings (to represent windows and fictitious boundaries between zones), doors (for large vertical openings), cracks (for infiltration), constant volume flow rate components (to represent fans). On-line help is available regarding the defining parameters required for each component (e.g. for dimensions, discharge coefficients etc).

Connections
The connections are then specified to represent the various flow paths. For each connection, the user is prompted for the positive and negative flow nodes and the component by which these are linked. The assignment of which side of the connection is positive and which negative is arbitrary, but in the results analysis positive flow is taken to be from the node representing the positive side of the connection to the node representing the negative side of the connection. A single component can be used more than once in different flow connections

If the automatic node generation facility is not invoked for generating internal nodes then nodes representing internal zones must be defined manually and linked with each zone. This is done via the 'Link nodes and zones' menu option.

Results analysis
Within ESP-r there are extensive results analysis facilities ranging from graphical and tabular presentation of flow rates, node temperatures, pressures at nodes, connections and components. Numerical results are also available with frequency bins, values above/below some datum etc.

Airflow network for the case of a blind in the cavity
The airflow network can be represented in two ways, which give close agreement. Figure 108 shows a segment of the overall network.

Airflow network 1

Airflow network 2 (simplified)
(2x inlet & outlets at ½ area of originals)
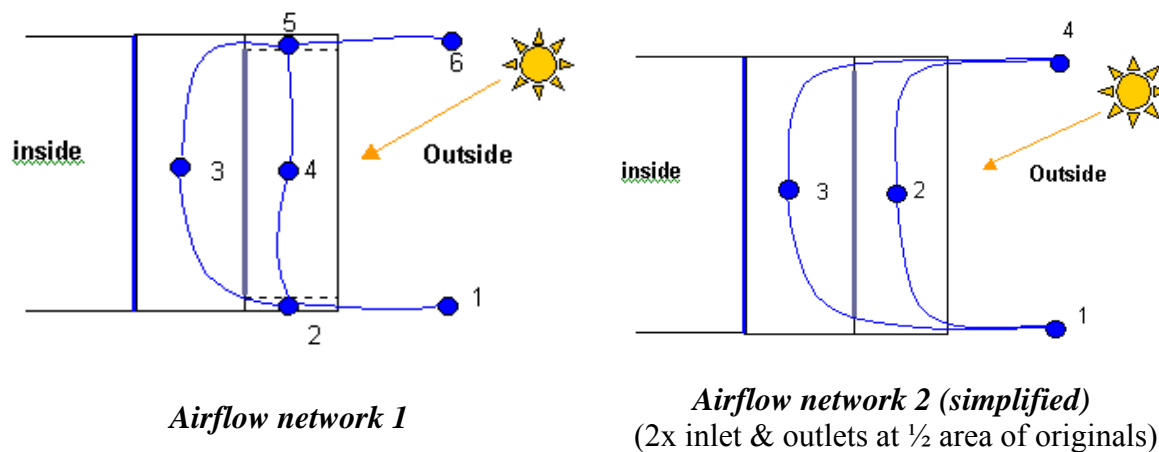
Figure 108: Single storey facade elevations: airflow network representations for cavity ventilation

Although airflow network 1 is a closer representation of reality, the flow of air is prone to rapid fluctuations, linked to its ability to represent back-flow, and the fact that pressure differences can sometimes be very small. The simplified model, however, is free of such fluctuations, although it cannot account for back flow. A study (Dickson 2004) showed that the results of the two options are similar, so the simplified network is generally preferred. Note that it is possible to have connections representing cracks or openings through the blind, if appropriate.

8.5.4 Simulation of the building, HVAC systems, and lighting

The thermal zones representing the double façade can be linked with the other zones representing other parts of the building, and with the building ventilation systems and plant. It is usual, at least in initial simulations, to represent the plant through an idealised control system which calculates the heating and cooling requirements according to defined sensors (type and location) and actuators (type and location) through a number of control laws which specify maximum and minimum plant sizes, control setpoint temperatures, control type (on/off, proportional etc). For detailed studies of the plant systems, it is possible to define a plant network comprising component models of heating coils, cooling coils, fans, ducts, humidifiers, heat exchangers etc.

The airflow network used in the double façade model can be connected through other connections to study, for example, the flow of air through adjacent offices, atria etc, taking into account the integrated wind and buoyancy-induced airflow.

8.5.5 Simulation of control systems and control strategies

The operation of the double façade may require several control options. The following relevant control options are possible in ESP-r.

- Control of ventilation: e.g. opening/closing vents according to zone temperature

- Control of blinds: e.g. changing optical and/or thermophysical properties according to solar radiation levels

- Control of convection regime: e.g changing connection correlations according to whether fans are on or off

- Control of heating/cooling and plant systems: e.g. switching heaters on/off according to setpoint temperatures

- Control of lighting: e.g. switching artificial lighting according to daylight levels at defined locations.

In the following, a brief description of the options for each of these controls is given, followed by an example. Control of the building zones, for the airflow network and plant networks is selected from the Model Definition menu of the Project Manager; other, more specialised, control options are specified as described below.

Control of airflow network
Within an ESP-r flow network, control can be imposed either on individual connections or on a component (with all the connections using this component). Several control loops can be specified, each one for a named connection or component. The user can specify a week as weekday/ Saturday/ Sunday to specify different types of control on each of these day types; alternatively the specification can be one day type for all days of the week. For each control loop, the user must specify details of the sensor, the actuator and the control law. The following list shows the current sensor options. In all cases, the actuated property is the flow rate.

- temperature/temperature difference
- enthalpy
- additional plant output
- relative humidity
- pressure/pressure difference
- mass flow rate
- wind speed/direction
- diffuse horizontal solar radiation
- direct normal solar radiation
- ambient relative humidity

The user must then specify the control laws that pertain to different periods of the day. The options for network airflow control are:
- On/off law: simply operates to switch on/off the connection/component based on the sensed property.
- Proportional with hysteresis: this is a linear controller - it requires a signal lower and upper limit with relative valve positions here along with required stimulus to overcome hysteresis.
- Range based controller: the flow or the area of flow can be controlled to be a fraction of the defined value with four ranges depending upon the sensed property.
- Multi-sensor on/off; this works similarly to the on/off control law but with more than one sensor.

Control of heating/cooling plant
Only a brief description is given here, because these controls are not particular relevant to the double façade operation. Sensors and actuators can be placed at the airpoint or at a surface, or be responsive to a weighted surface/air temperature, or within a construction (for underfloor heating, for example). A number of control laws can be specified for different times of the year and day. Examples are idealised control, PID control, and fixed heating/cooling.

Control of blinds
It is possible to control blinds by specifying a sensor type, an associated setpoint and then a pointer to a replacement set of optical properties in the optical database. Currently it is only possible to switch between two states. Options for sensors are the zonal temperature, the external temperature and the incident solar radiation. This control option is available in the construction definition menu of the Project Manager.

A new feature allows the user to change both thermophysical (e.g. conductivity, emissivity) and optical properties concurrently (as might be required for an insulated blind, for example), based on some sensed condition. In this case replacement constructions (with associated transparent properties can be selected. A limitation is that the constructions and the replacement constructions must have the same number of layers. At present, this feature is not available through the Project Manager – until the user interface is updated to allow this, details of how to effect this control can be obtained from ESRU.

Control of convective correlations
Switching between two convection regimes is currently possible, based on the binary condition of the operation of heating/cooling. The BBRI classification of double facades found that most frequently either natural or mechanical ventilation, but not both, are employed in the double-skin facade. This means that convection will typically only require to switch between natural/closed or mechanical/closed regimes. In natural ventilation in multi-storey type facades, when wind effects become prominent, a forced flow condition similar to that of mechanical ventilation will occur. The specification of convection control is included in the section of the Project Manager dealing with convection correlations (see previous section).

Control of lighting

Artificial light switching is specified in the casual gain control option. Lighting gains can be controlled as a function of the illuminance level according to a range of light switching models.

Control Example 1: **Airflow window**

The desired system control of the three different operational regimes:

- facade closed
- outer facade open (ventilated cavity)
- inner & outer façade open (full-ventilation)

is shown in the Figure 109.
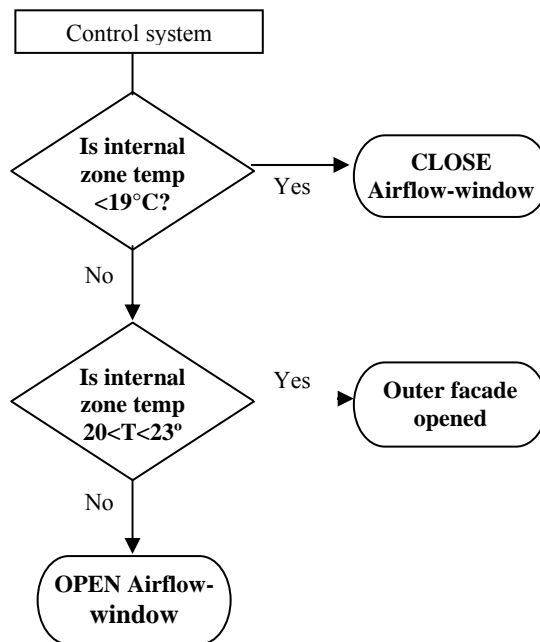
Figure 109: Airflow-window desired control characteristics

To achieve this requires control of both air flow and convection, as shown in Figure 110.
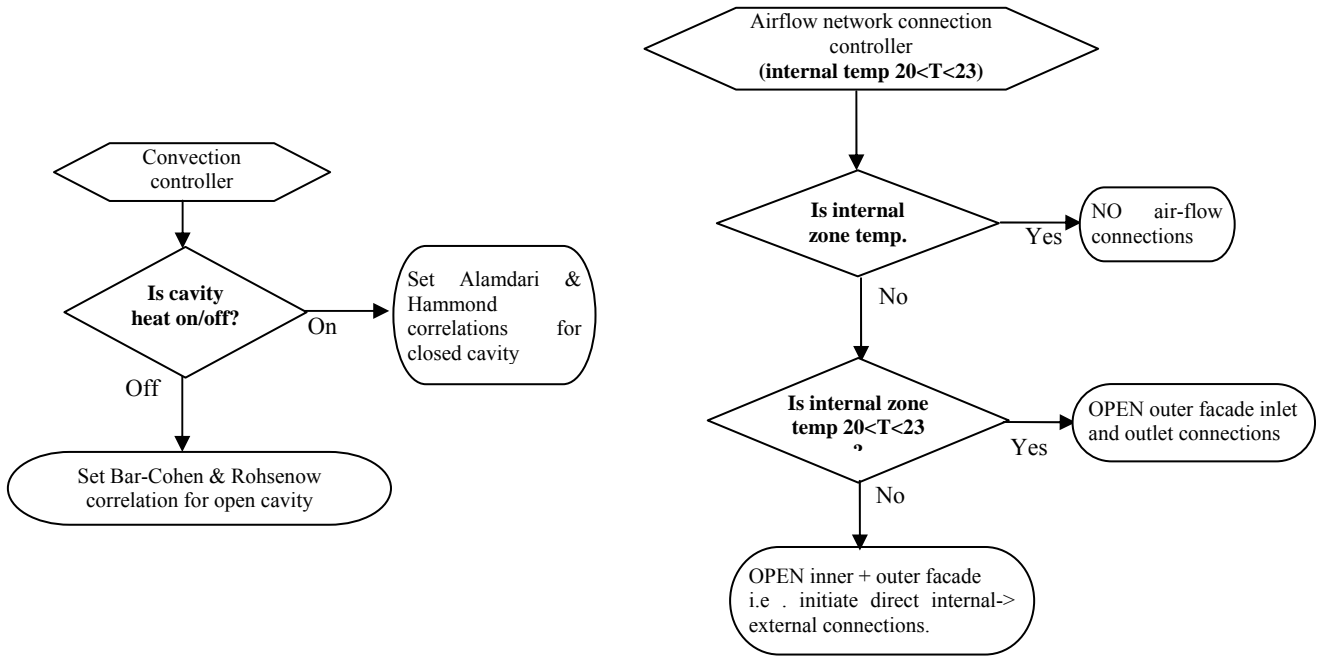
Figure 110: Airflow-window convection control and airflow control diagrams

Note: For the adaptive convection control to work, it is also currently necessary to set up a heating control for the cavity with a negligible dummy heat injection of, say, 0.1W into the cavity. This is because convection control is presently based upon the sensed condition of whether or not zone heating/cooling is in operation.

As an example output for this control, the Figure 111 shows the temperatures for a spring day. As the external climate warms, the complete opening of the window becomes apparent – control of the internal zone to 23°C setpoint. The outer facade opens slightly before this. The internal zone temperature is rapidly fluctuating because of the strict airflow setpoint. In reality, users would adjust windows to a suitable position to maintain steady conditions. The external ventilation in this case (between 4-10 ac/h) means that no cooling energy is required.
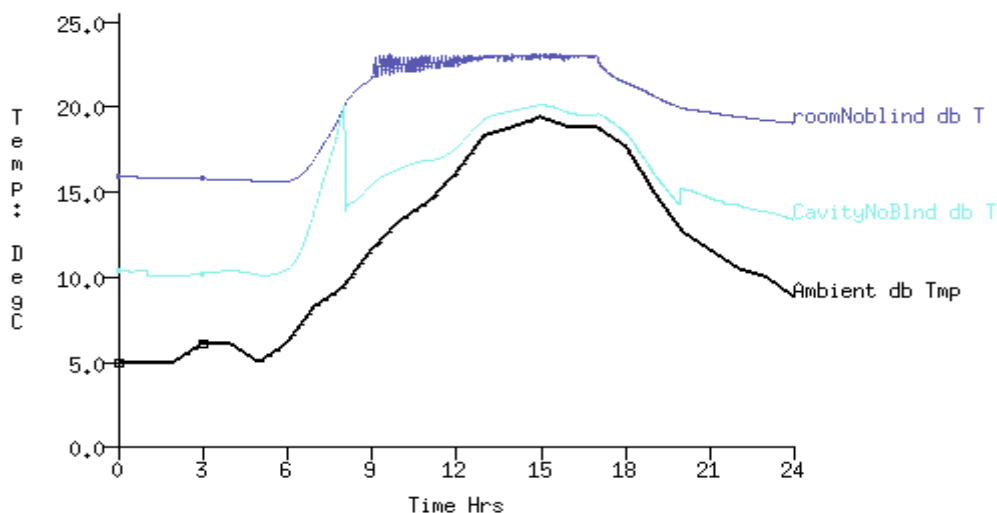
Figure 111: Temperatures in airflow-window model

Control Example 2: Naturally ventilated facade with shading

In this example, the cavity is ventilated during high solar and cavity temperature conditions. In this example, the fictitious division between the outer and inner façade thermal zones is replaced by a fabric roller blind of 0.2mm thickness and visible transmittance of 0.1. The roller blind is activated when a direct normal solar radiation setpoint of 400W/m^2 is exceeded.

- Cavity ventilation is initiated when cavity air temperature is greater than 15ºC.
- Convection control swap from Alamdari & Hammond correlations to Bar-cohen & Rohsenow correlations when cavity is opened.
- Internal lighting control (12W/m^2) – ideal dimming, set-point 500lux, (daylight sensor at 5m room depth).
- The internal zone is assigned 1000W of cooling capacity, set to cool the zone to 20ºC.

Figure 112 shows the effect of the shading control.

NO shading in cavity	*Blind control*
Solar radiation absorbed in internal room	**Solar radiation absorbed in internal room**
% of internal lighting ON	**% of internal lighting ON**
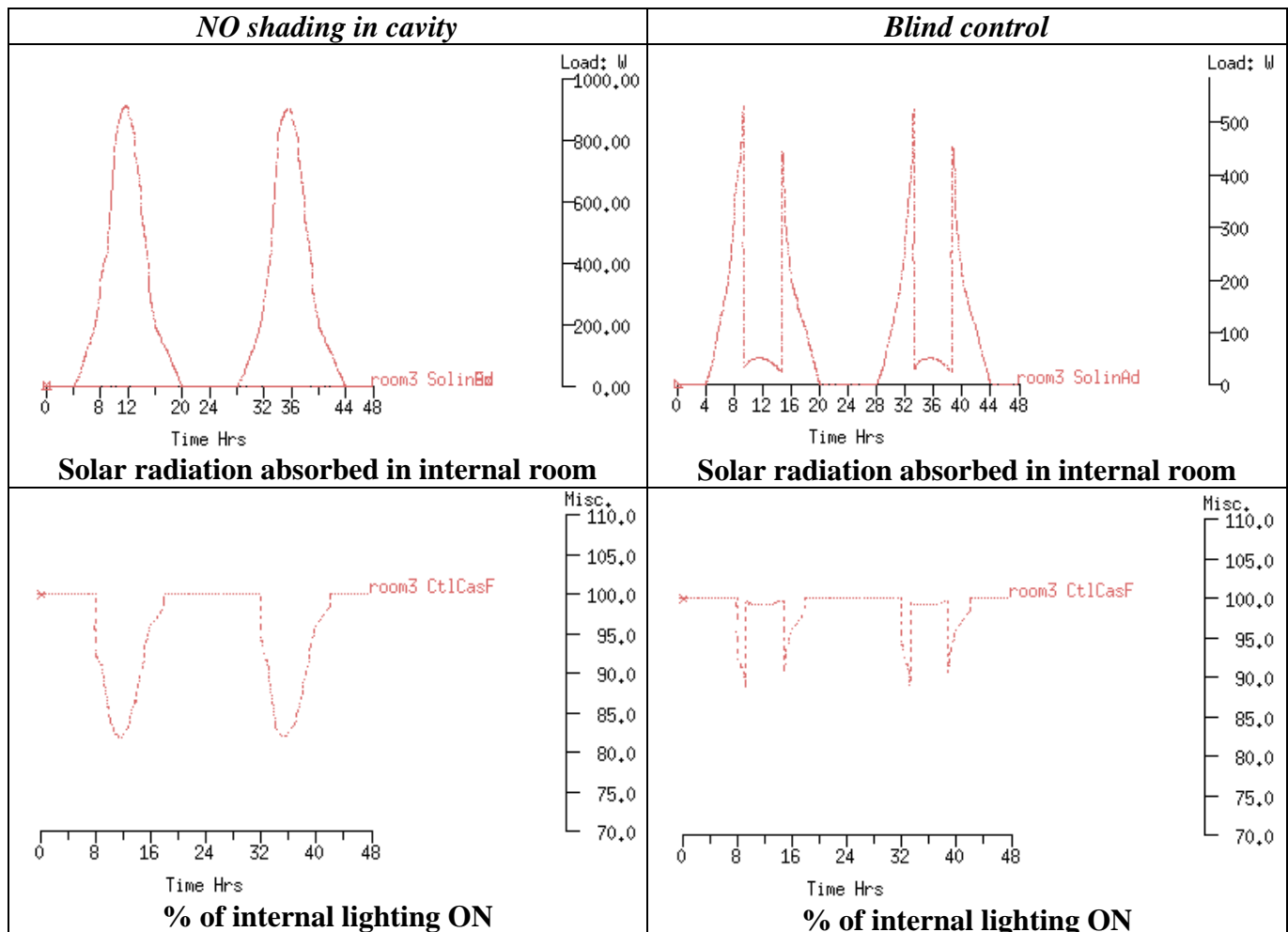
Figure 112 : Shading control

It is clear that the blind switching considerably reduces the solar absorbed in the room in line with the low blind transmissivity. On the other hand, the internal lighting load is increased when the blind is drawn. It is observed that the blind is open at the start and end of the lighting day when the solar radiation is low. As well as blind switching control based on direct solar radiation, it can also be controlled with an external air temperature or an internal temperature sensor.

The blind switching also has a significant effect on internal cavity convection, because significant quantities of solar radiation are being absorbed by the blind and consequently released to the cavity air. In Figure 113, it is clear that when the blind is down, surface convection is 2 to 3 times higher than when it is up. Also, the overall

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effect on internal cooling requirements is significant, with the cavity utilising shading control requiring no room cooling in this case.

NO shading in cavity	*Blind control*
Total surface convection in outer cavity division	**Total surface convection in outer cavity division**
Internal room cooling load	**Internal room cooling load**
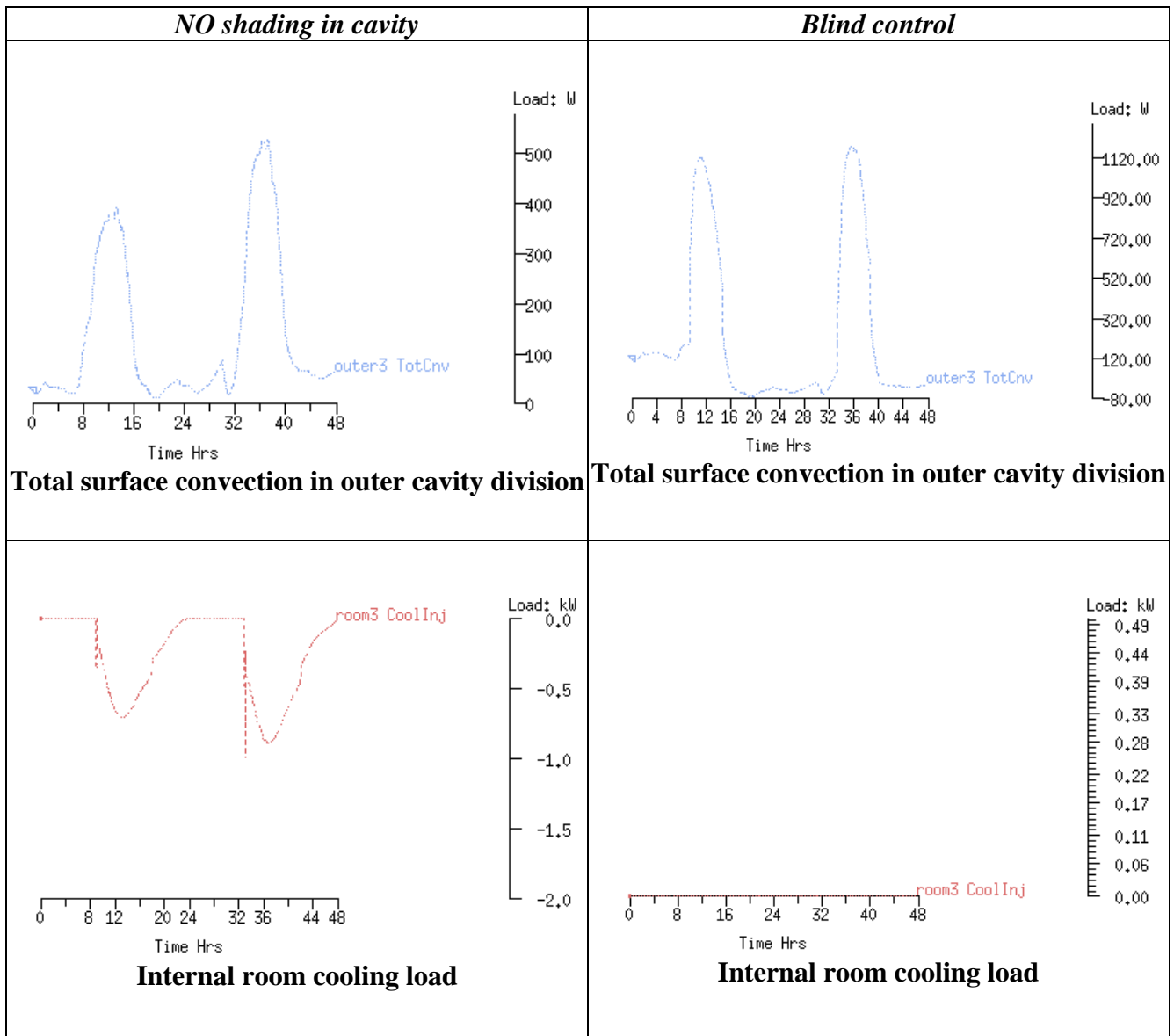
Figure 113: Impact of shading on surface convection and cooling load

8.5.6 Other modelling considerations

Link with CFD

One or more zones in the model can be designated as a CFD domain and linked thermally with the mass flow network to enable a combined building/airflow-network/CFD simulation.

As an example of its use, an airflow window was modelled (Dickson 2004) with all openings closed. Details of CFD model are:

- CFD domain included in cavity only – conflated with building solver with two-way conflation (see Beausoleil-Morrison 2000 for details)
- K-ε turbulence model solver employed with Yuan wall functions when buoyancy governed flow is apparent.
- Rectangular gridding of 30 cells x 30 cells x 5cells (width x height x depth)

- Velocity & temperature solved
- Boussinesq approximation for buoyancy (Reference temperature of 20°C)
- 15th March simulation - 5 time steps per hour and 1 start-up day owing to the long CFD simulation time at each time step

A comparison of results using the Alamdari and Hammond correlations with the CFD results is shown in Table 15:

Model convection regime	Maximum total convection in cavity (W)	Minimum total convection in cavity (W)	Heating in internal perimeter zone (kWh)	Number of heating hours required
Alamdari & Hammond correlations (ESP-r Defaults)	54.01	17.00	2.07	15
CFD results (k-e turbulence model with Yuan wall functions)	53.29	15.91	2.17	15.2

Table 15: Comparison of convection in closed cavity using Alamdari and Hammond correlations and using CFD (no blind)

It is apparent that the maximum convection values are very similar (within 2% of each other). However the degree of correspondence varies over the day, as the minimum convection values illustrate. The overall effect this variation has is around a 5% difference in the energy required to maintain the zone at 20°C. CFD simulations for deeper cavities were also investigated. Differences in the convection flowpath in the order of 5% to 15% were found over a range of cavity aspect ratios.

Figure 114 shows the flow fields predicted by the CFD simulations in the different cavities.
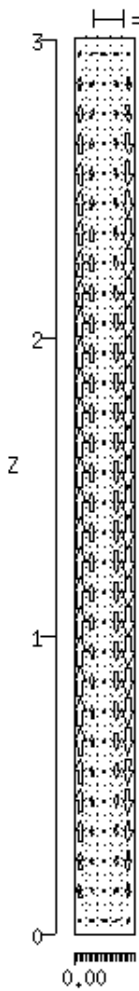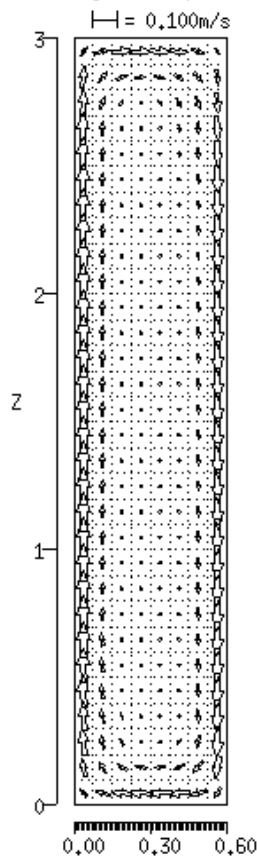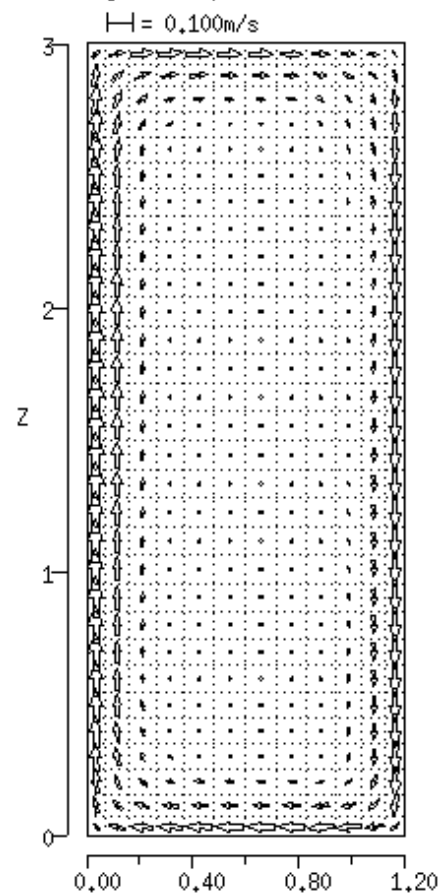
0.2m deep cavity
(aspect ratio = 15)   **0.6m deep cavity**
                                 (aspect ratio = 5)   **1.2m deep cavity**
                                                                 (aspect ratio = 2.5)

Figure 114: CFD predicted flow field (velocity vectors) for different cavity aspect ratios

Although the differences between empirically derived and CFD-predicted convective fluxes were relatively small in this case, they may be larger in other configurations. The use of CFD does have benefits in indicating the nature of the flow in the cavity. The drawback is the simulation time – in the order of 14 hours for a one-day simulation for the larger cavity width, compared to about 2 minutes using an airflow network.

Blind properties

It is important that correct emissivity and absorptivity is assigned to the blind as these properties significantly affect the performance of the double façade. There is a large variation of cooling load for the adjacent office depending on the solar absorptivity of the opaque roller blind material as shown in the results in Figure 115.

Figure 115: Variation of internal cooling load with solar absorptivity of the roller blind material

	abs = 0.35	abs = 0.6 (base case)	abs = 0.85
Absolute cooling Energy (kWh)	2.76	4.34	5.59
Mass flow (kg/s)	0.21	0.22	0.23
Max.Cavity Temp (°C)	34.93	36.75	38.18

Additional absorbed solar manifests itself in higher surface and cavity temperatures via convection and longwave radiation flowpaths. Consequently, cavity flow rates increase (5%) due to greater buoyancy forces helping dissipate heat. Even so, the system that directly reflects more solar provides the greatest protection against overheating.
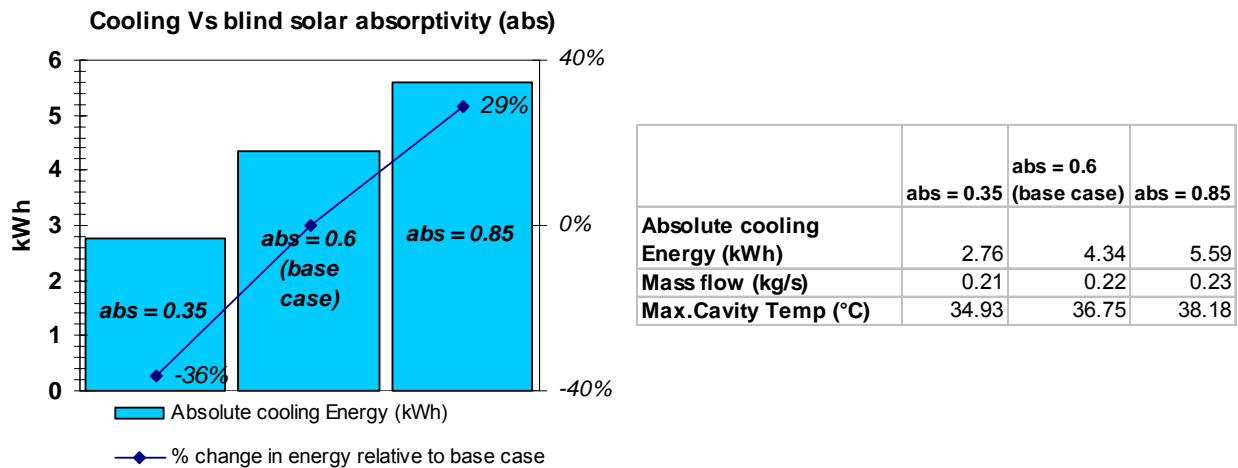
The emissivity of the roller blind material has similarly significant effects in terms of the internal cooling energy required. By holding the blind material's absorptivity at 0.6, the effect of the variation in surface emissivity was determined – the results are highlighted in the Table 16.

	Internal Cooling Energy (kWh)
ε_i =0.9 / ε_o=0.9	4.34
ε_i =0.6 / ε_o=0.6	3.68
ε_i =0.3 / ε_o=0.3	2.39
ε_i =0.9 / ε_o=0.6	4.65
ε_i =0.9 / ε_o=0.3	5.11
ε_i =0.6 / ε_o=0.9	3.39
ε_i =0.3 / ε_o=0.9	1.81

ε_i= internal surface emissivity
ε_o= internal surface emissivity

Table 16: The effect of blind surface emissivity on internal cooling energy

It is clear that a reduction in surface emissivity at the inside facing surface of the blind most positively effects the cooling requirements (over a 50% reduction). This highlights the significance of the longwave flowpath from the warm blind to the inside. Reducing the emissivity of the outside facing surface on the other hand increases the cooling requirements, because longwave radiation is less readily rejected to the cooler outside. This does not have such a significant effect, however.

Discharge coefficients
Discharge coefficients are an important factor in air-flow openings, describing pressure loss characteristics. However, little guidance can be found regarding their selection, particularly for natural ventilation studies.

A study of a multi-storey double façade was undertaken, with the inlet and outlet discharge coefficients varied about the standard value of 0.65, from 0.5 to 0.8. Results of the study show that mass flow through the cavity is significantly affected by a change in discharge co-efficient.
Figure 116 shows the variation in mass flow and cooling energy requirement for the adjacent offices for different discharge coefficients. It indicates that a lower coefficient will result in lower mass flows (by over 15%) because

of the increased flow resistance, and vice-versa. However the cooling energy required by the internal zones is much less sensitive to the mass flow.
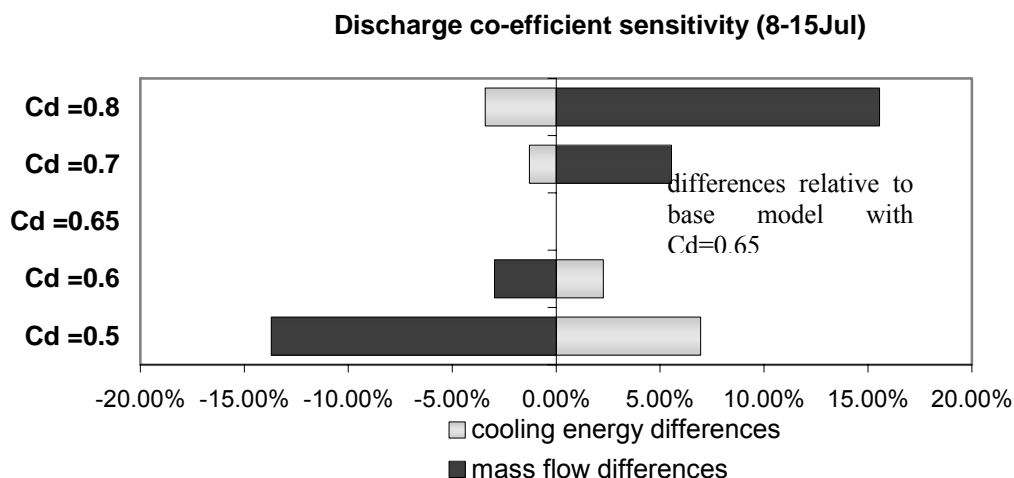
Discharge co-efficient sensitivity (8-15Jul)

Figure 116: Discharge coefficient sensitivity (cooling & mass flow differences)

Modelling of Venetian Blinds

Modelling Venetian blinds is complex. A detailed study was carried out in Dickson (2004) modelling the blinds in a number of ways as shown in the Figure 117.
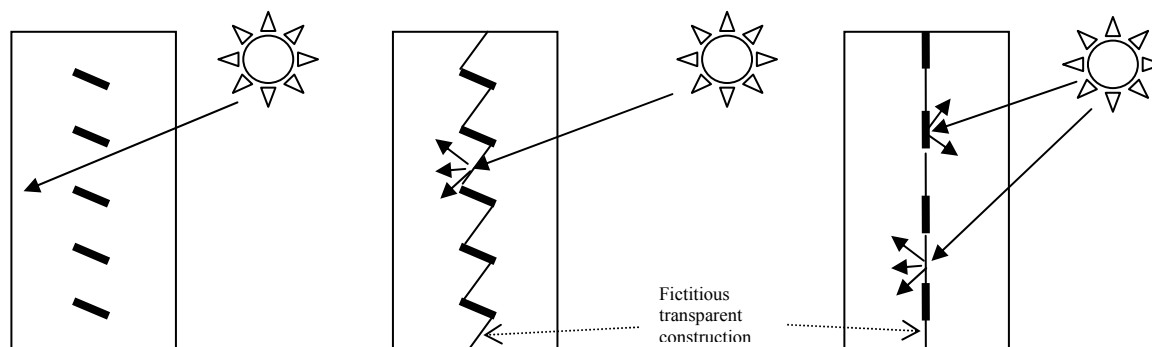

Figure 117: Actual cavity geometry using (1) floating surfaces, (2) saw-tooth type model, (3) simplified model

The first option, with the cavity modelled as a single zone with additional "floating" surfaces representing the blinds has the disadvantage that the whole zone would be represented by a single air temperature. The second option divides the cavity into two zones, separated by a series of sawtooth surfaces representing the blind and connecting surfaces as a fictitious boundary. The difficulty here is that there are many possible orientations, slat widths etc, so an automatic geometry builder would need to be developed to model this method routinely. Note that it would be possible to model airflow through the slats with this model, with some control of opening area according to slat orientation (again this would need some code development).

To test current capabilities a model was formed as shown in Figure 118. In this model, Venetian blind slats are 7cm wide and angled at 45° with a spacing of 14cm between the slats axis of pivot, which ensures the blocking of direct radiation at a solar altitude above 45°. Studies showed that the shortwave and longwave radiation transfers were approximated in a reasonable manner in this model. Although sensible results were achieved, the time taken to form the model is prohibitive at present. It may be possible to model the blinds in a simpler way by combining the individual slats into a small number of slats in a coarser sawtooth shape – this has not yet been studied.

A simpler representation may be to model the Venetian blinds as a flat roller blind with alternate solid and fictitious surfaces. However, the spacing would also need to be adjusted according to the slat angle.
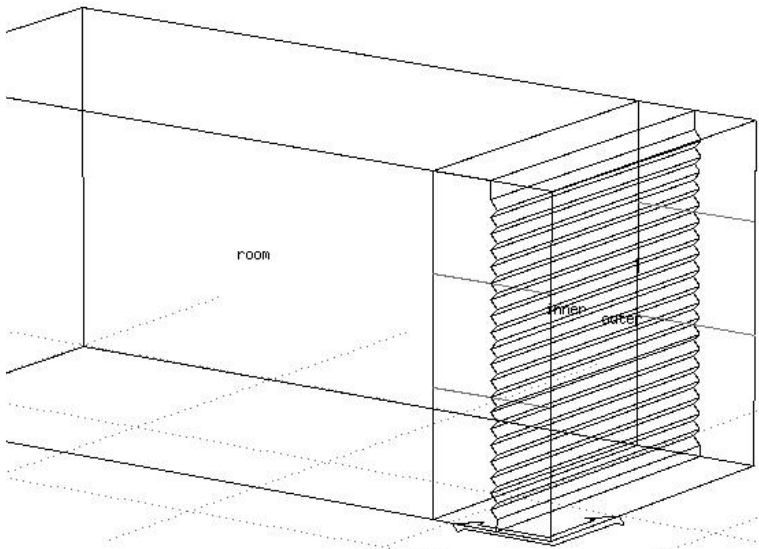
(1) Saw-tooth model consisting of inner/outer cavities & internal zone
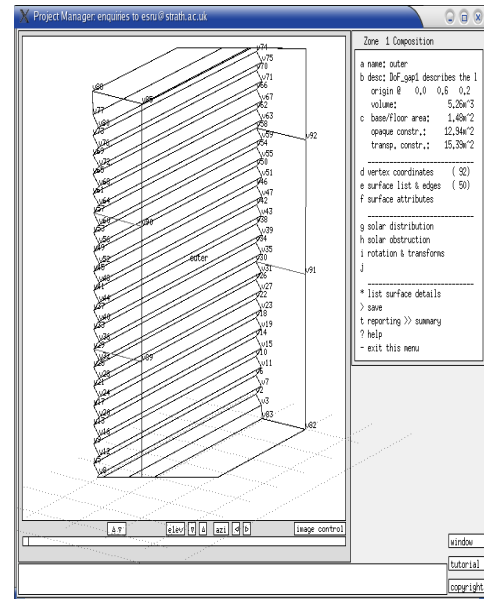
(2) Outer zone highlighting saw-tooth surface

Figure 118: Venetian blind saw-tooth model

Another factor is that the correct optical transmission, reflection and absorption characteristics of Venetian blinds requires bi-directional data so that these parameters can be calculated as a function of both solar altitude and solar azimuth (rather than incidence angle as appropriate for homogeneous glazings/blind systems). ESP-r has the capability of using bi-directional data in this way, but the practical problem at present is the lack of bi-directional data.

8.5.7   Examples of simulations

There are some given in the above sections to demonstrate some aspects of double façade modelling, such as shading and airflow control.

The paper by Hensen et al (2002) shows how ESP-r was used to model a double façade on a multi-storey office building in Prague, Czech Republic. The main features of the model are shown in Figure 99. The objective of the study was to determine the environmental conditions in the double façade and the cooling loads in adjacent perimeter offices under extreme summer conditions. The results showed that the double façade contributed a cooling load reduction varying between 7% and 15%, depending on the storey (due to the increasing temperature in the façade over the height of the building). Figure 119 shows some of the results obtained. Upper lines represent outlet temperatures. Middle lines represent inlet temperatures (ambient). Lower lines represent the temperature rise in the façade. The left graph corresponds to the final design of the double-skin façade. The right graph represents the situation where the outlet damper was closed due to malfunctioning or control error. The temperature scales are approximately equally spaced in the two graphs.
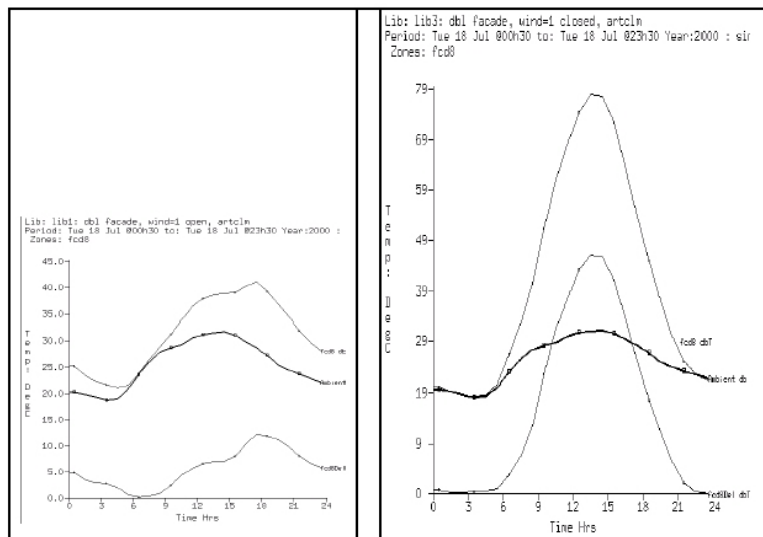
Figure 119: Predicted air temperatures in the double-skin façade during one of the warmest summer days in Prague.

Another example has been provided by Müller-BBM where ESP-r was used to predict zonal and double façade temperatures for the Museuminsel Berlin – Neues Eingangsgebäude. The predicted temperatures at several heights within the façade were used as boundary conditions for CFD simulations of the inner museum room, where thermal stratification and distribution of humidity was important. Figure 120 shows some of the result of this study.

Figure 120: ESP-r and CFD simulations of a museum building with a double façade.

8.5.8 References

Beausoleil-Morrison I, The Adaptive Coupling of Heat and Air Flow Modelling Within Dynamic Whole-Building Simulation', PhD Thesis, University of Strathclyde, 2000.

Clarke J A, Energy Simulation in Building Design, 2nd edition, Butterworth-Heinemann, Oxford, 2002.

Hensen J, Bartak M and Drkal F, Modelling and Simulation of a Double Skin Façade System, ASHRAE Transactions, vol. 108:2, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA, 2002.

Dickson A, Modelling Double-skin Facades, MSc thesis, ESRU, University of Strathclyde, 2004.

Grosso M, Wind Pressure Distribution Around Buildings: a Parametrical Model, Energy and Buildings, 18, pp101-131, 1992.

Janak M and Macdonald I, Current State-Of-The-Art of Integrated Thermal and Lighting Simulation and Future Issues, Building Simulation '99, Kyoto, Japan, 1999.

Leal V, Sandberg M, Maldonado E and Erell E, An analytical model for the airflow in a ventilated window with known surface temperatures, Roomvent, Coimbra, Portugal, 2004.

6: TAS SOFTWARE

8.6   TAS SOFTWARE

8.6.1   General software information.

TAS is a suite of software products, which simulate the dynamic thermal performance of buildings and their systems.

- The main module is **Tas Building Designer** (A-Tas), which performs dynamic building simulation with integrated natural and forced airflow. It has 3D graphics based geometry input that includes a CAD link.

- **Tas Systems** is a HVAC systems/controls simulator, which may be directly coupled with the building simulator. It performs automatic airflow and plant sizing and total energy demand.

- The third module, **Tas Ambiens**, is a robust and simple to use 2D CFD package which produces a cross section of micro climate variation in a space.

A-Tas is a software tool which simulates the thermal performance of buildings. The main applications of the program are in assessment of environmental performance, natural ventilation analysis, prediction of energy consumption, plant sizing, analysis of energy conservation options and energy targeting.

The fundamental approach adopted by Tas is dynamic simulation. This technique traces the thermal state of the building through a series of hourly snapshots, providing the user with a detailed picture of the way the building will perform, not only under extreme design conditions, but throughout a typical year. This approach allows the influences of the numerous thermal processes occurring in the building, their timing, location and interaction, to be properly accounted for.

These processes are illustrated schematically in this figure, which shows the movement of heat in various forms as it is conveyed into, out of and around the building by a variety of heat transfer mechanisms.
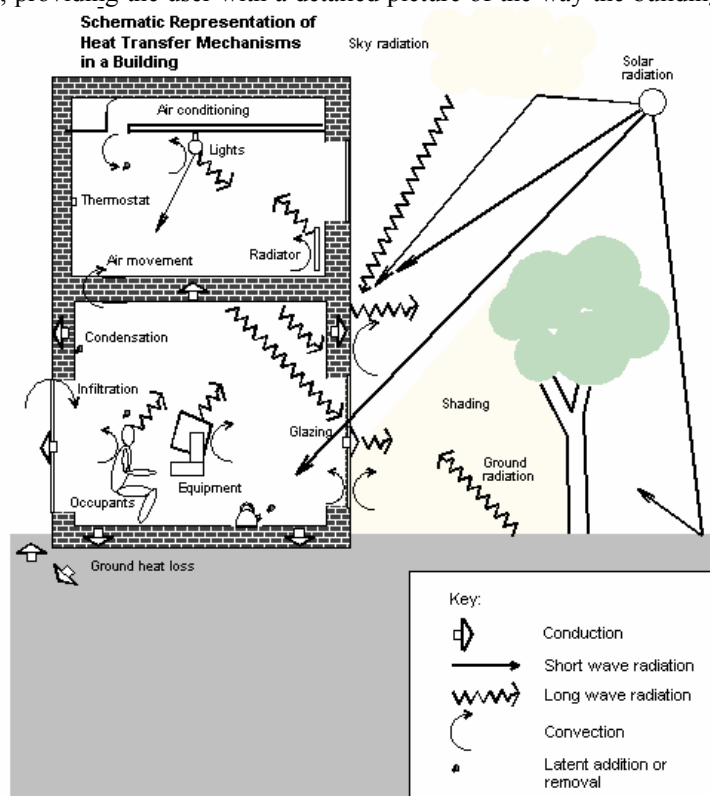
Conduction in the fabric of the building is treated dynamically using a method derived from the ASHRAE *response factor* technique.   This efficient computational procedure calculates conductive heat flows at the surfaces of walls and other building elements as functions of the temperature histories at those surfaces. Constructions of up to 12 layers may be treated, where each layer may be composed of an opaque material (e.g.. brick), a transparent material (e.g.. glass) or a gas (e.g.. air). Databases of materials and constructions are available.

Convection at building surfaces is treated using a combination of empirical and theoretical relationships relating convective heat flow to temperature difference, surface orientation, and, in the case of external convection, wind speed.

Long-wave radiation exchange is modelled using the Stefan-Boltzmann law, using surface emissivities from the materials database.   Long-wave radiation from the sky and the ground is treated using empirical relationships.

Solar radiation absorbed, reflected and transmitted by each element of the building is computed from solar data on the weather file. The calculation entails resolving the radiation into direct and diffuse components and calculating the incident fluxes using knowledge of sun position and empirical models of sky radiation. Absorption, reflection and transmission are then computed from the thermophysical properties of the building elements. External shading and the tracking of sun patches around room surfaces may be included at the user's option. Solar radiation entering a zone through transparent building components falls on internal surfaces, where it may be absorbed, reflected or transmitted depending on the surfaces' properties. Distribution of reflected and transmitted solar radiation continues until all the radiation has been accounted for.

Internal conditions, which include room gains from lights, equipment and occupants as well as infiltration rates and plant operation specifications, are grouped together in profiles which are applied to the various zones of the building. Internal Conditions profiles may be stored in a database for later retrieval. Gains are modelled by resolving them into radiant and convective portions. The convective portion is injected into the zone air, whilst the radiant gains are distributed amongst the zone's surfaces.

Infiltration, ventilation and air movement between the various zones of the building causes a transfer of heat between the appropriate air masses which is represented by terms involving the mass flow, the temperature difference and the heat capacity of air. TAs offers the capability to calculate natural ventilation air flows arising from wind and stack pressures.

Heating and cooling plant is represented by plant capacities, setpoints and control bands. Like gains, plant inputs may have both radiant and convective portions.

TAS solves the sensible heat balance for a zone by setting up equations representing the individual energy balances for the air and each of the surrounding surfaces. These equations are then combined with further equations representing the energy balances at the external surfaces, and the whole equation set is solved simultaneously to generate air temperatures, surface temperatures and room loads. This procedure is repeated for each hour of the simulation.

A latent balance is also performed for each zone which takes account of latent gains, moisture transfer by air movement and the operation of humidification and dehumidification plant.

8.6.2   Building up a model

In this paragraph, we will present the building up of a model, step by step.

8.6.2.1   Step 1: choice of the weather data

When creating a new model the first thing you need to do is to select the weather data for the location. TAS has a climate database. This one stores files containing hourly weather data. The weather files supplied with Tas cover different regions of the world and each represents a typical year's weather for the region in question. But the user can create a specific weather file.

8.6.2.2   Step 2: generation of the 3D model

After the introduction of general information and building floor to floor heights, the user can draw floor plans. When all the walls are placed, windows and doors are defined and easily placed in the walls. Various types of walls are automatically defined but new building elements can be defined.

The next floors are drawn on the base of the previous floor.
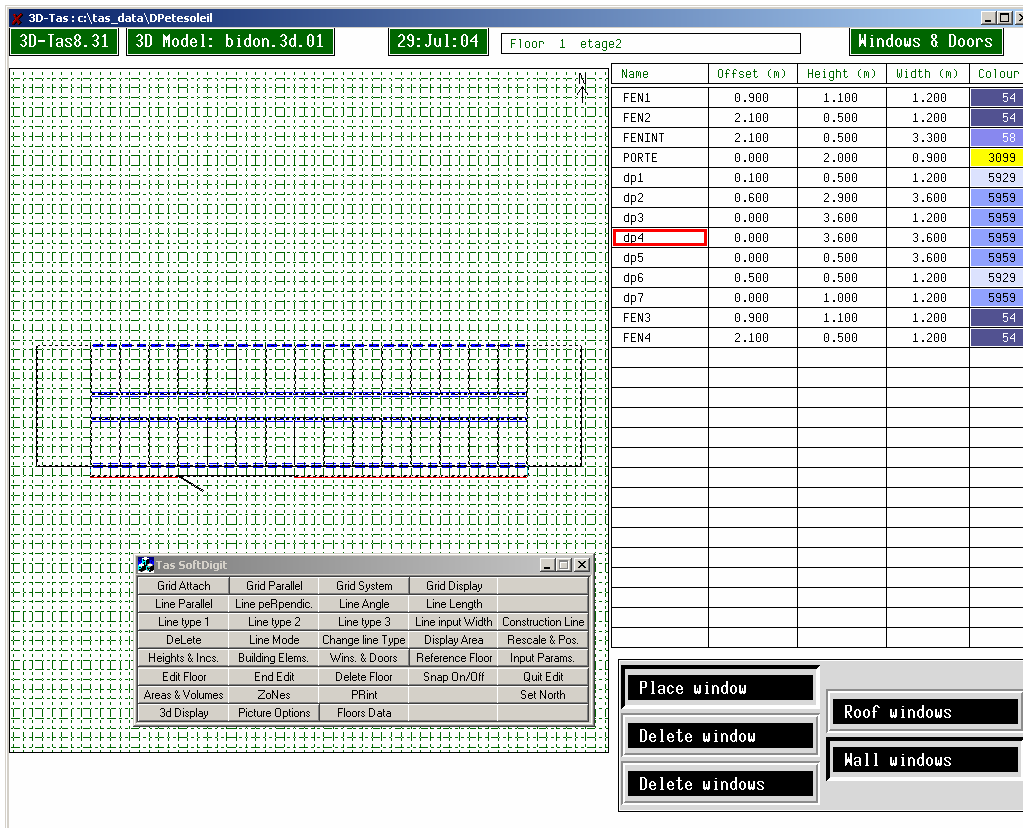
8.6.2.3   Step 3: viewing the model in 3D

You can control the model with perspective, elevations….
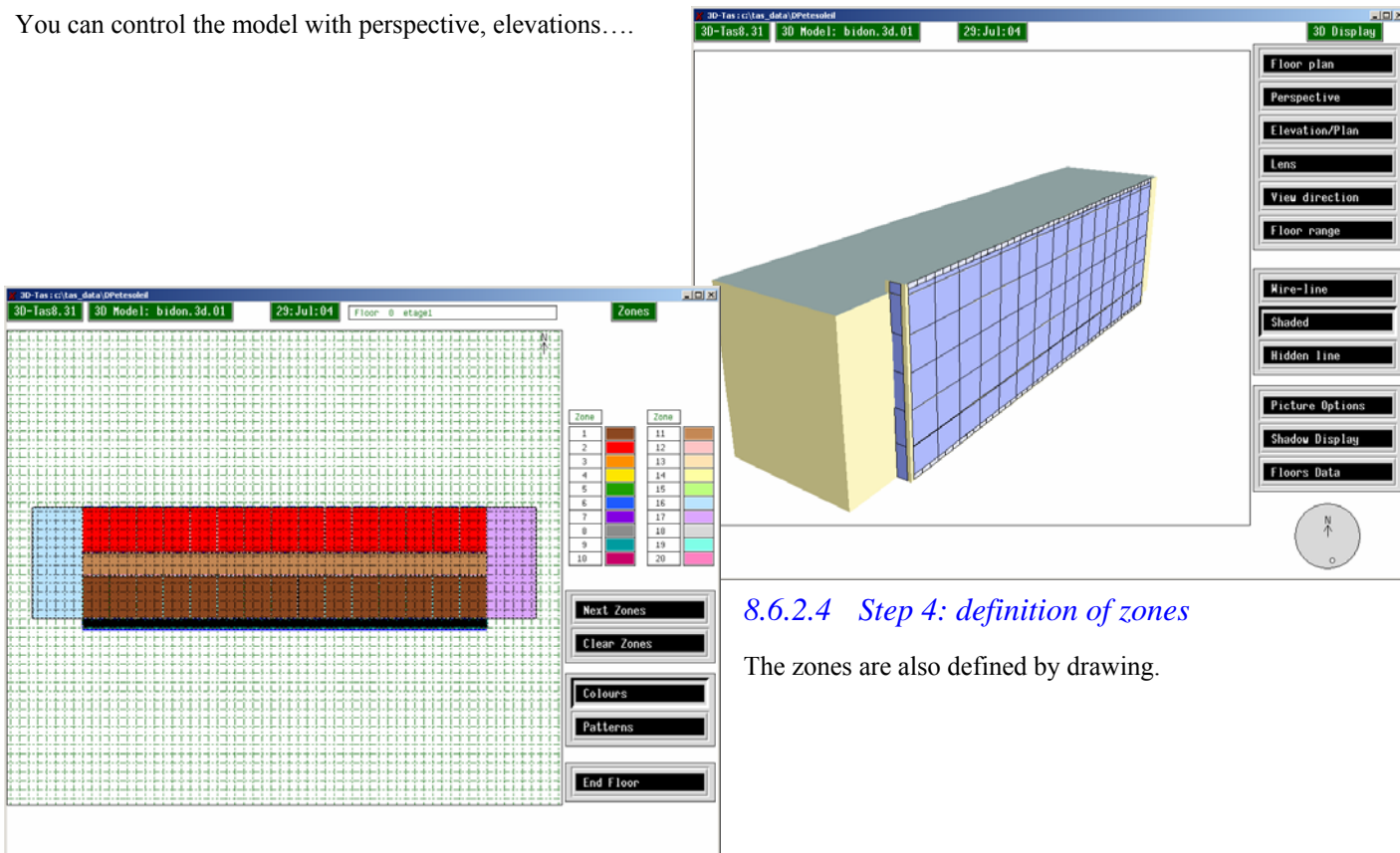
8.6.2.4   Step 4: definition of zones

The zones are also defined by drawing.

8.6.2.5 Step 5: definition of construction details, internal conditions, plant and controls, air movement.

For each zone, the software automatically defines the area, the orientation, the position (external, internal or neighbour of another zone) of all the walls. The user is invited to define building elements, internal conditions, plant characteristics, aperture type, feature shading, schedules and the air movement (for mechanical ventilation). The user is helped with database and the zones can be grouped; so the data for zones with identical characteristic are introduced only once.

8.6.2.6 Step 6: simulations

The user can realise interactive simulations (to study one day) or batch simulations (to study long period)

8.6.3 Outdoor climate and other context data

The Climate Database stores files containing hourly weather data. The weather files supplied with Tas cover different regions of the world and each represents a typical year's weather for the region in question. For Belgium, **Test Reference Years** compiled by the Commission of the European Communities are used.
A weather file consists of a group of parameters relating to the weather site and hourly values of seven weather variables.

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Site Parameters:

Parameters	Details
Latitude (degrees North)	The latitude of the weather site.
Longitude (degrees E)	The longitude of the weather site.
Time Zone (hours ahead of GMT)	The time zone of the weather site (in the range –13 hours to +13 hours).Note: the Longitude and Time Zone parameters indicate the location of the solar radiation measurements and the time convention used to record them; editing these parameters is NOT a valid way to allow for seasonal time adjustments such as British Summer Time.
Ground Temperature (deg. C)	The ground temperature at the weather site (degrees Celsius)

Hourly weather variables:

Hourly weather variables	Details
Global Radiation	Total solar radiation intensity on a horizontal plane.
Diffuse Radiation	Diffuse sky radiation intensity on a horizontal plane.
Cloud Cover	A number varying from 0 for a clear sky to 1 for overcast conditions. This quantity is used to estimate long-wave sky radiation during simulation.
Dry-bulb Temperature	The dry-bulb temperature as measured in a Stephenson screen.
Relative Humidity	The relative humidity as measured in a Stephenson screen.
Wind Speed	The wind speed measured at a height of 10 meters above the ground
Wind Direction	The direction from which the wind blows (degrees east of north).

Solar radiation:
In appropriate cases the direct incident radiation is reduced by a shading factor read from a shading file or by calculations of the effects shading features (overhangs, side-fins or recesses). These shading calculations may be applied to both transparent and opaque elements. For transparent elements the cosine of the angle of incidence is used in the calculation of transmission and absorption in the element. Tas does not account for diffuse radiation shading.

Ground Solar Reflectance
The proportion of incident solar radiation reflected by the ground in the vicinity of the building.

Aperture air flow:
The following parameters are taken into account to calculate aperture air flow.
Building Height (non-editable)
This parameter and the four which follow relate to the aperture air flow analysis facility, where they are used in the calculation of wind pressure on the external surfaces of the building. Building Height is set by 3D-Tas to the height of the highest part of any zoned space in the 3D model.
Building Height Adjustment Factor
This parameter allows you to adjust the building height used in the wind pressure calculations if the Building Height provided by 3D-Tas is judged to be inappropriate. The height used in the wind pressure calculations is the Building Height multiplied by the Building Height Adjustment Factor.
Mean Height of Surroundings
This parameter lets you make allowance for the wind-shading of the building by nearby buildings or other local obstructions. If a Wind Pressure Coefficient File is specified, this parameter is ignored.
Terrain Type (Open, Rural, Town, City) The type of terrain in the vicinity of the building. This parameter determines the type of wind profile used for the wind pressure calculations.
Wind Pressure Coefficient File (for imported wind pressure coefficients)

The name of a file containing wind pressure coefficients to be used in aperture flow calculations. This file name is optional. If it is specified, the wind pressure coefficients on the file override TAS's algorithms for estimating wind pressures on the building facade.

8.6.4   Simulation of a ventilated double facade

8.6.4.1   General methodology

Tas is a dynamic multizone model and VDF is simply simulated as an independent zone.

In Tas, only one temperature per zone is calculated. To try to take into account the stratification of the air in the VDF, we subdivided this one in several zones. Separations are factitious walls that can be completely open. The factitious walls have a very small thermal resistance and a solar transmission of 1. Vertically and horizontally subdivisions are possible.

The horizontal subdivisions are tracked floors. The Track label has a special function that allows the floor to be modelled as an air flow aperture. The solar radiation that strikes the tracked floor is not stopped by the floor and enters in the adjacent zone.

The vertical subdivisions are modelled by permanently open window.

If one studies only the double facade, this one can be divided in a maximum number of 60 zones. If the building is studied in its entirety, the number of subdivisions will be reduced since the software can allocate 60 zones max.

Examples of results:

The simulation was realized for a sunny spring day. The outside temperature evolves between 2 and 12.5°C. We fix a null wind speed to examine only the stack effect. The up and down double-skin windows are opened by a slit of 25cm. So, the aperture area is 0.25m X 54m = 13.5m². The figure shows the VDF temperature at 13h (outside temperature: 12.3°C) when the VDF is considered only as one zone or when it is divided in several zones. It also shows the aperture air flow in kg/s through the up and down double-skin windows (13.5m²).

Mean temp.= 19.7°   Mean temp.= 18.7°   Mean temp.= 19.5°
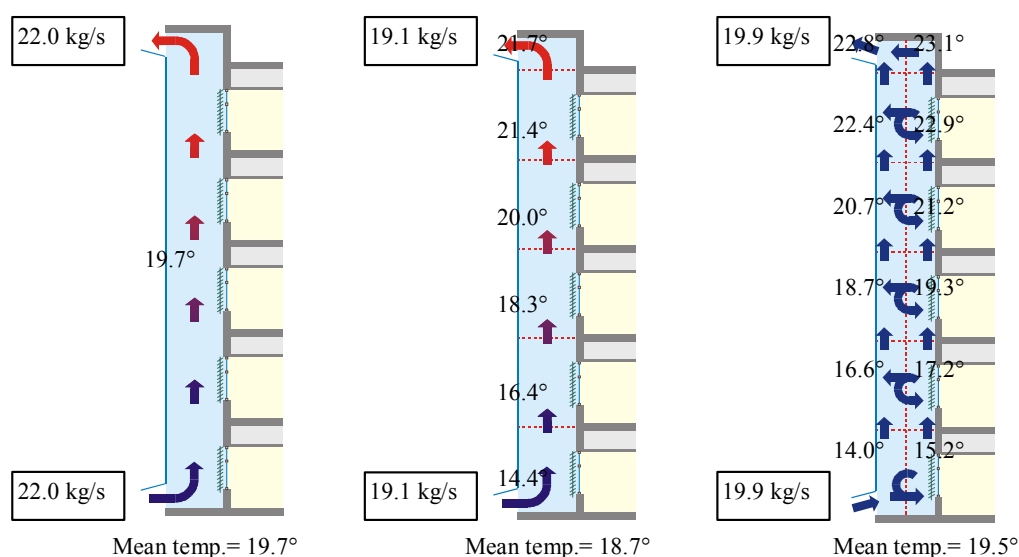
Zone divides

Another method to define the factitious subdivisions is the use of "zone divides".

A zone divide is a special surface used in Tas to represent the boundary between two zones where there is no physical barrier. A zone divide is indicated by a building element for which the construction code is set to '/'. The Zone Divide is modelled as highly conducting, non-convecting surfaces which are perfectly transparent to solar radiation and which are assigned an emissivity of one. This wall does not exchange any heat with the neighbouring air masses by convection. As this method does not take account of the exchanges of air between the zones, to take account of it, it is enough to place in this wall an opening whose "construction code" is also "/".

8.6.4.2   *Facade layers*

Glass layer

Transparent constructions may contain Transparent Layers and Gas Layers.   Transparent constructions are assumed to have negligible thermal mass.

This is the list of parameters for **transparent layers**:

Solar Transmittance	The fraction of solar radiation at normal incidence which is transmitted by the layer.
External Solar Reflectance	The fraction of external solar radiation at normal incidence which is reflected by the layer.
Internal Solar Reflectance	The fraction of internal solar radiation at normal incidence which is reflected by the layer. This will differ from the External Solar Reflectance if the layer is unsymmetrical (for instance a glass pane with a metallic coating on one side).
External Emissitvity	The fraction of external long-wave radiation which is absorbed by the layer.
Internal Emissitvity	The fraction of internal long-wave radiation which is absorbed by the layer. This will differ from the External Emissivity if the layer is unsymmetrical.
Width	The width of the layer.
Conductivity	The thermal conductivity of the material.
	The specific moisture diffusion resistance of the material (the ratio of the permeability of air (1.92e-10 kg/Ns) to the permeability of the material).

Optical properties are angular dependent.

Transmission and absorption characteristics of transparent constructions at non-normal incidence are calculated from the Fresnel equations.   The user specifies if the transparent layer is a blind because, in that case, the convection coefficient for gas layer adjacent to blind is automatically increased by a factor 4/3 to allow for the effects of convection currents in the larger gas space enclosing the blind.

The thermal properties are not function of the temperature.

The parameters for **gas layers** are width and convection coefficient

Shading devices

Movable shading devices

Shading devices (roller blind, venetian blind with orientable slats, etc.) are modelled only as transparent layers; so optical properties are only angular dependent.   There is thus no difference between roller blind and venetian blind if the solar transmittance and the external and internal reflectance are the same.   The convection coefficient for gas layer adjacent to blind is automatically increased by a factor 4/3 to allow for the effects of convection currents in the larger gas space enclosing the blind.

In a ventilated double facade, the shading device can be placed in various positions:

Shading device against a facade

If the shading device is against a facade it is modelled as a device associated to an external window.   Tas allows having substitute building element. The construction and feature shading properties of the building element are replaced by those of a Substitute Building Element at certain times.   These times are specified by the Substitution Schedule.   In the most common application of this feature, the main building element represents a window and the substitute building element the same window with a blind.   The substitution process then represents the drawing of the blind.

Shading device far from the facade

If the shading device is far from the facade, the double facade can be divided into several zones and air movement can be studied.   The impact of the size, the colour and the localization of those can be studied.

Examples of results:
Study of a sunny summer day, the VDF is closed.

Temperature in the VDF zones. Air flow between zones (kg/s). VDF length 54m.	Surface temperatures.	
14.3 8.1 8.1 14.0 *50.3 51.2* 14.2 7.9 7.9 13.3 *50.4 51.2*	33.0°C 35.1°C 69.8°C 37.6°C 35.2°C 28.8°C	**Blinds placed against the internal glass facade.** The heat transfer in the offices due to the heating of the window sills and the glazings close to the blinds is significant. The temperature of the interior facade being higher than that of the external facade, a movement of thermocirculation is established.
57.9 57.5 8.5 4.6 4.6 7.9 *57.8 57.6* 6.6 3.3 3.3 4.3 *50.8 52.0*	34.1°C 65.6°C 53.3°C 33.5°C 59.5°C 27.7°C	**Blinds placed against the external glass facade.** The temperature in the VDF is higher because the air cannot cool any more naturally by licking the simple external glass, the movement of thermocirculation is reversed. The temperature of the window sills and the glazings of the interior facade is lower than in the previous case. Indeed the totality of the interior facade is protected from the solar radiation and the internal glass is less affected by the hot radiation from the screens as in case 1.
0.4 8.4 8.4 0.1 *50.5 52.0* 0.1 8.6 8.6 0.3 *50.1 51.2*	33.9°C 36.3°C 62.5°C 62.6°C 52.6°C 33.1°C 28.6°C 27.3°C	**Blinds placed between the two glass facades, in the middle of the cavity.** The blinds transmit less heat by radiation to the interior facade. The air of the VDF can cool partially by licking the simple external glazing. The temperature of the interior facade (side offices) is lower than in both other cases.

Permanent shading devices
Overhangs and side-fins can also be modelled.
Feature Shading allows you to define simple Shading Types in terms of side-fins and overhangs. A shading type may be assigned to any building element, and will apply to all exposed surfaces of that building element type. The shading effect will be combined with any Shadow Calculations that are performed when exiting from the 3D Modeller. This type of shading affects only to direct solar radiation (not the diffuse component).

Frame
Frames can be modelled as an opaque material and aperture in these can be envisaged. The software calculates then the heat transmission through the frames and the air flowing through the apertures.

Ventilated double facade

Convective heat transfer in the cavity

For the two glass facades
With the exception of "zone divides", the calculation of internal convection coefficients in Tas follows the procedures set out by Alamdari and Hammond for the calculation of free convection heat transfer in rooms.
For windows, hc varies with

- the window height as defined in 3D-Tas,
- the absolute temperature difference (K) between the room air and the window surface temperature;
- the slope of the window

For walls, hc varies with
- the zone height as defined in 3D-Tas,
- the absolute temperature difference (K) between the room air and the wall surface temperature;
- the slope of the wall

The dependence of "hc" on the temperature difference means that the internal convection varies from hour to hour.

The user may override these convection formulae by setting the parameter a Fixed Convection Coefficient for one or more zones. If this is done, "hc" is fixed for all internal surfaces of the zone and for all times.

For shading device
The convection formulae are modified when the surface has an internal blind for its construction. In such cases, to make allowance for the fact that convection occurs at the surfaces of both the construction and the blind, "hc" is increased by a factor 4/3.

For fictive subdivisions
No convection for the "zone divides".

Exterior convection heat transfer
The convection coefficient at external building surfaces is calculated from hourly values of the wind speed provided on the weather file. Tas uses an expression provided by CIBSE (The Chartered Institution of Building Services Engineers).

Long wave radiation : transfer through the cavity

For the two glass facades and the shading device
Radiant exchange between room surfaces is modelled in Tas using Carroll's MRT method. This is one of a class of methods which simplify the complex radiant exchanges between the surfaces of a room by coupling each surface to a fictitious MRT (mean radiant temperature) node. This vastly reduces the amount of computation involved with little loss of accuracy.
There are three approximations in the method:
- Radiant exchange is linearised.
- Shape factors are calculated solely on the basis of surface area, and are therefore approximations to the true shape factors.
- The emissivity of the room air is neglected.

For fictive subdivisions
The "zone divides" are assigned an emissivity of one.

Exterior radiation heat transfer
Long-wave radiation exchange is modelled using the Stefan-Boltzmann law, using surface emissivities from the materials database. Long-wave radiation from the sky and the ground is treated using empirical relationships.

Short wave radiation : transfer through the cavity

For the two facades and the shading device
The final destination of solar radiation entering the building through transparent surfaces is determined in a series of radiation distributions. Each distribution is carried out in turn for each of the building's zones. Its purpose is to distribute the admitted radiation among the zone's surfaces by modelling the repeated bouncing of radiation around the zone. If, in this process, radiation falls on a transparent surface, transmission occurs. Radiation transmitted in this way to other zones is dealt with in the next distribution.
Inter-reflections between the slats of the venetian blind are not considered.

For fictive subdivisions
Zone divides are assumed to be perfectly transparent to solar radiation at all angles of incidence.

8.6.4.3 Ventilation in the cavity of the double facade

Forced convection

It is possible to model a fixed air flowrate in the cavity.

Air movement between zones and from the outside can be specified for each day type (WEEKDAY, SATURDAY, SUNDAY, etc.) for up to eight periods in the day. The movement of air is specified in terms of air movement into each zone from other zones and the outside. The air flow is specified in units of mass flow per unit time.

You should ensure that all air flows are correctly accounted for. Any air flow imbalance will be reported as an error when you attempt to simulate.

Natural convection

A-Tas allows the user to specify apertures in the building fabric through which air may flow. Each aperture, which may be a window, a door or a portion of a floor, has an area, a mean altitude, an orientation and a plan hydraulic diameter derived from the 3D-Tas geometric model. It also has a time-varying aperture factor which is specified in A-Tas. In addition, there is an option to indicate that the aperture is sheltered from the wind.

The aperture factor is a number, usually in the range (0,1), specifying the area of the aperture as a fraction of the area of the surface it is associated with.

Aperture air flows are calculated by Tas using a model which takes account of the pressure-flow characteristics of the apertures, wind and stack pressures, and any prescribed air flows.

Wind effect

The wind pressure on a building facade depends in a complicated way on the speed and direction of the wind, the geometry of the building and any nearby obstructions, and the nature of the terrain in the building's vicinity.

Possible approaches to the problem of estimating wind pressures include:
- 3-dimensional computational fluid dynamics (CFD) modelling,
- use of specific experimental data (from the building itself or a wind tunnel model of it),
- use of generic correlations based on wind tunnel measurements.

The first two approaches are catered for in Tas by the option of specifying, on a Wind Pressure Coefficient File, calculated or measured wind pressure coefficients for each aperture.

In the absence of such data, Tas also offers the third approach, using correlations based on wind pressure coefficients derived from wind tunnel experiments carried out at the National Research Council Canada.

Since the wind pressure correlations are expressed in terms of the wind speed at the building reference height, Tas requires a method for estimating this from the wind speed on the weather file, which is measured at an altitude of 10m. The wind speed as a function of altitude is assumed to follow a power law function and depends on the terrain type (open, rural, town or city).

Stack effect

The stack effect - pressure differences arising from gravity forces - is modelled on the assumption that within each Tas zone, and outside, the air temperature is uniform. The air density is assumed to be inversely proportional to absolute temperature.

Airflow modelling

The flow equations are solved iteratively. At each time step, wind pressures and wind pressure gradients are calculated for all exposed apertures. Then at each iteration step, air densities in all zones are calculated from the zone temperatures, and these are used (together with the wind pressures if appropriate) to calculate stack pressures and stack pressure gradients for both sides of each aperture. A set of equations is then set up describing the balance of mass flow into and out of each zone. This balance takes into account any forced air flows. These flows are then fed back to the Tas thermal analysis where they are used to generate updated zone temperatures. The iterative process continues until zone temperatures (both air and mean radiant) converge to an accuracy of 0.01K and flow rates converge to an accuracy of 0.0005 kg/s.

To define the apertures, an aperture schedule and the openable proportion must be indicate.
Aperture Schedule

This schedule is used to specify times at which apertures of the given type are open. Schedule is a time-series of 0's and 1's, one value for each hour of the year. These values may be specified either as 24 hourly values for each day type or as 8760 values for the whole year (in which case the values are read in from a file).
Openable Proportion
The area of the opening is expressed as a proportion of the surface area appearing. If the Openable Proportion is set to 0, no apertures will be created for the building element.

The aperture discharge coefficient used by Tas is 0.62 (we note in passing that for a narrower space, such as a double facade, it might be necessary to consider the resistance offered by friction with the walls).

8.6.5   Simulation of the building and HVAC systems

8.6.5.1   General methodology

As the double facade is one or many zones, it is an incorporated part of the building and so can be connected with its installations.
TAS has a module named "Tas-Systems". It is a HVAC systems/controls simulator, which may be directly coupled with the building simulator. It performs automatic airflow and plant sizing and total energy demand.

"Tas-Systems" is a software tool which simulates the thermal performance of heating and air conditioning systems. It is a software allowing systems to be assembled graphically from their basic components. The following are some of the components from which systems can be assembled: fan coils, induction system, heating coils, cooling coils, fans, ducts, spray and steam humidifiers, heat recovery devices, mixing boxes, collector boxes, duct networks, temperature and enthalpy optimisers, proportional controllers, with compensation option, boilers, chillers ……
The combined simulation of building and plant automatically determines component sizes, air flow requirements and energy consumption at component level and primary plant. Part load characteristics for fans, chillers, boilers etc may be described.

8.6.5.2   Connection between facade and building.

It is possible to model a fixed air flowrate between the cavity and the building. The airflow can also be natural by windows opening.
Aperture air flows are calculated by A-Tas using a model which takes account of the pressure-flow characteristics of the apertures, wind and stack pressures, and any prescribed air flows.

Examples of simulation results

The simulations were realized for a sunny summer day. The outside temperature evolves between 11.4°C and 23.3°C. The global solar radiation is high. For this study, we impose a constant wind speed. We will also change the wind direction during the study.
In a building with a southern double-skin, when the sun is shining, it is sometimes difficult to apply the strategy of day natural ventilation. Indeed, cross day ventilation by extraction through the double-skin is delicate and is a function of the wind orientation and of the building wind protection. The double-skin down opening has also an impact on the direction of air flow.

Case 1
For example, if the double-skin facade is oriented to the South and if wind orientation is North and only the top window of the double-skin is opened the following results are obtained:

Wind

±4.8 ach   *480 cm²*
±5.1 ach   *450 cm²*
±4.9 ach   *420 cm²*
±4.8 ach   *390 cm²*
±4.8 ach   *360 cm²*

ZONE AIR CHANGE RATE — Office 5N
ZONE AIR CHANGE RATE — Office 1N
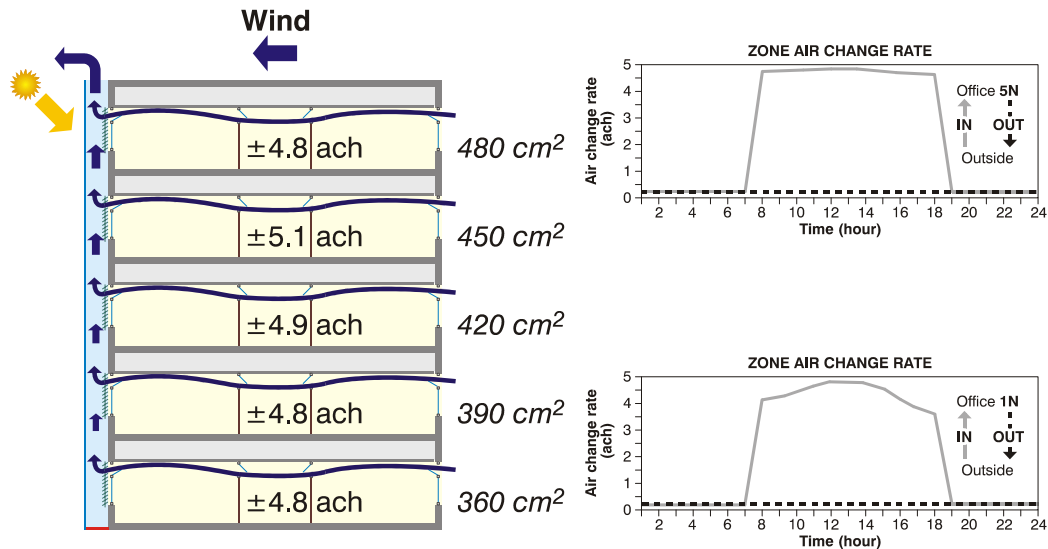
The figure gives zone air change rate and the opening area in each office for the various floors. On the right, the graphs represent the air change rate during the day for a north office at the ground floor and at the fifth stage. We also see that the air comes from outside to the north offices.

To obtain a ventilation rate of 4 Ach, the openings in the upper floors must be more significant due to the stack effect decreasing with the height in the building but also due to the wind pressure coefficients which are smaller on the level of the last stage. The stack effect is less significant than the wind effect but it is perceptible the day if we compare the evolution of the ventilation rate of the lower and higher stages. At the ground floor the zone air change rate follows the radiation and so the temperature evolution in the double-skin. Contrary, at the higher floor, the curve is horizontal; the stack effect is null due to the low ΔH whereas the temperature in the double-skin reached 35°C.

Case 2

Contrary, if wind orientation is South and only the top window of the double-skin is opened, these other results are obtained:

Wind

-4.0, -3.5, -4.0 ach   *480 cm²*
-3.6, -2.6, -3.6 ach   *450 cm²*
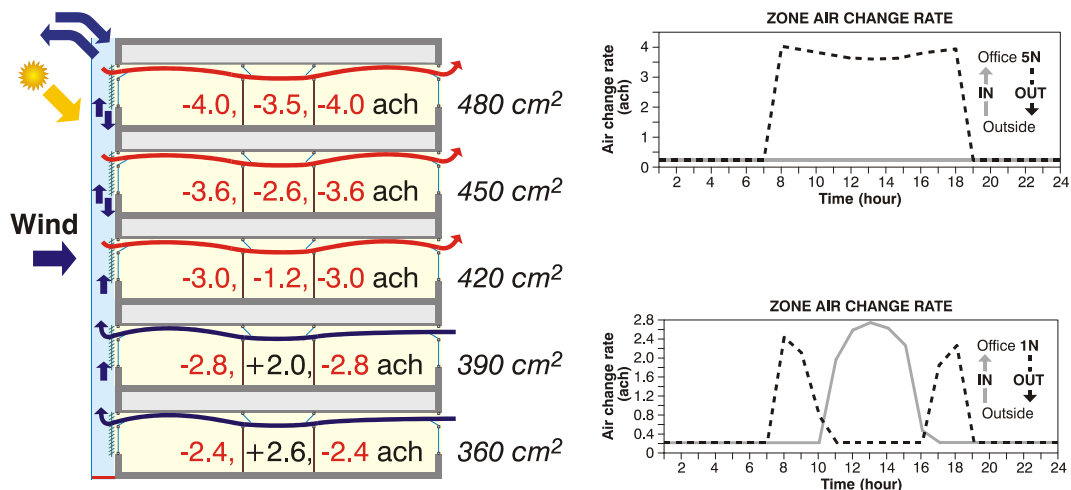-3.0, -1.2, -3.0 ach   *420 cm²*
-2.8, +2.0, -2.8 ach   *390 cm²*
-2.4, +2.6, -2.4 ach   *360 cm²*

ZONE AIR CHANGE RATE — Office 5N
ZONE AIR CHANGE RATE — Office 1N

In the lower stages, when the temperature in the double-skin is not very high (from 8 a.m. to 10 a.m. and from 5 p.m. to 6 p.m.) and so the stack effect is low, air flow is done in opposite direction. The figure gives the evolution (morning, midday, afternoon) of the zone air change rate during the day in each office for the various floors. When the air change rate is negative, the air flow is done in opposite direction.

Contrary, from 11 a.m. to 4 p.m., the air flow passes from offices to the double-skin. The temperature in the double-skin remains high because there is only one up opening and because the double-skin is ventilated by the air providing from offices.

In the upper stages, air flow is always done in opposite direction.

In that case, the upper stages are partially contaminated by the air providing from the lower stages and the cooling loads are important.

Case 3

If wind orientation is South and top and down windows of the double-skin are opened, these other results are obtained:

APERTURE AIR FLOW

Air flow (kg/s)
24 20 16 12 8 4 0
Time (hour) 2 4 6 8 10 12 14 16 18 20 22

Double-skin
IN   OUT
Outside

Wind

-4.2, -4.4, -4.2 ach   *480 cm²*

-4.1, -4.1, -4.1 ach   *480 cm²*

-4.0, -3.8, -4.0 ach   *480 cm²*

-3.8, -3.5, -3.8 ach   *480 cm²*

-3.7, -3.3, -3.7 ach   *480 cm²*

APERTURE AIR FLOW

Air flow (kg/s)
28 24 20 16 12 8 4 0
Time (hour) 2 4 6 8 10 12 14 16 18 20 22 24

Double-skin
IN   OUT
Outside

ZONE AIR CHANGE RATE

Air change rate (ach)
4 3 2 1 0
Time (hour) 2 4 6 8 10 12 14 16 18 20 22 24

Office 5N
IN   OUT
Outside

ZONE AIR CHANGE RATE

Air change rate (ach)
4 3 2 1 0
Time (hour) 2 4 6 8 10 12 14 16 18 20 22 24

Office 1N
IN   OUT
Outside

In all the stages, air flow is always done in opposite direction.

The double-skin being more ventilated, the temperature is less high, which implies cooling loads less unfavourable than in the preceding case.

The left graphs of the figure show the air flows through the up and down opening of the double-skin. In the double-skin, the air movement is ascending during the day, thanks to the sunning. Contrary, during the night, the movement is reversed due to the wind pressure which is more significant at the top of the building.

In that case, the air stages is not contaminated by the air providing from other offices but the ventilation air temperature is higher than the outside air temperature.

8.6.6   Simulation of control systems and control strategies

Currently 'tips' are needed to control shading device up or down, airflow regimes, opening of aperture….
The timing of building element substitution (shading devices) and the timing of aperture opening can be controlled by schedules. A schedule is a time-series of 0's and 1's, one value for each hour of the year. These values may be specified either as 24 hourly values for each day type or as 8760 values for the whole year (in which case the values are read in from a file).

Control of shading devices: only by schedules defined by the user before the simulations.

Control of apertures: by schedules defined by the user before the simulations and by the area of the opening expressed as a proportion of the surface area and determined by the user before the simulation.

Control of air movement (mechanical ventilation): the specification of air movement between zones and into a zone from the outside are specified in advance of a simulation as time-varying mass flow rates. They are specified for each day type (WEEKDAY, SATURDAY, SUNDAY, etc.) for up to eight periods in the day.

Control of infiltration air, ventilation air and internal gains are specified in advance of a simulation for each day type (WEEKDAY, SATURDAY, SUNDAY, etc.) for up to eight periods in the day.

Control of heating and cooling systems are specified in advance of a simulation for each day type (WEEKDAY, SATURDAY, SUNDAY, etc.) for up to four periods in the day.

New Generation of Tas.

A new generation of Tas has been developed and will be soon available. One of the modifications is about natural ventilation.

Automatic Aperture Control Functions (AACFs) are introduced. With Tas AACFs an opening can be controlled by simulation parameters as the calculations proceed. Occupant control of windows and mixed mode systems can be analyzed. The software calculates the balance between temperature, airflow and the Control Function ensuring conservation of thermal energy and mass for all the airflow paths and zones within the entire building.

For example, to overcome high temperatures an AACF can be introduce into the model to simulate the occupant control of window opening for natural ventilation. In this case the window will start to open when the room temperature goes above 22oC and gradually open until it is fully open at 25oC. With a particular AACF, there is also a wind speed cut-off that means the window will gradually start to close as the external wind speed goes above 10 m/s.

Control of heating and cooling systems, shading devices, infiltration air, ventilation air and internal gains will be also modified. Indeed, there is a general Function Profile Type that allows an input value to be prescribed from simulation values, e.g. control of aperture opening from simulated temperatures, or variation in lighting gain based on external solar values. This system of Profile Types and Schedules that is used in the Internal Condition database is also used within the building simulation software. In the simulation software the Profile Types allow the same mechanisms to be used to control Inter Zone Air Movement (IZAM), Substitute Building Elements and Aperture Opening.

Report on simulations of the energy performances

8.6.7 Tas Ambiens

8.6.7.1 *General software information.*

A natural extension to the A-Tas Building Designer module, Tas-Ambiens allows to generate a view of the micro-climate across a 2D section of an internal space.

One can create graphical displays for spacial variations in radiant, air and resultant temperatures. Plots of air velocity, humidity and PPD comfort levels are also included.

Ambiens is the only CFD software to be specifically developed for building services engineers. It has automatic mesh generation, no instability problems and always provides a solution to the specified boundary conditions.

When you use Ambiens in conjunction with the Tas Building Designer module, you can quickly and reliably convey the operational effectiveness of micro-climate control strategies. It's particularly useful in visualising and demonstrating the impact of natural ventilation regimes.

Ambiens enables you to easily evaluate the operation of systems such as displacement ventilation, chilled beams and chilled ceilings.

For atria, solar protection, summer ventilation and avoiding cold down-draughts are just some of the issues Ambiens can help to resolve.

Tas-Ambians calculates the movements of air and the distribution of the temperatures at a given moment.

Before running the calculations you must set the conditions for the model:
- temperatures for all solid surfaces,
- temperature, humidity and velocity of air entering the design through inlets,
- initial temperature inside the design,
- metabolic value and clothing value for inside the model. This is used for assessing comfort,
- heat gains (sensible and latent) and radiant proportion for the regions.

Temperatures for all solid surfaces, temperature, humidity and velocity of air entering the design through inlets and initial temperature inside the design must be calculated before by another software as A-Tas

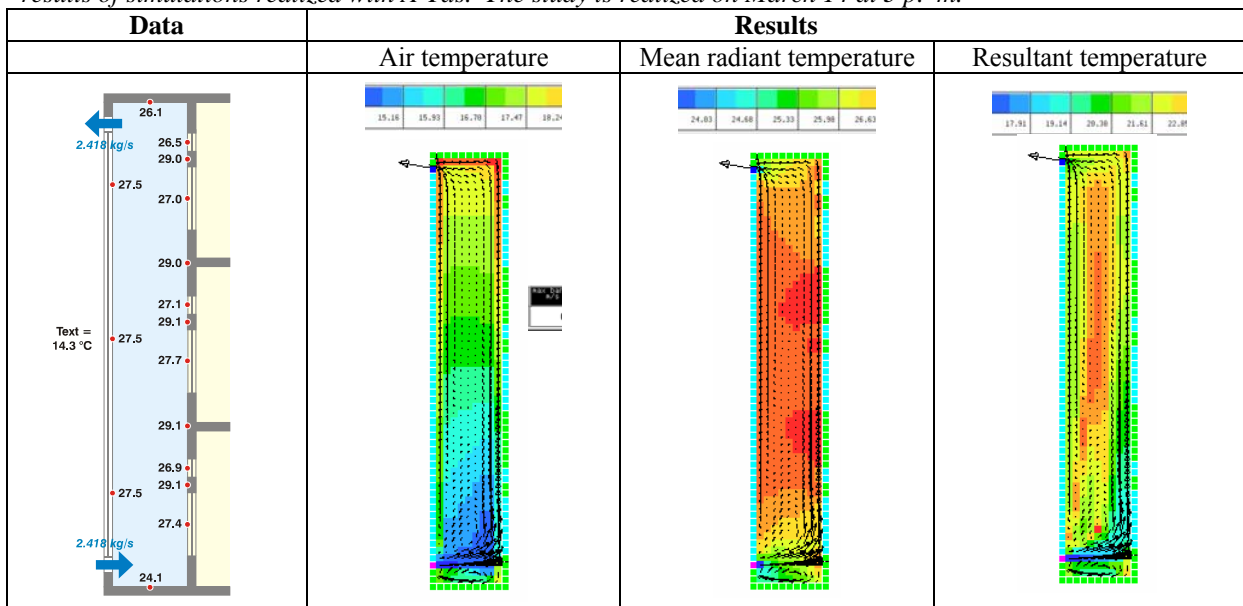#### 8.6.7.2 *Example of simulation of a ventilated double facade with Tas-Ambians*

One difficulty of the use of the software is the drawing of the section because there are some important rules when inseting points:
- Start from the bottom left corner because the absolute co-ordinates start there.
- The section should always be input in a clockwise direction.
- No line segments may cross (i.e. intersect each other)

So it is difficult to add internal walls, blinds in cavity….
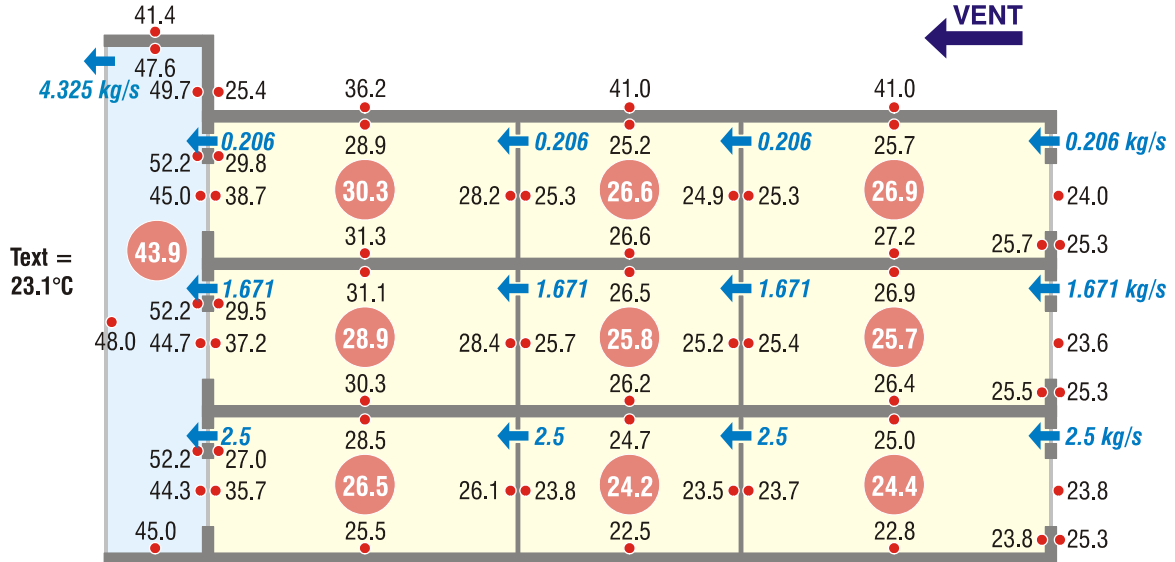
Case 1

The result below shows air movement and air temperature in a ventilated double facade. The data provide from results of simulations realized with A-Tas. The study is realized on March 14 at 3 p. m.

Data	Results		
	Air temperature	Mean radiant temperature	Resultant temperature

Case 2
The result below shows air movement and air temperature in a ventilated double facade when there is extraction of air from the offices to the double-skin. The data provide from results of simulations realized with A-Tas.

Data:

VENT

41.4		
47.6		
4.325 kg/s 49.7 • • 25.4	36.2	41.0	41.0

0.206   28.9   *0.206*   25.2   *0.206*   25.7   *0.206 kg/s*

52.2 • •29.8
45.0 • •38.7   **30.3**   28.2 • •25.3   **26.6**   24.9 • •25.3   **26.9**   • 24.0

31.3   26.6   27.2   25.7 • •25.3

Text = 23.1°C

43.9

1.671   31.1   *1.671*   26.5   *1.671*   26.9   *1.671 kg/s*

52.2 • •29.5
48.0   44.7 • •37.2   **28.9**   28.4 • •25.7   **25.8**   25.2 • •25.4   **25.7**   • 23.6

30.3   26.2   26.4   25.5 • •25.3

2.5   28.5   *2.5*   24.7   *2.5*   25.0   *2.5 kg/s*

52.2 • •27.0
44.3 • •35.7   **26.5**   26.1 • •23.8   **24.2**   23.5 • •23.7   **24.4**   • 23.8

45.0   25.5   22.5   22.8   23.8 • •25.3

Results:

Air temperature	Mean radiant temperature	Resultant temperature