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Impact of curtain wall configurations on building energy performance in the perimeter zone for a cold climate

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Abstract

The Analysis of Variances (ANOVA) approach is used to quantify the impact of nine curtain wall design parameters on the energy consumption of an office space in the perimeter zone of a typical office building in Montreal. The uncertainty analysis shows that the variation in curtain wall configurations has generally a greater impact on the cooling followed by heating, lighting and total energy consumption. The global sensitivity analysis shows that the window wall ratio is the most significant design parameter influencing the end-use energy consumption.

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Keywords: Curtain walls; Building envelope; Sensitivity analysis; Uncertainty analysis; Building simulations, Energy performance; ANOVA

1. Introduction

Curtain walls are commonly used in commercial buildings. Given the typically large glazing area used in curtain walls and the relatively low thermal performance of metal and glass, the energy consumption of buildings with curtain walls, especially in the perimeter zone, is more sensitive to the climatic conditions and the variation of façade design compared to buildings with opaque insulated façade [1]. The advancement of technologies in the thermal and optical properties of glazing helps improve the overall performance of curtain walls. Many high performance curtain wall systems can be achieved by integrating advanced glazing units, better insulated mullion and applying shading and

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daylight control strategies [2-5]. These improvements can significantly reduce the energy consumption in space conditioning or lighting. However, the significance of curtain wall performance on the energy efficiency of buildings is also influenced by other design parameters such as the internal heat gain and occupancy profiles, etc. [6-7]. To achieve the desired energy efficiency in the perimeter zone of curtain wall buildings, it is important to take into account the interaction among façade design parameters, climatic conditions and building operation parameters.

The global sensitivity analysis can assist designers to identify the most influential parameters by taking into account the interdependency among design variables. This approach has been widely used in building designs. A detailed review of the application of sensitivity analysis in modeling building energy performance was summarized in [8]. Shen and Tzempelikos [9] applied the global sensitivity analysis on a study of the automated interior roller shades for an office building located in Philadelphia. The extended-FAST sensitivity analysis showed that window-to-floor ratio and glazing types had the most significant impact on the daylighting and energy performance. Mechri et al. [10] used the analysis of variance approach as an evaluation tool to conclude that the envelope transparent ratio is the most important parameter influencing the building energy performance.

The objectives of this paper is to quantify the significance of individual design parameters on the energy performance of the perimeter zone of office buildings with curtain wall façade by taking into account the interacting effect of façade design parameters, and to provide information that can help maximize the energy efficiency in the perimeter zone by optimizing the façade design at the conceptual design stage.

Nine façade design parameters are considered. They are glazing U-value (U_{gl}); solar heat gain coefficient (SHGC); visible transmittance (T_v); U-value of the spandrel panel (U_{sp}); U-value of frame (U_{fr}); window wall ratio (WWR); infiltration rate, and depth and inclination of overhang. A generic model representing a typical office unit in the perimeter zone of an office building located in Montreal is created in EnergyPlus. In total, 24,576 curtain wall configurations are sampled and simulated for four cardinal orientations. There are in total 98,304 simulations performed. All simulations have the same settings for HVAC and lighting systems, plug loads, occupancy and operation profiles. The influence of façade design parameters on the annual heating, cooling, lighting, and total energy consumption is quantified through uncertainty and global sensitivity analyses. The coefficient of variation obtained from the uncertainty analysis indicates the sensitivity of the end-use energy consumption with respect to the variation of curtain wall configurations. The total sensitivity index obtained by variance-based global sensitivity analysis quantifies the total effect of each individual design parameter on the energy consumption by taking into account the interacting effect among the nine design parameters. The most significant design parameters are identified. The methodology, analysis procedure, results and conclusions are presented in the following sections.

2. Methodology

A hypothetical office unit representing a typical office space on the intermediate floor in the perimeter zone of an office building in Montreal is modeled in EnergyPlus. The exterior façade is completed with different curtain wall configurations. Simlab 2.2 , a program designed for Monte Carlo-based uncertainty and sensitivity analysis, is used for sampling. The uncertainty analysis is used to quantify the sensitivity of the end-use energy consumption in the perimeter zone to the variation of curtain wall configurations. The global sensitivity analysis is used to quantify and rank the significance of individual parameters on the end-use energy consumption. An open-source statistical computing program R [11] with a customized code is used to calculate the first order and total sensitivity index of individual design parameters.

2.1. Model setup in EnergyPlus

The hypothetical office unit is constructed for a single occupant according to common building practices for offices in North America [12]. One exterior façade is completed with curtain wall. The other three walls are regarded as internal partitions. An overhang is installed above the vision panel as the shading device. A highly energy efficient design is assumed for determining plug load and lighting power density. Continuous dimming (according to daylighting level) is activated when the illuminance is above the 500 lux set-point at the height of 0.8 m above the floor in the center of the office unit. The thermostat settings are 20ºC for heating and 25ºC for cooling during working hours of 08:00 to 18:00 with a night setback temperature of 13ºC in the winter and 30ºC in the summer, respectively.