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Climatic, parametric and non-parametric analysis of energy performance of double-glazed windows in different climates

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Abstract

In line with the growing global trend toward energy efficiency in buildings, this paper aims to first; investigate the energy performance of double-glazed windows in different climates and second; analyze the most dominant used parametric and non-parametric tests in dimension reduction for simulating this component. A four-story building representing the conventional type of residential apartments for four climates of cold, temperate, hot-arid and hot-humid was selected for simulation. 10 variables of U-factor, SHGC, emissivity, visible transmittance, monthly average dry bulb temperature, monthly average percent humidity, monthly average wind speed, monthly average direct solar radiation, monthly average diffuse solar radiation and orientation constituted the parameters considered in the calculation of cooling and heating loads of the case. Design of Experiment and Principal Component Analysis methods were applied to find the most significant factors and reduction dimension of initial variables. It was observed that in two climates of temperate and hot-arid, using double glazed windows was beneficial in both cold and hot months whereas in cold and hot-humid climates where heating and cooling loads are dominant respectively, they were advantageous in only those dominant months. Furthermore, an inconsistency was revealed between parametric and non-parametric tests in terms of identifying the most significant variables.

Keywords: Window; Building loads; Energy performance; Principal Component Analysis; Design of Experiment

1. Introduction

The growing trend in the population and lack of accommodation capacity in cities around the world has overshadowed the environmental health of our planet. This affliction, if not managed, will eventually result in irreversible changes and damages to the environment which consequently affects and endangers the biosphere (Haapio and Viitaniemi, 2008). The lack of sufficient non-renewable resources such as oil, coal and natural gas (Aleklett and Campbell, 2003); and some worldwide issues regarding climate change and global warming are two main reasons that make us redouble our efforts to revise current energy consumption patterns (Jonsson and Roos, 2010).

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The majority of countries are taking precautions to enhance the sustainability level specifically in the energy related fields in the construction industry and this is because of the excessive costs of energy and environmental issues relevant to this industry (Orhan, 2000).

Residential buildings amounted to 30% of the country' total energy consumption. Energy use of residential buildings can be reduced through numerous retrofitting actions such as; upgrading of windows, adding internal insulation to walls during renovations and through measures to reduce uncontrolled exchange of inside and outside air (Harvey, 2009). Along with this fact that windows are one of the most important components of buildings, they play a key role in the overall energy conservation plans for buildings. Moreover, the accessibility to outside provided by windows, which has many physical and psychological advantages, positively affects the health, motivation and productivity of occupants (Menzies and Wherrett, 2005a). However, it has been proven that windows act as the weakest thermal component in buildings. Improper insulation and extreme heat transfer attribute of glasses lead to considerable heat and thermal losses.

One way to reduce energy losses through windows is to install double-glazed windows (Orhan, 2000). Window energy performance depends upon window properties as well as the climatic conditions of the location and window's orientation (Burgett et al., 2013). The values of incident solar radiation and, hence, the values of solar heat gain that are useful in offsetting house heating loads, actually depend on local climatic conditions and the direction in which the window is installed. Similarly, outdoor temperatures and wind conditions which determine heat losses by transmission and by air leakage are also dependent on location (Shakouri Hassanabadi and Banihashemi Namini, 2012). During the last decade, many scholarly works were done in order to study and analyze the energy performance of windows with respect to different properties.

2. Review of the previous studies

Karlsson et al. (2001), developed a simple method for assessing the performance of windows in terms of energy consumption and cost based on three main categories; Climate data (direct and diffuse horizontal solar radiation), window data (U-factor, total solar energy transmittance, number of pains and the category of the window) and building data (balance temperature and the time interval). Impacts of the thermal transmittance characteristic of walls, roofs and floors on the total energy savings by different types of windows were studied by Singh and Garg (2009). It was shown that savings by a window depend upon window type, climatic conditions of the place, buildings dimensions, its orientation and thermal transmittance of its wall and roof among which; the last two factors play a critical role in saving energy.

Menzies and Wherrett (2005) studied about four buildings to rate the comfort and sustainability level based on diverse types of multi-glazed windows by concentration on the energy used to emphasize the importance of architectural design on the multi-glazed windows performance. Persson et al. (2006) evaluated the different dimension of windows in terms of energy performance for low energy houses during winter and summer by changing the orientation in Gothenburg. It was illustrated that by reduction in window area, there is a specific enhancement in performance of energy in winter. Gasparella et al. (2011) concluded that window surface does not have a significant role in winter energy requirements but, on the other hand, solar transmittance is the most effective parameter which conducts the major needs for energy in both winter and summer. Furthermore, energy transfer and sunlight absorption rate were analyzed for single and double-glazed windows for wintertime and it was found that around 40% of the solar energy was absorbed (Frederick, 2013). The need for the importance of daylighting and appropriate set of reference data for windows was also highlighted through a comprehensive study regarding the possibilities and limitations of energy performance evaluation (Trząski and Rucińska, 2015).

As a holistic view on the previous studies and in majority of the researches conducted in this field (Singh and Garg, 2009; Tian et al., 2010; Burgess and Skates, 2001; Maccari and Zinzi, 2001; Tahmasebi et al., 2011), the performance of the window was analyzed based on its impact on the annual energy consumption. In this paper, heating and cooling loads are used as the basis of comparison. It should be noted that these are heating and cooling loads, not energy loads. These loads determine how much cooling or heating is required to maintain spaces in a building within the thermal comfort band (Banihashemi et al., 2012). However, energy consumption depends on the efficiency of the devices used in cooling or heating those spaces and apparently, for the same load, different devices with different efficiencies result in different energy consumptions. Therefore, using cooling or heating load as the basis of the comparison shows a more realistic view in terms of the impacts of windows on buildings.

Additionally, many works (Tian et al., 2010; Karlsson and Roos, 2004; Rijal et al., 2007; Citherlet et al., 2000) studied the performance of windows by using a simple box representing a room or a house. However, the complex interconnections of the zones within a building (e.g. adjacency to warmer or cooler zones such as kitchen or staircase) and the impacts of inter-zonal gains and losses on total loads cannot be studied by using a simple box. Consequently, the role that windows play in augmenting or reducing loads due to those inter-zonal losses or gains is ignored and this leads to unrealistic energy performance results.

As the campaign to raise international awareness toward saving the environment is growing and along with the growth in construction activities, it has become imperative that if design tools are to be provided, they can give insights into the sustainability of a building at an early