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Genetic optimization of external fixed shading devices

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ABSTRACT

In the present paper a genetic optimization (GO) has been carried out on an office room with a south facing window in order to design an optimal fixed shading device. Two different glazing systems have been taken into account, one standard double glass and an high performance glazing system specifically designed to prevent high sun loads. The shading device is a flat panel positioned parallel to the window and inclined by its horizontal axis. The device shades the window from direct sun penetration reducing the cooling loads in summer, but also affecting daylight and heat loads in winter limiting the sun gains, therefore the impact on the overall building energy consumption is investigated. A genetic optimization has been performed for identifying a possible geometry with the lower energy impact. Lighting loads, computed by the DAYSIM code, have been considered as inputs for the code ESP-r which drives the energy computation. The results demonstrate that electrical energy absorbed by the lighting system has to be always taken into account in designing energy efficient shading devices.

1. Introduction

The constant increase in summer energy consumption due to building climatization is becoming a major concern for industrialized countries. Therefore energy saving strategies must be sought in order to guarantee both healthy conditions and low environmental impact. This is true especially for buildings with extensive glazed areas in Mediterranean area with high cooling loads because of solar irradiance. In Italy, national codes require the compulsory installation of external shading devices or glazing systems with low solar gain coatings. The choice of the external shading devices is left to the designer and no guidelines are available. The size and positioning of shading devices depend on the orientation of building façade, the size of the windows and the relative importance of heating and cooling loads. Furthermore external shading devices have an impact also on the internal daylight distribution. The architectural impact must also be taken into account by inserting shading surfaces as little as possible without jeopardizing energy savings. In designing an external shading device all the energetic, daylighting and architectural problems must be taken into account at the same time. In this paper the multiple aspects of the problem have been coped with using genetic optimization techniques. The software tool ESP-r [1], has been utilized for computing thermal loads, DAYSIM [2] for computing illuminance levels while the optimization has been driven by modeFRONTIER [3]. In literature can be found a number of papers who deal with the problem of the impact of shading devices on energy consumption, nevertheless they usually consider separately climatization and light analysis problems. A detailed comparison of solar gain models with external and internal shading screens have been presented in [4]. Different codes have been compared, among them the ESP-r tool used in this paper, the authors found that accurate results can be achieved when predicting the energy consumption for long period of time for highly glazed buildings. An insight on the coupling between daylight and thermal loads has been conducted in Franzetti [5], 14 parameters have been identified and the computations have been performed using "the experience plan" method with the aim of reducing the number of simulations. Different relations linking the most important parameters with lighting energy consumption and annual energy needs have been elaborated. It has been found that an efficient lighting control device has a favorable impact on global energy needs emphasizing the importance of taking into account the interaction between lighting and HVAC system. Li et al. [6], studied the effect of daylighting and energy use in heavily obstructed residential buildings in Honk Kong, they simulated the daylighting performance of high rise buildings varying five parameters for assessing daylight availability, they found limits for external obstructions in order to reach satisfactory internal levels of daylighting. Ho [7] analyses daylight illumination of a subtropical classroom, seeking an optimal geometry for shading devices, they also evaluated the lighting power required to improve the illuminance condition within the classroom. Gugliermetti et al. [8] used the solar system luminous efficacies method to compute indoor natural illuminance. They introduced three simplified approaches for dealing with the effect of horizontal and vertical shading devices, comparing the obtained results with experimental data. They also included the

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Nomenclature

d	shading device distance from the wall [m]
g	solar heat gain coefficient
h	shading device height [m]
L	shading device width [m]
N	number of hours [h]
Q	energy [kWh]
U	thermal transmittance [W/(m^2 K)]
UDI	Useful Daylight Illuminance

Greek

α	shading device inclination [°]
Δ	percent variation [%]
η	efficiency
τ	transmittance

Subscripts

100–2000 lux	illuminance between 100 and 2000 lux
2000 lux	illuminace values over 2000 lux
c	cooling
e	solar direct
el	electric
g	glass
h	heating
n	narrow
on	artificial lighting switched on
p	primary
V	visible
W	wall
w	wide

developed methods in a building energy simulation code to compare the impact of the different methods on the heating, cooling and lighting requirements of an office building. Pino [9] analyses the thermal and lighting behavior of an office building in Santiago del Cile, but although it uses dynamic parameters for lighting simulation the thermal and lighting computations are not linked since a constant load due to light appliances has been used. Wienold et al. [10] performed a comparison between different shading systems taking into account energy, daylight and visual comfort aspects, showing that external mounted systems offer best solar protection. For instance they used the same approach used in present paper to deal with the lighting and energy coupling by first computing with DAYSIM daylighting parameters and electric energy demand than performing energy calculations with ESP-r. Mazzichi and the author used in [11] a similar approach to study the interaction of fixed and movable shading devices, good results for both energy and daylighting distribution have been obtained using an overhang and deployable external Venetian blind.

In order to increase building energy efficiency a particular attention should be paid to glazing systems. Simple solutions consider the assembly of glasses with selective films while complex fenestration systems comprise shadings in the glazing assembly. Maestre et al. [12] develops a model to derive the optical properties of coated glazings using only a single thin film, they successfully compared the numerical results with experimental data. A model for optical properties of glazing systems have been also developed by Asdrubali et al. [13], they assert that, after a first calibration, the model can be applied to various combinations of glazing systems without much effort. Complex fenestration systems have been analyzed by Lauadi and Parekh in [14] they implemented an algorithm for simulating windows made up of a mixture of clear and scattering glazing layers, the results of the proposed method compared well with the ones obtained using the WIS program [15] for a double clear window with a diffuse interior roller blind.

Optimization techniques applied to building analysis is emerging as an interesting tool for designers and accordingly a number of applications are available in literature. In a previous work [16] the author applied genetic optimization to the same problem, but the daylighting calculations used daylight factors obtained with RADIANCE [17], thus limiting the analysis to overcast skies. Diakaki et al. [18] used multi-objective optimization for improving energy efficiency in buildings, for this aim they proposed decision criteria based on simplifying assumption on energy calculation, furthermore they used utility functions to reduce the decision model to one only criterion. Nevertheless they highlighted that optimization is an helpful tool for reducing energy costs. Genetic algorithms have been used in Znouda et al. [19] to tackle the problem of building design in Mediterranean area, they highlighted that the finding of best characteristics of a building for summer and winter seasons is always a trade off among conflicting options, interesting they discovered that the solution for saving energy and saving money is quite different. A Generalized Pattern Search has been developed in Wetter and Polak [20] to minimize the annual source energy in a house taking into account heating cooling and lighting, the main effort of the authors were devoted to the evaluation of a simulation-precision control algorithm to speedup the overall time for the computation. Shen et al. [21] performed an uncertainty and sensitivity analysis on an office building taking into account seven parameters and five performance metrics with the goal to identify the more important factors for building energy performance, the window-to-floor ratio resulted to be the dominant factor for daylighting illuminance distribution and energy demand. Furthermore, observing the significant dispersion on the results of the uncertainty analysis, the authors highlighted the need of carefully designing the studied factors in order to achieve predefined energy targets. A thorough review on optimal solar design strategies, among with the combination of shading and glazing types, has been performed by Stevanović in [22], the need of coupling optimization methods with energy simulations in order to explore the usually large building design space has been enforced.

2. Simulations

2.1. Problem description

Shading efficiency is strongly affected by the size and position of shading devices. In the present paper a genetic optimization (GO) has been carried out on an office room with a floor surface of 20 m^2 and a south facing window 4.0 m wide and 1.5 m high. The office, to be considered at the first floor of a multi-storey building, is 2.7 m high, 5.0 m wide and 4.0 m deep. Fig. 1 reports the geometry of the room with the shading device. The external wall has a thermal transmittance U_W of 0.32 W/(m^2 K). Two different glazing systems have been taken into account, one standard double glass and a high performance glazing system specifically designed to prevent sun loads. The characteristics of the considered glazing systems have been obtained using WIS [15] program and imported into the standard ESP-r optical parameters databases. The simulation parameters of the two glazing systems are reported in Table 1 which reports the values of solar factor g solar direct transmittance τ_e, light transmittance, that is the solar radiation transmitted

Table 1
Glazing systems characteristics.

	g	τ_e	τ_V	U_g (W/(m^2 K))
Standard	0.60	0.522	0.792	1.4
Low solar gain	0.27	0.234	0.538	1.4