

## IMPLEMENTATION AND APPLICATION OF A NEW BI-DIRECTIONAL SOLAR MODELLING METHOD FOR COMPLEX FACADES WITHIN THE ESP-R BUILDING SIMULATION PROGRAM

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### ABSTRACT

This paper provides an overview of a new method for modelling the total solar energy transmittance. It is implemented in the ESP-r building simulation program to model complex façades such as double glazed façades with external, internal or integrated shading devices. This new model has been validated and tested for several cases. The new model required changes to the solar control simulation algorithm and the user interface, so a new “Advanced optics menu” was also introduced into ESP-r.

The paper presents the interface development and application of the new technique to different simulation configurations (especially different complex façades with shading devices) in a standard office building.

### KEYWORDS

Solar control, ESP-r, building simulation, shading systems.

### INTRODUCTION

For the purpose of this paper, the authors define a complex façade as an external glazing/blind system with a complexity difficult to model by standard tools. Figure 1 shows some examples.

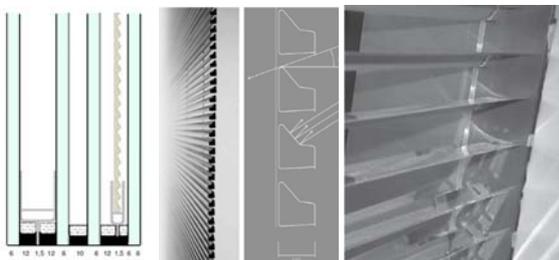


Figure 1: Examples of three different complex façades.

Architects frequently design buildings with large window areas with complex façades, in particular for office buildings. For such complex façades, there is a lack of models that can capture their detailed design. Simplified calculation methods are often

inappropriately used for the calculation of their thermal and optical properties. This can result in an incorrect performance evaluation. A new detailed approach is needed for the design stage to simulate complex façades and their control systems to determine their overall impact on the energy performance of buildings. This new model (called by the authors the “Black Box Model” (BBM)) is described in detail in Kuhn et al. 2009. In the work described in this paper, the model was integrated into a whole building energy simulation program in order to allow the modelling of the optical properties of complex façades without modelling the design details of the façade within the program itself. The integration of this BBM model within the ESP-r simulation program (ESRU 2009) and the associated interface is described in this paper.

### **Brief description of the BBM**

The reasons for this new approach are the following:

- Some new glazed façade constructions are too complex for the capabilities of building simulation programs, or even specialist glazing software such as WIS (2009) and WINDOW (2009). It is important for the success of new constructions that the advantages of innovations can be demonstrated by building designers. In some cases, the thermal and optical properties of façades can not be described by models with sufficient accuracy. This is especially the case when the real component deviates significantly from the ideal design. An example is a glazing unit with an integrated prism-layer (see Figure 1).
- Semi-empirical models have been developed for façades with venetian blinds which are able to describe the angle-dependent properties of the facade accurately, without needing too many measurements (Kuhn 2006a). However, to study the impact of such complex façades on overall building performance, it is necessary to integrate these models into a building simulation program.

The new model has already been validated and tested for several cases in Frontini et al. (2009). The general

idea of the model is to describe every complex facade with a two layer model (for example two panes of glass). The glazing system has defined bi-directional transmissivity and reflectivity; each of the two virtual layers has an effective solar absorption, again with a bi-directional definition. Therefore all optical properties are a function of both solar azimuth and altitude.

The implementation of the new model in *ESP-r* required changes to the *solar control* simulation algorithm and the user interface. The following functionality was added.

- Calculation of the solar absorptances of the two virtual glazing layers (which represent the complex facade).
- Calculation and use of the diffuse transmittances and layer absorptances, with separate treatment for sky and ground-reflected components of the solar radiation – this is necessary because the diffuse transmission through a glazing system that contains horizontal venetian blinds, for example, will differ for the diffuse radiation that comes from the sky and the diffuse radiation reflected by the ground.
- A number of control options to switch between data sets (possible switching criteria are the current zone dry bulb temperature, outdoor dry bulb temperature, incident radiation on an external surface and dry bulb temperature of any specific zone). This facility can be used to switch between optical properties that correspond, for example, to different blind angles
- A facility to read in multiple optical bi-directional data sets and to allow the user to specify which glazing in the model is associated with this data.

The input data for the model are measured or they are values calculated externally. Each data set “i” is valid for different directions of the incident solar radiation and different settings of a control parameter “ $\beta_k$ ” which, for a venetian blind, is the tilt angle of the slats, or, in the case of facades with switchable properties, a parameter field which characterises the setting.

## DESCRIPTION OF THE NEW IMPLEMENTATION

It is common practice in building energy simulation programs to model external blinds by globally reducing the irradiation or to model them as additional glass panes and to make the assumption that the angle-dependent properties are rotationally symmetric with respect to the normal to the surface. The first-order approximation in a more realistic model approach is to neglect the fact that the reflectance on the surface of one individual slat

depends on the angle of incidence, but to take into account the real geometry of the slats. The accuracy of this method is described in Kuhn (2006b). Results of such models can be used by the new BBM because it only needs properties of the complete facade. The BBM can also use directly measured values for the complete facade as input. The newly implemented BBM is described in detail in Kuhn et. al 2009.

The implementation of the new BBM within *ESP-r* involved the following steps:

- Extending the *ESP-r* facilities for optical modelling by incorporating the BBM.
- Implementing a new user interface for accessing the bi-directional data; this is set at present to expect a 2-dimensional array of data in 5 degree steps of solar azimuth relative to the facade normal (-90° to +90°) and solar altitude (-90° to +90°).
- Extending the optical control capabilities.

The new interface for the BBM needs as input only the bi-directional angle-dependent total energy transmittance (g-value) and direct solar transmittance ( $\tau_e$ ), and the U-value of the total facade unit under known laboratory conditions (this is used in the method described in Kuhn et al (2009) in the calculation of virtual layer absorptances) . If available, the solar reflectance  $\rho_e$  (for solar radiation hitting the outer surface of the facade unit) can also be used as input, which will improve the accuracy of the modelling of the external surface temperature.

It is emphasised that it is not necessary to measure g-value,  $\tau_e$  and  $\rho_e$  directly, but these properties can also be calculated with mathematical models (for example in case of facades with venetian blinds they can be calculated with the models given in Kuhn (2006a)).

The solar processing routine in *ESP-r* (Strachan 1990) was extended to use the direct transmittances and the calculated layer absorptances of the two virtual layers. At each time step, the simulation has a known solar altitude  $\alpha_s$  and azimuth  $\gamma_s$ . Using the 5-degree interval input data, a double linear interpolation is undertaken (azimuth and altitude) to find the transmittance and layer absorptances for the known solar angles.

The diffuse irradiation is very relevant for the solar gains. To include the diffuse irradiation in this calculation, a discretisation of the sky and of the ground was adopted previously and described by Kuhn (2006a). A simpler approach, that the authors use for the assessment of the new BBM, is to divide the diffuse irradiation into two main components, one coming from the upper half of the hemisphere (in most cases above the horizon) and the other part of the diffuse irradiation is reflected from the ground (the lower half of the hemisphere). Details of this calculation can be found in Kuhn et al. (2009).

## New user interface

In order to apply any type of bi-directional dataset and their control, surfaces in the model that represent complex façade elements are first identified. The bi-directional data input file must be prepared: an example is given in the Appendix.

Three different dataset input options are available, depending on the available façade data (laboratory measured or calculated):

- *Te\_abs\_n,diffuse*: this datatype assumes that the bi-directional data is available for direct transmittance, absorptance of each layer in the glazing system (which can be more than two for this datatype), and a direct-to-diffuse fraction. Known diffuse properties are also input for this data type. This datatype was previously available in ESP-r and does not use the BBM described in this paper.
- *Te\_g\_rho*: this datatype is for the case when direct transmittance, total transmittance (g-value) and reflectance are known for the complete façade at each of the bi-directional angle increments (in 5 degree steps). This datatype uses the BBM.
- *Te\_g\_only*: this is similar to the previous datatype, but for cases where reflectance data are not available. In this case, an assumption is made that total absorptance of the glazing system is 50% of the maximum possible total reflectance (Kuhn et al. 2009), i.e. the reflectance and total absorptance are the same.

Other data required are the U-value and the external and internal surface resistances for the measured condition – these are modified using ESP-r’s usual calculations for internal and external surface convection and radiation,

If a specific complex façade has many datasets, corresponding to different states of that system, for example different slat angles in the case of blind systems, these sets are listed sequentially in the input file (with a maximum of six configurations, at present). Each set, in addition to its own angle-dependent optical properties, can have its own thermal properties.

## Control options

Two options for control were implemented. The first (called method-A) involves specifying setpoints which are tested at each timestep in the simulation to determine which dataset to use. The second (called method-B) is to use a temporal definitions file to specify which datasets are to be used at each timestep in the simulation.

### Method-A

An option for “optics” control has been developed in the same way as for the other control options in ESP-r. A number of different control loops can be specified, each with its own schedule. For each control loop, the user specifies details of the sensor, details of the actuation and the associated control data.

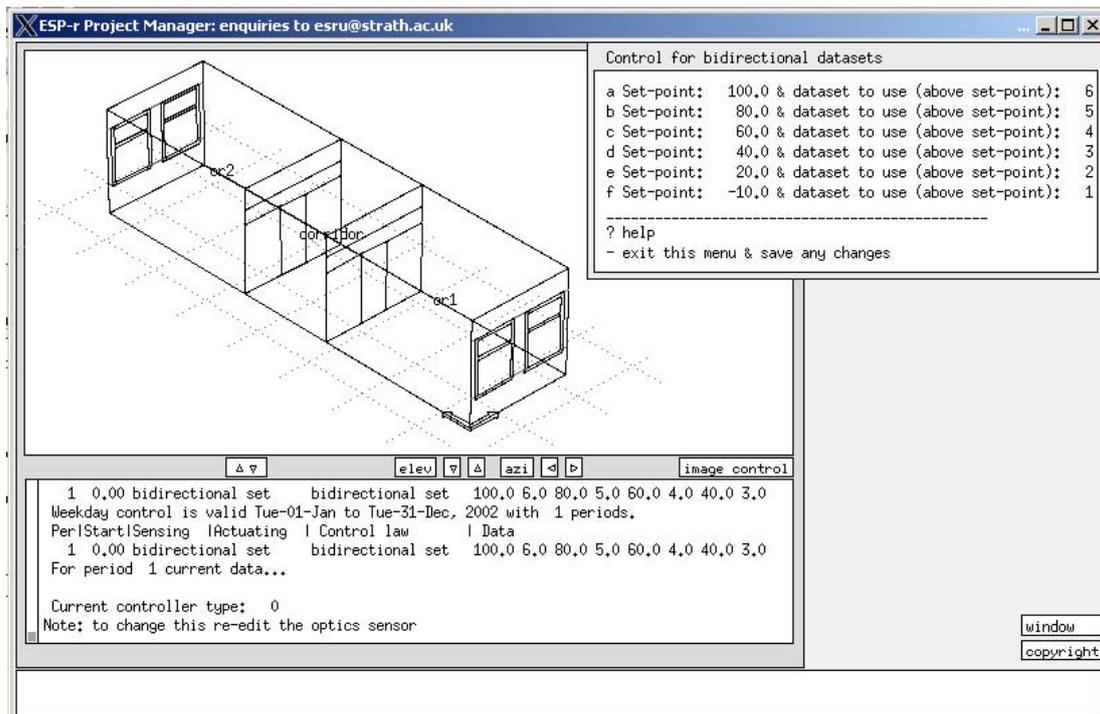


Figure 2: Example of set-points and datasets definition

The following options are available for the sensed condition:

- current zone dry bulb temperature
- external dry bulb temperature
- incident radiation on external surface
- lux levels (this option has not been tested in detail)
- dry bulb temperature in any specified zone

These five sensor options are exclusive: at present combinations of sensed conditions cannot be specified.

For the actuation, users simply define the appropriate facade construction to control.

The associated control data specifies the dates and times of validity for each control period and the setpoints at which different input datasets are switched. Up to a maximum of 6 set points can be selected, with the corresponding number of one of the six datasets (defined in the input file) that will be used if the sensed condition is above the particular set point. This can be used, for example, to switch between different states of the blind system depending on the incident external irradiance.

An example of the new interface panel, with the definition of the six different control steps, is shown in Figure 2.

#### Method-B

The second option is to use the temporal definitions file to specify which datasets are to be used at each timestep in the simulation. Usually this information is read in from an external file (e.g. in *csv* format).

After preparing the input file, users specify the association between the data specifying the datasets to use at each timestep and the corresponding facade construction that is to be controlled.

### CASE STUDY

This section provides an example of how this new integrated BBM can be used during the design of an office space with a complex facade.

#### Description of the reference building

Recently a reference office for simulation of lighting and energy has been defined by a group of researchers active in several international projects such as IEA Task 27 and IEA Task 31 (Platzer 2003).

The office segment consists of two offices separated by a corridor, which are assumed to be fully surrounded by identical office segments. Heavy construction materials are used for the opaque walls. The most significant dimensions of the modelled office and the facade are presented in Table 1 and Figure 5.

Occupants, light and equipment are taken as internal loads. The internal loads during weekdays were

calculated to be  $20\text{W/m}^2$  peak load from 8.00 to 18.00 (Figure 3). Weekends are treated the same as night time.

Table 1: Office model definition.

	NET FLOOR AREA	HEIGHT	EXT-FAÇADE AREA	WINDOW AREA
OR-1	18.9 m <sup>2</sup>	3.37 m	11.8 m <sup>2</sup>	5.4 m <sup>2</sup>
corridor	10.8 m <sup>2</sup>	3.3 m	-	-
OR-2	18.9 m <sup>2</sup>	3.37 m	11.8 m <sup>2</sup>	3.8 m <sup>2</sup>

To simulate night ventilation, a simple schedule of 1.5 ac/h is taken during the night in summer and 0.5 ac/h during the winter period.

Cooling system has a set point of 26°C (indoor air temperature).

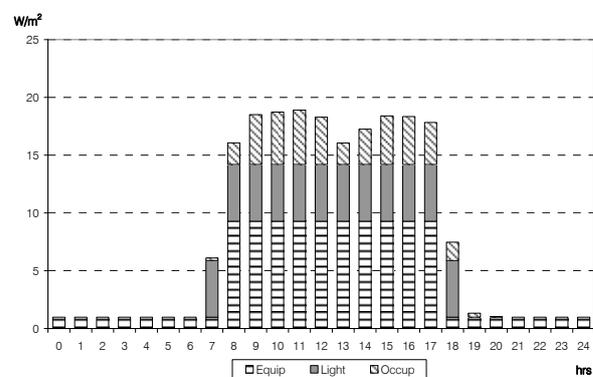


Figure 3: Internal gains, Occupant, Light and Equipments.

Two different shading devices are adopted (see Figure 4):

- external silver venetian blinds;
- internal Genius™ slats.

The effective g-values for both systems were calculated with the new method described in Kuhn 2006a (see Figure 6) which allows a more realistic calculation of these values.

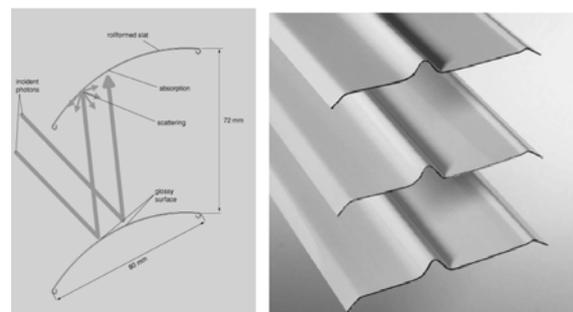


Figure 4: On the left the simulated external venetian blinds, on the right the Inter Genius™ blinds.

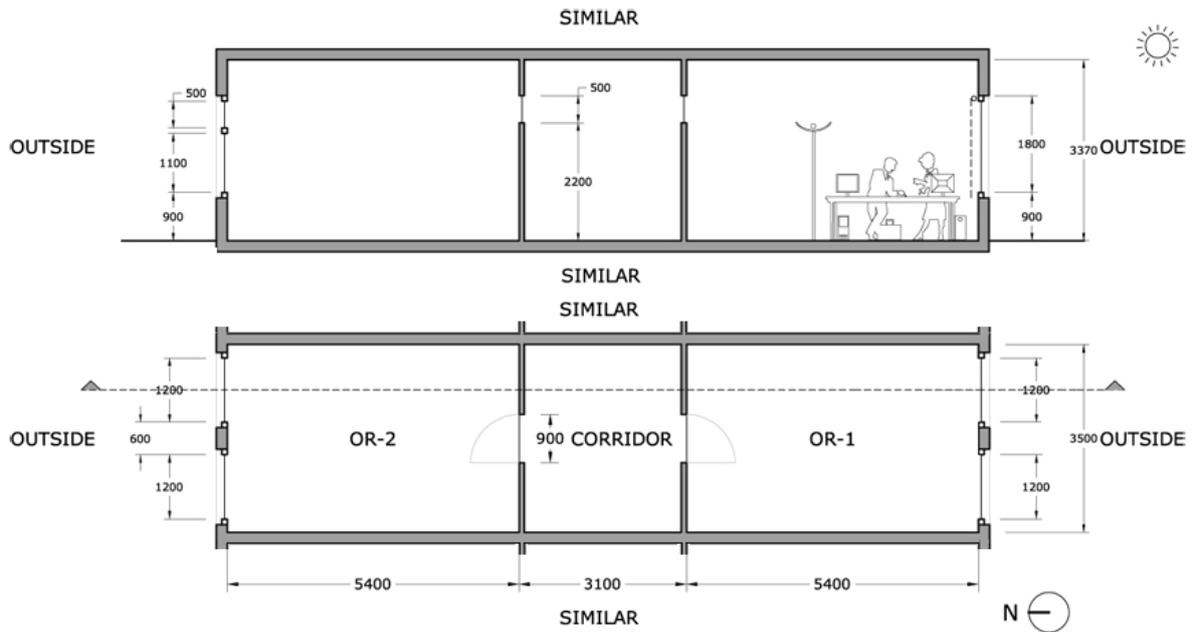


Figure 5: Section, plan view of the office-model

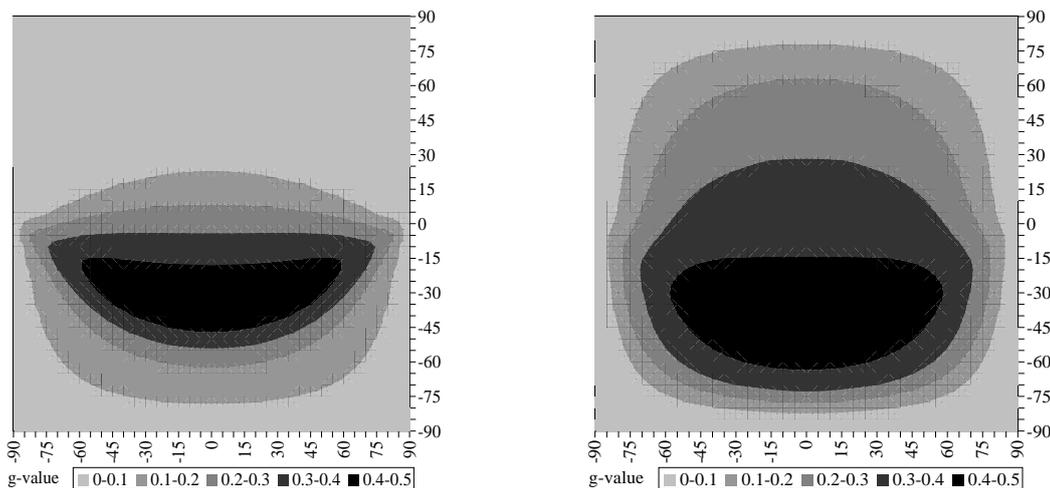


Figure 6: The left picture shows the g-value of the double glazing façade with external venetian blinds for slat angles equal to  $36^\circ$ . On the right the g-value of the double glazing façade with internal Genius<sup>TM</sup> blinds for slat angles equal to  $37.5^\circ$  is plotted.

Table 2: Strategy 2 slat angles definition. Two different slats are considered. The effective g-value of the systems are defined in Figure 6.

INCIDENT RADIATION [W/m <sup>2</sup> ]	SLAT ANGLE [°]	
	Genius <sup>TM</sup>	Venetian blinds
<20 W/m <sup>2</sup>	Blinds are retracted	
20 W/m <sup>2</sup>	0°	0°
40 W/m <sup>2</sup>	18.8°	18°
60 W/m <sup>2</sup>	37.5°	36°
80 W/m <sup>2</sup>	56.2°	52°
100 W/m <sup>2</sup>	(closed position) 77°	(closed position) 72°

Two different control strategies were used to define the position of the shading device (up or down and slat angles) depending on the incident solar radiation (W/m<sup>2</sup>).

- Strategy 1: A fixed slat angle is used ( $36^\circ$  for venetian blinds and  $37.5^\circ$  for Genius<sup>TM</sup>): only the position of the blinds is changed depending on the incident radiation. When it is more than 100W/m<sup>2</sup> the blinds are completely down. When it is less than 100W/m<sup>2</sup> the blinds are retracted.
- Strategy 2: the slat angles of the blinds depend on the solar incident radiation (see Table 2): as the radiation level increases, the slat angles are increased to reduce the amount of transmitted radiation.

## RESULTS

The impact of the different control strategies on the internal room temperature and energy load was investigated for the south facing office (OR1 in Figure 5).

The simulations were carried out for the summer period (starting from the 21st of June to the 21st of September). Freiburg (Germany) is taken as weather data. Only the working hours are considered in the evaluation.

The results are plotted in Figure 7, Figure 8, Figure 9 and Figure 10.

Table 3 reveals the importance of modelling correctly the control strategies of the blind and the effective g-value of glazed façades with shading devices. The maximum difference in the internal temperature between the two simulated control strategies could reach, for the rooms in this model, 1.5°C for the case of external venetian blinds (see Figure 8).

With the new interface it is easy to evaluate the impact of different shading devices on the internal temperatures and cooling loads. The two different shading devices considered in this paper give different results for the indoor resultant temperature.

This results reveal two important aspects:

- The examples demonstrate that different control strategies can have a big influence on the performance of buildings and should therefore be considered by designers.
- The examples show that different control strategies can now be assessed and their effect can be quantified with the new BBM for complex facades in ESP-r.

Table 3: Simulated energy demand for the summer period (21 June to 21 September) for the two control strategies of the blinds.

	SENSIBLE ENERGY [kWh]	NUMBER OF HOURS [h]
Venetian blinds		
Strategy 1	102.93	540
Strategy 2	58.03	403
Difference	44.90	137
Genius™ slats		
Strategy 1	186.41	695
Strategy 2	116.66	583
Difference	69.75	112

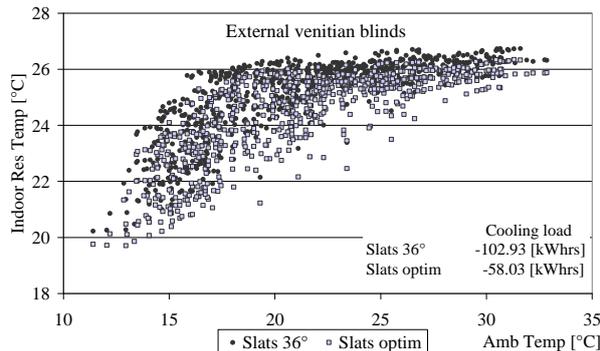


Figure 7: Indoor temperature for the two simulated strategies for the case of external venetian blinds, as a function of ambient temperature. Only the working hours are considered.

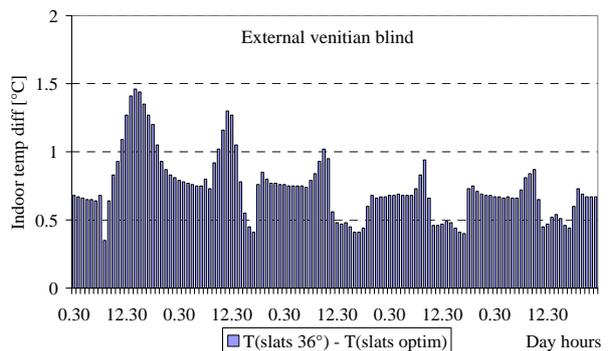


Figure 8: Indoor temperature difference between the two simulated strategies.

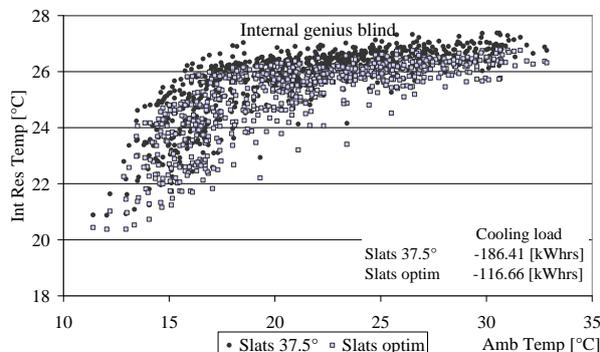


Figure 9: Indoor temperature for the two simulated strategies for the case of Genius™ blinds as a function of ambient temperature. Only the working hours are considered.

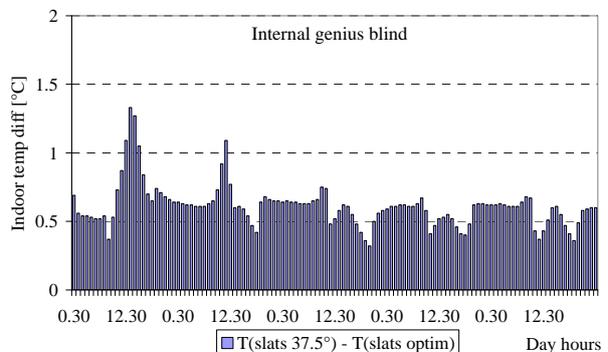


Figure 10: Indoor temperature difference between the two simulated strategies. If different strategies are considered the indoor temperatures change and the energy demand for cooling power decreases.

## DISCUSSION AND CONCLUSION

This paper describes the implementation of a new method for modelling the solar energy transmittance and absorption for complex glazing façades in the ESP-r building energy simulation program.

The new model can be used by architects, planners, engineers or manufacturers.

The previous section demonstrates that complex façades can have both positive and negative effects on the thermal comfort of occupants for an office space, depending on the control strategy used. It also proves that accurate modelling of the characteristics of the system (geometry, slat reflectance, etc.) is necessary for an accurate prediction of energy consumption and thermal comfort.

The case study further demonstrates that the new ESP-r interface can be used to better evaluate the impact of different technologies (different shading devices, different complex façades) on the thermal comfort of an enclosure and on the energy demands.

## FURTHER DEVELOPMENT

Some limitations are still not solved and further analysis and studies must be done by the authors:

- Only UP or DOWN positions for the blinds are considered (e.g. the blinds cannot be positioned to cover only half of the window).

## NOMENCLATURE

SYMBOL	DESCRIPTION
$\gamma$	façade orientation ( $0^\circ$ = south, west positive)
$\gamma_s$	solar azimuth angle ( $0^\circ$ = south, west positive)
$\gamma_f$	$\gamma_f = \gamma_s - \gamma$ (façade azimuth angle, $0^\circ$ parallel to façade normal)
$\alpha_s$	solar altitude angle
$\alpha_p$	solar profile angle $\alpha_p(\alpha_s, \gamma_f) = \arctan\left(\frac{\tan(\alpha_s)}{\cos(\gamma_f)}\right)$
$\alpha_{in}$	angle of incidence $\alpha_{in}(\alpha_s, \gamma_f) = \arccos(\cos(\alpha_s)\cos(\gamma_f))$
$\beta_k$	tilt angle of the slats of a venetian blind or, in the case of façades with switchable properties, a parameter field which characterises the actual setting
$g_{tot}$	total solar energy transmittance of glazing and blind depending on $(\alpha_s, \gamma_f, \beta_k)$ .
“i”	number of the possible sets (for blinds, representing the angle of the slats)
abs	absorptance
$\rho$	reflectance
g	g-value, total transmittance
Te	direct transmittance
tauvis	visual transmission

- The Solar Façade group of Fraunhofer ISE is currently preparing a library of pre-calculated complex façade constructions that will be available for users.
- Slat angles are pre-determined (no glare analysis is done to determine appropriate slat angles)
- Pre-calculation of the façade properties is needed; at the moment there are no user friendly tools for this pre-calculation.
- Further model development must be done to take into account more accurately the diffuse irradiation. A new model for daylighting calculation is available for the software Daysim. This new Dynamic Daylight Simulation (DDS) was developed as a mechanism for sharing daylight coefficient data between lighting and energy simulation programs (Laouadi et al. 2007, Bourgeois et al. 2007).
- Additional control options should be added to allow combinations of sensed conditions (e.g. temperature and irradiation) to determine the appropriate slat state.

## ACKNOWLEDGMENT

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