Building and Environment 126 (2017) 207–220

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

A daylight optimized simulation-based shading controller for venetian blinds

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A B S T R A C T

A new controller for office spaces with venetian blinds has been developed to explicitly address both daylight maximization and glare control. Conventionally, systems that operate on these principles require numerous sensors to monitor the visual conditions in the room, leading to expensive, complicated and impractical installations. To address this problem the developed controller substitutes the illuminance sensors with real-time daylight simulations based on the Three-phase method and uses bi-directional scattering distribution functions (BSDF). An optimization engine based on the principles of fuzzy logic has been added to the system in order to evaluate the visual conditions in the room and decide on the optimal shade configuration.

A prototype of the controller has been built and tested under real life conditions in a rotatable test facility located in Freiburg, Germany. The accuracy with which the simulation engine predicts horizontal and vertical illuminances in the room has been satisfactorily evaluated against measurements and the operation of the controller has been assessed. A case study has been conducted in order to demonstrate the benefits of the new simulation-based controller over two widely used control strategies.

1. Introduction

The direct solar radiation transmitted through the fenestration systems is a major factor influencing the indoor visual and thermal comfort as well as the lighting and cooling energy demand. Commercial solar control systems aim at regulating the solar heat gains and at preventing glare without compromising the daylight levels in the room in order to enhance the building energy performance. In the IEA-SCH Task 21 [1] a detailed comparison of available daylight systems was presented and venetian blinds were proposed as an appropriate solution in terms of glare protection, view out, daylight potential and commercial availability. As Kuhn et al. [2] pointed out, careful design of solar control in commercial buildings can improve the visual and thermal comfort of the occupants while reducing the lighting and cooling energy demands.

As far as the device configuration is concerned, manual control has been traditionally used since it allows the user to adjust the shades at will to achieve visual and often thermal comfort. According to Lindsay and Littlefair [3], commercial building occupants tend to readjust their venetian blinds in order to prevent glare and often block excessive solar heat transfer. On the other hand, the user reactions are rarely a response to the dynamically changing solar position. As a result, the shades often remain unaltered over long periods of time, therefore reducing the potential of energy savings [4].

Innue et al. [5] developed one of the first automatic solar control systems for high rise offices by correlating the sunlight penetration depth with the direct radiation on the facade, based on monitoring data. Other systems developed analytical models using solar angles to adjust the height or tilt angle of the shading device in order to block the direct solar component, like in the works of Zhang and Birru [6] and Koo [7]. Other strategies focused primarily on energy efficiency by selectively accepting the solar heat gains according to the space occupancy. Such a system was implemented at the main building of Fraunhofer Institute for Solar Energy Systems in Freiburg, Germany [8]. The installed controller allowed a seasonal variation of the window occlusion during the hours of low occupancy while allowing the users to configure the shading device at will the rest of the time.

To explicitly address glare, a number of projects used measurement schemes to apply a shading control based on user defined set-points at given positions. Lee et al. [9] developed a control strategy installed at the New York Times headquarters and added the computer screen visibility in the glare protection parameters. In a more recent work, Konstantzos et al. [10] investigated the correlation of vertical illuminance at the eye level of the occupant with the Daylight Glare Probability (DGP) and the simplified DGP and created a real-time glare control for roller shades using vertical illuminance measurements as

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http://dx.doi.org/10.1016/j.buildenv.2017.10.003
Received 2 August 2017; Received in revised form 20 September 2017; Accepted 1 October 2017
Available online 04 October 2017
0360-1323/

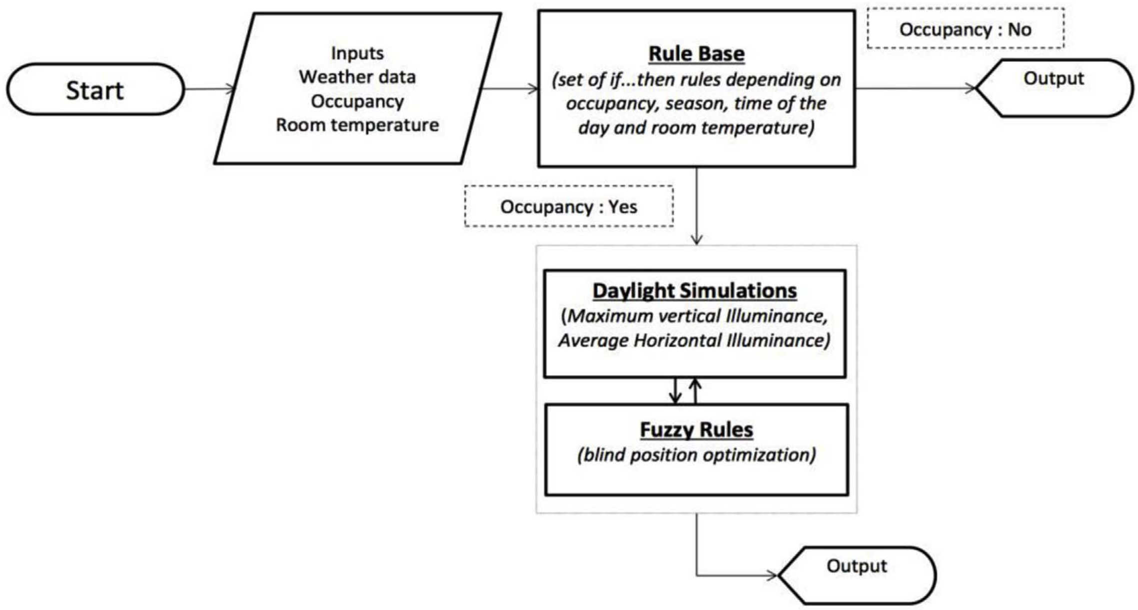

Fig. 1. Flowchart of the control algorithm.

input.

To address the hardware related disadvantages, the idea of simulation-based systems emerged. Shade controls are often available in building simulation softwares while glare has been also recently introduced in the pre-defined control strategies. EnergyPlus offers a glare control based on a user defined glare index value calculated by the EnergyPlus engine for daylight simulations [11]. The DIVA plug-in for Rhino (http://diva4rhino.com/) also offers glare control addressing, however, only glare from direct sunlight by defining an illuminance sensor at the facade. The control is activated when the facade illuminance exceeds a prescribed threshold and the solar angles remain within a user-defined range.

A number of works also demonstrated different variations of simulation-based controls for shading devices. Athienitis and Tzempelikos [12] developed a controller for highly reflective blinds enclosed within two glass panes, combined with an electric light control. The developed system was based on detailed numerical daylight simulations and the daylight transmittance equations of the fenestrations system were derived from measurements. Another elaborated real-time, model-based glare control strategy for roller blinds was developed by Xiong and Tzempelikos [13]. The system calculated the Daylight Glare Probability (DGP) [14] and vertical illuminance at the eyes of the user for a predefined sitting position and corresponding view directions using forward ray-tracing and a radiosity daylight model. Mahdavi [15] proposed a predictive simulation based control which evaluated a number of possible system states at every time step. The daylight simulations used were based on luminance distribution maps of the sky obtained by synchronous digital photographs with a fisheye lens. Eltaweel and Su [16] developed a control strategy for reflective blinds in order to parametrically redirect the incident light responding to the changing solar altitude using the Grasshopper plug-in for Rhinoceros 3D.

To enhance user satisfaction, however, a control system must not only address visual and thermal comfort but also avoid unnecessary disturbances such us frequent movements of the shades, sensors on the working surface and strict limitations concerning the sitting position of the users. To avoid the two latter issues, commercial solar control systems focus mainly on preventing the glare caused by direct solar irradiance which has also been identified as the prime cause of overheating. On the other hand, most of the times glare due to diffuse radiation is not explicitly addressed resulting to reduced visual comfort.

In this paper a simulation based controller for venetian blinds is presented. The proposed controller addresses the aforementioned problems in the following ways.

- •The sensors are replaced by daylight simulations to calculate horizontal and vertical illuminance in order to optimize the visual conditions in the room including both glare and daylight penetration.
- •By calculating the average horizontal and the maximum vertical illuminance for points of high interest in the room, the commissioning process can be significantly simpler since detailed knowledge on the sitting position of the occupants is no longer mandatory.
- •Both the height of the shading device and the tilt angle of the slats are adjusted so that the controller-defined positions cover only the necessary window area in order to favor daylight admission and view contact to the outside.
- •The controller calculates the optimal shade position internally before sending the signal to the actuators, reducing the number of movements.
- •The calculation of the visual conditions in the room, can potentially allow the adaptation of the controller to different user profiles, which would further improve the user acceptance of the system

A prototype of the simulation-based controller, built and tested at Fraunhofer ISE (Freiburg, Germany), is presented along with a detailed description of the control algorithm and the prototype set-up. The accuracy of the controller's daylight simulations is evaluated and the real life operation of the system is also assessed. Finally the performance and energy saving potential of the system is further examined through a simulated case study in comparison with two common control strategies. The aim of the presented research is to create an efficient controller for venetian blinds based on daylight simulations which can be commissioned in a flexible and cost effective way.

2. Algorithm

The control algorithm is described in this section. The proposed strategy is separated in two parts depending on the room occupancy. While the users are present, visual comfort is prioritized, however, excessive solar heat gains are blocked to prevent overheating should such a probability arise. On the other hand, energy efficiency is prioritized during unoccupied periods.