INVESTIGATING INFLUENCE OF DIFFERENT SHADING DEVICES ON WINDOW THERMAL PERFORMANCE

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ABSTRACT

Up to 60% of the total energy loss through the building envelope may come from windows, hence their thermal performance needs to be improved. One possible solution is the use of shading devices with insulating properties such as external roller shutters and internal roller blinds.

In this study Computational Fluid Dynamic (CFD) simulations are carried out in order to investigate the influence of external shutters and internal roller blinds on window thermal performance. Significant thermal improvements were achieved for windows with and without low-emissivity (low-e) coating on glazing, 50 and 66% respectively when both external and internal shading were added (with low emissivity surfaces). This study showed that applying shading devices with low emissivity surfaces give the same result in terms of thermal performance as using low-e coatings on glazing. Moreover, it appears that the simulation software WINDOW 6.0 can be used for assessing internal shading influence on thermal performance of center-of-glazing.

INTRODUCTION

Nowadays, saving energy and reducing carbon emissions is one of the top priorities in each sector of human activity. Buildings are an important part of human life, since people use them for a majority part of the day. Energy use in buildings worldwide accounts for over 40% of primary energy use and for around 24% of greenhouse gas emissions. Energy and emissions include both direct usage of fossil fuels (on-site) and indirect use of energy in form of electricity, district heating, district cooling and embodied energy in construction materials (Voss and Musall, 2011).

Windows are inseparable components of the building envelope. In modern designs a trend of increasing the area of fenestration products for residential and commercial constructions is seen worldwide. Windows contribute to a better standard of living with daylight and useful heat gains. On the other hand windows may cause higher heat losses and undesirable heat gains. Currently, the thermal transmittance of fenestration components is not as low as for walls. The study by Gustavsen et al. (2008) shows that even up to 60% of the total energy loss through the building envelope can be due to windows. Therefore improved fenestration products have a huge potential to provide energy savings.

In order to reduce heat loss from windows the thermal insulation needs to be improved. Despite the recent developments the window frames are still the weakest point of windows (Gustavsen et al., 2010). Thermal performance of window glazing can be improved in a several ways. One option is adding more layers of glass, but this makes the window heavier, more expensive, and requires more solid frame/operating hardware. Another solution involves adding low emissivity coatings (low-e) on the glass surfaces. Both of these methods lower the factor of solar heat gain coefficient (SHGC), which has the negative influence on possible heat gains. An alternative solution to address this issue seems to be the use of external or internal shading devices with insulating properties.

One type of external shading devices is the external roller shutter (see example in Figure 1). This kind of shading has the following advantages: relatively easy to install, improves sound insulation, gives additional protection to the window (against burglary and hurricanes), reduces undesired solar heat gains, and adds some additional thermal resistance to the window when closed. Application of the roller shutters can lead to a new solution/approach in window technology. Reducing the number of panes or low-e coatings can increase the solar heat gain coefficient (SHGC) and thus increase solar gains. Expected higher heat losses during night can be balanced by the shading's additional insulation. This would make windows more adjustable/dynamic components and hopefully lead to better building thermal performance. Moreover, the use of external shutters along with highly insulating windows can also lead to lowering the risk of outside condensation on the window in the morning.

Currently, on the market there are various designs of internal shadings made of a wide range of materials. One promising type in terms of a thermal insulation seems to be the internal roller blind (example is presented in Figure 2). Internal blinds are mainly used to provide privacy to occupants during evenings and stop glare/solar gains during sunny days. Usually the materials used for its construction are relatively thin (0.5 – 1 mm). Taking into account thickness and material thermal conductivity those are not able to give additional insulation in terms of simple solid state conduction. However, when installed close to a glass surface (in a way that gives relative good air tightness) creates an additional air gap which could add additional insulation to the glazing by reduced convection and radiation. Also changing the blind's surface emissivity can give reduction in heat losses by radiation.

Figure 1 - Example of external roller shutter. (Evermotion.org, 2012)

Figure 2 - Example of internal roller blind (SOD, 2010)

LITERATURE REVIEW

The topic of window shading has been studied in literature, however there are hardly any publications addressing the issue of thermal effects from roller shutters and internal blinds on window thermal performance. Some studies were addressing this issue but mostly on poorly performing windows.

Wood et al. (2009) together with Glasgow Caledonian University experimentally investigated adding insulation to relatively low-performing historic windows. An example double-hung window has been restored and tested in a climate chamber. Additional insulations have been added on the interior side, tested and compared with window without insulation. It was found that heavy curtains give 39% reduction in heat loss through glazing, well fitted expanded polystyrene (EPS) shutters 64% and reflective roller blinds 66%. Improvements are relatively high because the investigated window initially had relatively high thermal transmittance (single pane glazing, wooden frame without thermal brake).

Zaheer-Uddin (1990) investigated thermal performance of shutters at dynamic conditions which occurred after the shading device was closed. In the literature concerning shading devices, usually it is assumed that instantaneously after the shutter is closed the thermal resistance rise to the maximum level (obtained by steady-state calculations). Zaheer-Uddin (1990) claimed that this assumption is not correct. Experimental studies showed that temperature in the air gap between window glazing and shutter was stabilizing for at least 4 hours. Those findings motivated Zaheer-Uddin (1990) to further experimental and numerical investigations. It was finally concluded that it takes at least 2-6 hours to achieve its fully insulating effect and that time is strongly dependent on shutter assembly air tightness. Moreover the importance of dynamic effect of thermal resistance and air tightness on annual energy performance for an example house was assessed.

The calculation standard ISO 10077-1:2006 (ISO, 2006) describes the influence of shutters on window performance. It is noted that installing window shutters with a certain thermal resistance (R_{sh}), adds additional thermal resistance to the window. The formula which allows the calculation of additional insulating effect (for different air permeability of shutter) can be found in Table 1.

Table 1 - Additional thermal resistance for windows with closed shutters. (ISO, 2006)

Air permeability of shutters	**Additional thermal resistance ΔR [(m^{2}K)/W]**
Very high	0.08
High	$0.25\ R_{sh} + 0.09$
Average	$0.55\ R_{sh} + 0.11$
Low	$0.80\ R_{sh} + 0.14$
Airtight	$0.95\ R_{sh} + 0.17$

The ISO standard (ISO, 2006) also includes procedure of calculating shutter air permeability. Those guidelines however do not account for shutters with low emissivity surfaces. The ISO standard (ISO, 2006) has been used for validation of the developed model in this study.

SCOPE

The scope of this study is to:

- determine the external roller shutter and internal roller blind influence on window, glazing and frame thermal performance for two windows with different glazing units (glazing U-values of 1.60 and 0.79 W/(m^{2}K)),
- compare thermal insulation improvements for external roller shutters obtained from the developed model with the evaluation method proposed by the ISO standard (ISO, 2006)
- investigate whether the ISO evaluation method (ISO, 2006) is valid for external roller shutters with relatively low surface emissivity,
- consider different materials and their influence on thermal performance of external roller shutters,
- determine the influence of lowering emissivity of shading surfaces facing window and compare thermal and solar gain performance of such designs with glazing unit using low-e coatings placed on glazing surfaces,
- investigate the possibility of using WINDOW 6.0 software for assessing internal shading influence on glazing thermal performance.

It should be noted that this is a preliminary study in which the main scope is to indicate the potential of window thermal improvements by using roller shutters and internal roller blinds. Further investigations must be carried out in order to determine the influence and insulating effects in detail (including dynamic behavior and actual geometries including shutter box, etc.). The 2D simulations were performed using CFD software. Only the steady-state has been considered. It was assumed that the gap between window and internal/external shading is airtight and no infiltration is occurring.

GEOMETRY

The 2D geometries have been built in order to investigate different configurations/cases. Different roller shutter modules/designs have been reviewed. The general shape and dimensions have been established and used in the simulations (refer to Figure 3 and Figure 4). Internal roller blinds were simulated as a 1 mm thick homogenous material.

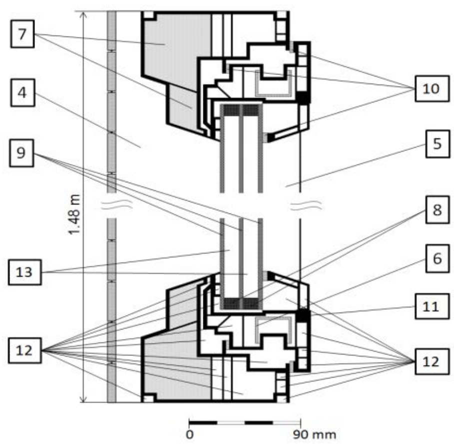


Figure 3 - Full geometry including shading devices. Numbers indicate the flowing parts: 4 - outside air, 5 -inside air, 6 - frame support, 7 - frame foam, 8 - glass pane spacer, 9 - glass, 10 - seals, 11 - PVC frame, 12 -frame air gaps.

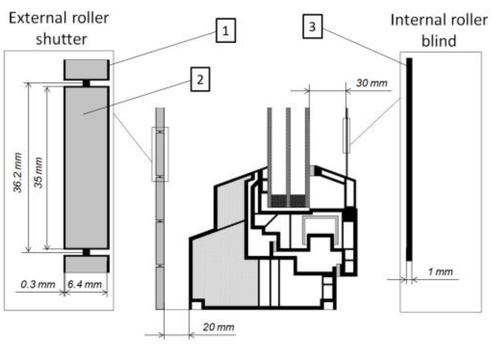


Figure 4 - External roller shutter and internal roller blind geometry sketch. Numbers indicate the flowing parts: 1 - external roller shutter material, 2 - external roller shutter fill and 3 - internal roller blind material.

The shading devices were modeled with an example PVC frame designed for 3 pane glazing. In order to investigate the convection occurring between glazing unit and shading devices a standard size window (1.48 m high) has been created. The full geometry with material description can be found in Figure 3.

NUMERICAL PROCEDURES

In the CFD program (ANSYS Fluent Release 13) a control-volume method is used to solve the coupled heat and fluid-flow equations in two dimensions. Conduction, convection and radiation are simulated numerically. ANSYS Design Modeler and ANSYS Meshing were used as a pre-processor to create the geometry, mesh and to construct the computational domains.

In order to assess the flow nature, Rayleigh numbers were calculated. Estimates for the frame cavities show maximum Rayleigh number to be approximately 1.5×10^4, which indicates laminar flow. Also Rayleigh numbers for glass cavity and cavities between shutter/blind and glazing/frame were calculated. For some cases the results indicated turbulent flow or transition state between laminar and turbulent flow. In order to check/validate model cases with external and internal shading, the model cases were calculated with different solver settings. The following models were tested before final simulation: (a) laminar – some studies indicate that for similar cases CFD solver assuming laminar flow gives reasonable results (Defraeye et al., 2011), (b) k-ω SST model (including and excluding low Reynolds corrections) which was reported in many studies as one of the most suitable turbulence models for modeling natural convection flows with low Reynolds number (Kayne, 2012) and (Menter et al., 2003). In addition, a case with gravity vector equal to 0 has been calculated to determine the impact of convection flows on window thermal performance. The simulation comparison is given in Table 2.

Table 2 - Comparison of window U-values for cases with different solver settings.*

Simulation	**Window U-value [W/(m²K)]**	**Percentage difference to the case with gravity vector equal to 0 [%]**
No gravity	0.94	-
Laminar	0.97	3.98
k-ω SST	0.97	3.86
k-ω SST low re	0.97	3.83

**Calculations were performed using a mesh with maximum cell size 0.9 mm, where emissivity for all surfaces has been set to 0.84.*

Viscous dissipation was not addressed, and all thermophysical properties are assumed to be constant except for the buoyancy term of the y-momentum equation, where the Boussinesq approximation is used.

The Semi-Implicit Method for Pressure-linked Equations Consistent (SIMPLEC) was used to model the interaction between pressure and velocity. The energy and momentum variables at cell faces were found by using the Quadratic Upstream Interpolation for Convective Kinetics (QUICK) scheme. The CFD program uses central differences to approximate diffusion terms and relies on the PREssure STaggering Option scheme (PRESTO) to find the pressure values at the cell faces.

Radiation heat transfer was included in the simulations through use of the Surface to Surface (S2S) radiation model, which calculate the energy exchange between surfaces taking into account size, separation distance and orientation using a geometric function called "view factor". The S2S model ignores absorption, emission and scattering phenomena in the air cavities. The cavity walls were assumed to be diffuse gray. Convergence was determined by checking the residuals for energy and ensuring that they were lower than 1×10^{-6}. Prior to the final calculation a mesh test has been performed for geometry including both inside and outside shading. Mesh sensitivity study was necessary in order to make the solution mesh-independent. Grid sizes of 0.5, 0.9, 1.5 mm have been tested. The window U-value only change by 0.5% from the finest (0.5 mm) to the coarsest (1.5 mm) mesh. It was determined that this difference in grid size was not significant, hence grid sizes less than or equal to 0.9 mm were used in the final simulations for all of the cases.

Table 3 and Table 4 display the material properties used in the numerical simulations. Material data were mainly obtained from NFRC 101 (NFRC, 2012b) and WINDOW 6.0 (LBNL, 2012).

Table 3 - Conductivities and emissivities of window and shading materials used in the study.

Material	**Fig no. / element no.**	**Conducti-vity [W/(m K)]**	**Emissi-vity [-]**
Glass	Fig. 6/9	1	0.84
EPDM seals	Fig. 6/10	0.25	0.9
PVC - rigid	Fig. 5/1* Fig. 5/3 Fig. 6/11	0.17	0.9
Steel	Fig. 6/6	50.0	0.6
Basotect foam	Fig. 5/2 Fig. 6/7	0.035	0.9
Spacer	Fig. 6/8	0.25	0.9
Aluminum (Al) (painted)	Fig. 5/1*	160	0.9

**material and emissivity used for some parts differ among some cases (refer to Table 6).*

Table 4 - Air properties for frame cavities and cavities created by shading devices used in the CFD simulations.

Fig. no. / element no.	**Property**	**Value**	**Unit**
Fig. 6/4 Fig. 6/5 Fig. 6/13 Fig. 6/12	Average air temperature	10.0	°C
	Thermal conductivity	0.02482	W/(m K)
	Specific heat capacity	1005.5	J/(kg K)
	Dynamic viscosity	1.7724×10^{-5}	kg/(m s)
	Density	1.2467	kg/m^3
	Expansion coefficient	3.5317×10^{-3}	1/K

The simplified ISO 10077-2 (ISO, 2012) boundary conditions which were used in the CFD simulations are displayed in Table 5.

Table 5 - Boundary conditions used in the CFD simulations (ISO, 2012).

Boundary condition		**Value**	**Unit**
Indoor temperature		293.15	K
Outdoor temperature		273.15	K
Combined convection and radiation surface coefficient of heat transfer for frame and vision sections	indoor	7.692	$W/(m^2 K)$
	outdoor	25.0	$W/(m^2 K)$
Heat flow density at the frame/wall interface		0	W/m^2

RESULTS AND DISCUSSION

In the study 14 different cases have been modeled, where for each case the U-value has been calculated (refer to Table 6). For some cases surface emissivity of shading facing glazing/frame has been changed from characteristic for material to 0.087 (refer to columns: external shutter emissivity and internal shading emissivity in Table 6). Glazing cavity gas differs between cases (air, argon and xenon). Moreover, for some cases low-e coatings have been added, which lower the glass emissivity from 0.84 to 0.087 on surfaces 2 and 5 (refer to Figure 5).

Frame materials and external shutter fill material have been kept the same for all cases.

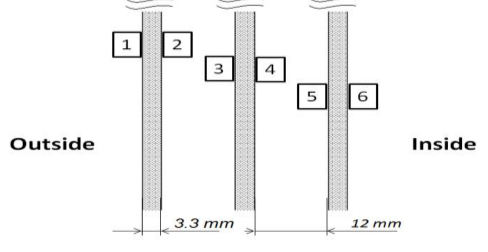
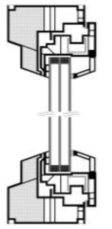
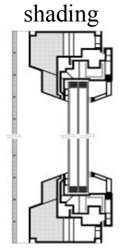
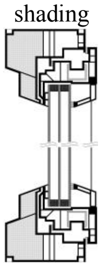
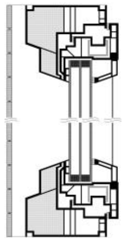


Figure 5 - Sketch of glazing unit used in the simulation. Boxes indicate numbers of glazing surface.

Table 6 - Characteristic of cases investigated in the study.

Geometry	**Case no**	**Glaz-ing fill**	**Low-e on glass**	**External shutter material**	**External shutter emissivity**	**Internal shutter**	**Internal shutter emissivity**	**U-value Window [W/(m²K)]**
Base window 	1	air	no	-	-	-	-	1.74
	2	argon	no	-	-	-	-	1.60
	3	argon	yes	-	-	-	-	0.79
	4	xenon	yes	-	-	-	-	0.54
Window + external shading 	5	argon	no	Al	0.84	-	-	1.19
	6	argon	no	PVC	0.84	-	-	1.01
	7	argon	yes	PVC	0.84	-	-	0.61
	8	argon	no	PVC	0.087	-	-	0.77
Window + internal shading 	9	argon	yes	-	-	PVC	0.84	0.69
	10	argon	yes	-	-	PVC	0.087	0.58
	11	argon	no	-	-	PVC	0.087	0.89
Window + external + internal shading 	12	argon	yes	PVC	0.84	PVC	0.84	0.54
	13	argon	no	PVC	0.087	PVC	0.087	0.55
	14	argon	yes	PVC	0.087	PVC	0.087	0.45

In order to validate the model, U-values of center-of-glazing have been compared with U-values obtained from simulations carried out using WINDOW 6.0 software. It was concluded that air gaps between shading and glazing have similar properties (air as gas-fill, aspect ratio, Rayleigh number), thus if a model is valid for a center-of-glazing, it is also valid for air cavities created by shading. In Table 7 U-values for center-of-glazing obtained from CFD simulations and WINDOW 6.0 were compared.
Very good agreement has been achieved for cases 1 and 2 (respectively air and argon as gas-fill with no low-e coatings). Case 1 is crucial for validation purpose since air is used as gas-fill, the same as for cavities between shading – window. Also, for case 3 which includes argon as glazing cavity fill and low-e coatings good agreement was achieved. Case 4 (xenon with low-e coatings) is characterized by a high percentage difference and absolute change about two times higher than for other cases. In further calculations glazing with xenon as gas-fill has not been included.

Table 7 - Comparison of U-values for center-of-glazing obtained from CFD calculation and WINDOW 6.0. Cases as given in Table 6.

Case no.	**U-value CFD**	**U-value WINDOW 6.0**	**Percentage difference [%]**	**Absolute Change (W/(m2 K))**
Case 1	1.88	1.90	0.87	-0.02
Case 2	1.73	1.75	1.50	-0.02
Case 3	0.76	0.78	2.30	-0.02
Case 4	0.46	0.41	12.55	0.05

Furthermore, the influence of external roller shutters has been evaluated and compared using CFD method and ISO standard (ISO, 2006). In the CFD simulation it was assumed that shutters are airtight, thus the following formula was used for ISO calculation: $0.95 R_{sh} + 0.17$ (ISO, 2006), where R_{sh} equals to shutter thermal resistance (procedure of calculating according to the ISO standard (ISO, 2006) is shown in Table 1). Comparison of results is presented in Table 8.

Table 8 - Influence of thermal shutter according to ISO (ISO, 2006) and CFD calculation. Cases as given in Table 6.

Case no. (description of case)	**Shutter thermal resistance**	**Case U-value CFD**	**Case U-value determined by ISO (2006)**	**Percentage difference [%]**
Case 5 (case 2 + Al/foam shutter)	0.09	1.19	1.13	4
Case 6 – (case 2 + PVC/foam shutter)	0.17	1.01	1.03	3
Case 7 – (case 3 + Al/foam shutter)	0.17	0.61	0.62	3
Case 8 – (case 2 + Al/foam shutter + shutter low emissivity surface (0.087) facing window)	0.17	0.79	1.03	31

Good agreement has been achieved for cases where the shading surface has emissivity equal to 0.84 (percentage difference below 5%). However, comparison shows that the ISO standard (ISO, 2006) cannot be used for assessing U-value of assembly window/shading which includes surfaces with low emissivity. For such cases the difference between ISO (ISO, 2006) and CFD calculations is reported to be around 31%.

The next step of the study was to determine the influence of different shading options on window/frame U-value. First, external roller shutters and internal blinds have been used with a relatively low-performing generic window – case 2 (3P, no low-e on glazing, air as gas-fill). Evaluations of different options of improving window thermal performance are presented in *Table 9*.

Results show that thermal improvements on relatively low-performing windows by use of external shutters are substantial (both percentage and absolute changes), for case 8 around 50% reduction of U-value was achieved compared to the initial solution. Improvements higher than 60% have been achieved using both internal and external shading device made of PVC with low emissivity surfaces facing the glass surface (case 13).

Table 9 - Comparison of different options for enhancing window thermal performance by shading devices. Cases as given in Table 6.

Case	**2**	**11**	**6**	**8**	**13**
Window U-value [W/(m²K)]	1.60	0.89	1.01	0.77	0.55
Percentage difference with case 2 [%]	-	-44	-37	-52	-66
Absolute difference with case 2 [W/(m²K)]	-	-0.71	-0.60	-0.83	-1.05

It was concluded that the application of internal blinds (with low emissivity surface) gives slightly better improvements than using external shutters with surface emissivity equal to 0.84 (respectively case 11 and case 6), while installing internal blinds is less time, cost and effort consuming. However, internal blinds give lower improvements when the low emissivity surface is added to external shutters because external shutters reduce the heat flow through the entire system (including frame).

The highest improvement to frame thermal performance has been recorded to be around 48% (lowered by 0.46 W/(m²K)) for case 8 (by application of external roller shutters with low emissivity surface).

Similar comparison has been performed using a base window with lower thermal transmittance (window U-value for case 3 equals to 0.79 W/(m²K)). The results are presented and compared in *Table 10.*

Table 10 - Comparison of different options for enhancing window thermal performance by shading devices. Cases as given in Table 6.

Case	**3**	**9**	**10**	**7**	**12**	**14**
Window U-value [W/(m²K)]	0.79	0.69	0.58	0.61	0.54	0.41
Percentage difference case 3 [%]	-	-12	-26	-23	-31	-49
Absolute difference with case 3 [W/(m²K)]	-	-0.10	-0.21	-0.18	-0.24	-0.38

For the window with argon filling and low-e glass the improvements of window U-value are also substantial – the highest recorded improvement is 49% while using external and internal shutters with low emissivity surfaces. Application of internal roller shutter (with surface emissivity equal to 0.84) causes reduction of thermal loss by 12%, which can be doubled by lowering shading device surface emissivity to 0.087.

Further, comparison between cases with low-e coatings on the glazing and cases with lowered emissivity on shading devices has been carried out. Table 11 indicates that the overall window U-value did not change. SHGC for both cases has been evaluated using WINDOW 6.0 (for center-of-glazing only, assuming that shutters are opened). It was concluded that changing emissivity of external and internal shading can give the same thermal properties while keeping higher SHGC value of around 31%. This configuration can find application for certain climates/situations.

Table 11 - Comparison of cases with different location of low emissivity surfaces (case 12 is window with no low-e- coating on glass while case 13 has low-e caring on two glass panes). Cases as given in Table 6.

Geometry	**Case 12**	**Case 13**	**Percentage difference [%]**
U-value window [W/(m^{2}K)]	0.54	0.55	0.5
SHGC	0.68	0.47	- 31

In the next step CFD modeling results of center-of-glazing (defined according NFRC 100 (NFRC, 2012a) in order to isolate the spacer influence) has been compared to the results from WINDOW 6.0. For each case simulation in WINDOW has been performed by creating a 4-layer glazing unit, where the 4th layer represented an internal blind (this required creation of a custom glazing layer which thickness and conductivity was set to the same values as for the CFD simulation). Space between 3rd and 4th pane was filled with air (refer to Figure 6), and the space between the glass layers was argon. The same ISO (ISO, 2006) boundary conditions and glazing height (860 mm) were used for CFD and WINDOW simulations. Results of the comparison are presented in Table 12.

The comparison shows good match for all of the cases (percentage differences lower than 5%). WINDOW 6.0 indicates in general higher U-values than CFD simulation, which was also observed for prior comparisons (Table 7). The actual difference for all cases are lower than 0.05 W/(m^{2}K) which are acceptable with regards to ISO and NFRC standards. It was concluded that WINDOW is able to give relatively good estimation of center-of-glazing thermal performance while using internal blinds.

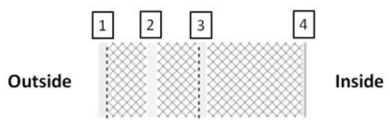


Figure 6 - Screen from WINDOW 6.0, numbers in squares indicate layers, broken lines indicate low-e coatings.

Table 12 - Comparison of results from CFD and WINDOW 6.0 simulations for center-of-glazing with internal roller blinds. Cases as given in Table 6.

Case	**2**	**3**	**9**	**10**	**11**
CFD U-value centre of glazing [W/(m^{2}K)]	1.73	0.76	0.66	0.50	0.83
WINDOW U-value centre of glazing [W/(m^{2}K)]	1.75	0.78	0.67	0.52	0.84
Absolute difference [W/(m^{2}K)]	0.02	0.02	0.01	0.02	0.01
Percentage difference [%]	1.5	2.3	1.0	4.8	1.1

CONCLUSIONS

Some conclusions can be drawn regarding thermal influence of external shutters and internal roller blinds on window thermal performance. Firstly it was shown that the calculation method presented in the ISO 10077-1:2006 standard gives good results which are comparable with relatively accurate CFD investigations. However, the method is only valid if the external roller shutter surface emissivity is high, which is typical for shutter materials. Secondly, very good improvements were achieved for windows with and without low-e glazing, respectively 50 and 66% when both external and internal shading were added (with low emissivity surfaces). For considered shading devices higher in improvements can be assigned to external roller shutters, since that type of shading also reduces the heat loss through the frame. The study identified the important role of shading device surface emissivity (for surfaces facing glazing). Studies showed that using low emissivity on shading devices give the same result in terms of thermal performance as using low-e on glazing (while shades are closed) while improving substantially the solar hear gain coefficient (SHGC) (while shades are open). There is good agreement between LBNL software WINDOW 6.0 and the CFD simulations carried out in this work.

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FUTURE WORK

The work presented in this study might form an adequate basis for further investigations to determine the shading influence on window thermal performance. Further work should may on:

- determining the effect of thermal insulation in transient state occurring subsequently after closing shading,
- developing/validate methods of using LBNL software (THERM, WINDOW) for evaluating shading influence on window thermal performance,
- determining shading influence on fenestration products in different orientations than vertical (e.g. roof windows),
- developing methods for certification of window shadings in order to encourage manufactures to create new and improved designs,
- determining the influence of shutter boxes and other elements which can been see in actual designs of shutters.

REFERENCES

Defraeye, T., Blocken, B. & Carmeliet, J. 2011. Convective Heat Transfer Coefficients for Exterior Building Surfaces: Existing Correlations and CFD Modelling. Energy Conversion and Management.

Evermotion.org 2012. External Roller Shutter. http://static1.evermotion.org/files/model_images/a8a54d9dc39f49f74ce931e8f2ae65cc.jpg

Gustavsen, A., Arasteh, D., Jelle, B. P., Curcija, C. & Kohler, C. 2008. Developing Low-Conductance Window Frames: Capabilities and Limitations of Current Window Heat Transfer Design Tools - State-of-the-Art Review. Journal of Building Physics.

Gustavsen, A., Arasteh, D. K., Goudey, H., Kohler, C., Jelle, B. P., Talev, G. & Uvsløkk, S. 2010. Experimental and Numerical Examination of the Thermal Transmittance of High Performance Window Frames. Thermal Performance of the Exterior Envelopes of Whole Buildings XI International Conference. Clearwater Beach, FL, USA.

ISO - International Organization for Standarization 2006. ISO 10077-1:2006 - Thermal Performance of Windows, Doors and Shutters - Calculation of Thermal Transmittance - Part 1: General.

ISO - International Organization for Standarization ISO 10077-2:2012 Thermal Performance of Windows, Doors and Shutters - Calculation of Thermal Transmittance - Part 2: Numerical Method for Frames.

Kayne, A. 2012. Computational Fluid Dynamics (CFD) Modeling of Mixed Convection Flows in Building Enclosures. School of Engineering - Mechanical Engineering. Washington Univeristy, USA.

LBNL - Lawrence Berkeley National Laboratory 2012. Simulation software: Window 6.0.

Menter, F. R., Kuntz, M. & Langtry, R. 2003. Ten Years of Industrial Experience with the SST Turbulence Model. Turbulence, Heat and Mass Transfer.

NFRC - National Fenestration Rating Counci 2012a Procedure for Determining Fenestration Product U-factors - 100.

NFRC - National Fenestration Rating Council 2012b. Procedure for Determining Thermophysical Properties of Materials For Use in NFRC-Approved Software.

SOD 2010. Roleta wewnetrzna. (eng. Internal roller blind). http://www.oknapila.pl/images/rolety_n1.jpg

Voss, K. & Musall, E. 2011. Towards Net Zero Energy Solar Buildings. International Energy Agency.

Wood, C., Bordass, B. & Baker, P. 2009. Improving the Thermal Performance of Traditional Windows. United Kingdom.

Zaheer-Uddin, M. 1990. Dynamic Effects of Thermal Shutters. Building and Environment.