Abstract

Many traditional markets in Korea have been remodeled into arcade-type malls. The openings along the arcade roof are an important design factor that makes the marketplace more comfortable, healthy, and safe. Thus, a wind tunnel test and computational fluid dynamics (CFD) model analyses have been conducted to determine the optimal openings in terms of size and location. A 1/20-scaled model for an arcade-type traditional market was constructed. Experiments were also conducted in a wind tunnel. The test variables were the opening ratios of 100% and 0% and the wind directions of 0° and 90°. In this study, to validate and quantify the air exchange rate in the model, SF6 as a tracer gas was employed. The tracer gas was released into the scaled model and the concentration of the gas within the model was monitored to predict air change rates. The gas was injected at a constant rate during the experiment and its concentration was measured with a precise gas monitor. The wind tunnel experiment was used to validate the CFD model. The results of the wind tunnel experiment were carefully reviewed and compared with the output results of the CFD model. This validated CFD model was used for many analyses, which reviewed various design parameters of the arcade roofs. Through these validations, the optimized opening design is offered.

Keywords: traditional market; wind tunnel experiment; air exchange rate; tracer gas; CFD

1. Introduction

The physical environment of traditional markets in Seoul is being improved to activate the regional economy. The city government has decided to commence with the physical improvement of 77 traditional marketplaces to be completed by 2006. Many traditional markets have seen much growth after the renovation of their physical environments. One of the ways to improve the physical environment of traditional markets is to cover their streets with arcades. Prior to remodeling, traditional markets were in unsanitary disorder, and most customers felt gloomy due to intercepted sunlight from parasols or tents, as shown in Fig.1.(a).

After remodeling, in case of some of the markets with earlier installation of the arcade (see Fig.1.(b)), customers and merchants have suffered from high temperature and poor indoor air quality due to

(a) Before

(b) After

Fig.1. Improvement of Physical Environment
overheating from the green house effect of an enclosed arcade with the low rate of ventilation (Kim and et al., 2003). There were also a lot of difficulties in fire prevention or extinguishment because of the enclosed arcade. These discomforts are due to the lack of design standard of the installed arcade making the space and environment better. The ventilation opening of the arcade is especially an important part, serving as a pathway for exchanging heat, emitting indoor pollutants outside and preventing the harmful smoke in case of a fire. Therefore, a study dealing with the size of or the air exchange rates of the ventilation opening needs to be conducted for arcade design.

In this study, the ventilation performance of the arcade-type traditional market was investigated with the wind tunnel experiment and the CFD method which is much used in the contemporary field of architecture (Kato and et al., 1997; Shen and et al., 2003; Robins, 2003). The results of the wind tunnel experiment were carefully reviewed and compared with the output results of the CFD method.

2. Wind Tunnel Experiment

The large-scale wind tunnel in the Hyundai construction technology laboratory was used. It is 4.5m in width, 2.5m in height and 25.0m in length, as shown in Fig.2. This open-ended wind tunnel makes a natural wind flow. The wind speed and the turbulence intensity of the boundary layer of the wind tunnel experiment, provided in Fig.3.

1) Model

Table 1. shows the physical characteristics of the design elements in the arcade-type traditional market based on the result of the study by Kim and et al., 2003. In Table 1., the market buildings along the street have one to four floors, and most buildings have two.

The street width ranges from 4.0m to 12.0m while most of traditional markets have the street width of 8.0m. The typical shape of the arcade roof is a vault or monitor type. Most roof shapes are vault-type. The size of the ventilation opening ranges from 0.5m to 1.0m. The height of the roof ranges from 4.5m to 8.0m. Fig.4. shows the 1/20-scaled basic model of the arcade-type traditional market, which was used for the wind tunnel experiment.
The basic market model, as shown in Fig.6., was made to analyze the air-exchange rate according to the opening height (ratio) and the wind direction. The opening of the model consisted of ventilated openings and paths between buildings. Four cases were tested. The wind direction was changed between 0° and 90°, and the height (ratio) of the opening for the ventilation was varied between 0.0m (0%) and 1.0m (100%).

2) Experimental set-up

Fig.5. shows the experimental set-up for the measurement. There were also twenty measurement points and three release points. Fig.6. shows measurement points displayed with alphabetical letters, which were arranged in 0.12m intervals. Each release point displayed with black points was arranged every 5 measurement points.

Three experimental methods using tracer gas: 1) decay/growth, 2) constant concentration, and 3) constant injection (ASHRAE, 2001). In this study, the constant injection method, in which the tracer gas is injected at a constant rate, was used. The tracer gas was injected at 5cc/sec at each release point. The gas measurement instrument was the INNOVA Air Tech Instrument '1312 Photo acoustic Multi-gas Monitors (Anon)', and the tracer gas SF6 was used.

3) Wind tunnel experiment results

The measured mean concentration of tracer gas was converted to a dimensionless concentration by using...
equations (1) and (2):

\[
Ci = \frac{C}{Co}
\]

(1)

\[
Co = \frac{q}{Zo \times Uo}
\]

(2)

where \(Ci\) is the dimensionless concentration; \(C\) is the measured mean concentration; \(q\) is the amount of SF6 released; \(Zo\) is 30cm, the standard height of the model; and \(Uo\) is 3.92m/s, the standard wind speed in the wind tunnel experiment.

Fig.7. shows the dimensionless concentration distribution of SF6 at the measurement points under the two wind directions, 0° and 90°. Table 2. shows the mean concentration from the wind tunnel experiment. Considering the opening ratio, the concentrations for the 0% opening ratio were almost two times those for the 100% opening ratio. The concentrations for the 0° wind direction were higher than those for the 90° wind direction.

In Fig.7.(b), both two measuring points, J and K, have low concentrations, because they are located in the cross section of the market model.

3. CFD Simulation

To analyze the air-exchange rate of the arcade-type traditional market, CFD simulation must be conducted under the same conditions applied in the wind tunnel experiment. Therefore, boundary conditions as well as the market model for analysis were the same as those of the wind tunnel experiment. In this study, the Star-CD, a commercial CFD simulation program, was used. The turbulence flow was calculated by the SIMPLE model, as a CFD model, with the first order upwind differential scheme under an isothermal state. The details are presented in Table 3.

1) Boundary condition

Boundary condition of the CFD model was set to be equal to that of the wind tunnel experiment. The \(k-\varepsilon\) model was used, with the values of \(k\) and \(\varepsilon\) obtained by equations (3)-(6) (Murakami and et al, 1991):

\[
\left( \frac{U}{Uo} \right) = \left( \frac{Z}{Zo} \right)^{\frac{1}{2}}
\]

(3)

\[
k = \frac{3}{2}(U \times I)^{2}
\]

(4)

where \(U\) is the wind speed (m/s), \(Z\) is the specific height (m), \(k\) is the turbulence kinetic energy (m²/s²), \(\varepsilon\) is the dissipation rate of \(k\), \(C_u\) is 0.09, \(I\) is 0.12 as the turbulence intensity based on the wind tunnel experiment, and \(l\) is the specific length.

2) Validation of CFD model

Fig.8. shows the concentration contours and velocity vectors as well as distributions of each case from the CFD analysis.

Table 3. Boundary Condition

| Item            | Condition                        |
|-----------------|----------------------------------|
| Turbulence model| Standard \(k-\varepsilon\) model |
| Scheme          | 1st order upward differential Scheme |
| Inlet           | Using equations (3)-(6)          |
| Outlet          | Free slip                        |
| Wall            | Log-law                          |
| Number of mesh  | 553,446(0 degree), 493,060(90 degree) |

Table 4. Comparison of Air-exchange Rates(1/h)

| Opening Rate | Wind direction 0 degree | Wind direction 90 degree |
|--------------|-------------------------|--------------------------|
|              | Measured | CFD   | Measured | CFD   |
| 0%           | 34       | 12    | 45       | 31    |
| 100%         | 81       | 62    | 83       | 96    |

To compare the ventilation performances of the four cases, the air-exchange rate of each case was calculated by equations (7) and (8). \(Q\) is the amount of air flow,
Fig. 8. Concentration Contours and Velocity Vectors as well as Distributions of Each Case from CFD Analysis.
and \( N \) is the air-exchange rate.

\[
Q = \frac{q}{C} \quad (7)
\]

\[
N \propto \frac{U}{L} \quad (8)
\]

With respect to the air-exchange rate of Table 4, there is about 13-30% difference between the results of the wind tunnel experiment and those of the CFD model. The air-exchange rate was affected by the wind direction and the opening ratio. This result means that the opening ratio for ventilation exerts a major influence on the ventilation performance of the arcade-type traditional market since the wind direction is not controlled by the architect.

4. Conclusion

The wind tunnel experiment and CFD method were used to investigate the ventilation performance of the arcade-type traditional market and consequently, to suggest the basic design standard that can improve the indoor environment of the arcade-type market. The results of the wind tunnel experiment were also carefully compared with those of the CFD model. The results of this study are summarized as follows:

In the wind tunnel experiment, the concentrations of SF6 for the 0% opening ratio were almost twice as those for the 100% opening ratio. The concentrations of the 0° wind direction were higher than those of 90° wind direction. The size (rate) of the ventilation opening and the main wind direction of the region were important factors for determining ventilation performance. The opening ratio for ventilation, determined by the architect, greatly affects the ventilation performance of the arcade-type traditional market because the wind direction is not controlled by the architect.

In the comparison of the results from the wind tunnel experiment and the CFD model, the curve pattern of the measured concentration of SF6 from the wind tunnel experiment was similar to that of the calculated concentration by the CFD model except for the 0% opening rate and 0° wind direction, which presented a possibility of a collision flow against the vertical object, an enclosed entrance. There was about 15-30%
difference in air exchange rate between the results of the wind tunnel experiment and the CFD model.

As a further study, to provide a design standard for the openings of the arcade-type traditional market, several alternative openings for ventilation according to business type and thermal environment can be tested by using the CFD model.

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