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# COMPARATIVE THERMAL SIMULATION OF CONVENTIONAL AND DAYLIGHT DEFLECTING SYSTEMS WITH BSDF-BASED MODELS IN TRNSYS AND ENERGYPLUS

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## Abstract

Upcoming trends in implementing complex façade systems in the modern architecture of office buildings requires the development of improved methods and validation tools for planning and engineering purposes. For a detailed modeling of complex fenestration systems (CFS) within dynamic thermal simulation tools like TRNSYS17 and EnergyPlus8.0, models based on bi-directional scattering distribution functions (BSDF) are available. Thus, in combination with the well-established software tool WINDOW7 from LBNL, a flexible implementation of different glazing systems including blinds and other shading layers is possible. This paper shows the theoretical concept of CFS modeling including BSDF-data by a new model, which is implemented as beta-version in the multizone building model (Type 56) of TRNSYS17. In cooperation, static validations of the new model with WINDOW7 by comparative simulations under varying system parameters were worked out. Ongoing improvements on the CFS modeling algorithms during the validation process are described in this work. In addition, the TRNSYS model was compared to the validated BSDF model of Energy Plus8.0 under varying boundary conditions. The results of the TRNSYS model show excellent accordance with WINDOW7 under static conditions after optimization. The comparison to Energy Plus 8.0 show slight deviations which result from non-steady boundary conditions. The actual models based on BSDF data allow a complete modeling of daylight deflecting systems for the optical properties, but show still limitations in flexible thermal algorithms especially for complex blind geometries.

## 1. Introduction

The use of complex façade systems offers a high potential in energy savings compared to the state of the art shading systems mainly installed in the commercial building stock. Especially for office buildings light-redirecting systems allow an improvement of both, visual and thermal comfort. Former research work showed a significant potential in reduction of artificial lighting due to higher workplace luminance by daylighting. Furthermore a reduced solar gain in summer season through transparent facades and energy efficient shading control leads in a significant reduction of the cooling energy demand.

To fulfill these requirements in planning, a detailed numerical method for a coupled thermal and lighting simulation of complex façade systems with integrated daylight deflecting (specular) systems is worked out on the national research project lightSIMheat, funded by the Austrian Research Agency (FFG).

An inquiry on existing research work and modeling approaches present the concept and state of the art in CFS modeling. In more detail the modeling approach with integrated BSDF data for shortwave radiation treatment and algorithms based on ISO 15099 standard (ISO 15099, 2003) for thermal calculation is introduced. Based on these concept a simulation model was by (Schöttl 2013) lately and has been integrated in the multizone building model of TRNSYS (Hiller and Schöttl 2014). This model is tested and validated as beta-version for research purposes in lightSIMheat. Based on the results modeling improvements as well as necessary extensions for the simulation of daylight deflecting systems are discussed and will built the basis for ongoing work in the research project.


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| Nomenclature | Symbol | Nomenclature | Symbol |
|---|---|---|---|
| Effective emissivity, front (f) / back (b) | $\varepsilon_{eff,f}$ / $\varepsilon_{eff,b}$ | Transmittance | $\tau$ |
| Slat material emissivity, front (f) / back (b) | $\varepsilon_{slat,f}$ / $\varepsilon_{slat,b}$ | Reflectance | $r$ |
| Solar heat gain coefficient | *SHGC* | Radiosity from surface k | $J_k$ |
| Near infrared radiation | *IR* | Temperature in surface k | $T_k$ |
| Far-infrared radiation | *FIR* | Heat flux | $q$ |
| Temperature surface inside | *TSI* | Irradiance on surface k | $E_k$ |
| Temperature surface outside | *TSO* | View factor from surface p to q | $F_{p\rightarrow q}$ |

## 2. Overview on CFS modeling research

Compared to conventional glazing systems, CFS including a shading layer (venetian blinds, screens or woven shades) shows a bidirectional scattering of the radiation striking the shading layer. Several investigations were already done in the modeling of venetian blinds incorporating with glazing layers.

Due to the high flexibility of the system setup of CFS and the interconnection of the occurring physical phenomena, (e.g. radiative heat exchange, natural or forcing convection, conduction) the modeling of optical and thermal properties of such a system is very complex. Beside them blind surface properties (diffuse reflective or specular reflection) as well as their geometry (planar, curved, or multi-curved) extend the variations in modeling purposes.

Decreasing high efforts in modeling and providing detailed product data as simulation input, major simplifications were realized in previous simulations by treating the amount of shaded solar fraction by a constant percentage representing the blocked sun radiation (shading factor). Occurring radiation exchange between glazing and blind and blinds itself were neglected. As these processes have considerable effects on the amount of absorbed solar radiation in the different layers and their temperatures, it is obviously decisive for exact calculation of heating and cooling demand as well as comfort situation in a room.

An initial work was done by (Parmelee and Aubele 1956) in compiling first analytical expressions to model the transmittance and absorptance of venetian blinds. Based on these work further improvements presented in studies by (Pfrommer et.al. 1996) and Rosenfeld (Rosenfeld et al. 2001) in deriving an analytical model out from geometrical and physical properties of the shading system to characterize the solar radiation transport. All models mentioned above implied simplifications by (i) neglect the slat thickness, (ii) assume flat and opaque slats and (iii) define the optical characteristic of the slat surface as ideal diffusing.

Further investigations in improving geometrical modeling details were done by (Tzempelikos 2008) and later also by (Chaiyapinunt and Worasinchai 2009) incorporating a curved blinds geometry. (Rosenfeld et al. 2001) firstly developed an improved model inspired by the observation that the behavior of lamella reflectance is highly anisotropic and is strongly peaked about the specular direction.

Detailed numerical analysis was investigated by (Collins et al. 2009) in determining the complex behavior of convective heat transfer with between-the-glass louvered shades and deriving an appropriate physical model. To quantify the longwave radiation exchange between the layers and blinds all models above are based on the layer-by-layer radiosity-approach.

Several modeling studies with strong focus on modeling simplification were presented by (Kuhn et al. 2011) respectively (Yahoda and Wright 2005), (Yahoda et al. 2004), (Wright 2008) in order to decrease data and simulation efforts. Former developed a semi-analytical model only based on the bi-directional heat transfer coefficient and transmission values, second presented in several works a new method in quantifying the convective and radiant heat transfer of multilayer-systems using a flexible resistor network.

## 3. Optical and thermal modeling with BSDF data and ISO 15099 algorithms

### *3.1. Modelling algorithms of ISO 15099*

For glazing systems without shading devices a one-dimensional dependency of the SHGC is enough. For an accurate modeling of a complex glazing system including a shading layer, the solar heat gain coefficient (SHGC) has to be defined in a two-dimensional dependency of the incoming solar angle.

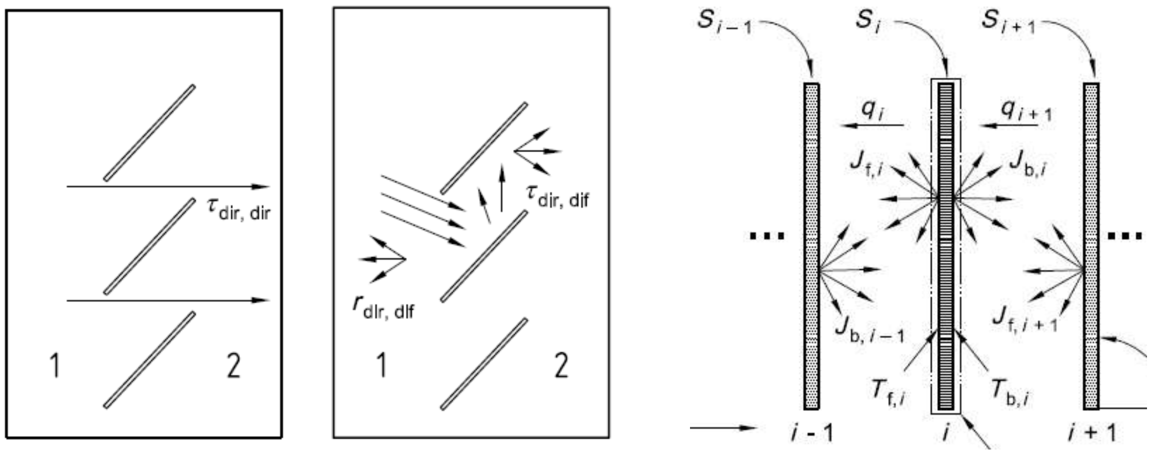



**Figure 1: Optical and thermal modeling of CFS according to (ISO 15099 standard 2003)**

The ISO 15099 standard specifies detailed calculation procedures (partly based on above mentioned works) determining the optical properties and thermal transmission properties of a glazing system incorporating with a shading layer. Both, transmitted solar radiation depending on optical surface properties and the thermal driven radiosity balance depending on solar-thermal properties, determines the overall energy transmittance of the CFS, usually defined as solar heat gain coefficient (SHGC).

Based on the established concept of a layer-by-layer calculation for glazing systems (Fig. 1 right), the ISO15099 standard is an enhancement of this method to be adaptable also for CFS with a discretized venetian blind model. Depending on slat geometry and optical properties, bi-directional transmission- and reflection values of the shading layer are calculated by an optical slat model, which is based on the radiosity exchange by view-factors.

Transmitted and reflected radiation (Fig. 1, left) is subdivided in a *direct-direct* component ($\tau_{dir,\ dir}$), which doesn't strike the slat surface, a *direct –diffuse* component ($\tau_{dir,\ dif}$ / $r_{dir,\ dif}$), which strikes the slat surface and is reflected ideal diffuse and a *diffuse-diffuse* component ($\tau_{dir,\ dif}$ / $r_{dir,\ dif}$). Radiation which is neither transmitted, nor reflected, is the part which is absorbed in the slat material. It will be stored as thermal energy in the different layers which occurs in a rise of the layer temperature and serves as a source term for the radiosity-balance in a second step. Due to ideal diffuse characteristics of the infrared radiation part, it can be modeled identical to the diffuse shortwave radiation part.

Compared to glazing layers, shading layers are also semi-transparent for IR/FIR radiation exchange as well for thermal driven air-interchange within the gaps next to the shading layer. The convective behavior of the slats is modeled by a complex pressure-difference model including an openness fraction, which describes the hole-area depending on slat geometry and slat angle. The optical algorithms of the optical blind model are mainly restricted to conventional raffstores with standard geometries like planar or curved blinds and ideal diffusely reflective surfaces. For an accurate modeling of more complex shading systems with flexible geometries or specular surfaces the optical blind model has to be replaced by shading layer defined with pre-calculated BSDF data.

### 3.2. Optical modeling with BSDF data

The method of BSDF (bi-directional scattering distribution functions) was introduced by (Klems 1994) and describes a flexible method to calculate the bi-directional solar transmission of a CFS by simple matrix multiplications. In discretizing the hemisphere at the front and the back side of the CFS-layer into 145 areas (Fig. 3), a detailed specification of the optical properties of each layer depending on azimuth and zenith angle is possible. Due to the matrix-layout, the overall properties of the CFS are calculated by a matrix-layer calculation. The BSDF dataset contains 145 outgoing values in overall transmission and reflection of the CFS for each of the 145 ingoing values at the CFS. This method fully displaces the optical blind model.

The modeling algorithms in the ISO 15099 are restricted to blinds with ideal diffuse reflecting surfaces. Concerning daylight deflecting systems including specular surfaces the optical behavior can’t be modeled accurate enough by using the optical slat model (Rosenfeld et al. 2001). By replacing the analytical model calculation with a pre-calculated BSDF, generated by ray-tracing or measurement technique, the part of optical modeling can be fulfilled as the algorithms consider specular reflection.

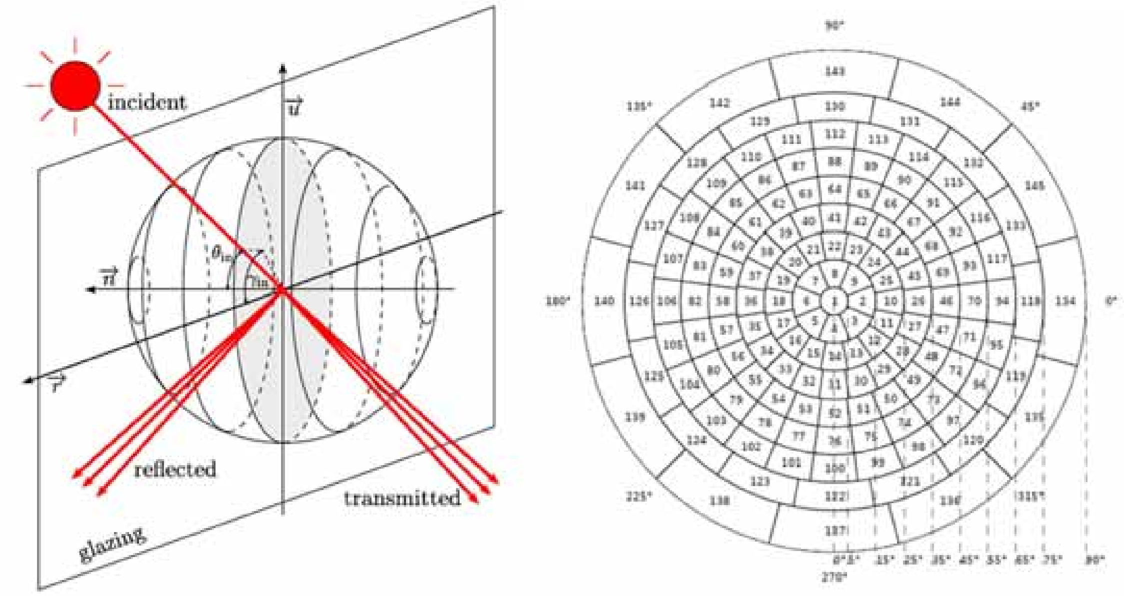



**Figure 2: Optical modeling with BSDF data (Schöttl 2013)**

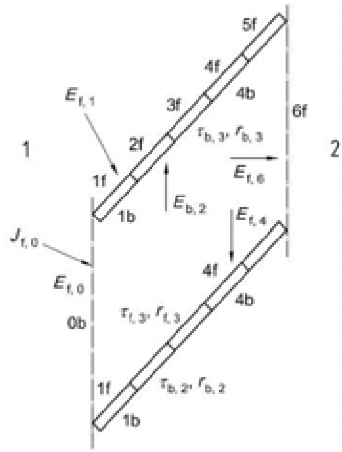
### 3.3. Thermal modelling of diffuse and specular blinds with effective layer properties

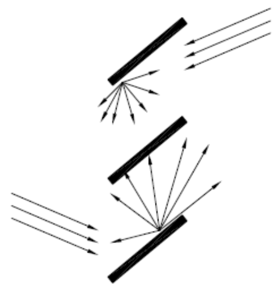
For the FIR radiation exchange within the different CFS layers, the emissivity of the surrounding surfaces is deterministic. In case of a venetian blind the effective emissivity (equivalent value perpendicular to the shading layer), which is in relevance for the thermal radiation exchange within the glazing layers next to, differs from the material emissivity of the slat surface and depends on slat geometry (planar or curved) respectively slat angle. By calculating the view factor within a slat cavity as shown in Figure 4, the effective emissivity for a fictive surface 1 (back side of slat) and surface 3 (front side of slat) can be calculated due to following formulations. In Table 1, this is exemplarily done for a planar slat (Venetian_B45) defined as a standard blind in the WINDOW shading library. The result from view factor calculation by eq.1 and eq.2 shows good agreement as shown with the internal calculations in WINDOW ($\varepsilon_{eff,f}$, $\varepsilon_{eff,b}$ = 0,729).

$$\varepsilon_{eff,f} = \varepsilon_{slat,f} * F[3,2] + \varepsilon_{slat,b} * F[3,4] = 0{,}9 * 0.08637 + 0{,}9 * 0.69216 = 0{,}7006 \quad \text{(eq.1)}$$

$$\varepsilon_{eff,b} = \varepsilon_{slat,b} * F[1,4] + \varepsilon_{slat,f} * F[1,2] = 0{,}9 * 0.69216 + 0{,}9 * 0.08637 = 0{,}7006 \quad \text{(eq. 2)}$$

Beside the emissivity also the value for IR transparency is dependent on the radiosity exchange within the surfaces surrounding the slat cavity. Therefore it is also depending on the view factor of surface 3 → 1 (front infrared transmittance) and surface 1 → 3 (back infrared transmittance). Both calculations shown by eq.5 were compared to results documented in the ISO 15099 and show a good accordance.



$$E_{f,i} = \sum_k \left[ \left( r_{f,k} + \tau_{b,k} \right) E_{f,k} F_{f,k \to f,i} + \left( r_{b,k} + \tau_{f,k} \right) E_{b,k} F_{b,k \to f,i} \right] \quad \text{(eq. 3)}$$

$$E_{b,i} = \sum_k \left[ \left( r_{b,k} + \tau_{f,k} \right) E_{b,k} F_{b,k \to b,i} + \left( r_{f,k} + \tau_{b,k} \right) E_{f,k} F_{f,k \to b,i} \right] \quad \text{(eq. 4)}$$

**Figure 3: Discretized slat cavity model with radiosity balance based on View factors (ISO 15099 standard 2003)**

**Table 1: View factors (F) for diffuse reflecting slat in Figure 3 calculated with software View3D**

| | Surface 1 | Surface 2 | Surface 3 | Surface 4 | Surface 5 | Surface 6 | |
|---|---|---|---|---|---|---|---|
| Area | 0.012 | 0.016 | 0.012 | 0.016 | 0.0001358 | 0.0001358 | Sum |
| Surface 1 | | ***0.08637*** | ***0.21664*** | ***0.69216*** | 0.002418 | 0.002418 | 1.0 |
| Surface 2 | 0.064774 | | 0.519118 | 0.41125 | 0.002429 | 0.002429 | 1.0 |
| Surface 3 | ***0.21664*** | **0.692157** | | ***0.086366*** | 0.002418 | 0.002418 | 1.0 |
| Surface 4 | 0.519118 | 0.41125 | 0.064774 | | 0.002429 | 0.002429 | 1.0 |
| Surface 5 | 0.21372 | 0.286259 | 0.21372 | 0.286259 | | 0.000043 | 1.0 |
| Surface 6 | 0.21372 | 0.286259 | 0.21372 | 0.286259 | 0.000043 | | 1.0 |
| Emissivity | 0.84 | 0.9 | 0.84 | 0.9 | 0.999 | 0.999 | |

$$\tau_{IR,f} = \tau_{IR,b} = F(1,3) = F(3,1) = 0{,}216 \qquad \tau_{IR,ISO\ 15099} = 0{,}227 \quad \text{(eq. 5)}$$

As also longwave radiation belongs to the physical phenomena of specular reflection, in contrary to diffuse reflecting blinds the thermal radiation modeling for specular blind surfaces has to be done separately for the near-infrared (IR) and far-infrared (FIR) range. Despite to the IR radiation part, which is included in the solar spectrum and therefore directed radiated from the sun, the FIR radiation part belongs to the thermal radiation from surrounding surfaces (ground, neighbor facades), which has a diffuse characteristic due to emitted radiation. While IR-radiation strikes a specular surface, it will be reflected specular, which should be considered in WINDOW data by modeling with the optical BSDF within the solar spectrum including visible and near-infrared. After striking a diffuse surface (e.g. bottom surface of a slat) IR will be diffusely reflected or absorbed and diffusely emitted. Due to a high reflective part of specular surfaces less radiation will be absorbed in the blind compared to blinds with diffuse reflecting surface and higher absorption. Therefore higher slat temperatures can be expected at diffuse blind systems which can have particular effect on the convective circulation in the slat gap.

Exact modeling of the effect of convective circulation in the slat gap is a difficult task and still under research (Collins et al. 2009). The ISO 15099 offers a quite complex pressure drop algorithm to consider the thermal driven convection occurring in the gap between the glazing layer and the shading as well as between the two slats itself. Depending on slat angle and slat geometry the effective openness factor, which describes the ratio of slat area to overall window area, can theoretically change between 0 and 1. An exact description of the algorithm behind is still missing and under research. Furthermore an additional thermal model named “Convective Scalar” is implemented in WINDOW to consider this effect of convective circulation within the slat gap.

# 1. Comparative simulations: WINDOW7 – TRNSYS17 – EnergyPlus8.0

## *4.1. Static validations: TRNSYS 17 BSDF – WINDOW7*

The algorithms from ISO 15099 standard as well as the BSDF method are fully implemented in WINDOW7. For a first validation the new implemented BSDF model in TRNSYS is compared against static calculations results from WINDOW7. A reference room with adiabatic envelope and ideal heating and cooling according to boundary conditions by the National Fenestration Rating Council (NFRC) in Table 2 is modeled. For the evaluation of the layer temperatures as well as the SHGC summer conditions are valid. The U-value calculation is done under winter conditions mentioned in brackets.

**Table 2: NFRC summer (SHGC) and winter (U-value) boundary conditions for static simulations**

| | outside | inside |
|---|---|---|
| Air temperature | 32°C (-18°C) | 24°C (21°C) |
| Radiation temperature | 32°C (-18°C) | 24°C (21°C) |
| Incident radiation | 783 W/m² (0 W/m²) | - |
| Wind speed | 2.75 m/s (5.5 m/s) | - |
| Effective emissivity | 1 | 1 |

For the static validation 3 conventional systems (System 1-3) with standard components from the internal WINDOW7 library and one daylight deflecting system modeled by external BSDF data (System 4) are defined. In Table 3 the layer setup is shown starting with the outer layer (1) and ending with the inner layer (5). Layer 2/4 is representing the gas fillings.

**Table 3: System definition for static validation**

| L | SYSTEM 1 | ID |
|---|---|---|
| 1 | Clear Glass | 103 |
| 2 | Argon/Air (90/10%) | 9 |
| 3 | Clear Glass | 103 |
| 4 | Argon/Air (90/10%) | 9 |
| 5 | Clear Glass | 103 |

| | SYSTEM 2 | |
|---|---|---|
| 1 | Clear Glass | 103 |
| 2 | Argon/Air (90/10%) | 9 |
| 3 | Venetian blind 45deg | 30 |
| 4 | Argon/Air (90/10%) | 9 |
| 5 | Clear Glass | 103 |

| | SYSTEM 3 | |
|---|---|---|
| 1 | Venetian blind 45deg | 30 |
| 2 | Air (100%) | 1 |
| 3 | Clear Glass | 103 |
| 4 | Argon/Air (90/10%) | 9 |
| 5 | Clear Glass | |

| | SYSTEM 4 | |
|---|---|---|
| 1 | Clear Glass | 103 |
| 2 | Argon/Air (90/10%) | 9 |
| 3 | BSDF | X |
| 4 | Argon/Air (90/10%) | 9 |
| 5 | Clear Glass | 103 |

**Table 4: Specification of the conventional venetian blind in System 2 and 3**

| | *System 2/ 3* | *System 4* |
|---|---|---|
| *Slat width* | 76.2 mm | 53.0 mm |
| *Spacing* | 57.2 mm | 50.0 mm |
| *Slat thickness* | 53.9 mm | 37.7 mm |
| *Rise* | 6 mm | 9 mm |
| *Tilt angle* | 45° | 45° |
| *Slat material* | ID31100 | BSDF |
| *Material emissivity (f/b)* | 0.9 / 0.9 | 0.04 / 0.9 |

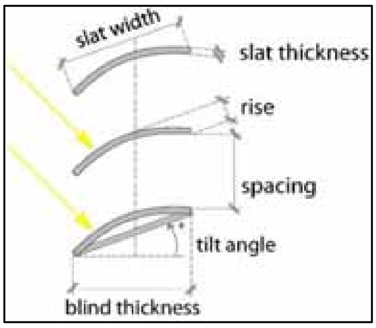



**Figure 4: Definition of blind geometry**

By varying the slat angle for System2 (interior shading) between fully open (00_deg) and fully closed (90_deg) the effective IR properties of the layer change. The values listen in Table 5 are taken from the WINDOW debug file.

**Table 5: IR properties for the effective shading layer**

| | System 2 and 3 | | | | | System 4 |
|---|---|---|---|---|---|---|
| *Slat angle* | *0_deg* | *30_deg* | *45_deg* | *60_deg* | *90_deg* | *45_deg* |
| *IR transmittance* | 0.33554 | 0.28112 | 0.21577 | 0.13063 | 0.00070 | 0.30513 |
| *Effective emissivity, f* | 0.64171 | 0.68280 | 0.73482 | 0.80320 | 0.90526 | 0.31519 |
| *Effective emissivity, b* | 0.64171 | 0.69940 | 0.74393 | 0.81396 | 0.91345 | 0.63414 |
| *Eff. openness factor* | 1 | 0.67 | 0.5 | 0.33 | 0 | 0.4 |

### 4.2. Dynamic ("quasi-static") validations: TRNSYS17 BSDF – ENERGY PLUS 8.0

While the static validation with WINDOW7 are strongly focused on validation of the modeling algorithms itself, a comparison with the Energy Plus 8.0 model check the modeling capacity on dynamic influences at the CFS modeling by coupling with variable environmental conditions including internal and external radiation exchange. For the modeling of a CFS the simulation software Energy Plus 8.0 has implemented an analytical modeling approach based on defining the blinds geometries as well as the possibility to import pre-calculated BSDF data from WINDOW for the optical modeling. The thermal modeling is also done according to the ISO 15099 standard.

For the comparative simulations a reference room according to Table 6 is modeled. The geometry as a 3D SketchUp-model according to Figure 5 was drawn and imported into TRNSYS17 and Energy Plus 8.0. All surfaces are set to adiabatic except the south façade including the CFS, which is exposed to variable environmental conditions depending on the variants table (Table 7). For the exterior wall a standard construction with a U-value of 0,219W/m²K was defined, all boundary walls are modeled as massless layers. The heat transfer coefficients of the walls and glazing are constant with 3,055 W/m²K inside respectively 17,778 W/m²K outside facing. The emissivity of the inner walls is set to 1 due to allow an ideal distribution of the longwave radiation within the room.

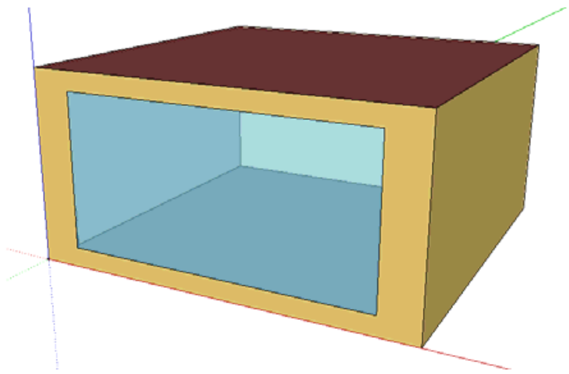


**Figure 5: 3D Sketch up model of NFRC reference room**

**Table 6: Definitions NFRC reference room**

| | |
|---|---|
| Dimension Room | 10m x 10m x 5m |
| Dimension CFS | 8m x 4m |
| Heating/Cooling | 24°C |
| $h_{c\_in}$ / $h_{c\_out}$ | 3,055 / 17,778W/m²K |
| $\alpha_{sol\_in}$ / $\alpha_{sol\_out}$ | 0.5 / 0.5 |
| $\varepsilon_{sol\_in}$ / $\varepsilon_{sol\_out}$ | 1 / 1 |

TRNSYS17 and Energy Plus use in principal identical methods for internal and external radiation modeling, which allows under certain boundary conditions a direct comparison of the simulation results. As it is unfortunately not possible in Energy Plus to fix the incident solar angle on a certain value for static simulation conditions, the model comparison was done by "quasi-static" simulations. Therefore one exemplarily week in January with climate conditions of the location Innsbruck is fixed.

Both programs use the same climate date in the Energy Plus format (.epw). To quantify the influences of the boundaries in CFS modeling, several variants by stepwise increase of dynamic environmental conditions, shown in Table 7, are defined and evaluated.

**Table 7: Simulation variants for the quasi-static validation**

| | *Fixed values* | *variable values (from weather file)* |
|---|---|---|
| *Variant 1* | $T_a = 0°C$ / $T_{sky} = 0°C$ | $I_{sol}$ |
| *Variant 2* | $T_{amb} = 0°C$ | $I_{sol}$ / $T_{sky}$ |
| *Variant 3* | $T_{sky} = 0°C$ | $I_{sol}$ / $T_{amb}$ |
| *Variant 4* | - | $I_{sol}$ / $T_{amb}$ / $T_{sky}$ |

In both programs the external solar radiation on a tilted surface (direct and diffuse) is calculated by the Perez model. Solar radiation passing the CFS strikes a certain interior wall surface depending on the incident solar angle and will be absorbed depending on $\alpha_{sol.}$ The internal longwave radiation exchange is depending on view factors between the inner surfaces, which are calculated based on the geometrical Sketch up model. To ensure a similar treatment of the solar radiation, the values for the solar absorptance ($\alpha_{sol}$) as well as the longwave emission coefficient of inside and outside facing surfaces are set uniformly in both programs. Due to modeling differences of the fictive sky temperature between both programs, the coefficient in both programs is set to a constant value or the calculated values from Energy Plus 8.0 are also used in the TRNSYS17 simulation. To keep the focus of influence on the radiation modeling, all other parameters like infiltration, ventilation and internal gains are set to zero.

## 1. Results

### *5.1. Static validation results TRNSYS 17 BSDF – WINDOW7*

In Table 8 absolute temperature values of the layers as well results for U-value and SHGC by WINDOW (WIN) and TRNSYS (BSDF) are listed. High model accuracy for conventional systems (System 1-3) as well as for light deflecting systems (System 4) with a high reflective surface can be shown. Differences in the gap temperatures result from different modeling approaches, in which the results from TRNSYS seem to be more realistic.

**Table 8: Static results for all systems with slat angle of 45deg: WINDOW7 (WIN) - TRNSYS17-BSDF (BSDF)**

| **Absolute values** | **System 1** | | **System 2** | | **System 3** | | **System 4** | |
|---|---|---|---|---|---|---|---|---|
| | *WIN* | *BSDF* | *WIN* | *BSDF* | *WIN* | *BSDF* | *WIN* | *BSDF* |
| *Layer1, front* | 39.46 | 39.47 | 45.33 | 45.34 | 46.24 | 46.23 | 39.82 | 39.82 |
| *Layer1, back* | 40.00 | 40.01 | 46.50 | 46.50 | 46.24 | 46.27 | 40.36 | 40.37 |
| *Gap1* | 29.99 | 37.40 | 29.34 | 43.61 | 30.99 | 36.26 | 29.23 | 38.35 |
| *Layer2, front* | 45.29 | 45.29 | 66.49 | 66.48 | 38.39 | 38.40 | 50.10 | 50.11 |
| *Layer2, back* | 45.25 | 45.25 | 66.49 | 66.47 | 38.21 | 38.23 | 50.10 | 50.10 |
| *Gap2* | 27.46 | 42.65 | 28.28 | 56.42 | 31.75 | 36.26 | 27.87 | 45.20 |
| *Layer3, front* | 37.85 | 37.84 | 44.52 | 44.51 | 31.60 | 31.61 | 38.86 | 38.86 |
| *Layer3, back* | 37.40 | 37.40 | 43.60 | 43.61 | 31.32 | 31.33 | 38.35 | 38.35 |
| *U-value NFRC=Winter* | 1.620 | 1.620 | 2.170 | 2.166 | 1.967 | 1.966 | 2.080 | 2.077 |
| *SHGC NFRC=Summer* | 0.622 | 0.622 | 0.306 | 0.305 | 0.149 | 0.149 | 0.532 | 0.533 |

In Table 9 as result difference values between the WINDOW calculation and simulation results with the TRNSYS17- BSDF model for variation of the slat angle is shown. By further modification of the model in implementing effective layer properties (Table 5), the model show high accuracy also for different slat angles and different material properties.

**Table 9: Result differences in static simulations between WINDOW7 and TRNSYS17_BSDF for varying slat angles**

| Differences | System_2 | | | | System_3 | | | |
|---|---|---|---|---|---|---|---|---|
| *Temperatures* | *0deg* | *30deg* | *60deg* | *90deg* | *0deg* | *30deg* | *60deg* | *90deg* |
| *Layer1, front* | 0.01 | 0.01 | 0.00 | 0.01 | -0.01 | -0.01 | 0.00 | 0.01 |
| *Layer1, back* | 0.01 | 0.00 | 0.00 | 0.01 | 0.03 | 0.04 | 0.02 | 0.03 |
| *Layer2, front* | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | -0.05 |
| *Layer2, back* | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 | -0.05 |
| *Layer3, front* | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | -0.02 |
| *Layer3, back* | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.02 |
| *Ucenter* | -0.005 | -0.004 | -0.003 | 0.000 | 0.000 | 0.000 | 0.000 | -0.001 |
| *SHGC* | -0.003 | 0.001 | -0.001 | 0.000 | -0.001 | -0.000 | -0.001 | 0.000 |

### 5.2. Quasi-static validation results: TRNSYS17 BSDF vs. Energy Plus 8.0

For the first result all external and internal boundary conditions influencing the CFS modeling (ambient temperature, sky temperature and convective heat gain coefficients) set to constant values (Variant 1). Emission and Absorption values are set uniformly. The solar radiation is held as variable input from the weather file as decisive parameter.

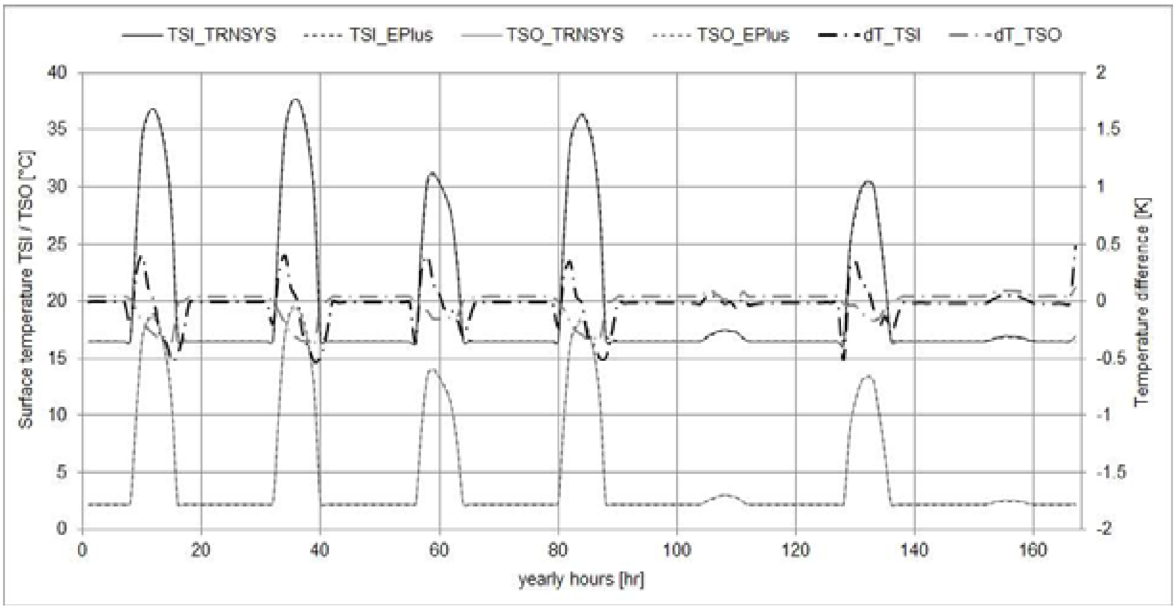



**Figure 6: Quasi-static comparison results of System 2 with fixed boundaries (Variant 1)**

In Figure 6 the trend of the inner glazing surface temperature (TSI, black graphs) and outer glazing surface temperature (TSO, grey graphs) is shown for the first week in January. The solid lines describe the TRNSYS results respectively the dashed line represents the results with Energy Plus. Due to fixed boundary conditions in the first run the deviation tends to be constant at around 0 in times without incident radiation. Highest differences are given during high incident radiation for both surface temperatures with around max. 0,5K. Therefore also the absorbed solar energy in the layers of the CFS was evaluated. As it shows mostly perfect agreement for diffuse blinds, varying boundary conditions can be mentioned as a reason.

In Figure 7 simulation results with variable simulation inputs for ambient temperature, fictive sky temperature and incident solar radiation are plotted. The heat transfer coefficients are still fixed and identical in both programs. In this case the surface temperature trends for the CFS shows again a very good accordance except at times of high incident radiation. Deviation in times without incident radiation shows dependencies of the temperature results in the longwave radiation exchange and thermal modeling.

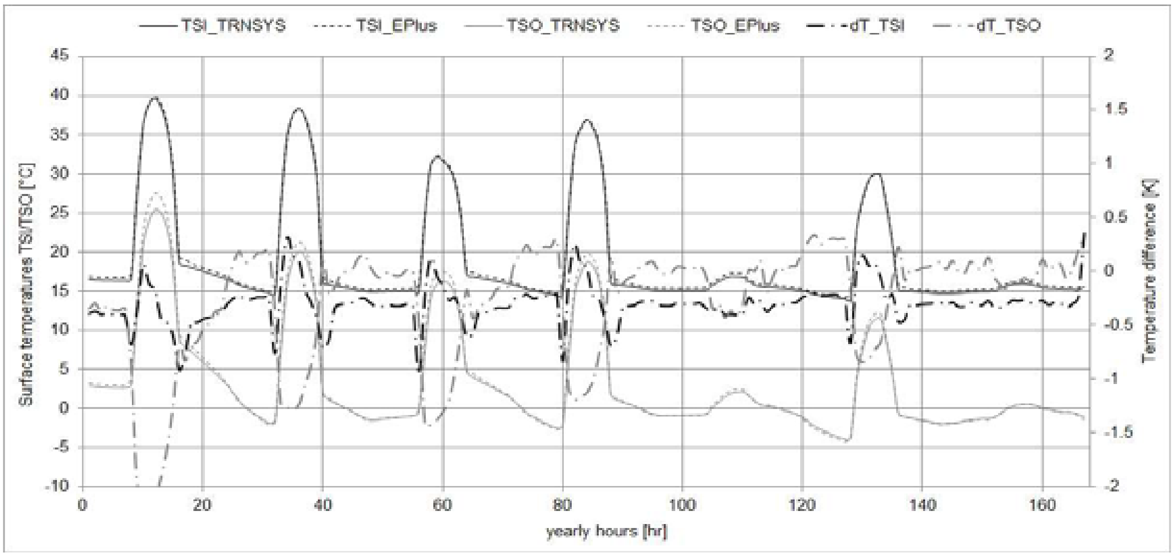



**Figure 7: Quasi-static comparison results of System 2 with variable boundaries (Variant 4)**

## 2. Conclusions

The comparative simulation results of the new implemented BSDF model in TRNSYS17 on a variety of system definitions shows very good accuracy under static conditions as well as sufficient results for dynamic boundary conditions. Although the overall results are satisfying, slightly differences in the results between TRNSYS17 and EnergyPlus8.0 occur, which are also influenced by the non-steady boundary conditions. Differences in the CFS layer temperatures as well as absorbed radiation amounts on the different inner wall surfaces depending on the internal solar distribution have been determined at arguable values for conventional systems, but still higher deviations for light redirecting systems, which results from a different modeling. Beside this, also in terms of thermal modeling a detailed review on the algorithms and methods concerning daylight deflecting systems will be subject for further studies in the project lightSIMheat. Although, the actual models based on BSDF data allow already a very detailed and highly flexible modeling of conventional as well as daylight deflecting systems.

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