Characterization and performance evaluation of solar shading devices

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SUMMARY:
In the decision process of office building design, it is important to take the effect of solar shading devices into account as they have a large influence on the indoor climate and energy consumption.
This paper describes a user-friendly method, based on the use of the programs WIS and BuildingCalc/LightCalc, of how to evaluate the performance of different solar shading devices during an early design phase of a building. The window systems combining glazing and shading devices are characterized in WIS giving the transmittance and reflectance as functions of the solar profile angle. BuildingCalc/LightCalc allows defining a simple model of the building in which the windows systems characterized in WIS may be integrated. Heating, cooling, ventilation, lighting and solar shading may be dynamically controlled and the energy and daylight performances of the building, as well as the indoor thermal climate, may be evaluated.
A case study of a landscaped office building in which different solar shading devices are tested for two different cities (Copenhagen and Lisbon) is presented. Examples and suggestions of how to overcome the lack of information available about thermal and optical properties of solar shading devices are included in the paper.

1. Introduction

Energy savings are essential for the general long term solution of the problems with use of energy from fossil fuels. In buildings, to maintain a good indoor environment, energy is used for heating, cooling, ventilation and electrical lighting. If correctly selected and used, solar shading devices may decrease the overheating and cooling demand of buildings significantly without largely increasing the electrical lighting demand. As solar shading devices influence the appearance of the building façade and they have a large impact on the energy demand, it is important that they are included in the early design phase of buildings. In this way, methods to characterize the properties of shading devices and simple calculation tools to determine the effect on indoor climate and energy demand are required.

However, there is often neither sufficient optical data available nor calculation tools that can determine the optimal use of solar shadings and their effect on indoor climate in a satisfactory way. Therefore, there was a need for developing a new calculation program that can simulate the performance of solar shading devices, used in a building, in a realistic way, taking the variation of the optical properties over the day and year into account.

In this paper a simple and user-friendly method of how to evaluate the energy and daylight performance of solar shading devices in buildings in an early design phase is illustrated. The method is based on the use of two simulation tools: WIS and the recently developed program, LightCalc, which is an extension of BuildingCalc. A case study of a landscaped office building in which different solar shading devices are applied is presented and two different locations are studied: Copenhagen and Lisbon. Also some suggestions of how to overcome the lack of information characterizing the solar shading devices available on the market are included in the paper.

2. Solar shading devices

There are many different types of solar shading devices available on the market. When designing a building, besides the aesthetical component also the energy performance and indoor comfort including temperature and daylight must be taken into account.

The solar shading devices should be as flexible as possible so they can adapt to the outdoor conditions. According to their position on the window, they may be categorized in internal, interpane and external (Wall M. and Bülow-Hübe H., 2001 and 2003). The external solar shading devices are the most efficient in reducing the cooling loads. As they are placed outside they reflect the solar rays before they enter the room. Furthermore, the heat they absorb is dissipated to the outside air by radiation and convection. The solar control glasses are not included in the groups referred before but also constitute a type of solar shading device. They are integrated in the window, replacing the panes.

Different types of internal, interpane and external roller blinds and venetian blinds were studied. Also external glass lamellas devices and solar control glasses were investigated. Some of the results are presented in this paper.

3. Method to evaluate the performance of different solar shading devices: WIS and BuildingCalc/LightCalc

To evaluate the performance of different solar shading devices two softwares were used: WIS (TNO, 2004) and BuildingCalc/LightCalc (BYG.DTU, 2007).

Traditionally, the performance of solar shading devices has been described by a simple fixed shading factor defined as the fraction of transmitted solar energy through a standard glazing including the shading device compared to the transmitted solar energy through a standard glazing alone. This measure can be useful for comparison of different solar shading devices, but it is not sufficient when evaluating their performance in a specific building, since the performance depends on the actual glazing and on the position of the sun.

In order to take the varying performance of solar shading devices into consideration, the optical properties, transmittance and reflectance of the window system, consisting of the solar shading device and the actual glazing, must be given for specific positions of the sun. This can be done in the program WIS (TNO, 2004), in which is possible to calculate the thermal and optical properties of window systems combining solar shading devices with glazings available on the market. The properties of the window systems are calculated as a function of the solar profile angle which is defined as the incidence angle projected into the vertical plane normal to the window.

In most existing building simulation tools, the dynamic impact of solar shading devices on indoor climate and the energy demand are not taken into account in a satisfactory way. Therefore, with the purpose of increasing the accuracy of simulations, the calculation tool LightCalc was developed and integrated in the existing program BuildingCalc. With BuildingCalc/LightCalc, it is possible to evaluate the energy and daylight performance of buildings in which the window systems defined in WIS are applied. BuildingCalc/LightCalc simulates the performance of solar shading devices used in a building in a realistic way taking the variation of the optical properties over the day and year into account. It is possible to set different systems: heating, cooling, ventilation, venting and variable solar shading. The systems are controlled by different settings which can be specified for different periods.

The solar shading devices may be automatically controlled according to the indoor temperature. If at the same time the indoor daylight is not enough to accomplish the standard requirements, electrical lighting is switched on and its energy demand is calculated. BuildingCalc/LightCalc is described in detail in (Hviid C. A. et. al., 2008).

4. Case study - Landscaped office building

The test room is a storey of a landscaped office building located first in Copenhagen (North Europe) and then in Lisbon (South Europe).

The inner dimensions of the room are 20m width, 10m depth and 3.3m height (*Fig. 1*).

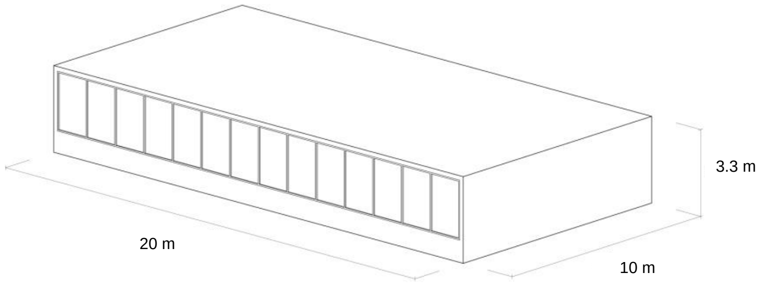

FIG. 1 - Model of the landscaped office building used in the calculations in BuildingCalc/LightCalc.

The window area is 44.7m^2 and it is facing south. The reference glazing is a triple pane with a U-value of 0.68W/m^{2}K, g-value of 0.49 and visual transmittance of 0.68. The frame profiles have a U-value of 0.73W/m^{2}K. The overall UA-value of the building envelope is 15.46W/K for Copenhagen (this value takes into account the sum of transmission losses through the elements facing outside excluding the window). For the building in Lisbon less restrictive thermal solutions were selected because of the warmer climate and the UA-value is 61.85W/K. The heat capacity of the building was assumed to be middle light and also the heat capacity of the furniture was taken into account.

The systems in the building were defined by specifying the settings for heating, cooling, ventilation, lighting and solar shading for different periods (winter / summer / working hours / non-working hours). Two different scenarios were studied: no mechanical cooling available (when there is need for cooling, the cooling systems are activated in the following order: shading and venting); mechanical cooling available (when the previous solutions are not sufficient to set the required level of indoor comfort, the mechanical cooling is activated). The first scenario is the more environmental friendly, however, in most cases this solution is not enough to achieve the indoor comfort level required, especially regarding South European countries like Portugal.

The office is equipped with district heating and cooling. There is a heat exchanger (with an efficiency of 0.85) incorporated with the heating system. The heating system and the mechanical cooling (when available) are only active during working hours. The heating setpoint is 20ºC while the cooling setpoint is 22ºC (in this way the cooling process will start before the indoor temperature reaches 26ºC which is a measure of discomfort (CEN, 2007, EN 15251).

Only during working hours mechanical ventilation is active with a constant air change rate of 0.9h^{-1} (minimum required in (CEN, 2007, EN 15251)). Venting is set only during non-working hours (in Lisbon during all the year and in Copenhagen only outside the coldest months).

The internal loads due to people and equipment were also taken into account (2250W considering 15 working places).

The artificial lighting level is automatically controlled during the working hours in order to keep a general indoor lighting level of 200lux and a level of 500lux at working areas.

5. Energy Performance and indoor comfort evaluation

5.1 Requirements and expected results

To be in accordance with the (Danish building regulations, 2005) the office room should have a total energy demand for heating, cooling, and lighting lower than 78kW/m^2. However, a much lower energy demand should be expected due the nowadays need to save energy. (The hot water and the ventilation (assumed to be constant during the working hours) are excluded from this calculation since they are not influenced by the shading devices).

In Portugal, as a complement to the requirement for total energy demand for heating, cooling and lighting (estimated as 104kWh/m^2, according to the Portuguese building code (RCCTE, 2006), there are also limits for the different types of energy needed in a building: for this office room, the limit for heating is 52kWh/m^2, while for cooling it is 32kWh/m^2.

Regarding indoor comfort, it was assumed that the landscaped office building should fulfil category II of the indoor environment standard (CEN, 2007, EN 15251): this means less than 108 working hours per year above 26º and a PPD index (predicted percentage of dissatisfied) lower than 10%.

5.2 Results and discussion

In *Table. 1* and *Table. 2*, the performance of the office building is presented for the different solutions of solar shading devices in combination with the reference glazing for both locations: Copenhagen and Lisbon. The results painted as grey are the ones that do not fulfil the standards (For the solar control glazing, the outer pane of the reference glazing is replaced by a solar control glass).

Table 1 and *Table 2* are organized in three distinct groups of columns:

- *System properties* - where the performance of the different solar shading devices in combination with the reference glazing is presented (U-value: thermal transmittance, g-value: total solar energy transmittance and τ_V: visual transmittance of the reference glazing. These values were obtained in WIS and refer to the solar shading devices completely activated: venetian blinds slats and glass lamellas tilted 90 degrees from the horizontal position and roller blinds pulled down).
- *Without mechanical cooling* - the values presented in these columns were calculated in BuildingCalc/LightCalc. They represent the performance of the landscaped office room (previously described) when different solutions for solar shading devices are applied on its façade. No mechanical cooling was set. The performance of the office room with the different solar shading devices is presented in terms of energy demand for heating and total energy demand, hours of overheating and PPD index. To calculate the total energy demand, the demand is multiplied by the factor 2.5 because it is provided by electricity. The same does not happen with the cooling demand since it is assumed to be provided by district heating (Danish building regulations, 2005).
- *With mechanical cooling* - these columns also refer to the performance of the office building with the different solutions for the solar shading devices. In this case mechanical cooling was applied to eliminate completely the hours of overheating (as 22ºC is the setpoint defined for cooling, no hours above this temperature will be registered).

The results for the reference glazing for the office room in Copenhagen show that the total number of working hours with overheating is 260 per year which is higher than the requirement, 108. However, using mechanical cooling (air-conditioning system), the indoor comfort may be achieved with a total energy demand of 31kWh/m^2.year. With most types of solar shading devices the indoor comfort may be achieved even without the use of mechanical cooling. However, if better indoor comfort level is desired, mechanical cooling may be used and the total energy demand may be reduced by 50% (for the case of the external venetian blind) when compared to the reference glazing.

For Lisbon the scenario is different. For the reference glazing, the total number of working hours with overheating is 1009 per year, which is extremely high. On the other hand, when using mechanical cooling, the cooling demand is 61kWh/m^2 year which is twice the requirement, 32kWh/m^2 year. In this way, this solution is not possible for Lisbon. Results for the different solutions of solar shading devices show that most of them are not able to allow the required indoor comfort without the use of mechanical cooling. And even with mechanical cooling some of them are not viable solutions since the cooling demand is higher than the limit (32kWh/m^2 year). With the use of mechanical cooling the optimal analyzed solution regarding energy consumption is the external venetian blind, which reduces in more than 50% the total energy demand of the office room, when compared to the reference glazing.

6. Some tips on how to overcome the lack of data available for solar shading devices

As it was stated before there is a lack of information about the properties of the solar shading devices available on the market. Often the shadings properties that are required in WIS, to characterize a shading device are not given by the manufacturers. For instance, some of the WIS inputs are the thermal conductivity (λ), outdoor and indoor

TABLE. 1 - Energy and indoor comfort performance of the landscaped office room in Copenhagen for the reference glazing and for the combination of the reference glazing with the different solar shading devices.

		system properties			without mechanical cooling					with mechanical cooling				
ID	Position/Type (Product name)	U-value [W/m^{2}K]	g-value [-]	τ_v [-]	heating [kWh/m^2]	lighting [kWh/m^2]	total [kWh/m^2]	T>26ºC [h]	PPD [%]	heating [kWh/m^2]	cooling [kWh/m^2]	lighting [kWh/m^2]	total [kWh/m^2]	PPD [%]
REF	Reference Glazing	0.68	0.49	0.68	0.6	3.2	8.6	260	12	0.6	22.6	3.2	31.2	7
A	Internal Roller Blinds													
	Verosol SilverScreen white ED01 HT	0.51	0.25	0.05	0.4	7.2	18.3	101	9	0.4	12.5	6.7	29.6	8
B	Interpane Roller Blinds													
	Verosol SilverScreen white ED01 HT	0.70	0.10	0.05	0.8	6.6	17.4	2	8	0.8	5.4	6.4	22.2	8
C	External Roller Blinds													
	Verosol SilverScreen white ED01 HT	0.62	0.04	0.01	0.8	6.3	16.6	0	8	0.8	3.2	6.2	19.5	8
D	Internal Venetian Blinds													
	Luxaflex venetian blind High Mirror	0.58	0.23	0.00	0.5	4.5	11.7	214	12	0.5	19.8	4.3	31.0	7
E	Interpane Venetian Blinds													
	Luxaflex venetian blind High Mirror	0.57	0.07	0.00	0.5	4.3	11.3	89	9	0.5	11.4	4.2	22.3	8
F	External Venetian Blinds													
	Aluminium lamellas_60mm	0.62	0.01	0.00	0.7	4.1	11.0	0	8	0.7	4.0	4.1	14.9	8
G	External Glass Lamellas													
	SGG_Antelio Silver_500mm	0.63	0.28	0.20	0.8	4.1	11.1	74	9	0.9	9.1	4.0	20.1	8
H	Solar Control Glazings													
	SSG Reflectasol Green	0.96	0.17	0.21	3.8	5.7	17.9	0	9	3.8	4.0	5.6	21.9	9

TABLE. 2 - Energy and indoor comfort performance of the landscaped office room in Lisbon for the reference glazing and for the combination of the reference glazing with the different solar shading devices.

		system properties			without mechanical cooling					with mechanical cooling				
ID	Position/Type (Product name)	U-value [W/m^{2}K]	g-value [-]	τ_v [-]	heating [kWh/m^2]	lighting [kWh/m^2]	total [kWh/m^2]	T>26ºC [h]	PPD [%]	heating [kWh/m^2]	cooling [kWh/m^2]	lighting [kWh/m^2]	total [kWh/m^2]	PPD [%]
REF	Reference Glazing	0.68	0.49	0.68	0.0	1.5	3.8	1009	28	0.0	61.3	1.5	65.1	5
A	Internal Roller Blinds													
	Verosol SilverScreen white ED01 HT	0.51	0.25	0.05	0.0	9.5	23.8	451	14	0.0	36.5	8.4	57.6	6
B	Interpane Roller Blinds													
	Verosol SilverScreen white ED01 HT	0.70	0.10	0.05	0.0	8.8	22.1	168	9	0.0	20.5	8.0	40.6	6
C	External Roller Blinds													
	Verosol SilverScreen white ED01 HT	0.62	0.04	0.01	0.1	8.2	20.5	108	8	0.1	14.6	7.6	33.8	6
D	Internal Venetian Blinds													
	Luxaflex venetian blind High Mirror	0.58	0.23	0.00	0.0	4.4	11.1	763	22	0.0	51.6	3.9	61.3	5
E	Interpane Venetian Blinds													
	Luxaflex venetian blind High Mirror	0.57	0.07	0.00	0.0	4.2	10.6	431	14	0.0	35.1	3.7	44.4	6
F	External Venetian Blinds													
	Aluminium lamellas_60mm	0.62	0.01	0.00	0.0	3.9	9.7	136	9	0.0	17.4	3.6	26.4	6
G	External Glass Lamellas													
	SGG_Antelio Silver_500mm	0.63	0.28	0.20	0.0	3.6	8.9	392	13	0.0	31.2	3.2	39.3	6
H	Solar Control Glazings													
	SSG Reflectasol Green	0.96	0.27	0.21	0.3	3.8	9.8	159	10	0.3	17.3	3.8	27.1	7

IR emissivities (IRε_{out} and IRε_{ind}) and IR transmissivity (IR transm.) of the material that composes the shading device and usually manufacturers do not have this information available. Regarding optical properties, the preferred input for WIS is spectral data but most manufacturers only give simplified information such as the solar transmittance (τ_S), solar reflectance (ρ_S), light transmittance (τ_V) and light reflectance (ρ_V). These values are also accepted in WIS, though they represent integrated data and include direct and diffuse components (which should be set separately in WIS).

In *Table. 3* some tips are suggested on how to input new solar shadings systems in WIS when the complete technical information is not available (the tips are organized according to the different WIS input fields: geometry, thermal properties and optical properties).

TABLE. 3 - Tips on how to use simplified data from manufacturers.

WIS input field	Properties to be defined	Tips
Geometry	*Roller blinds* (thickness) *Slat shading device* (thickness, slat chord width, crown height, slat pitch)	The shading system geometry must be given by the manufacturer.
Thermal properties	Material conductivity	*Roller blinds* (assume 0.2W/mK for ordinary fabrics) *Venetian blinds* (assume 150W/mK for aluminium slats)
	Material IR emissivity (outdoor/indoor)	Assume 0.5 for metallic surfaces and 0.8 for non-metallic surfaces*.
	Material IR transmissivity	Assume that it is zero.
Optical properties	*Roller blinds* Integrated data (solar, visual and UV) for outdoor and indoor transmittance and reflectance for different angles of incidence - the values must be separated into direct and diffuse components	*Roller Blinds* Assume that the optical properties are equal for the different angles of incidence. However, assume that for 90º or -90º angles of incidence there is only reflectance and no transmittance. Assume that all of the transmittance is direct and that all of the reflectance is diffuse (Assuming that the transmittance is direct is valid for the normal angle of incidence. For different angles of incidence the shape of holes has an influence on the direct and diffuse components of the transmittance through the fabrics. Through thick and long holes (tunnel shape) the diffuse component is higher while through wide and short holes the direct component is higher. More studies should be done regarding this subject). Assume that the optical properties are equal for the outside and inside surfaces. If no information about the UV transmittance (τ_{UV}) and UV reflectance (ρ_{UV}) is given by the manufacturer assume that they are equal to the solar transmittance (τ_S) and solar reflectance (ρ_S)*.
	Venetian blinds Integrated data (solar, visual and UV) for transmittance and for outdoor and indoor reflectance for normal angle of incidence - the values must be separated into direct and diffuse components	*Venetian Blinds* Assume that all of the transmittance is direct and that all of the reflectance is diffuse. (see comments above for the same assumption for the roller blinds). Assume that the optical properties are equal for the outside and inside surfaces. If no information about the UV transmittance (τ_{UV}) and UV reflectance (ρ_{UV}) is given by the manufacturer assume that they are equal to the solar transmittance (τ_S) and solar reflectance (ρ_S)*.

* These suggestions are in accordance with typical solar shading devices available in the *WIS* database (TNO (2004)).

TABLE. 4 - Comparison of the complete and simplified data of the solar shading devices.

		thermal properties					optical properties			
ID	Position/Type (Product name)	thickness [mm]	λ [W/mK]	$IR\varepsilon_{out}$ [-]	$IR\varepsilon_{ind}$ [-]	IRtransm* [-]	τ_S [-]	ρ_S [-]	τ_V [-]	ρ_V [-]
A	Internal Roller Blinds									
	Verosol SilverScreen black EB01 HT	0.50	0.15	0.160	0.810	0.000	0.05	0.75	0.05	0.74
	SIMPLIFIED_Verosol SilverScreen black EB01 HT	0.50	0.20	0.500	0.800	0.000	0.05	0.75	0.05	0.74
C	External Roller Blinds									
	Verosol SilverScreen black EB01 HT	0.50	0.15	0.160	0.810	0.000	0.05	0.75	0.05	0.74
	SIMPLIFIED_Verosol SilverScreen black EB01 HT	0.50	0.20	0.500	0.800	0.000	0.05	0.75	0.05	0.74
D	Internal Venetian Blinds									
	Luxaflex venetian blind High Mirror 4078	0.22	100.00	0.710	0.680	0.000	0.00	0.83	0.00	0.83
	SIMPLIFIED_Luxaflex venetian blind High Mirror	0.22	150.00	0.800	0.800	0.000	0.00	0.83	0.00	0.83

*IR transm= IR transmissivity

TABLE. 5 - Comparison of results obtained with complete and simplified data. Landscaped office building in Copenhagen.

		system properties			without mechanical cooling					with mechanical cooling				
ID	Position/Type (Product name)	U-value [W/m²K]	g-value [-]	τ_V [-]	heating [kWh/m²]	lighting [kWh/m²]	total [kWh/m²]	T>26ºC [h]	PPD [%]	heating [kWh/m²]	cooling [kWh/m²]	lighting [kWh/m²]	total [kWh/m²]	PPD [%]
REF	Reference Glazing	0.68	0.49	0.68	0.6	3.2	8.6	260	12	0.6	22.6	3.2	31.2	7
A	Internal Roller Blinds													
	Verosol SilverScreen black EB01 HT	0.51	0.25	0.04	0.4	7.3	18.6	101	9	0.4	12.4	6.8	29.8	8
	SIMPLIFIED_Verosol SilverScreen black EB01 HT	0.57	0.27	0.04	0.5	6.8	17.5	112	9	0.5	13.2	6.4	29.7	8
C	External Roller Blinds													
	Verosol SilverScreen black EB01 HT	0.62	0.03	0.03	0.8	6.3	16.6	0	8	0.8	3.0	6.2	19.2	8
	SIMPLIFIED_Verosol SilverScreen black EB01 HT	0.62	0.03	0.04	0.8	6.0	15.8	0	8	0.8	3.0	5.9	18.4	8
D	Internal Venetian Blinds													
	Luxaflex venetian blind High Mirror 4078	0.58	0.23	0.00	0.5	4.5	11.7	214	12	0.5	19.8	4.3	31.0	7
	SIMPLIFIED_Luxaflex venetian blind High Mirror 4078	0.59	0.25	0.00	0.5	4.4	11.6	173	11	0.5	17.6	4.2	28.7	7

For a better understanding of *Table.5* see the explanation of *Table.1* and *Table.2* in section 5.2.

Simulations for some solar shading devices studied before were performed but using the data usually given by the manufacturers and doing the assumptions proposed. (For the simulations, the solar shading devices were integrated in the landscaped office building in Copenhagen)

The purpose was to compare the results between the use of complete and simplified data and analyze the influence of the proposed simplifications and assumptions on the final performance of the office room. The goal was also to demonstrate whether or not results closer to reality can be obtained when using simplified data.

For a better understanding of the different results when using simplified and complete data, the complete data (from WIS) and simplified data (from manufacturer and assumptions) for the analyzed solar shading devices are presented in *Table. 4*. The spectral optical properties are not presented but they can be consulted in the WIS database (TNO, 2004).

In *Table. 5*, the results of the performance of the landscaped office room in Copenhagen obtained when using complete and simplified data are presented. When simplified data is used the name of the solar shading system is preceded by the word “SIMPLIFIED”. The similarity obtained between results for complete and simplified data shows that the used simplified data is valid. However, only few cases were studied and more research should be done in this field.

7. Conclusions

The combination of WIS and BuildingCalc/LightCalc is a very promising tool when evaluating and comparing the performance of buildings with different types of solar shading devices in an early design phase. From the simple model of the room and the thermal/optical properties of shadings devices, it is possible to calculate on an hourly basis the yearly energy demand for heating and cooling as well as some indoor comfort parameters. The program takes the dynamic influence of solar shading devices on the energy demand and indoor climate into account, which makes the performance evaluation of the shading device much more realistic when compared to the use of fixed values.

Nowadays there is still a lack of data about the thermal and optical properties of the solar shading devices. Some particular cases studied show that the use of simplified data gives raise to results close to the ones obtained with the complete data. However, only few cases were studied and more research should be done in this field.

8. References

BYG.DTU (2007). BuildingCalc/LightCalc, Building simulation tool, Computer program, Department of Civil Engineering, Technical University of Denmark.

CEN (2007, EN 15251). EN 15251, Indoor environment input for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.

Danish building regulations (2005). Danish Ministry for Housing and Urban Affairs.

Hviid C. A., Nielsen T. R. and Svendsen S. (2008). Simple tool to evaluate the impact of daylight on building energy consumption, Nordic Symposium on Building Physics 2008, Copenhagen, Denmark.

RCCTE (2006). RCCTE - Regulation for the Thermal Performance Characteristics of Buildings, Collection Regulamentos, Vol. 1, Porto Editora, Porto, Portugal (only Portuguese version available).

TNO (2004). Advanced Window Information System, WIS - Window simulation program, TNO Building and Construction Research, Delft, The Netherlands.

Wall M. and Bülow-Hübe H. (2001). Solar Protection in Buildings, Lund University, Sweden.

Wall M. and Bülow-Hübe H. (2003). Solar Protection in Buildings - Part2:2000-2002, Lund University, Sweden.