The Indoor Environment Measurement Analysis of Arcade-Type Markets in Korea

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Abstract
The arcade has been applied to traditional markets to improve their physical environment in Korea. However, thermal discomfort and poor indoor air quality can arise from certain physical characteristics of arcades. This study compares the indoor environments of three traditional markets after their streets have been transformed into arcades and finds the design elements affecting indoor environment. The actual temperature, humidity, air velocity, CO/CO₂ and etc. in the arcades were measured. The indoor environment of the arcade was greatly influenced by its shape/size, roof materials and opening for ventilation.

Keywords: traditional market; arcade; indoor environment; measurement; thermal comfort; indoor air quality

1. Introduction
To maintain the primary function of traditional markets and promote their low-income merchants and the local economy, the Korean government has passed the revitalization policy of the traditional markets. Following the policy, the improvement of the physical environment around the traditional market has been in progress including establishment of parking lots, organization of its facilities, and coverage of its street with an arcade. Such arcade has been applied to several street-type traditional markets such as those of Woorim, Myunmok, and Waljung-Ro (see Fig.1.) in Seoul, Korea (B.S. Kim and et al., 2003a).

However, in some of the markets already with the installed arcade, customers and merchants have suffered from high temperature due to overheating from the green house effect and poor indoor air quality due to low rate of ventilation (B.S. Kim and et al., 2003b). The characteristics of design elements in each arcade, including shape/size, opening rate for ventilation, and roof material, have induced these problems in the indoor environment.

Several studies have been performed on an enclosed arcade. Based on one study (Kaynakli and et al., 2005), thermal comfort conditions are very difficult to control in certain volumes and transitional spaces such as corridors and lobbies, which receive direct sunlight. The difficulty increases especially in the warm or hot seasons, when these volumes reach higher temperatures than those of the smaller controlled volumes. Edmonds et al. (1997) noted that level of transparency of the walls and roof in the heat season determines the decrease of discomfort from glare and solar radiation, and the increase of thermal comfort, which generally requires the blockage of sunlight from interior spaces. According to the three studies by Tsujihara et al. (1998a, 1998b, 2004), who investigated air temperature distribution inside an enclosed arcade located in the area with mild and sunny climate, air temperature in the arcade was a little higher than the outdoor temperature, and vertical temperature showed a temperature slope from the upper part of the arcade space to the lower part of the arcade space due to the amount of solar radiation and the rate of ventilation. Also, solar radiation physically influenced the thermal environment inside the arcade.

This research compares the indoor environment of three traditional markets with arcades through field measurements and identifies the design elements that affect the indoor environment.

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Lastly, the measured data of the three cases were compared, and the differences were analyzed according to the design elements.

2. Selection of Markets

Considering the design characteristics of each arcade-type traditional market, three markets already with arcades were selected; Woorim market (W-Market) and Myunnok market (M-Market) in Seoul, and Jukdo market (J-Market) in Pohang. The exterior shape and arcade of each market are shown in Fig.3. Table 1. with Fig.2. shows the distribution of business types, and the characteristics of streets and buildings around each market. Table 2. with Fig.2. shows the design characteristics of each arcade.

The comparison of the design characteristics of the M-Market and W-Market show that the market scale, the building size, the orientation of the main street, and the distribution of business types in the both markets are similar. With respect to the openings for ventilation, the opening rate of the W-Market side opening is 100%, larger than that of M-Market by 50%; however, the opening area per arcade volume is similar, with 0.037/m of W-Market and 0.035/m of M-Market. With respect to the roof material, there is much difference between W-Market made from yellow opaque vinyl with the transmission of 5 % and M-Market made from milky polycarbonate with the transmission of 30%.

The comparison of the design characteristics of M-Market and J-Market show much difference with respect to the market scales and the business-type distributions: the volume of J-Market is smaller than that of M-Market because the street width and roof height of J-Market are much smaller than those of M-Market by 3.3m (8m-4.7m) and 1.5m (4.5m-3.0m) respectively.

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Table 1. Characteristics of Three Markets

| Market | Food Raw | Food Process | Clothing | Sundries | Etc. | 1F | 2F | 3F | 4F | Height | Width | Max. Direction |
|--------|----------|--------------|----------|----------|------|----|----|----|----|--------|-------|----------------|
| W-     | 41%      | 27%          | 18%      | 7%       | 7%   | 1  | 24 | 9  | 9  | 3.0m   | 12m   | SW-NE         |
| M-     | 50%      | 24%          | 9%       | 8%       | 8%   | 4  | 9  | 13 | 13 | 3.0m   | 8m    | SW-NE         |
| J-     | 100%     | -            | -        | -        | -    | -  | 9  | -  | -  | 2.5m   | 4.7m  | N-S           |

Table 2. Characteristics of Three Arcades

| Market | Layer | Height | Trans. | Type   | Continuity | Opening for ventilation | Max P/m² | Heating/Cooling |
|--------|-------|--------|--------|--------|------------|-------------------------|----------|----------------|
| W-     | Pair  | 4.5m   | 5%     | Moni   | Cont.      | 0.60m (100%) 2.0m (100%) | 0.037/m  | 1.0 100/40%    |
| M-     | Pair  | 4.5m   | 30%    | Vault  | Inter.     | 0.50m (100%) 2.0m (50%) | 0.035/m  | 1.0 100/40%    |
| J-     | Pair  | 3.0m   | 80%    | Vault  | Cont.      | 0.75m (0%) 2.2m (0%) | 0.000/m  | 0.5 100/40%    |

*Trans.: Transmission, Cont.: Continuous, Inter.: Intermittent, A/V: opening Area/arcade Volume by 1m, the unit length of arcade, Max P/m²: Maximum number of persons per m²
With respect to the distribution of business types, J-Market selling only raw fish and its processed foods is different from M-Market selling various raw foods and processed foods. With respect to the street orientation, J-Market is north-to-south oriented, unlike M-Market, which is oriented southern west to the north east; therefore, the effect of solar radiation to each market is different. The roof material transmission of J-Market is 80%, and the openings for ventilation are all closed with the 0% opening ratio. Consequently, the market scale, the orientation of the main street, distribution of business types, the transmission of roof material, and the opening ratio for ventilation all show large differences among the three selected markets.

Table 3. Weather Data and Measurement Date

| Market m/d/y | Meteorological administration data | Measured outdoor data |
|--------------|------------------------------------|-----------------------|
|              | Ave T. | Max T. | Min T. | Ave R.H. | Duration | Cloud | Ave T. | Max T. | Min T. | Ave R.H. |
| W- 02/18/03  | 5.6    | 7.0    | 2.9    | 67.1     | 0.0      | 8.5    | 5.9    | 7.4    | 2.9    | 59.4    |
| 05/28/03     | 28.1   | 30.0   | 24.2   | 32.1     | 8.4      | 3.0    | 28.2   | 30.0   | 24.2   | 31.8    |
| M- 02/27/04  | 3.3    | 5.4    | -0.4   | 34.9     | 9.5      | 0.4    | 4.3    | 6.4    | 0.6    | 34.4    |
| 06/12/04     | 28.5   | 30.3   | 24.3   | 31.7     | 11.0     | 0.9    | 28.4   | 30.2   | 24.3   | 31.1    |
| J- 02/15/03  | 9.0    | 10.5   | 6.2    | 38.8     | 8.6      | 4.0    | 9.1    | 10.7   | 6.2    | 42.6    |

*Ave : Average, Duration : Sunshine Duration(unit: hour), Cloud : Amount of Cloud(1/10), T : Temperature(unit: ºC), R.H. : Relative Humidity(unit: %)

Table 4. Measured Items and Equipment

| Item                  | Equipment               | Points | Interval |
|-----------------------|-------------------------|--------|----------|
| Temperature & Relative Humidity | SATO Data logger        | 5      | 10min    |
| Vertical Temperature  | Grant 1250series Remote Squirrel Logger | 11     | 10min    |
| CO/CO2                | TSI IAQ Meter           | 3      | 1hr      |
| Wind Speed            | TSI Air Velocity Meter  | 3      | 1hr      |
| Dust                  | Piezobalance Aerosol    | 3      | 1hr      |
3. Measurement of Thermal Environment

3.1 Survey period and items

W-Market was surveyed in the periods of late winter between 2003.02.17 and 02.20, and late spring between 2003.05.25 and 05.28. M-Market was surveyed in the periods of late winter between 2004.02.26 and 02.29, and late spring between 2004.06.12 and 06.15. J-Market was surveyed in the period of late winter between 2003.02.12 and 02.15.

The surveys were conducted for 4 days in each market and each season, and the survey was carried out from 9 AM to 6 PM. Air temperature was measured every 10 minutes, and CO/CO2 along with wind velocity/direction were measured every hour. Table 4. shows the measured items, instruments and time intervals. The location of each measured item is shown in Fig.4. In the four days, the two dates which best reflect the characteristics of each season considering the temperature and humidity were selected. Also, the date of which the measured outdoor data shows little difference from the outdoor weather data of the meteorological office was selected as the measurement date for analysis. Therefore, for W- Market, 2003.02.18 (winter) and 2003.05.28 (summer) were selected; for M-Market, 2004.02.27 (winter) and 2004.06.12 (summer) were selected; and for J-Market, 2003.02.15 (winter) was selected.
Table 3. shows the weather information from the meteorological office and the actual measurement. The date for W-Market for the summer season was selected as 2003.05.28 since the highest temperature was above 30°C, and the lowest as well as the mean temperature show not much difference with those of 2004.06.12 of the early summer. The meteorological office data are only slightly different overall from the measured data, except for the microclimatic aspect.

### 3.2 Thermal Environment of W-Market

Tables 1. and 2. show that W-Market has the area per volume (A/V) ratio of 0.037/m, which indicates the effect of the outdoor weather condition on its indoor condition by infiltration, and that effect from solar radiation is relatively small since the transmission of roof material is less than 5%.

For the winter season, Fig.5. shows that the outdoor temperature changes slightly because of the cloudy sky, and the difference between the outdoor and indoor temperatures changes almost equally because the average difference between them is 0.1°C. Similar pattern can be found in the summer season of Fig.6. As the outdoor temperature increases from morning on and decreases after sunset in the late afternoon, the indoor temperature is not much affected by solar radiation due to the low transparency of the roof material and changes with the outdoor temperature accordingly. Also, the vertical temperature difference inside the arcade from 0.5m to 4.5m from the ground level shows only slight variation, with the average
of -0.3°C in cloudy winter and the average of 0.9°C in sunny summer. Note, however, that the ground temperature is higher than the indoor temperature in the winter season, and is lower than the indoor temperature in the summer season. Also, in both seasons, the absolute humidity rarely changes daily but only the relative humidity changes slightly according to the temperature changes.

### 3.3 Thermal Environment of M-Market

Shown in Tables 1. and 2., the side opening (height of 1.5m) of 50% of M-market is less than that of the W-Market, but the area per volume (A/V) ratio of M-Market is 0.035/m, which is similar to that of W-Market. However, the transmission of roof material of M-market is about 30%, so the effect from solar radiation is relatively larger. Figs.7. and 8. show that in winter, the outdoor temperature increases from the sunrise and decreases after sunset. The difference between the outdoor and the indoor temperature is rather large, with the average of 3.4°C. Unlike W-Market, the higher transmission of the roof material has caused the increase in solar radiation and consequent increase of the indoor temperature. The vertical temperature difference inside the arcade from 0.5m to 4.5m from the ground level shows variation of the average of 1.5°C in winter and the average of 2.1°C in summer. Note that the surface temperature is higher than the indoor temperature before sunrise in winter, and is lower than the indoor temperature after sunrise in the morning and afternoon.

### 3.4 Thermal Environment of J-Market

J-Market is smaller than the other two markets as shown in Tables 1. and 2. Even though there is an opening (height of 0.75m) for ventilation, openings except for the entrance and exit are closed so that the opening ratio is 0%. Also, the high transparency of the roof material of 80% is highly affected by solar radiation. Fig.8. shows that the difference between the indoor and the outdoor temperature in winter is 5.2°C on average, and this difference is about 2°C higher than that of the M-Market. With respect to the vertical temperature difference, despite of the narrow gaps, there is a large temperature difference of 3.0°C in height from 0.3m to 3.0m from the ground level. The ground surface temperature is lower than the indoor temperature. The relative humidity of indoor is higher than that of outdoor because the raw fish market contains many fishbowls with water, and cooking indoor induces vapor.

### 4. Measurement of Indoor Air Quality

#### 4.1 CO/CO2

Indoor air quality of the arcade is affected by the opening rate for ventilation. As shown in Tables 1. and 2., the area per volume (A/V) ratios of W-Market and J-Market are 0.037/m and 0.000/m, respectively, which show the extreme difference between the two markets. In W-Market, the indoor temperature is similar to the outdoor temperature. Also, the CO2 concentrations of the indoor and outdoor are similar with the mean difference of 8ppm, as shown in Fig.10.(a). The CO2 concentration of the indoor varies between 500ppm and 600ppm, and the average is 541ppm. On the other hand, in J-Market, there is a large temperature difference between the indoor and outdoor, and the CO2 concentration difference is relatively large, with the average of 186ppm, as shown in Fig.11.(a).
Also, the average indoor concentration of the indoor is 722ppm, and the CO2 concentration varies in the range between 700ppm and 800ppm, which is relatively higher than that of W-Market. However, both markets satisfy the indoor air quality standard of 1000ppm. With respect to CO, J-Market with mostly restaurant type business, which uses gas and boiler, shows CO concentration of 0~5ppm, which is lower than the standard 10ppm but higher than the outdoor concentration. W-Market shows, on the other hand, almost zero concentration of CO during the non-traffic period of automobiles.

4.2 Wind Velocity and Floating Dust
With the wind velocity in Fig.10.(b) and 11.(b), the indoor wind velocity of J-Market is 0.1~0.6m/s. The market is not affected by the outdoor wind velocity, which may reach to 3m/s. On the other hand, the indoor wind velocity of W-Market is 0.3~0.8m/s, and does not vary much; however, the market is rather much affected by the outdoor wind velocity, as shown in Fig.10.(b). With respect to floating dust, J-Market with raw-fish stores where the ground is always wet, the concentration of floating dust ranges between 0.02mg/m$^3$~0.04mg/m$^3$, which is relatively low. On the other hand, the concentration of floating dust in W-Market with its variety of stores ranges between 0.03mg/m$^3$~0.06mg/m$^3$, which is slightly higher than that of J-Market. However, the two markets have concentration lower than the standard 0.15mg/m$^3$.

5. Conclusion
This research identified the design standards for thermal, air and ventilation planning by establishing the major design elements that affect the indoor environment of the arcade-type traditional markets through actual measurements. The results of this study are summarized as follows: The environmental differences between the indoor and outdoor according to the design characteristics of each market are shown in Table 5. The following are the list of the findings without considering the relationships among the design elements.

First, with respect to the types of businesses in each market, J-Market, where processed foods are the dominant business, showed the largest difference between the indoor and outdoor temperature. With respect to humidity, W-Market and M-Market showed negative (-) sign while only J-Market showed positive (+) sign, which resulted from the higher the indoor humidity than the outdoor humidity.

Second, the difference of CO2 concentration in J-Market between the indoor and outdoor was higher than those of the other two markets, and its air flow speed was stable.

Third, even though the effect of the building size and the street orientation on the indoor environment of
arcades could not be derived precisely from Table 5., as the height of nearby buildings increases, more solar radiation could be blocked. Also, the orientation of streets affected the amount of solar radiation.

As the transmission of roof materials increased, the temperature difference between the indoor and outdoor clearly increased. Consequently, the transmission of roof materials, which affects the solar radiation gain, can be considered as a major design element.

As the opening area per total volume (A/V) increased, the CO2 concentration difference between the indoor and outdoor decreased, and total CO2 concentration decreased. Therefore, a higher ratio of the opening for the ventilation to the total volume of the arcade market increased the ventilation, and thereby, improved the indoor air quality. In other words, the width of street, the height of the arcade roof, the opening rate for ventilation, all of which determine the inside space of the arcade, are major design elements.

To summarize, the design elements that affect the indoor environment of the arcade-type markets can be classified into design elements of the market and design elements of the arcade, and are as follows.

- **Design elements of the traditional market**
  ① formation of stores
  ② the number of floors of nearby buildings
  ③ width and orientation of the streets

- **Design elements of the arcade**
  ① height of the arcade
  ② transmission of roof material
  ③ occupancy and schedule of merchants and shoppers

Because of the limited number of case markets, we were not able to determine the effect and relationship among major design elements.

For the future study, the results from actual measurements will be verified by energy simulation method, and the sensitivity analysis on the major design elements will be done under verified boundary conditions. Consequently, a proposal for the design standard of each variable will be presented.

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**Table 5. Summary of Measurements**

| Market | Characteristics of market | Difference between indoor & outdoor | Vertical T. |
|--------|---------------------------|------------------------------------|-------------|
|        | Store | Floor | Direct. | Trans. | A/V | T. | RH. | CO2 | Speed |         |
| W-Market | Raw | 2     | SW-NE  | 5%     | 0.037 | +0.1/+0.5 | +0.4/-0.3 | +8 | -0.14 | -0.3/+0.9 |
| M-Market | Raw | 3/4   | SW-NE  | 30%    | 0.035 | +3.4/+2.0 | -15.1/-5.2 | --- | ---    | +1.5/+2.1 |
| J-Market | Process | 2 | N-S   | 80%    | 0.000 | +5.2/--- | +6.6/--- | +186 | -1.02  | +3.0/--- |

*Store : Major Store, Floor : Average number of floors, Direct. : Street Direction, A/V : opening Area/arcade Volume by 1m, the unit length of arcade(unit: m), T. : Temperature(unit: °C), R.H. : Relative Humidity(unit: %), Speed : Wind Speed(unit: m/s), CO2 : (unit: ppm)