Executive Board

Navigation address: De Zaale, Eindhoven
P.O. Box 513, 5600 MB Eindhoven
The Netherlands
www.tue.nl

Energy performance analysis of advanced interior solar shading systems – Kindow Rollerblinds vs. state-of-the-art alternatives

Author
O. Ghosh
S.B. de Vries
R.C.G.M. Loonen

Date
27 August 2019

Version
1

Technische Universiteit
Eindhoven
University of Technology

Table of contents

Title
Energy performance analysis of advanced interior solar shading systems – Kindow Rollerblinds vs. state-of-the-art alternatives

1 Synopsis

This report discusses the results of a series of simulation studies carried out by researchers at Eindhoven University of Technology. The study analyses the performance of rollerblinds using an advanced solar-tracking control strategy – Kindow Rollerblinds [Kindow, 2019] – in comparison to commercially available automated shading systems like external and internal roller shades with façade irradiance sensors. The results are analysed in terms of energy consumption and visual comfort. The performance of the investigated system is examined in relation to shading material properties and settings for the control parameters. The simulations are run for a test office building of 27m^2 area and 80% WWR for a South orientation in Amsterdam.

The comparison with conventional shading systems shows that careful combination of shade materials with reflective properties and the Kindow Rollerblind control strategy can lead to 6.5% energy savings compared to external shading and 20% against internal shading systems. A common rule-of-thumb in the building industry states that “indoor shading is not effective for reducing energy demand, because the heat is already trapped inside”. This study provides clear indications that this conventional wisdom can be refuted with carefully chosen material properties and modern-day control technology. The results furthermore show that the application of the Kindow Rollerblind strategy can lead to an average increase of up to 65% (sDA300/50) in the amount of daylight entering the building. Furthermore, the simulation studies showed an increase of 22% in the operating time with an unobstructed view for the occupant. In terms of glare, the Kindow Rollerblind system has a 5 – 9% reduction to a conventional system.

2 Simulation Setup and Methodology

The reference office space developed by the International Energy Agency (IEA) Task 56 (2018) was used in this study [D'Antoni et al, 2018]. The office model has an area of 27m^2 and a South facing façade with a window to wall ratio of 80%. Table 1 illustrates all the assumptions made for the reference office. The differences amongst the cases are due to variations in shade materials, shade positioning and control strategy. In order to compare and benchmark the performance of Kindow Rollerblinds, the following case studies were considered.

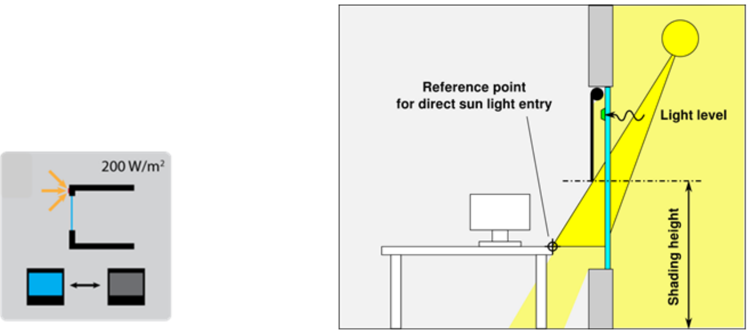
- Case 1: External roller shades with reflective material properties (shade 1).
- Case 2: External roller shades with non-reflective material properties (shade 2).
- Case 3: Internal roller blinds with reflective material properties (shade 1).
- Case 4: Internal roller blinds with non-reflective material properties (shade 2).
- Case 5: Internal roller blinds with the Kindow control strategy (shade 1).

Cases 1 to 4 are the baseline cases which are chosen in such a way to represent the performance of conventional automated shading systems available in the market. Case 5 uses the same reflective shade material as case 1 and 3, but with the advanced Kindow control algorithm. The control strategies (Figure 1) are elaborated below:

- The industry standard control strategy where the roller shades are either in up or down position based on a threshold value of 200W/m^2 façade irradiance value.
- The latest Kindow Rollerblind control strategy where the rollerblind movement is based on sun tracking and senses high light and low light condition to control shade movement.
  To elaborate more on this, the system calculates the time and location of the sun at every moment. If the sun is behind the façade, the roller blind will be fully opened to allow daylight and view to enter. If the sun does fall into the field of vision of the facade, the system will try to determine whether there is a cloudy sky or a clear sky. If it is a cloudy sky, the blinds are fully opened. But when the sun is in sight and there is a clear sky, the system will lower the roller blind to such an extent that the sun is kept out of sight of the user. The height of the roller blind is determined based on the calculated position of the sun. This prevents glare from direct sunlight and reflections from the workplane. At the same time, the uncovered part of the window still allows daylight to enter the room and allows the user to retain part of his view to the outside. It is one of the more comprehensive control strategies available for Kindow products.

Performance of advanced solar shading systems depends on the interaction between the thermal and visual domains of physics. This study, therefore, uses a co-simulation method in which advanced models for thermal performance and daylight access are linked.

The co-simulation model (Figure 2) uses a link between four existing software environments where information is exchanged between the different models during simulation. EnergyPlus, a dynamic building simulation program developed on behalf of the U.S. Department of Energy, is used to simulate the thermal behaviour and energy performance of the building. The co-simulation model uses Radiance to describe the behaviour of daylight. Radiance is a collection of programs which uses 'backward raytracing' to make accurate predictions about daylight access, glare and the amount of artificial lighting required. Matlab, a mathematical programming environment, was used to implement the Kindow control algorithm. The information exchange within the co-simulation model is made possible by the software environment BCVTB (visualized by arrows in Figure 2).



$I_{g;v}$ >200 W/m^2 – shades down
$I_{g;v}$ <200 W/m^2 – shades up

- Light level sunny: Dynamic shade height based on solar zenith and azimuth angle
- Light level cloudy: Shades are open

Figure 1: Baseline strategy and latest Kindow Rollerblind control strategy

Table 1: Modelling assumptions for the reference office for test cases.

		EnergyPlus	**Radiance**
	Dimensions	width: 4.5m; depth: 6m; height: 3m (27 m2)	
Geometry	**Window to wall ratio:**	80%	
	Type:	Solar Coating (pos. 3) double glazing with argon cavity filling,	
Fenestration	**Glazing:**	Ugl: 1.12 W/m2K Uframe: 1.5 W/m2K, SHGC: 0.306, CEN	Tvis: 0.688
	Shade 1 (Reflective):	Tsol: 0.02, Rsol: 0.74, Tvis: 0.01, Rvis: 0.72	
	Shade 2 (Non-Reflective):	Tsol: 0.02, Rsol: 0.48, Tvis: 0.01, Rvis: 0.45	
Facade		Rc = 4.5 m2K/W	rvis = 0.5
Ceiling, walls, floor		Mixed: heavy weight floor/ceiling, lightweight walls	Ceiling: rvis = 0.8, Wall: rvis = 0.5
			Floor: rvis = 0.2
	People:	3 (variable occupancy). 120 W/pers.	
Internal gains	**Occupancy:**	Weekdays: 8:00-19:00 (2860 hours/year)	
	Lighting:	10.9 W/m2 Dimming (linear between 0-500 lux) Two sensors (Figure 1) each control 50% of loads	
	Equipment:	7.0 W/m2	
	Infiltration:	ACH: 0.15	
	Ventilation:	Demand driven, 40 m3/(h*pers.), ACH: 1 (average)	
		Sensible heat recovery, eff: 70%	Sensor grid: 5x25
HVAC and settings	**Setpoints:**	Lower set point: 21°C, Upper set point: 25°C (constant)	V: -ab 12 -ad 5·104 -lw 2·10-6,
		Idealised: unlimited capacity and ideal response	D: -ab 2 -ad 103 -lw 5·10-4 -c 3000
	System efficiencies	ηe = 0.39, ηcool,deliv = 0.7, COPcool = 3, ηh = 0.95	
		Anisotropic optical model for shade	s and D: MF3
		5 min. time step	hourly time step
Weather		IWEC, Amsterdam	
Orientation		South	

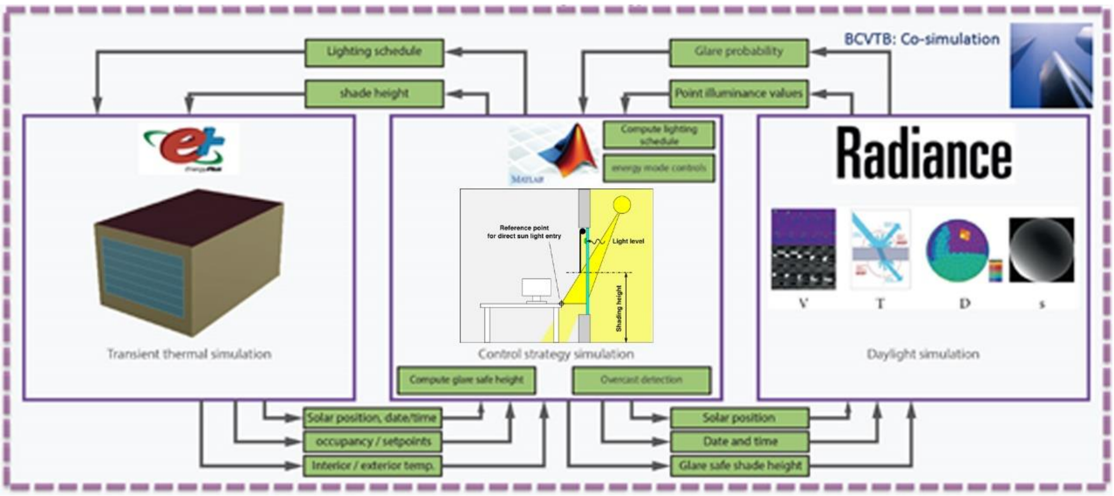


Figure 2: The co-simulation model

2.1 Performance indicators

In this study, energy performance is assessed on the basis of the energy demand for lighting, cooling and heating at room level in combination with an estimate of the primary energy consumption based on a number of system efficiency assumptions. The energy demand at room level provides an insight into the savings potential in general. It can be used to estimate the actual energy and cost savings when the Kindow Rollerblind control system is applied in combination with specific shade materials. In order to gain insight into the environmental savings potential, the primary energy consumption is also taken into account. The following reference figures have been used for this purpose. (Beck et al. 2010; Aa van der 2012).

$$E_{Prim} = \frac{E_{Light}}{\eta_e} + \frac{E_{cool}}{\eta_e \eta_c COP} + \frac{E_{heat}}{\eta_h} \quad \text{met: } \eta_e = 0.39, \quad \eta_c = 0.7, \quad COP = 3, \quad \eta_h = 0.95$$

In order to assess the performance of the shading systems, a series of performance indicators have been selected. In order to quantify the degree of daylight access, this study will use daylight autonomy (DA) and spatial daylight autonomy (sDA). Daylight autonomy can be interpreted as the percentage of time that a measuring point receives 'sufficient' daylight. For this indicator, the abbreviation DA300 is often used, where 300 stands for the number of lux that is set as a limit value. Spatial daylight autonomy enables us to express daylight access to a room as a whole in one number. It is defined as the percentage of the floor area with a daylight autonomy higher than fifty percent. Spatial daylight autonomy can be interpreted as the fraction of the floor area that receives sufficient daylight most of the time (Reinhart, Mardaljevic, and Rogers 2006). For this indicator, the abbreviation sDA 300/50 is often used, where 300 stands for the limit value in lux and 50 for the required exceeding percentage of the usage time.

In this report, 'daylight glare probability simplified' (DGPs) is used as an indicator to assess the risk of glare (Wienold 2009). Although much is still unknown in the field of glare perception and assessment, it is certain that glare is associated with high luminance differences in the field of view, with the total luminance at eye level, as well as with the position of glare sources in relation to the focus area of the eye task. The DGPS indicator is primarily based on vertical illuminance but neglects the influence of peak glare sources. In this report, a DGPs limit of 0.40 has been considered for occupied hours when the glare is weaker than ‘disturbing’. And the DGPs values are considered at the two sensor points as shown in figure 3, one has a viewing angle of 45 degrees and the other at 0 degrees meaning it is directly facing the wall. The maximum value out of the two sensor points is considered at each timestep and then the DGPs is evaluated for the whole year.

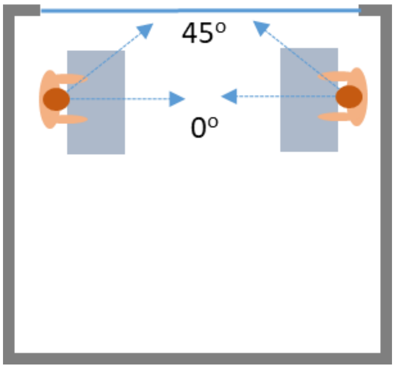


Figure 3: Positioning of the sensor point and the viewing angles considered for dgp calculations

3 Results

3.1 Energy Performance

Figure 4 shows the comparison of energy demand of the different cases considered for a south-facing office space in Amsterdam. The external shading system has much lower cooling demands in comparison to the internal shading systems as it can keep the solar radiation from entering the test space, but this also increases their heating demand considerably. Simple changes like the choice of using reflective shading material instead of the conventional non-reflective one can have quite an impact on the performance of these systems. For external shades (cases 1 and 2), this change accounts for 5.0% and 12.5% reduction in lighting and cooling demands. For internal shades (case 3 and 4), use of reflective shade material leads to 6.5% and 24.0% reduction in lighting and cooling demands respectively. The reductions seen in lighting demands is due to the angular behaviour of the reflective material which leads to difference in transmittance. And reduction in cooling is due to the reflectance property of the material, hence the reduction in cooling demand is more apparent for internal shades than external ones.

Since case 1 to 4 (conventional indoor and outdoor shading systems) use the same control strategy based on façade irradiance, the lighting demand is comparable for all these cases. Although at a closer look, one can notice a 5 – 6% reduction in lighting demand because of the use of reflective shades in cases 2 (baseline_externalshade) and 4 (baseline_internalshade) respectively. Case 5 (Kindow Rollerblind control), which uses the same reflective shading material as case 2 and 4, has an improved heating and lighting demand in comparison to the rest of the cases. For example, heating demand is reduced by an average of 25% in comparison to internal shades (case 3 and 4) and by an average of 50% against external shades (case 1 and 2). And lighting demand is reduced by an average of 44% against all cases 1 - 4. This improvement is because of its use of the complex sun tracking algorithm that considers sun position and sky brightness for its positioning during occupied hours.

On the other hand, there is also a 25% increase in cooling demand in comparison to case 4 (baseline_internalshade_reflective), as the current version of the control strategy allows more time with its shades up and unobstructed view of the outdoors to the occupant. This increase in cooling demands is less decisive for the total primary energy consumption and the influence of lighting is relatively large due to the system efficiency factors associated to meeting different types of loads.

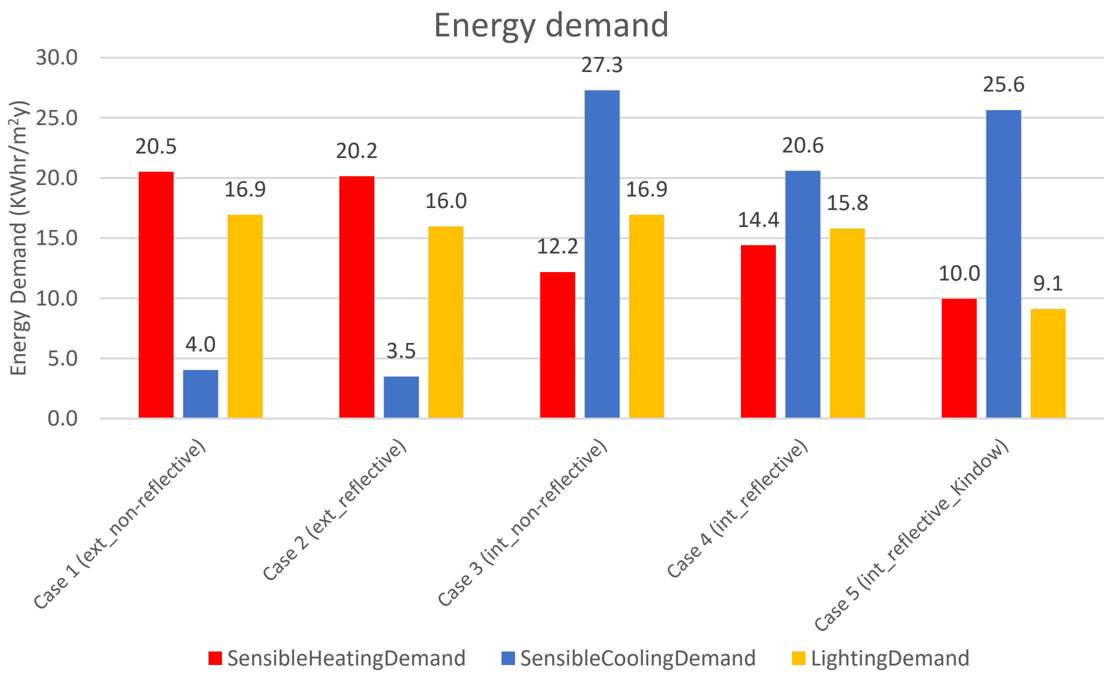


Figure 4: Annual energy demand comparison

As we can see in figure 5, the primary energy consumption shows that indoor shading systems with careful combination of shading material and control strategy (case 5) can outperform external shading systems (case 2) by a 6.5%.

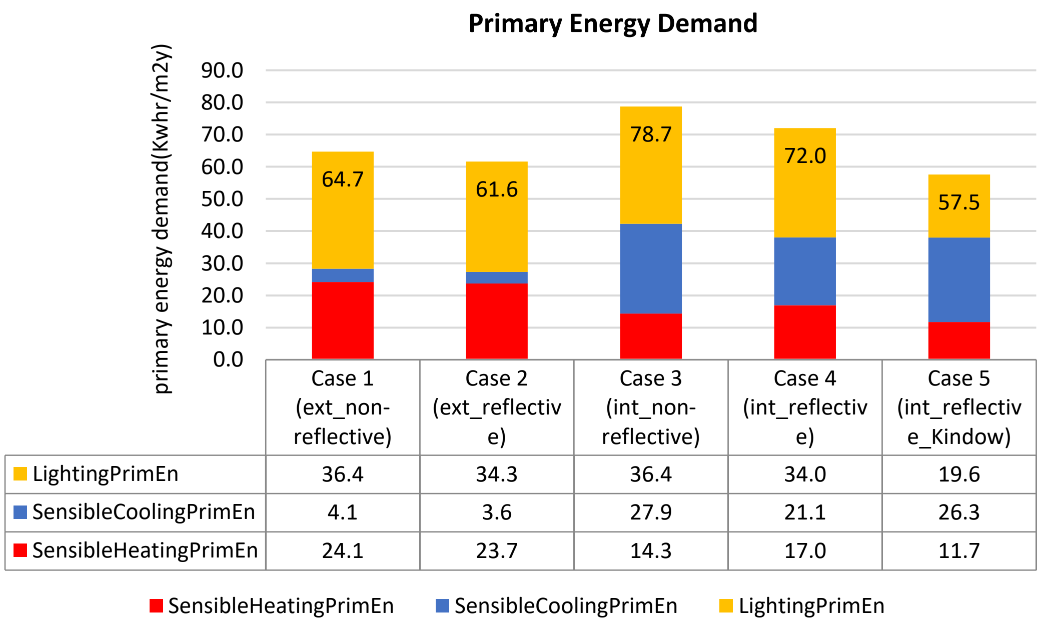


Figure 5: Primary energy demand

It can also be seen that the use of Kindow Rollerblind control strategy (case 5) leads to an average 40% reduction in primary lighting energy demand in comparison to the rest of the cases. This also highlights that lighting energy has a greater influence on overall energy consumption compared to heating or cooling loads.

As the visible transmittance of both shade materials were kept identical at 0.012, the variation in reflective and non-reflective shading did not have a significant impact on visual performance. There is, however, a remarkable difference because of the change in control strategy.

3.2 Visual Performance

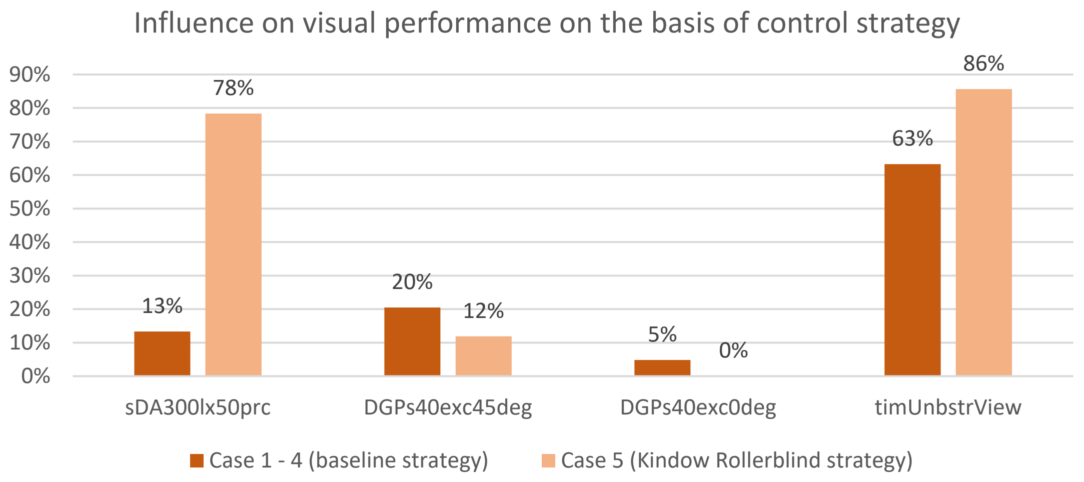


Figure 6: Influence of control strategy on visual performance.

There is a 65% increase in spatial daylight autonomy and 23% increase in percentage of time with an unobstructed view. An Unobstructed view means whenever the shades are above the height of the occupant's eyelevel. The Kindow Rollerblind strategy allows the shades to be more open than the baseline strategy thereby causing this remarkable improvement in the daylighting gains and view in the space. Also, its strategy for obstructing direct sun and instances of high illuminance sky conditions has resulted in 8% reduction in Glare values for 45^o viewing angle and complete removal of glare problems when the occupant is sitting parallel to the window (0^o).

3.3 Conclusion

From this study it can be concluded that use of reflective materials and the Kindow Rollerblind control strategy has great potential to optimise automated indoor shading systems according to building characteristics, user preferences and objectives. The possibilities in terms of energy saving and optimizing user comfort can be significantly increased. Primary energy consumption is reduced by 6.5% in comparison to external shading systems whereas there is a 20% drop in primary energy demand when compared to indoor shading systems. The use of the Kindow Rollerblind strategy greatly improves the amount of daylight entering the space. As much as 65% increase in terms of spatial daylight autonomy and 9 and 5% decrease in glare probability for viewing angles 45 and 0 degrees respectively. It also questions the common rule-of-thumb that outdoor shading systems perform better as it keeps the solar radiation out before it enters the building through the glazing. And also illustrates that such conception doesn't necessarily guarantee good building performance. The study provides clear pointers that that careful combination of glazing and shading properties, and control strategies is important for optimal energy performance. Using reflective shade material instead of conventional non-reflective ones is likely the first step to improving energy demands. Consequently, major improvements in visual performance as well as energy demands can be obtained by using a refined and complex control strategy as used by Kindow.

4 Reference

1. Aa van der, R. 2012. "NEN 7120+ C2: Energieprestatie van gebouwen-Bepalingsmethode." In. Delft: Stichting Nederlands Normalisatie-instituut (NEN/CEN).

2. Beck, W, D Dolmans, G Dutoo, A Hall, and O Seppänen. 2010. "Solar Shading. REHVA Guidebook 12." In.: Forssa, Finland.

3. D'Antoni, Matteo, Paolo Bonato, David Geisler-Moroder, Roel Loonen, and Fabian Ochs. 2018. "IEA SHC T56 - System Simulation Models: part C." In. Paris: IEA.

4. Kindow B.V. 2019. Last accessed 27 august 2019. http://www.kindowblinds.com/

5. Reinhart, Christoph F, John Mardaljevic, and Zack Rogers. 2006. 'Dynamic daylight performance metrics for sustainable building design', Leukos, 3: 7-31.

6. Wienold, J. 2009. Daylight glare in offices. (Fraunhofer and Universität Karlsruhe (TH): Freiburg, Germany).