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Role of atrium geometry in building energy consumption: the case of a fully air-conditioned enclosed atrium in Cold Climates, China

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ABSTRACT:

Fully air-conditioned atria have become increasingly popular in architecture design due to their appealing aesthetic and iconic features to general public. In certain regions of China, climate diversities in winter (freezing-cold) and summer (warm-humid) are huge. Energy consumptions due to air-conditioning of atria in these regions are enormously high. Thus, their corresponding energy managements without compromising the indoor thermal comfort are extremely challenging. The geometric configuration of the atrium has preliminary and significant impacts on the indoor environment and further influences the energy consumption. The impacts of atria’s geometric configuration on indoor thermal condition and energy consumption under highly diversified climate conditions in China are studied in this paper. A fully air-conditioned enclosed atrium with square plane and cross-section is considered in this research. Atria with different section aspect ratio (SAR) and skylight sizes are investigated with a combination of (1) field measurements and computational fluid dynamics (CFD) simulations for temperature distribution and (2) energy simulations for the corresponding energy performance. Case studies for the temperature distribution profile for atria with different SAR and the quantitative correlations between atria’s SAR and its energy performance are presented. Optimum skylight size based on the objective function to minimize the annual energy consumption will also be reported.

1 Introduction

The energy consumption in large-scale public buildings is much higher than that in other types of buildings in China. Large-scale public buildings with a total construction area of more than 20,000 m\textsuperscript{2} equipped and central air-conditioning systems consume two to four times more energy than small-scale public buildings apart from heating [1]. These buildings, aiming to serve more people, usually consist of a large atrium as a common space. A non-conditioned atrium, serving as an attachment to the main building, decreases the building energy consumption by reducing winter heating load as a thermal buffer [10]. However, it increases the overall energy cost when it is occupied continuously; in addition, full-time air-conditioning is necessary to maintain thermal comfort [2, 7]. A geometry-based optimization of the annual energy cost of an atrium without compromising thermal comfort is the key issue that will be addressed in this study.

Studies on an atrium’s energy performance have been conducted since the 1980s. In the Skylight Handbook (1987) and Design for Energy Conservation with Skylights (1981), it was reported that daylight introduced by the fenestration of the atrium could decrease lighting and cooling energy consumption [3, 4]. The relationship between atrium temperature and energy consumption for different building shapes and technical solutions for energy consumption reduction with given building shapes and materials were reported in [5]. The corresponding impacts on indoor air quality and thermal comfort were also examined [5]. The effect of various design factors for atria on their energy performance in cold climate was studied in Ref. [6]. The design factors include fenestration glazing types, fenestration surface area, skylight shape, atrium type, and interaction of the atrium with its adjacent spaces. A study compared the solar heat gain of two types of skylights on three types of atria. In addition, the study presented the impact of fenestration glazing types, fenestration surface area, skylight shape, and adjoining spaces on the cooling and heating peak loads, annual cooling, heating energy, and total energy cost [6]. A simulation on an atrium’s thermal and energy performance using a
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