Counterbalancing daylighting, glare and view out: the role of an external shading system control strategy

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Abstract
To protect building shells from solar radiation, allow daylight in and improve the envelope's performance, it is critical to adopt shading systems with advanced controlled strategies. This research explores the definition of an optimized control strategy that counterbalances solar protection – daylight adequacy, glare reduction and view out. More specifically it examines a new dynamic control strategy for an exterior non-retractable louver system installed in a typical office space. Primary goal of the control system is to increase daylighting levels and maintain a predefined illuminance level on the work plane surface, while managing solar gains and protecting from glare. The proposed control strategy is defined with the optimization process of three different control strategies based on three performance criteria accordingly:

- *required illuminance levels;*
- *glare reduction and;*
- *view out.*

To define the dynamic control strategy, a series of simulations were performed in EnergyPlus. Consumption for lighting, heating and cooling has been calculated for a set of slat angles of the shading system. Hourly daylighting simulations calculated illuminance levels on predefined sensor points. For each point and each hour of the day and year, tilt angle is estimated while illuminance is calculated using linear interpolation between adjacent tilt angle values. To optimize the control performance based on occupants' visual comfort, an annual glare analysis was conducted using the daylight glare index concept (DGI).

Keywords – shading control; dynamic façade; daylighting; illuminance; glare; view out; dynamic; control strategy

1. Introduction

Energy efficiency in modern architecture is a growing necessity. Fully glazed, multilayered skins that tend to be more lightweight have an impact on occupants visual and thermal comfort and buildings energy consumption.

Combined, they typically account for more than 50% of the overall energy demand of office buildings and often even as much as over 70% [1].

To improve the envelope's performance, an integrated design approach should be considered in facade design with shading devices that modulate the external conditions [2]. Louvers, venetian blinds and shades can be located internally, externally or in between panes to control daylight and reduce solar heat gains. Shading devices performance is highly affected by the occupants' operational patterns in manual systems and control patterns in automated systems. In a literature review on patterns of occupant interaction with blinds, Wymelenberg [3], identified categories that influence the use of blinds such as physical factors (workstation position) and psychological factors (access to view). Studies on occupants' behavior argue that "lighting quality" requirements should not only refer to visual comfort but should also comprise conditions for task work and energy performance. To assess the impact of behavioral models and associated control patterns of shading devices in buildings energy performance da Silva et al. [4] selected and compared a comprehensive set of models. Results show that different control patterns have significant impact on the energy performance. Also the behavioral model where blinds are activated if glare is present (DGI > 22) better represents the average of the whole group of models in terms of the results they produce [4].

The present study focuses on automated shading devices used to meet a set of performance criteria that affect occupants' reaction and influence energy performance. "Dynamic" window technologies often refer to conventional components such as motorized louvers and venetian blinds [2]. Vertical irradiance levels, temperature levels and illuminance levels on the workplane surface are commonly used to define control rules. Studies on control strategies use illuminance as a measure to determine the presence of direct light and luminance to examine glare [3]. To examine the performance of a dynamic system, Lee et al. [2] developed a prototype that activated blinds to block direct solar radiation and maintain required illuminance levels. The study concluded that a dynamic system could achieve energy savings of 7%–15% and 19%–52% for cooling and lighting energy, respectively, compared to a static shading device. To control glare, a predominant criteria in control rules definition, the Lightswitch model [5] proposed that blinds are automatically fully lowered to block direct irradiation with a fixed angle of 0, 45 or 75. Moeseke et al. [6] examined the impact of control rules on the efficiency of the shading devices and concluded that the most effective control strategy in terms of comfort and energy savings is the one that is based on internal temperature and solar irradiation.

Based on the kind of performance criteria they address, some control strategies define the position of the blind (lowered/opened) with fixed slat angles, while some others focus on a schedule for the slat angle for every hour of the day. Meek et al. [7] pre-calculated workplane illuminance levels for every slat angle for chosen dates. This data was then combined in order to define slat angles based on the required range of illuminance levels and calculate percentages of lighting power consumption. Two research studies by Konstantoglou and Tsangrassoulis [8], [9] defined slat angle schedules for the whole year based on work plane illuminance and examined the performance of a dynamic system that consists of a sun tracking lightshelf with fixed slat angles or automated blinds at the lower part of the window.

To optimize an automated control system based on performance (sum of cooling, heating and lighting energy use) Kim and Park [10] highlight the advantages of a fuzzy logic-based control algorithm. Following previous studies that mostly focused on blind position control (lowered/retracted) [11], Kim and Park [10] considered slat angle as a control variable on building energy performance optimization. This research explores the definition of an optimized control strategy that counterbalances solar protection – daylight adequacy, glare reduction and view out.

2. Evaluation Study

To assess the performance of the blinds control strategies an energy model of a south facing office space was created in Daysim and EnergyPlus. The office room is 5.4m long and 3.4m wide, resulting in a floor area of 18.36 m^2. The room is daylit by a south oriented window defined by three Window to Wall Ratio scenarios (WWR: 40%, 60% and 80%). The window is shaded by a normal (width=distance) system of external non-retractable blinds. The room occupancy and hours of operation were defined as 0.1 person/m^2 from 08:00 to 19:00 during weekdays, the artificial lights electric power as 16 W/m^2 and the electric power as 15 W/m^2.

Table 1. Model Properties

Office space properties	
Floor Reflectance	0.2
Walls Reflectance	0.5
Ceiling Reflectance	0.8
Window properties	
Area	3.9 m^2, 5.5 m^2, 7.3 m^2
U-Factor	2.314 W/m^2K
Visible Transmittance	0.74
SHGC	0.615
Blinds properties	
Width	0.1 m
Reflectance	0.5
Material	Aluminum

3. Framework of Simulations

A first set of ten simulations regarding the fixed slat angle (0°-90°) of static blinds with a step of 10° for six south oriented Window to Wall Ratio options (WWR:10%, WWR:30%, WWR:40%, WWR:60%, WWR:80%, WWR:100%). The first set of simulations performed in Daysim, calculated Daylight Factor values in the center of the office space for every slat angle (Fig. 1). Results have shown that acceptable values (DF>1%) are present for scenarios WWR:40%, 60%, 80% and 100% for slat angles 40° and above. Whereas preferable values (2%<DF<5%) are present for scenarios WWR:60%, 80%, 100% for slat angles 60° and above. Daylight values for WWR:80% and 100% are very close. To further examine the role of control strategies in relation to Window to Wall Ratio scenarios, the following three scenarios were selected (WWR:40%, WWR:60% WWR:80%).

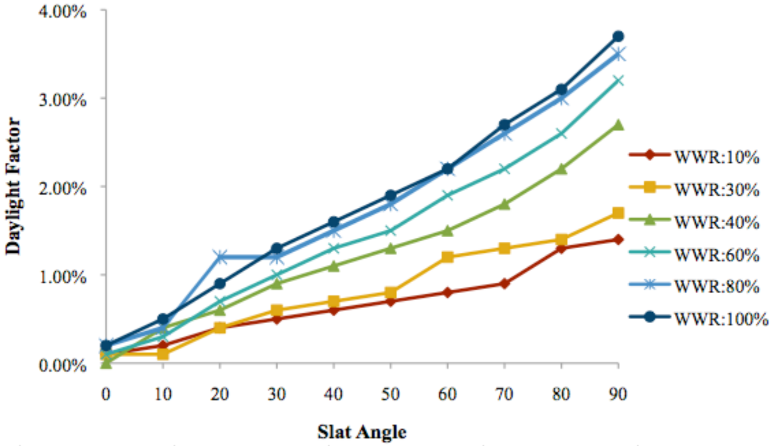

Fig. 1 Daylight factor as function of Slat Angle for six Window to Wall Ratio scenarios

The framework of the second set of conducted simulations consists of seven variations of control strategies presented in Table 2.

Table 2. Control Strategies

S1	No Shading (Base Case)
S2	Static Blinds (90°)
S3	Sunblocking Control Strategy (blocks direct solar radiation)
S4	Glare Control Strategy (minimizes glare)
S5	View Out Control Strategy (ensures visual contact)
S6	Dynamic Control Strategy based on Illuminance levels (500 lux)
S7	Optimized Control Strategy (combines S5 and S6)

The second set of simulations performed a daylighting and glare analysis in EnergyPlus. Illuminance levels and DGI values were calculated on the work plane surface in the middle of the room for a predefined set of slat angles for each of the three Window to Wall Ratio options. EnergyPlus was used to calculate interior daylight levels, glare and lighting power use. A series of hourly simulations were performed with fixed slat angles from 0° to 90° with a step of 10°. Thus, when a control strategy is scheduled for certain tilt angles all daylight variables are estimated using linear interpolation between adjacent tilt angle values considering that this variable value is not changing rapidly between known values. Using the above described methodology strategies S4 to S7 have been set up by creating a schedule file with blind tilt angles for every hour on a yearly basis. The procedure is schematically presented in Fig. 2.

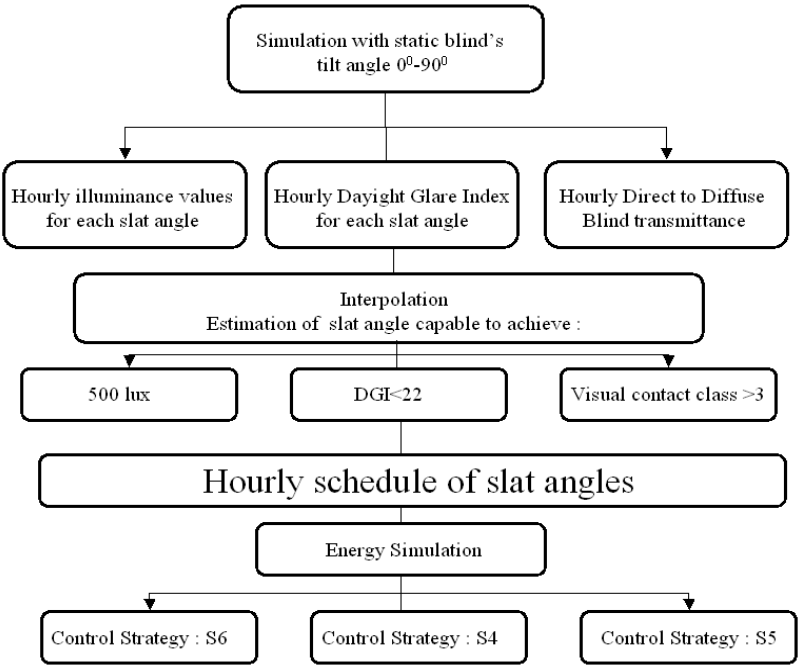

Fig. 2 Schematic representation of the S4, S5, S6 control strategies set up procedure.

In more detail control strategies S1 and S2 are used as the base case scenarios, with no blinds (S1) and static blinds scenario in 90° tilt angle (S2). Control strategy S3 refers to the sun blocking control strategy as defined in EnergyPlus. The slat angle is set in each time step to just block beam solar radiation. Strategy S4 is a glare control strategy that adjusts the tilt angle to avoid glare by decreasing slat angle tilt in 10° steps based on the Daylight Glare Index. If no glare is present (DGI<22), blinds are set to horizontal position (90°) during occupancy hours. In strategy S5, view out is the determining factor. Blinds slat angle is scheduled in order to assure visual connection to the exterior. Visual contact with the outside is estimated and classified based on the Standard EN 14501:2005 “Blinds And Shutters - Thermal And Visual Comfort - Performance Characteristics And Classification”. Visual contact represents the ability for an observer, standing 1m away from the shading system on the inside to distinguish a person or an object 5 m away from the blind on the outside. It is characterized by two parameters a) the normal-normal visible transmittance and b) normal-diffuse transmittance (Fig.3) which can be replaced by direct-diffuse transmittance when oblique angles of incidence occurs.

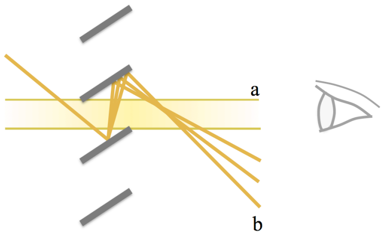

Fig. 3 Schematic diagram of the visual contact classification method. a: normal light transmittance b: diffuse part of light transmittance

The classification, based on five classes from 0 to 4 is presented in Table 3. For strategy S5 hourly blind tilt angle values have been calculated so that visual contact is at least 3.

Table 3. Classification of visual contact with the outside

$t_{v,n\text{-}n}$	$t_{v,n\text{-}dif}$		
	$0 < t_{v,n\text{-}dif} \leq 0.04$	$0.04 < t_{v,n\text{-}dif} \leq 0.15$	$t_{v,n\text{-}dif} > 0.15$
$t_{v,n\text{-}n} > 0.15$	4	3	2
$0.05 < t_{v,n\text{-}n} \leq 0.10$	3	2	1
$t_{v,n\text{-}n} \leq 0.05$	2	1	0
$t_{v,n\text{-}n} = 0.00$	0	0	0

Strategy S6 is a dynamic control strategy that adjusts blinds tilt angle in order to meet a set-point of 500 lux on a sensor point located on the work plane surface in the center of the room. If there is no illuminance on the window, blinds are closed (the slat angle is set to a default value input of 0°). Tilt angle is then estimated based on the calculated illuminance levels for each timestep, using linear interpolation between adjacent tilt angle values of static blinds (0^0-90^0) as described above. The selected tilt angle performs so that the set-point of 500 lux is met by the adjustment of the blinds alone, if that condition is not met then the daylight control system is enabled to compensate in order to maintain the set-point during the hours of operation of the space. Strategy S6 differs from the "setpoint" control strategy in EnergyPlus that deploys blinds instead of changing their tilt. Strategy S7 combines strategies S5 and S6 and balances performance requirements for illuminance and view out. S7 tilt angle schedule is a combination of S5 and S6 schedules based on the following rule: For each hour of the day it adopts the strategy with higher tilt angles. This is to assure a certain class (3) of visual contact to the exterior in any case. Strategies S3 to S7 adjust the blind tilt angle based on the performance criteria for each scenario without retracting the blinds.

4. Results Analysis

For each control strategy hourly values of blind slat angle are different as presented in Fig. 4.

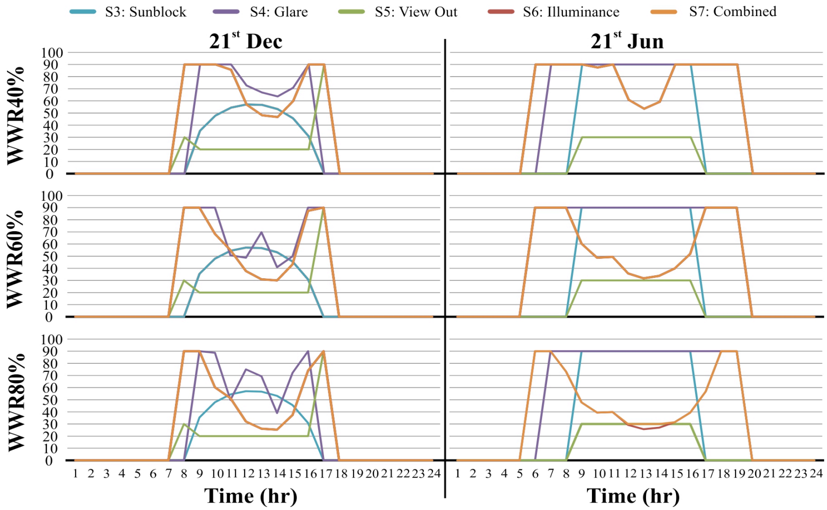

Fig. 4 Tilt Angles of the Dynamic Control Strategies: December 21st (left) and June 21st (right)

The variation of the slat angle values is a direct result of each of the simulated control strategies based on the selected criteria. These differences in blind slat angle values affect the energy balance of the examined space. Results concerning primary energy consumption are presented in Fig. 5 and underline a significant interaction of the shading system control strategy with both on the overall energy consumption and the occupants visual comfort. Primary energy consumption was estimated out of energy loads with the use of the following conversion factors: 2.9 for electric lights and cooling, 1.05 for heating.

The implementation of the external non retractable louver system reduces solar heat gains and thus affects significantly the cooling

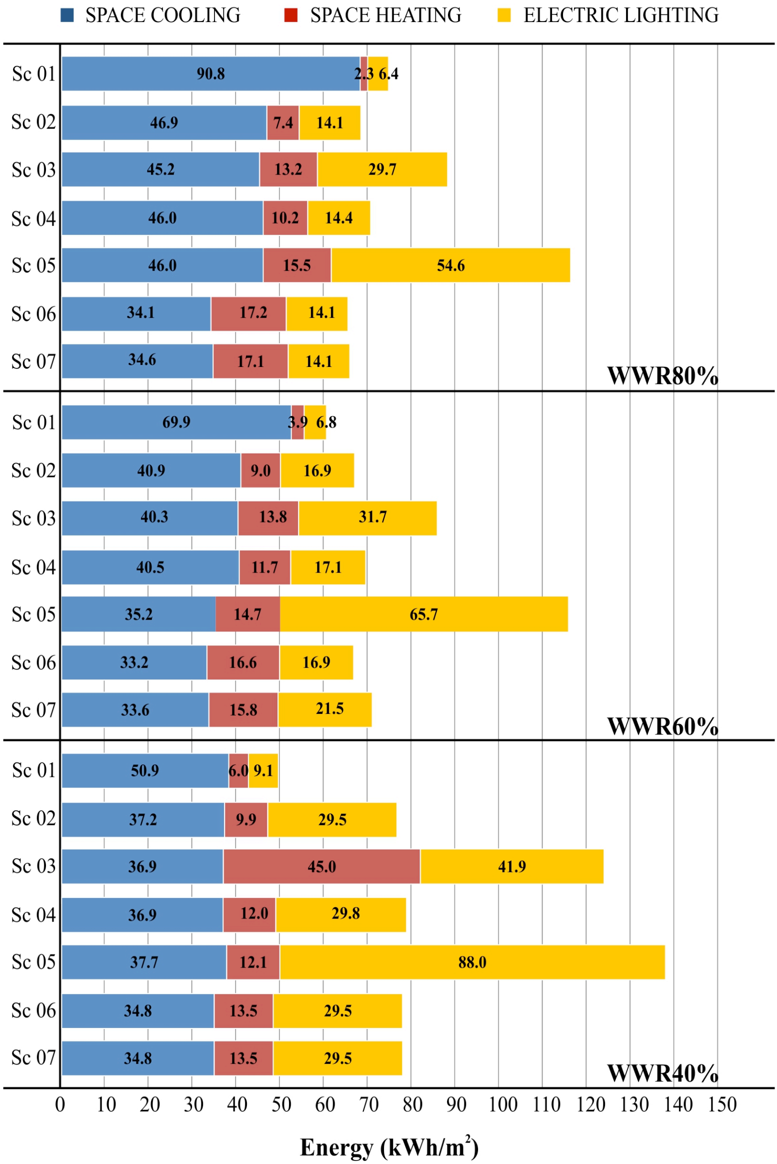

Fig. 5 Primary Energy Consumption for all five Dynamic Control Strategies (S3-S7). Comparison with base case scenarios (S1, S2)

requirements with a slight increase on the spaces heating requirements. This trend is apparent as the proportion of the glazed area increases. As shown in Fig. 5 the implemantation of shades, regadless the WWR or the adopted shading control startegy (S2-S7), results reduction of cooling compared to the same model without the shading enabled (S1). For WWR=80%, primary consumption for cooling for strategies S2 to S7 decreases by up to 60% compared to S1. Change of blinds tilt angle doesn't seem to further affect energy consumption for cooling. For WWR:60%,strategies S6 and S7 reduce primary energy consumption for cooling by about 27% compared to S2 whereas for WWR:40% strategy S7 reduces cooling loads by 6% compared to S2.

Shading increases primary energy conssumption for heating for all cases reaching about 220% for WWR:80%. Compared to static blinds (S2) dynamic control strategy S6 increases energy consumption by about 135%, 77% and 35% for scenarios WWR:80%, 60% and 40% respectively. Nevertheless increase of heating loads doesn't significantly influence the overall energy consumption.

The most prominent effect of control strategies concerns lighting consumption. External louvers highly affect the energy consumpton for lighting. Compared to the base case scenario (S1), static blinds (S2) reduce energy consumption for electric lighting by up to 48% for scenario WWR80%. For every WWR case strategy S5 represents the highest electrical lighting load whereas strategies S6 and S7 represent minimum loads. This is due to the fact that achieving visual contact class 3 blinds are placed in small tilt angles (0^0 closed, 90^0 horizontal) and thus daylight usage is minimized. Compared to static blinds (S2), dynamic control strategies (S6, S7) that balance the required set of performance criteria reduce electric lighting loads by 25%, 19% and 5%

Strategy S7 balances the required set of performance criteria by ensuring visual contact, minimizing energy consumption and providing illuminace levels of 500 lux on the work plane surface. Requirements to minimize glare are met by scheduled tilt angles for control strategy S6. For the case of WWR:40% and WWR:80% strategies S6 and S7 provide the same energy consumption and therefore S7 is the best control strategy since it meets all performane criteria. For WWR:60% strategy S7 consumes about 5.5% more energy than S6. Therefore there is no control strategy that meets the whole set of performance criteria.

To further develop the optimized control strategy S7 and translate its schedule into a controller's slat tilt schedule, a series of issues need to be solved. Illuminance levels measured in the sensor location need to be subdivided into daylighting levels and the amount of light coming from the electrical lighting for every timestep. Conclusively, dynamic control strategies that change the slat tilt angle seem to significantly influence the energy consumption for lighting and therefore affect the buildings overall energy consumption.

5. Acknowledgements

This research has been co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: Heracleitus II. Investing in knowledge society through the European Social Fund.

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EUROPEAN SOCIAL FUND

Co-financed by Greece and the European Union