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Survey and numerical effect analyses of the market structure and arcade form on the indoor environment of enclosed-arcade markets during summer

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Abstract

In South Korea, enclosed arcades have been applied to traditional markets in order to improve the physical environment of the markets. However, in some enclosed-arcade markets, occupants suffer from thermal discomfort during summer due to solar radiation overheating the indoor space. This discomfort level varies according to the market structure and arcade form.

This paper presents the results of thermal surveys and temperature/humidity measurements carried out on four enclosed-arcade markets, each having a different market structure and arcade form. The paper then presents analyses of the thermal effect of the market structure and arcade form on the indoor climate. During the summers of 2003, 2004 and 2006, thermal surveys were conducted which polled responses from 156 market occupants while air temperatures and humidity levels were measured simultaneously. Numerical simulations were performed in order to evaluate eighteen different design approaches in relation to the enclosed-arcade market. The results from the temperature/humidity measurements revealed that the indoor temperature was affected by roof transmittance. In particular, in one of the four markets, where the roof transmittance was 0.7, the difference between indoor and outdoor temperatures was recorded as +4.3 °C. The occupants complained of the thermal discomfort and that much of their goods had become spoiled and discolored by solar radiation. To solve this problem, the arcade roof was eventually covered with an opaque plastic material. The results from the numerical analyses using computer simulations revealed that the transmittance of the roof material was the primary design element that thermally affected the indoor climate, followed by the ventilation opening, the roof height, and the roof type. However, the effect of the ventilation opening on the indoor climate increased as the roof transmittance increased, which created a greater temperature difference between the indoor and outdoor climates on sunny summer days.

Keywords: Comfort level; Enclosed arcade; Market; Thermal survey; Measurement; Energy simulation

1. Introduction

In order to promote the local economy, the Korean government passed a revitalization policy for traditional markets in 2002. Subsequent to the passing of this policy, the physical environments around traditional markets have been improved through the establishment of parking lots, the organization of facilities, and by covering the market streets with an enclosed arcade. Consequently, in order to alleviate inconveniences caused by inclement weather, enclosed arcades, as shown in Fig. 1, have been installed in many of the traditional markets that had previously been established along street edges. However, because an enclosed arcade is essentially a semi-indoor space on a street that was once exposed to the outside air, and thus was previously naturally ventilated, various problems have arisen in terms of heat gain, air humidity, and an increase

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(a) Before (b) After

Fig. 1. Change of traditional market.

in the number of fire disasters. In some of these enclosed-arcade markets, occupants often suffer the consequences of an unsatisfactory comfort level, with significant loss of goods due to decay and discoloration caused by excessive heat during summer (Kim et al., 2005). Although it has been revealed that solar radiation is the cause of this problem, the effect of solar radiation can manifest in different ways depending on aspects related to the structural design of the market, such as the orientation, the width and length of the street, the height of the market buildings, and the form of the arcade, as well as the type, height and transmittance of the roof, and the design of the ventilation openings.

Thermal comfort and solar radiation problems related to various building types have been extensively studied. Kaynakli and Kilic (2005) revealed that thermal conditions are very difficult to control in transitional spaces that have volumes such as corridors and lobbies, which receive direct sunlight. The difficulty increases particularly during summer, when these volumes reach higher temperatures than any other controlled space. Furthermore, the thermal discomfort in these overheated spaces can cause occupants to experience physical stress, which is commonly responsible for illness and a poor work performance.

Kim et al. (2007) presented the results of a comfort survey and measurements of the indoor environment of a small glazed-envelope building. In their study, the indoor-air and interior-surface temperatures, which were increased by the solar heat gain, caused office workers to suffer from thermal discomfort and uncomfortable glare. To avoid the thermal discomfort and glare, office workers turned on the air-conditioning system for all working hours and attached objects such as a sheet of newspaper onto the interior surface, which interfered with the architect's intended expressions for the building. La Roche and Milne (2004) analyzed the effects of mass, window size, and air-exchange rate on the air-conditioning system and demonstrated that solar radiation, if not controlled, may decrease the efficiency of the air-conditioning system. Edmonds et al. (1997) noted that the principal objective of a window design during summer is to decrease the discomfort glare and solar radiation for the improvement of thermal comfort, which generally requires the exclusion of sunlight entering the interior. Kuhn et al. (2001) showed that daylight and solar heat gains in buildings could be manipulated by the use of appropriate sun-shading systems, together with an associated control strategy. In addition, the results of a test carried out in Delhi by Raman et al. (2000), on a solar house design in a single room structure, demonstrated that the incorporation of solar chimneys for heating, cooling and ventilation significantly decreased the thermal discomfort caused by solar radiation. Several researchers have recognized the overheating and ventilation problems of enclosed-arcade markets and are attempting to solve them. Tsujihara et al. (1998a,b,2004) and Kim et al. (2006), carried out a survey on the air temperature distribution inside an enclosed arcade that was located in an area with a mild and sunny climate. This study revealed that the indoor temperature of the measured arcade was a little higher than the outdoor temperature, and that the vertical temperature showed a temperature slope from the lower part to the upper part of the arcade space due to the greenhouse effect. In particular, Kim et al. (2006) emphasized that an enclosed arcade made of transparent material with small-sized openings may be frequently overheated and have a low IAQ (indoor-air quality) during summer because the incoming solar radiation, heat and CO_2 from occupants and cooking cannot be properly discharged or dissipated by natural ventilation. Hong et al. (2005) conducted wind tunnel experiments and CFD (computational fluid dynamics) simulations to analyze the effect of the design of the arcade-roof opening on IAQ. Their experiments demonstrated that the low air-exchange rate of enclosed-arcade markets was primarily caused by the height of the market buildings as well as by the roof opening. In particular, natural ventilation by wind was considerably low for a typical enclosed-arcade market with three or more storeys of market buildings. Kim et al. (2003) also compared the gas-discharge time with the occupant-evacuation time in order to evaluate the safety of the ventilation opening according to the opening rate during a fire.

While there have been a significant number of such studies, there have been very few studies related to the influence of the market structure and arcade form on the indoor climate. Furthermore, the basic data for the design criteria of the enclosed arcade has been insufficient.