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A systematic workflow for retrofitting office façades with large window-to-wall ratios based on automatic control and building simulations

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ABSTRACT

Fully glazed façades are still preferred by many architects due to their aesthetic features. Although this choice offers opportunities for daylighting and view contact with the outside, it can lead to overheating and glare problems if climate is not taken into account in the design. This paper presents a workflow for retrofitting that can be applied to different office façades with large window-to-wall ratios. The workflow consists of analysing the space from the point of view of the functions of its façade and then applying a retrofitting strategy based on state-of-the-art building simulations and automated shading control. The proposed workflow is illustrated by a case study at an office in Malaga (Spain), in which the originally installed, manually-controlled interior vertical blinds are replaced with automatically controlled interior roller blinds with a metallized reflecting surface facing towards the glazing unit. A full optical characterization of the roller blinds is presented. A simulation-based control strategy is applied to the motorized roller blinds in order to maximize view contact with the outside and daylighting while controlling glare and overheating.

1. Introduction

The design of highly transparent façades in office buildings presents a particular challenge. The building façade provides the aesthetic signature of a building, but it also provides important functions [1,2], such as visual contact with the outside, daylight provision, glare protection and solar gain management, which make the building usable and energy-efficient. These functions often oppose each other, so the selection and design of façade systems and their control for a certain building application should depend on those functions that the designer wants to promote to the detriment of the other functions. The risk of not designing carefully in this direction is that the initially planned functions may not play a role in practice, if the day-by-day use of the fenestration system is completely different to the plan [3].

Movable shading devices or switchable elements are necessary in order to dynamically balance the different façade functions, which are of varying relevance, depending on the time of the day and season. This implies the consideration of a control strategy. Several studies show that manual control is neither optimized in terms of energy efficiency nor in terms of comfort. Building occupants generally close a shading system to prevent direct solar radiation but then forget to retract it [4,5]. State-of-the-art automatic control of fenestration system, on the other hand, often consists of an on/off strategy activated on the basis of an outdoor illuminance sensor installed on the rooftop or an indoor luminance meter on the ceiling in order to estimate workspace illuminance [6]. Numerous studies have shown that these control systems have low occupant acceptance [7,8]. The hypothesis of this paper is that user dissatisfaction is caused by the lack of consideration of all (or at least the most important) facade functions in the control strategy. Taking these into account lead to good examples of automatic shading control implementation such as the New York Times Headquarters [9] and the San Francisco Federal Building [10].

The goal of this paper is to present a systematic workflow for retrofitting office façades with large window-to-wall ratios. The workflow consists of analysing a façade from the point of view of its functions for a particular application. Then, a retrofit strategy is designed to optimize these functions, for which daylighting building simulations and automated shading control is required. Additionally, in order to build a reliable numerical model of the room, the fenestration system must be characterized and the model must be tested. An evaluation of the dynamic performance of the façade system can then be carried out by whole-year building simulations. At this point, changes in the retrofit solution can be made before it is implemented and finally tested.

In summary, the steps of the proposed workflow are the following:

1. Analysis of the case study.

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2. Design of the retrofit solution.
3. Characterization of the solar control system.
4. Evaluation of the numerical model.
5. Evaluation of the annual performance of the retrofit solution.
6. Testing the implementation of the retrofit solution.

In this workflow, the automated shading control system operates on the basis of visual contact with the outside, glare protection (including the glare from diffuse solar radiation), daylight maximization and overheating prevention [11]. A computationally efficient simulation engine reads real-time weather data and calculates horizontal and vertical illuminance at different positions in the room [12]. By using this information, the control strategy is able to evaluate daylight sufficiency and glare risk without the need of any interior illuminance sensor or luminance camera [13]. Additionally, air temperature is directly measured inside the room as a means to evaluate the overheating risk. In contrast to illuminance sensors and luminance cameras, which can be intrusive and interfere with the daily use of the room, air temperature sensors are discrete and inexpensive. Therefore, simulations are preferred to obtain illuminance values while measurements are more effective in providing air temperature values. Other real-time, model-based control strategies that can be found in the literature do not consider the thermal effects of façade systems on the room and require transmitted illuminance measurements [14,15]. On the other hand, studies that focus on reducing energy use and improving thermal comfort do not include visual comfort considerations [16,17].

The workflow described in this paper is illustrated by a case study for a fully glazed office in Malaga (Spain). The problem to be addressed here is that, although the space offers open and valuable views of a semi-natural landscape, the originally installed, manually controlled interior blinds are constantly activated by the occupants to mitigate glare and overheating, which prevent them from enjoying the views and, in many cases, from taking advantage of natural lighting.

	List of symbols
α_i	Incidence angle
λ	Thermal conductivity [W m^{-1} K^{-1}]
ρc	Volumetric heat capacity [J m^{-3} K^{-1}]
$\rho_{v,nh}$	Visible normal-hemispherical reflectance
$\rho_{e,nh}$	Solar normal-hemispherical reflectance
$\rho_{v,ndif}$	Visible normal-diffuse reflectance
$\rho_{e,ndif}$	Solar normal-diffuse reflectance
SHGC	Solar Heat Gain Coefficient or g-value
$\tau_{v,nh}$	Visible normal-hemispherical transmittance
$\tau_{e,nh}$	Solar normal-hemispherical transmittance
$\tau_{e,dirh}$	Solar direct-hemispherical transmittance
$\tau_{v,ndif}$	Visible normal-diffuse transmittance
$\tau_{e,ndif}$	Solar normal-diffuse transmittance
U-value	Global heat transfer coefficient [W m^{-2} K^{-1}]
ϕ	Azimuth angle of a sample (angle between a characteristic direction of the sample and the plane of incidence)
θ	Polar or incidence angle of a sample

In the selected retrofit intervention, the installed interior vertical blinds were replaced by interior roller blinds with a metallized reflecting surface facing towards the glazing unit. The automated control system was designed to maximize view contact with the outside and daylighting while controlling glare and overheating. The controller evaluates the visual and thermal conditions in the room to decide on a trade-off between opposing aspects such as blocking of solar radiation to prevent glare and overheating and allowing enough daylight to enter the room and ensuring visual contact to the outside. The controller calculates the optimal shading configuration internally before sending the signal to the actuators, decreasing unnecessary blind movement that would disturb the occupants.

The simulation engine of the controller requires information about the angular and scattering behaviour of the roller blind. For this, a detailed optical characterization of the roller blinds is carried out, including photogoniometer and integrating sphere measurements at the TestLab Solar Façades at Fraunhofer ISE. The simulation engine is also used to evaluate the annual performance of the control algorithm in terms of window cover, daylighting, glare protection and cooling energy reduction. To do that, in-situ measurements were used to verify the model of the office space. An evaluation of the actual implementation of the control system is presented at the end.

2. Analysis of the case study

The first step of the proposed workflow is to analyse the case study in order to determine the relevance of the different façade functions. Based on this analysis, a customized control strategy, adapted to the requirements of the particular case study, is designed (see section 3).

The case study under consideration is an office at the Faculty of Health Sciences at the University of Malaga (Spain). The building, constructed between 2013 and 2015, received an award by the Architects' Association of Malaga, commending the light geometry of the building, the choice of materials, the building transparency and natural lighting (Fig. 1).

The office under consideration has one external façade, which is 4.75 m wide and 3.17 m high, with all the other surfaces being internal partitions. The depth of the room is 3.57 m. The external façade is oriented south-west (−63° from south or zero-solar azimuth) and consists of a fully-glazed curtain-wall (Schueco/Kawneer) with up to three white aluminium mullions. The window is composed of a double glazing unit filled with argon. The glazing unit has a low-e coating on the cavity-facing surface of the outside pane, which is suitable for warm climates.

The façade is equipped with vertical interior textile blinds (Fig. 2). Given the location and the dimensions of the room and the fenestration system, the transmittance of the blinds is sufficient to provide enough daylighting in the room during the central hours of the day. However, the interior blinds cannot prevent high solar heat gains in the afternoon, which produce a high cooling energy demand and even thermal discomfort during some days in the summer period in which the air-conditioning system is unable to meet the demand created by the high

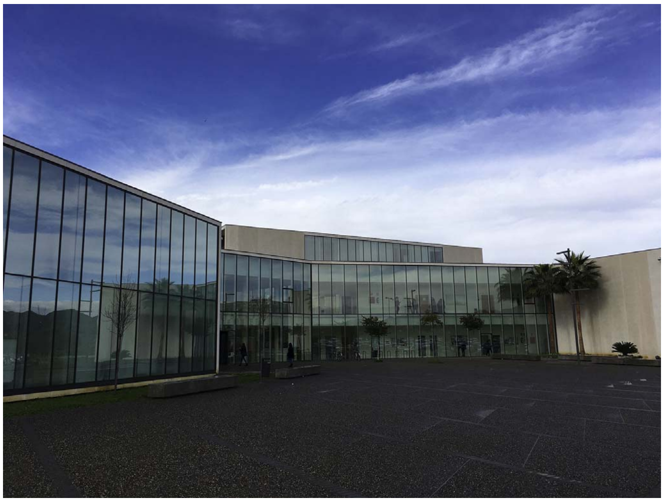

Fig. 1. Picture of the entrance of the Faculty of Health Sciences at the University of Malaga.