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ScienceDirect

Solar Energy 132 (2016) 467–492

SOLAR ENERGY

www.elsevier.com/locate/solener

Search for the optimal window-to-wall ratio in office buildings in different European climates and the implications on total energy saving potential

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Received 20 January 2016; received in revised form 8 March 2016; accepted 16 March 2016
Available online 6 April 2016

Communicated by: Associate Editor Jean-Louis Scartezzini

Abstract

This paper deals with the search for the optimal window-to-wall ratio (WWR) in different European climates in relation to an office building characterized by best-available technologies for building envelope components and installations. The optimal WWR value is the one that minimizes, on an annual basis, the sum of the energy use for heating, cooling and lighting.

By means of integrated thermal and lighting simulations, the optimal WWR for each of the main orientations was found in four different locations, covering the mid-latitude region (35° to 60° N), from temperate to continental climates. Moreover, the robustness of the results was also tested by means of sensitivity analyses against the efficiency of the building equipment, the efficacy of the artificial lighting and the compactness of the building.

The results indicate that although there is an optimal WWR in each climate and orientation, most of the ideal values can be found in a relatively narrow range (0.30 < WWR < 0.45). Only south-oriented façades in very cold or very warm climates require WWR values outside this range. The total energy use may increase in the range of 5–25% when the worst WWR configuration is adopted, compared to when the optimal WWR is used.

Keywords: Window-to-wall ratio (WWR); Passive solar architecture; Low-energy office buildings; Energy conservation; Integrated thermal-lighting simulations

1. Introduction

1.1. Background

The façade – and in general the entire building envelope – can be considered the main system for solar energy conversion at the building scale. Even without considering the possibility of incorporating active systems, such as building integrated photovoltaics (BIPV) (Jelle et al., 2012) or an integrated solar thermal panel (Matuska and Sourek, 2006), the configuration of the façade itself plays a role in the way solar energy is exploited within the building. First of all, the balance between glazing and opaque areas alone has an impact on many aspects of the energy balance, influencing solar gain (and thus energy use for heating and cooling) and heat loss (mainly affecting energy use for heating), but also daylight availability (with implications on

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http://dx.doi.org/10.1016/j.solener.2016.03.031
0038-092X/

Nomenclature

ACH	Air Change per Hour (h^{-1})
DA	Daylight Autonomy (%)
E	(specific) energy ($kW\,h\,m^{-2}$)
HVAC	Heating, Ventilation and Air Conditioning
SA:V	Surface Area over Volume ratio (m^{-1})
SCOP	Seasonal Coefficient of Performance (–)
SHGC	Solar Heat Gain Coefficient (–)
UDI	Useful Daylight Illuminance (%)
WWR	window-to-wall ratio (–)

Subscript

C	cooling
EE	electrical energy
H	heating
L	(artificial) lighting
NC	night cooling (free cooling)
PE	primary energy
TOT	total

energy use for artificial light). Second, the use of solar shading systems increases the capability of the façade to dynamically control solar gain and daylighting in order to improve further the building's energy performance and passive solar energy exploitation. Finally, the selection of materials and components with appropriate thermal and optical properties greatly influences all aspects of the total energy balance when the building envelope is used as the control volume on the indoor environment, i.e. the space to be conditioned and kept within a certain comfortable range.

The influence of the façade configuration in preserving a comfortable indoor environment was previously related to the energy for space heating alone, while implications on cooling and artificial light energy use have only become the subject of dedicated research activities in the last few decades. However, in the present-day R&D panorama, aimed at reaching the nearly Zero Energy Buildings (nZEB) target (Marszal et al., 2011), the influence of the building envelope needs to be fully evaluated from a total energy approach, i.e. considering heating, cooling and artificial light use together.[1]

From this perspective, the optimization of the façade configuration is not a straightforward problem: measures to minimize one aspect (e.g. the energy use for heating) often have a negative impact on the others (e.g. on the energy use for cooling and artificial lighting). The optimal solution is thus the best compromise of different possibilities and needs to be found by means of an integrated (thermal and lighting) approach.

Among all the aspects involved in the design of a façade system, the window-to-wall ratio (WWR) – i.e. the ratio between the transparent area and the opaque surface[2] – is a parameter that has a deep impact on both the energy balance (Lee et al., 2013; Shen and Tzempelikos, 2013) and architectural appearance of the construction. The "transparency" of a building is often set more by looking at the architectural and aesthetic implications rather than at the energy performance. Moreover, this choice is often made in the very first stage of the design process and will not be subject to later changes, while many other aspects (such as materials, equipment and operations) can be more easily decided and modified at a later stage. The selection of an appropriate WWR value for a façade should thus be carried out at the very beginning using an energy-wise approach, and it is therefore important that this selection is made carefully.

1.2. Window-to-wall ratio and climate: a short overview

The first records (Arumi, 1977; Johnson et al., 1985, 1984) concerning dedicated investigations into the impact of the WWR on the energy balance of a building showed that selecting an optimal WWR value would have halved the energy use. In general, the early research showed that for each climate and orientation it was possible to find an optimum WWR that minimized the annual energy use. It is important to highlight that potential for energy saving was quite significant and that these analyses did not include the use of solar shading systems. A short overview of the development of the research activities about the impact of the WWR can be found in Goia et al. (2013).

It is worth noting that some of the articles available (e.g. Johnson et al., 1985, 1984) tackled the impact of the transparent percentage of the façade from the perspective of the climate.

[1] As defined in the European Standard EN 15603 ("EN 15603:2008 – Energy performance of buildings – Overall energy use and definition of energy ratings," 2008), the annual energy use of a building is given by the sum of the annual energy use for heating, cooling, lighting, ventilation and humidification, hot water and other services. The first three elements are those directly affected by the façade configuration while the others can be considered independent from it.

[2] In this paper the term WWR identify the ration between the net transparent area and the total opaque area and not the ratio between the window surface (including the frame) and the total façade area (i.e. the area of the frame of the window is included in the total opaque area; this means, for example, that in a façade with an area of 10 m^2 and a WWR of 0.20, the area of the glazed unit is 0.20 m^2).