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Energy and environmental performance optimization of a wooden window: A holistic approach

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ABSTRACT

The paper reports the results of an extended investigation performed on a sample of wooden window selected as case study. A holistic approach was chosen to define all the main parameters characterizing the sample from the thermal, acoustic, mechanical, optical and environmental points of view. After an accurate state of the art survey, experimental measurements and numerical simulations were performed in order to evaluate the following parameters: thermal transmittance, airborne sound insulation, solar, light and UV transmittance, air permeability, water tightness, resistance to wind load. A LCA study allowed to correlate the energy and environmental impacts. By means of a comprehensive results analysis, a standard configuration of the window was defined (Scenario 0); two optimized scenarios were then selected, one including a solar control film in the glazing (Scenario 1) and another with a warm edge spacer replacing a common aluminium spacer (Scenario 2). A complete energy and environmental analysis was performed for all scenarios achieving a holistic evaluation of the benefits. Results show that in temperate climates the improvement of the window thermal characteristics, obtained through a proper control of solar radiation, is the most relevant criterion to optimize the overall energy and environmental performance of the window.

1. Introduction

Over recent years, the European Commission encouraged the development of more sustainable construction products through a new industrial policy. Some priority sectors have been identified to foster energy efficiency and savings in the use of non-renewable natural sources. The product group "Windows" is subject to the Construction Products Regulation [1] and indirectly addressed by the Energy Performance of Buildings Directive [2]. According to the Ecodesign Directive 2009/125/EC [3], the Commission adopted the Ecodesign Working Plan for the period 2012-2014, including windows in the indicative list of energy-related products which will be considered in priority for the adoption of implementing measures, as this product group has significant sales and trade in the EU, as well as a significant environmental impact and potential for improvement. The Final Report of the Task 3 of the Study on Amended Ecodesign Working Plan under the Ecodesign Directive [4] reports that in 2009 more than 700 million square metres of sheet glass were sold in Europe (taking into account of export and import activities). The document shows also the results of a study of the Technical University of Denmark and one of Eurowindoor (an organization of the 4 European associations of fenestration and door sector, representing the interests of more than 50,000 companies employing around one million workers in Europe in the field of fenestration and door). The market of windows is estimated to be of 90 million square metres in the DTU study and of 137 million square metres in the Eurowindoor one.

As a matter of fact, windows and fenestrations are amongst the components of the building envelope that are developing faster in the last years. Beyond the traditional windows with double or triple glazing, new products including innovative elements and solutions are appearing on the market providing excellent overall performance: quadruple (or quintuple) glazing [5], vacuum glazing [6], selective and low-emissivity coatings [7,8], electrochromic windows [9], aerogels [10] and others. A comprehensive market review of the various innovative products and an analysis of the future development can be found in [11].

Windows are particular components of the building envelope having two contrasting functions: they have to separate the places where people live, work or relax from the outer environment and

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in the meantime they must assure a visual continuity towards the outer environment, letting the natural light in; in most cases, they can be opened to favour air ventilation. These multiple functions can be obtained by means of the correct design of each component of the window (frame, glazing, coatings, gaskets, etc.) and by the correct connection of the single elements.

Several aspects must therefore be considered when dealing with the performance of a window: thermal transmittance, UV, IR and visible transparency, sound insulation, wind and rainwater resistance. Furthermore, a global evaluation of the environmental impacts of a building product, such as windows, in the production, exercise and disposal phase can be assessed with Life cycle assessment (LCA) procedures.

Within this context, this paper aims to analyse all the various properties of a wooden window, optimizing its energy and environmental performance through a holistic approach. The first part is devoted to the literature review of the characteristics that are further analysed in the paper: thermal and acoustic insulation, optical properties, mechanical properties and environmental impact. The methodology and instrumentation used in the present research for measurements/simulations are then reported. The results of several measurements and numerical simulations of a wooden double-glazed window chosen as a reference sample and on its alternative, optimized design are presented; many different window configurations were considered in order to evaluate the influence on the various properties and three complete LCA studies were performed to compare the different environmental impacts. The discussion finally presents the overall performance, considering all the various aspects.

2. Literature review

The energy and environmental performance of a green building is the result of many different solutions: proper orientation, choice of materials, high performance plants, integration of renewable energy systems. A low energy demand for winter heating and/or summer cooling is therefore an essential requisite, but many other aspects have to be taken into account, such as indoor comfort (thermal, visual, acoustic), materials embodied energy, production of renewable energy. An integrated, holistic approach may represent the solution to study and optimize both the entire building and its single components.

The holistic approach was proposed by Kalz et al. [12] in a research conducted on the performance of low energy buildings; R. Yao et al. [13] proposed a method to assess the general quality of buildings, including indoor thermal comfort, lighting and acoustic parameters beyond the energy consumption. Franzitta et al. [14] showed that a by-component analysis could be more effective than a global procedure to achieve a European Eco-label brand for residential buildings. Following this indication, J. Yao et al. [15] focused the attention to a particular kind of transparent enclosures: the thermotropic windows, embracing the energy, thermal environment, and lighting conditions generated by these innovative products.

Researches dealing with a single property of windows are more frequent. As a matter of fact, many studies were carried out to evaluate the thermal performance of windows, since they are responsible of a large part of the energy losses through the buildings envelope. Three different parts of the window can be improved to increase the thermal performance of the whole system: glazing, frame and spacer. As previously mentioned, several solutions are available to improve the energy properties of the glazing, that is usually the component that is most responsible for poor energy performance: multilayer glazing, suspended films, vacuum glazing, low-emissivity coatings, glazing cavity gas fills and aerogels. Jelle et al. [11] showed the state-of-the-art of fenestration and the future research to develop more advanced products, introducing innovative technologies to be applied to spacer, frame and glazing. At the aim of evaluating the energy behaviour of this particular element of the buildings, Karlsson et al. [16] proposed a simple model for calculating the annual balance of a window, taking solar radiation and heat losses into consideration. The model was based on energy balance equations with hourly meteorological data to assess the yearly energy saving with different orientations and locations of the window; moreover, several types of glazing were analysed. A more detailed analysis was carried out with a dynamic software (TRNSYS) by Jaber et al. [17] who studied the annual heating and cooling energy demand of four types of windows for different climate zones and orientations. Energy and investment costs were also considered to conduct a thermal and economic optimization process varying the windows percentage in the entire façade. Grynning et al. [18] used another dynamic software (Energy plus) to examine the coupled effects of incident solar radiation and thermal transmission losses, in order to obtain minimal heat losses and optimal solar gains during wintertime. A numerical calculation is often implemented to assess the thermal transmittance of the sole window frame and the thermal bridge between frame and glazing. These values are part of the global window thermal transmittance that is calculated with different methods proposed by Standards [19–21]. Blanusa et al. [22] compared the differences (algorithms and boundary conditions) between the methodologies proposed by the Standards and found small discrepancies.

As far as the acoustic performance, the sound insulating properties of windows are affected by the fact that most of transparent surfaces are installed in order to be opened. This aspect requires the assembly of several parts of the system that, when closed, has to be air tight. If cracks or leakages are present (due to design or installation errors), a substantial reduction of sound insulation is unavoidable [23]. If the connections between the window and the frame are working properly, the sound insulation of the glazing represents the most influential factor on the global acoustic performance of the window, since it occupies the widest part of the window surface.

Nowadays, single glazing are outclassed for their poor acoustic performance (low mass and high decrease of the sound reduction index in correspondence to the coincidence frequency), while triple glazing are still too expensive, considering also that they allow the same sound insulation of double glazing with the same mass and thickness [24]; therefore, the double glazing is the most common solution used in temperate regions. Double glazing is composed of two (stratified or not) glass sheets with an interposed air gap. As far as sound insulation of glazing, the golden rule is to use glass panes with different thicknesses (for instance 8-12-4 instead of 6-12-6), in order to have different coincidence frequencies for the two panes. Higher sound reductions can be achieved through high mass of the glass sheets and/or wide thickness of the air chamber. However, an exaggerated increase in mass and thickness is limited by daylighting, weight and cost issues, thus, some alternatives have to be applied. For instance, the chamber can be filled with gases different from air such as Argon or Krypton. The first gives no benefit to sound insulation while Krypton, being denser than air, usually brings to a 1 dB increase in sound reduction index [25]. Other heavy chemical gases could also be considered (such as sulfur hexafluoride, 6.5 times denser than air), but their use is limited by their environmental impact. Though the acoustic effect is quite irrelevant, the inclusion of Argon or Krypton in the gap improves the thermal insulation properties of the glazing. In fact, the thermal conductivity of air at 300 K (about 0.0262 W/(m K)) is higher than the one of Argon (0.0179 W/(m K)) and Krypton (0.0095 W/(m K)).