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Thermal performance of atria: An overview of natural ventilation effective designs

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ABSTRACT

Despite significant impacts of natural ventilation on atria, indoor thermal conditions and decreasing energy usage load, there is lack of knowledge about how various design parameters influence atria thermal conditions. The complexity of natural ventilation design of atria and inadequate simulation design tools may lead to inaccurate atria thermal prediction. In the past 25 years, researchers have developed and suggested various methods such as experimental, theoretical and numerical modeling to identify thermal and ventilation performances of atria. However, the diversity of the modeling conditions makes it difficult to achieve proper conclusions which link all contributing parameters to atrium thermal conditions. This paper provides a comprehensive review of previous studies on the role of natural ventilation in atrium buildings in different climates, efficient design parameters and their application to improvement of thermal performance and decrease of energy consumption. These parameters include various atrium configurations and components such as atrium geometry, opening characteristics, roof properties, materials and fenestration characteristics. The review further highlights different ventilation techniques which can be applied in atria as assisted ventilation methods. The cited parameters can be categorized into those affecting thermal performance and ventilation performance. The outlet opening size is the most influential parameter that affects both indoor thermal condition and ventilation behaviors of atria and consequently decreases energy usage load.

Contents

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1. Introduction

Atrium space, a large and almost glazed central space, especially in non-residential buildings, is a popular space which has been in use with an increasing trend throughout centuries since ancient times starting in Mesopotamia. Atrium provides impressive aesthetic space, exposing adjacent indoor spaces to daylight, maximizing benefits from direct solar gain, and increasing inhabitants' socialization and interactions [1–4]. It also provides air circulation and communication among different stories of the building. Furthermore, atrium is considered as a factor contributing to scale up of market values of buildings [5].

Modern Atria has its origins in regions with temperate climate and was first developed in the early 1990s, and then spread and proliferated by just adopting their aesthetics in different regions with more unsuitable climates without adequate materials and conditions. The interest in employing the new technology and glass walls, especially in some office and commercial buildings, resulted in neglecting environmental potentials (radiation, wind, and other natural conditions) [6]. Therefore, despite all the advantages mentioned above, providing thermal comfort in atrium requires high amount of energy [7] due to excessive solar heat gain during summer daytime and heat loss during cold seasons from large glazing walls and continuous air stratification [8]. However, it is estimated that consumption of energy in this type of buildings with optimal design is below 150 kWh/m^2/year in some regions in Europe [9].

Natural ventilation in such buildings plays a key role in providing optimum quality of indoor circulation of air within the building and maintaining acceptable level of thermal comfort without necessity for employment of mechanical systems such as Heating, Ventilation, and Air Condition (HVAC). Therefore, natural ventilation is capable of decreasing HVAC energy consumption which has substantial contribution to saving energy amount in buildings [10,11] with more than 60% of the total building energy consumption [12].

Although more studies have been conducted in the past decades on natural ventilation system in atria, the investigations relating atria design parameters are still limited. Due to its complexity and lack of accurate measurement tools, predicting thermal performance in atrium is difficult [13]. Many of the studies are without detailed parametrical results or just focus on validation of analytical methods in their experiments. Therefore, providing a comprehensive review of all atrium building designs can facilitate to find an effective use of natural ventilation in a wide range of atria buildings for better energy efficiency. This maximizes atria energy saving potential in various climates by replacing or assisting mechanical systems with natural ventilation, the result of which leads to a decrease in maintenance and operation expenses while providing better thermal comfort and higher indoor air quality.

This paper attempts to bring together the previous studies achievements about naturally ventilated atria and influential atrium design parameters. It demonstrates how they can be applied and improved to provide a better thermal condition for atrium and adjacent spaces. It begins with reviewing the evolution of atria design approaches throughout history, the generic forms of atria and recent considerations about atria effective design factors.

2. A brief review of atria

Atrium is a Latin word originally referring to a main room or central court with hearth, which caused the room walls to be covered with black soot (ater) though time, giving it its name (atrium) in a typical ancient Roman house. However, in the modern era, its design has changed in a way that it is usually covered with glass walls and roof creating a common space interconnecting the adjacent galleries and stories within an atrium building.

Atria and courtyards are commonly embedded in some buildings for natural ventilation and cooling purposes. Both atria and courtyards form centerpieces in buildings and connect them to the environment [14] by providing natural ventilation and sunlight through exchange of the internal air with the external one [15]. Comparative analyses of the central atria and courtyard reveal that atrium, with the same geometric dimensions against varying climatic and glazing conditions, is more energy efficient with increasing building height [16], while applying an open courtyard to low-rise dwellings during summer and an atrium for the rest of the year, leads to an optimal balance between energy consumption and summer comfort in tough climates [17].

2.1. The evolution of atria through history

The history of traditional atrium can be traced back to 3000 BC in the archeological remains of a courtyard house in Ur, Mesopotamia [1] as shown in Fig. 1(a). It was later found as a central courtyard in ancient Roman and Greek houses. Atrium has served not only as a climate modifier but also as a space for socialization of the inhabitants of the building. In hot areas courtyards are commonly utilized to fulfill the dual functions [18]. For instance, in the Tropics, courtyard provides natural ventilation and light for "Shop house" buildings [19] (Fig. 1(b)). Including atria in the design of buildings in the modern era started during the Industrial Revolution with the availability of plate glass and slender structural