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FAST energy and daylight optimization of an office with fixed and movable shading devices

Marco Manzan [a, *], Alberto Clarich [b]

[a] University of Trieste, Department of Engineering and Architecture, via A. Valerio 10, 34127, Trieste, Italy
[b] ESTECO SpA, AREA Science Park, Padriciano 99, 34149, Trieste, Italy

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ABSTRACT

This paper describes the Energy and Daylighting optimization of a fixed inclined panel which shades an office room with a south exposed window. The window features also user deployable internal Venetian blinds. Energy analysis takes into account the primary energy required for heating, cooling and artificial lights. Different numerical codes have been employed in order to perform the simulations required by the optimization process: Daysim estimates the artificial light consumption based on daylighting distribution, ESP-r computes heating and cooling loads and modeFRONTIER integrates the simulation codes in an automatic optimization loop. The performance of an algorithm specifically designed to deal with problems involving long simulation times (combining response surfaces and genetic algorithms) has been successfully evaluated; the algorithm has then been applied in the optimization loop. The optimized solutions are analysed in this paper, in particular three solutions have been selected: minimum primary energy consumption, minimum hours of blind deployed and an intermediate solution. The analysis compares the primary energy consumption and daylighting performance on the basis of the Useful Daylight Illuminance indicator and the time history of illuminance on predefined locations.

1. Introduction

Healthy conditions in occupied spaces is a common goal for designers and this involve a series of interlocked problems since different aspects of the problem must be taken into account simultaneously. In the process physical and psychological points of view should also be taken into account. Internal condition are usually maintained using air conditioning plants responsible for the constant increase of energy consumption, therefore, passive approaches are drawing great interest from researchers and designers with the aim of reducing the overall energy requirement. The key component of an energy aware building is the façade since it separates the internal comfortable environment from the external ambient. Nowadays office buildings present extensive glazed areas for enhancing daylighting availability but, especially in Mediterranean area, this leads to high cooling loads and increasing problems related to glare. The installation of external shading devices or glazing systems with low solar gain is becoming a natural solution for reducing the aforementioned problems. External shading devices can be fixed or moveable and each solution has its drawbacks and advantages. Fixed shading devices has low maintenance cost, but can be optimized for a single season, on the other hand a moveable device such as an external Venetian blind, can be efficient in reducing cooling loads and glare problems but with the drawback of obstructing the view towards the external environment.

In this paper the coupling between a fixed external shading device and an internal moveable blind system for avoiding excessive direct sunlight is considered. The external device geometry is optimized taking into account the overall energy consumption for building air conditioning and illumination.

The impact of shading devices on building energy consumption has been widely dealt with in scientific literature. Franzetti, Fraisse and Achard [1] analysed the connexion between daylight and thermal loads emphasizing the effect of light control devices on luminaries, heating and cooling energy consumption. Shen, H. and Tzempelikos [2] considered the effect of internal roller shades on daylighting and energy consumption for offices with different orientation showing that automated roller shades are energy efficient with windows covering 30–50% of the façade. Some authors used different numerical codes for solving daylight and energy problems. A common tool for daylighting analysis is DAYSIM, used

* Corresponding author.
E-mail address: manzan@units.it (M. Manzan).

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in Ref. [3] together with ESP-r for computing first daylighting parameters and then performing energy simulation. A similar approach, but using TRNSYS for energy analysis has been used be Lee et al. [4]. An integrated thermal and daylighting analysis for perimeter office spaces is a common approach for comparing different façade designs, usually by changing the window-to-wall ratio and considering the effect of moveable external shadings. In Ref. [5] a decrease in total annual energy demand using an external shading is found in spite of an increase of electrical demand for lighting. An integrated daylight and thermal simulation for an office building with three blind configurations and orientations has been performed in Ref. [6] highlighting the interdependence of different parameters and the importance of investigating design alternatives from early stages of design. External shading devices can be also used for the installation of PV modules, Mandalakia [7] analysed thirteen shading types and found that the Canopy inclined single geometry, the same proposed in this paper, demonstrated a very good performance in terms of visual performance. A similar approach has been followed by Li in Ref. [8]: the introduction of an integrated thermal system resulted in a marginal reduction of energy consumption but bringing a beneficial effect on internal illuminance distribution. Coplanar shading systems have been analysed by Hoffman in Ref. [9] developing a complex fenestration system not only for daylighting analysis but also for distributing the solar loads on the surfaces of internal environments. The authors found that the paradigm of reducing window to wall ratio for reducing cooling loads could be relaxed employing shading devices.

Optimization techniques are widespread in industrial design and are attracting further interest in building design. The main goal of an optimization tool is to explore different configurations during the early design phase process allowing the designers to investigate innovative solutions. The main characteristics of an optimization techniques are the robustness, intended as the capability to explore designs without been stuck in local minima or maxima, the possibility of dealing with multiple optimization objectives and the time required by the process [10].

Several algorithms can be used to solve optimization problems. Wetter [11] carried a comparison between deterministic and probabilistic optimization algorithms on non-smooth problems; they highlighted that gradient-based algorithms may typically converge to local optima with problems to reach the global optimal solution for every application problem. The most robust algorithms can be considered the ones belonging to the category of evolutionary (or stochastic) algorithms, and in particular the ones based on Genetic Algorithms [10,12]. One limitation of these algorithms when applied to real practice underlies on the large number of simulations that might be required, since they generally grow linearly with the number of input parameters and objectives considered.

Also in Daylighting analysis optimization techniques are attracting interest among researchers: Futrell [13] compared different algorithms using GenOpt for optimal daylighting, Manzan, one of the present authors, in Ref. [14] applied genetic one-objective optimization to design an external shading system, but without considering moveable shading systems.

The time required by numerical simulation, in particular using raytracing techniques, is the main difficulty a researcher faces in dealing with optimization and daylighting. The same difficulty arises in industrial optimization problems, especially the ones involving CFD simulations. As an effort to reduce the computational burden, surrogate models [10] have been introduced. A common approach is to simplify the problem by training, with a reduced set of solutions, a response surface or RSM [10,15,16]. The method has been applied to the optimization of daylighting and energy consumption for cooling by changing windows geometry [17]. The authors created response surfaces of Daylight autonomy and cooling loads depending on the main geometrical parameters of the window.

In this paper the obstacle of applying optimization techniques with an underlying computational intensive problem, involving large simulation times, has been coped with using an approach which mixes RSM and genetic optimization. A comparison between a classical genetic algorithm and the present method has been carried on, comparing the results in terms of individuals pertaining to the Pareto front and the time required by each optimization. This paper considers the geometry optimization of an external fixed shading device. A similar approach has been adopted by Manzan in Ref. [17], but applying a single slat angular position completely obstructing the external view. Furthermore in Ref. [17] the blinds were driven using an idealized controller yielding the upper bound of usable daylight possible for a given space. In the present paper the limitations of previous approaches have been removed considering a manual control for Venetian blind deployment, with two slats positions. This approach is consistent with existing office rooms operation where the users desire to control internal daylighting while conserving a free outside view if possible. Moreover, the interaction of shading systems with a double and triple glazing systems is taken into account. As in Ref. [17] the software ESP-r, has been used for computing thermal loads, Daysim for computing illuminance levels and luminaries thermal and electrical loads while the optimization has been driven by modeFRONTIER® a product commercialized by Esteco, an Italian company located in Trieste.

The paper first introduces the optimization problem with a description of the office room and shading systems geometry in section 2, then presents in section 3 the Daylighting and Energy simulation codes, the parameters required by DAYSIM for daylighting analysis and ESP-r for energy computation. The description of the optimization algorithm adopted follows in section 4, pointing out the computing performance by comparing it with a classical genetic algorithm. The results of the optimizations carried on are presented in section 5, identifying the individual designs of the Pareto front and considering two glazing systems. Among the solutions three cases has been analysed comparing energy and then daylighting performance using useful daylight illuminance profiles and illuminance temporal maps.

2. Problem definition

Air conditioning loads and internal illuminance levels are strongly affected by the size and position of shading devices. Present paper considers an office room with a floor surface of 13 m^2 with a south facing window 2.47 m wide and 1.9 m high. The window is placed 0.2 m from the external wall surface in order to take into account the shading effect of window reveal. The office has an external fixed shading device and an internal Venetian blind that can cover the whole area of the window in order to protect the office from excessive direct solar radiation. The Venetian blind can be deployed in two positions with horizontal slats or inclined by 45° thus blocking completely the sun rays and also the external view; no other inclinations have been considered since a manual control is adopted and the two positions correspond to the situations in which an user partially shades the window, guaranteeing the view by blinds in horizontal position, either completely shades the window blocking solar direct radiation. Fig. 1 reports the geometry of the office with the shading systems.

The south surface represents an externally insulated refurbished wall with a thermal transmittance U_W of 0.32 W/(m^2 K), whose composition is reported in Table 1. All the other walls are internal

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