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The energy performance of windows in Mediterranean regions

Katerina Tsikaloudaki*, Konstantinos Laskos, Theodoros Theodosiou, Dimitrios Bikas

Civil Engineering Department, Aristotle University of Thessaloniki, PO BOX 429, 54124 Thessaloniki, Greece

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ABSTRACT

The paper focuses on the assessment of the windows' contribution to the energy performance of buildings in the warmer regions of Europe. This is derived by calculating the cooling energy index q_c and the area weighted energy needs for different window configurations installed on a reference room for two different building uses, office and residential. The examined window types differed with regard to their thermophysical and optical properties (*U*- and *g*-value), geometry (frame and window fractions) and orientations. The energy parameters used for the performance assessment were calculated with the help of a dynamic simulation tool for a location with a representative Mediterranean climate. The extensive multi-parametric analysis exhibited interesting results. It was found that for the cooling mode the energy performance of windows in warm climates is influenced significantly by their thermophysical properties. More specifically, the impact of solar transmittance is significant and its optimal selection can contribute in minimizing the energy consumption, especially in environments with controlled ventilation, such as offices. On the contrary, advanced fenestration products with low thermal transmittance seem to behave unfavorably, since their extremely low thermal transmittance prohibits the dissipation of heat toward the ambient environment and results ultimately in higher cooling energy loads.

1. Introduction

The building's sector – i.e. the buildings of the residential and tertiary sector – is the largest user of energy and CO_2 emitter in the European Union and is responsible for about 40% of the total final energy consumption and greenhouse emissions [1]. The sector has significant potential for cost-effective energy savings which, if realized, would lead to a number of benefits, such as reduced energy needs, reduced import dependency and impact on climate, reduced energy bills, an increase in jobs and the encouragement of local development [2].

Although the transparent elements usually occupy a limited area of the buildings' façade, their impact on the building performance is crucial, as they influence every aspect of the building behavior by providing protection against the environmental conditions (sun, cold, wind, noise, safety, etc.), daylight, ventilation, as well as view and interaction with the exterior. These often conflicting and time variant functions of the windows ask for properties that are correspondingly incompatible. In parallel, the heat transfer attributed to the windows accounts for a significant proportion of all energy used for covering both heating and cooling needs [3].

The identification of the window characteristics for achieving the optimum performance constitutes an ongoing pursuit for many researchers; indicatively some of the major published results are reported herein, mainly for showing the plethora of the different aspects examined and results derived. Gasparella et al. [4] have evaluated heating and cooling loads of an office building with regard to the window area, the glazing type and the ventilation patterns. They suggested that the thermal needs can be optimized by utilizing low emissivity glazings, as well as appropriate window areas. In a later study of the same authors, the window energy performance of a well-insulated residential building was analyzed with respect to the glazing type and size, the orientation, as well as the internal gain levels. Among others, they concluded that the use of large glazed surfaces can enhance the winter performance, but may worsen the summer one. Persson et al. [5] studied the influence of the window size on the energy balance of low energy houses in Sweden. After consecutive simulations they concluded that the superior thermal insulation of a house reduces the need for solar radiation to keep the house warm during winter, while during summertime the minimization of southern windows would constitute the optimal solution. Cappelletti et al. [6] have assessed the heating and cooling energy needs of an open-space office with different windows' characteristics (glazing systems, area,

* Corresponding author. Tel.: +30 2310995770; fax: +30 2310995603.
E-mail addresses: katgt@civil.auth.gr (K. Tsikaloudaki), klaskos@civil.auth.gr (K. Laskos), tgt@civil.auth.gr (T. Theodosiou), bikasd@civil.auth.gr (D. Bikas).

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disposition and orientation) under controlled internal comfort conditions considering the climatic conditions of Paris, Milan and Rome. They found that the optimum window characteristics differ with regard to the building location, the season and the façade orientation; for southern locations a double-glazed window with a low *g*-value is preferred, while in northern latitudes a triple-glazed window would perform better.

Manz and Menti [7] analyzed the energy performance of glazings in European climates based on the steady-state modeling of solar gains and thermal losses by displaying graphically the ratio between total solar energy transmittance and thermal transmittance, which is used for characterizing the quality of a glazing, against the ratio between interior–exterior temperature difference and solar irradiance, which is used for characterizing the severity of the climate, for different glazing qualities, orientations and local climate conditions. The study focused on wintertime and showed that thermally advanced windows exhibit highest gain to loss ratio, particularly at south facades.

Karlsson et al. [8] developed an hourly-based simple simulation tool for the energy efficiency of windows. The model takes into account the solar radiation, thermal leakage, angle-dependence of the windows and to some extent the thermal mass of a building. It has been found that the solar control windows become energy/cost effective below certain latitude, and the triple glazed low-e windows become cost effective above certain latitude.

The plethora of different approaches and outcomes inspired the authors to work not only on the pursuit of the optimum window considerations but also on identifying the impact of the window design choices on the building energy balance. More specifically, the authors have used the energy performance index of windows in order to identify their cooling energy performance in Mediterranean regions [9,10]. The work includes both residential [9] and office buildings [10], due to the fact that the internal heat gains and the ventilation modes vary significantly between these buildings types, leading to different window performance patterns as well as design concepts [11].

This paper attempts to interrelate and compare the window energy performance of office and residential buildings, as well as to identify their impact not only on the cooling energy needs, but also on the overall energy performance of Mediterranean buildings. For the estimation of the heating and cooling energy needs a reference building unit has been employed, the geometry and the operation profiles of which are defined by the European or international standards. The study concerned a plethora of fenestration products with varying thermophysical and optical properties (combinations of *U*- and *g*-value) and configurations (frame and window fractions, orientations), as well as for two different building uses, office and residential.

2. Methodology

The cooling energy performance of windows was assessed through the calculation of the cooling energy index q_c, which represents the energy contribution of the rated window. It is calculated as the difference between the annual needs for covering the cooling requirements of the reference room with the examined window system (Q_c) and the annual needs for cooling requirements of a notional room (Q_{c,no_win}), which is identical to the reference one, but its window is adiabatic ($U=0$) and non-transparent to solar radiation ($g=0$), divided by the surface of the window, A_w [9,10,12]:

$$q_c = \frac{Q_c - Q_{c,no\_win}}{A_w} \quad (1)$$

This methodology is in accordance with ISO 18292, which mentions that “the window energy performance for cooling (EPC,w) is expressed through the energy needs per unit area of the window per year that is the contribution of the window to the energy needs of the reference building for cooling” [12]. The cooling energy needs, Q_c and Q_{c,no_win}, were calculated with the help of Energy+, an energy analysis and thermal load simulation program, which enabled the detailed dynamic analysis. Beyond the cooling energy performance index of windows, it was regarded necessary to present the area weighted cooling energy needs, Q_c/A, and overall energy needs, Q/A, of the reference room, which have been estimated for each examined window type, configuration and usage mode.

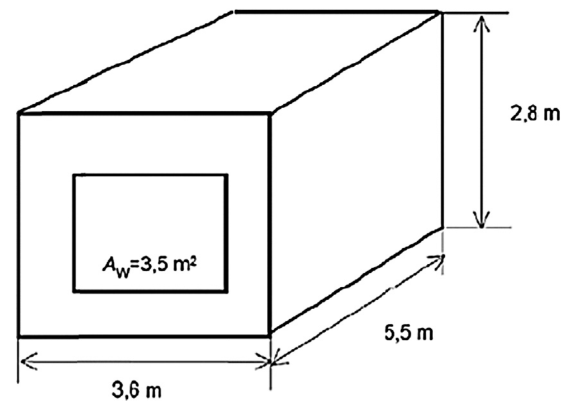

Fig. 1. Axonometric plan of the reference room.

2.1. The reference building unit

The cooling needs derived for each examined window were calculated for a reference room (Fig. 1), the geometry of which is defined in ISO 15265 and ISO 13790. The reference room is of rectangular plan, 3.6 m wide and 5.5 m long, with a storey height of 2.8 m. This configuration was selected as representative to both an office and a residential building, since it can serve as a building unit that can be multiplicated in order to form the whole building entity.

For the analysis, all opaque building components of the reference room were regarded as adiabatic, with the exception of the front wall, which was regarded as thermally insulated with a 0.05 m layer of EPS ($\lambda = 0.04$ W/(m K)) positioned on its external surface.

2.2. The usage profiles

The study was applied in buildings of the residential and tertiary sector.

As regards the office usage, it was assumed that the building is occupied during the working days of the week (Monday to Friday) from 07:00 to 17:00 all year long. Only during this operating time the HVAC systems are in operation. The cooling and the heating set-points were considered equal to 24.5 °C and 22 °C; although these values differ from the ones found in national standards, they were selected in accordance with EN 15251 [13], in order to approach the European specifications. Internal loads were regarded equal to 13.76 W/m^2 during the operating time and 2 W/m^2 for the remaining time. Infiltration was considered equal to 0.50 air changes per hour (ACH) and ventilation was set equal to 1.50 ACH during operating time.

For the residential usage, a full occupational status was taken into account. The cooling and heating set point was considered equal to 26 °C and 22 °C respectively in line with EN 15251. However, it was assumed that the user would open the window when the indoor air temperature exceeded 24 °C with the condition that the ambient air temperature is lower than the one in the interior. In that case, ventilation was regarded equal to 2 ACH. With closed