Characteristics of Cold-air Release from Air-conditioned and Open-entrance Shops to Outside Street Spaces in Summer

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ABSTRACT
This study clarifies the characteristics of cold air release from open-entrance and air-conditioned shops, and the microclimate formed in the outside street space during the summer, using both field measurements and a numerical simulation. Two streets in Tokyo were selected for comparison measurements. One street is comprised of a line of small shops that have large open entrances, and the other is comprised of a line of various small shops with closed entrances. The air temperature in front of open-entrance shops was much lower than that in the spaces with closed entrances. In particular, an accumulation of cold air was observed near the ground. A numerical simulation was then applied to quantitatively analyze the effect of spatial geometry and surface temperatures on the release of cold air from open-entrance shops. A coupled simulation method with a 3D CAD-based thermal environment simulator and a CFD simulation was applied to the microclimatic analysis. It was clarified that the accumulation range of cold air was concentrated in the spaces close to the shop entrances, and that the quantity of waste cold air released from the shops decreased when the ground surface temperature decreased by applying a water-retentive pavement and awning, and also when outside shelves provided a shield against the surrounding airflow.

KEYWORDS
Microclimate, Open-entrance shop, Air conditioning, Field measurement, CFD

INTRODUCTION
When focusing on the microclimatic characteristics of urban spaces, it is important to recognize that buildings are not always closed to outdoor spaces, and that microclimatic interactions exist between indoor and outdoor spaces. Open-entrance shops are common, with the open door being used to attract customers into the shopping space. However, air conditioning is used in shops during the summer, and

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therefore cold air is released to the outdoor space, contributing to changes in the outdoor microclimate (Figure 1). This results in a cool spot in the outdoor space, which is considered wasteful from an energy-saving perspective. This problem is related to both outdoor microclimate and building cooling load. It is therefore important to control this cold air release using certain architectural designs and methods. Previous studies that dealt with outdoor microclimates have not considered the effects of indoor climates and air conditioning on the microclimates around open entrances, as well as the possibility that a cool spot is created in those spaces. In addition, most building thermal simulations and energy simulations assume that building envelopes are closed to the outdoors, and they do not deal with “large-openings” which connect the indoor climate to the outdoor microclimate (He et al. 2009). This study clarifies the characteristics of cold air release from open-entrance shops, and the microclimate formed in the street space outside, using both field measurements and a numerical simulation. The latter part of this study examines a method to control the cold air release from shops, using architectural designs and techniques.

**RESEARCH METHODS – OUTLINE—**

The Akihabara district in Tokyo, where many open-entrance shops are present along the streets, was used as the research site. Four urban blocks were included in the site, and two streets were selected for comparison measurements. One street is comprised of a line of small shops selling electronic goods that have large open entrances (target street), and the other is comprised of a line of various small shops with closed entrances (comparison street). The map of the site is shown in Figure 2.

Firstly, field measurements of the air temperature distribution along these streets were conducted, in order to clarify the effects of cold air release from open-entrance shops on outdoor air temperature. Secondly, a numerical simulation was used to quantitatively analyze the effect of spatial geometry and surface temperatures on the

![Figure 1. Image of cold-air release from an open-entrance shop](image1)

![Figure 2. Research site and streets](image2)
cold air release from open-entrance shops.

FIELD MEASUREMENT OF MICROCLIMATE
Measurement methods
The detailed air temperature distributions of the site were observed by making measurements on foot, using a T-type thermocouple with an aspirated radiation shield. The aspirated radiation shield, which was highly accurate in measuring air temperature and was easy to use, was created by the authors. The measurement sensor installed in the shield was set at heights of 0.2 m, 0.9 m, and 1.5 m respectively, to confirm the vertical distribution of air temperature near the ground. The distance between each measurement point along the walking line was 1 m, and four walking lines in each street were utilized. The measurements were conducted from morning to evening on a clear-sky day with calm wind conditions in the summer. Air temperature maps in the target area were made by applying the spline interpolation method to the measured air temperature data for all measurement points.

Results
In order to confirm the characteristics of cold air accumulation near the ground in front of open-entrance shops, the air temperature distribution at a height of 0.2 m at 3 p.m. is shown in Figure 3. The target street runs from north to south, and most of the ground surfaces were shaded by street-side buildings. The air temperature in front of the open-entrance shops was much lower than that in the other spaces, including the comparison street, which had no open-entrance shop at the time. Figure 4 shows the vertical air temperature distribution along each measurement line.

Figure 3. Air temperature distribution at 0.2 m height (15:00)
The accumulation of cold air released from the open-entrance shops was confirmed from the ground level up to a height of 1.5 m. A high-rise building sited on the southern side of these streets contributed to the shielding of airflow from the south and prevented the cold air from dispersing to the surroundings. These characteristics can be seen in the detailed air temperature distribution, in which a low air temperature area appeared in the following spaces: the space near the outside shelves of the shops, near an entrance with an awning tent, and near the ground with low surface temperatures. There was more accumulation of cold air near the ground in the evening as compared to midday, because the ground surface temperature was affected by solar radiation and cold air that diffused into the surrounding atmosphere under unstable atmospheric conditions present near the ground at midday.

Figure 5 shows the average air temperature of the target street and comparison street at 3 p.m. This figure also includes the averaged air temperature of each divided area on the street. The division of the street is shown in Figure 4. The measured average air temperature of the target street was found to be approximately 2 °C lower than that of the comparison street at midday in the summer, and the maximum recorded difference was over 3.5 °C. The lowest air temperature value was recorded at an area (division) G in front of an open-entrance shop with outside shelves and an awning tent.
This chapter takes a numerical approach to confirm which architectural factors affect cold-air release from shops and cold air accumulation in front of the shops. As well, this chapter also examines an architectural method to control the cold air release from the shops.

A coupled simulation method with a 3D CAD-based thermal environment simulator developed by author’s group (Asawa et al. 2008), and a CFD (Computational Fluid Dynamics) simulation was applied to the microclimatic analysis (Asawa et al. 2012). As for the CFD simulation, an LES (Large-Eddy Simulation) was used to quantitatively analyze cold air accumulation, heat dispersion, and turbulent heat flux between indoor and outdoor spaces.

The 3D surface temperature distributions calculated by the 3D CAD-based thermal environment simulator were used for the surface thermal boundary conditions used by the LES simulation as Dirichlet boundary conditions, and an unsteady and non-isothermal turbulent simulation was conducted. The Smagorinsky model was used for the turbulence model and the Boussinesq approximation was used for buoyancy-driven flow. Inflow air temperature and velocity were set using meteorological data obtained at the nearest observation point by the Japan Meteorological Agency (Figure 6).

3D building models were reproduced in the study site, and the simulation area was approximately 3.5 ha. For open-entrance shops, the open-entrance and air outlet of the air conditioning system were reproduced in the building models.

Seven cases in Figure 7 were established for the comparison, including the effect of air conditioning use, layout of indoor shelves, and the existence of awning tents, outside shelves and water-retentive pavement. Figure 8 shows the simulation layout of buildings and the street.
**Figure 7. Simulation cases**

<table>
<thead>
<tr>
<th>Case</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case-1</td>
<td>Not use air conditioner (base)</td>
</tr>
<tr>
<td>Case-2</td>
<td>Use air conditioner (air-con)</td>
</tr>
<tr>
<td>Case-3</td>
<td>Put shelves parallel to the opening (shelf)</td>
</tr>
<tr>
<td>Case-4</td>
<td>Put awning tent (awning)</td>
</tr>
<tr>
<td>Case-5</td>
<td>Lay water retentive pavement (water)</td>
</tr>
<tr>
<td>Case-6</td>
<td>put outdoor shelves (out-shelf)</td>
</tr>
<tr>
<td>Case-7</td>
<td>Composite model. Case-2,4,5,6(all)</td>
</tr>
</tbody>
</table>

**Figure 8. Building models and the street used for the simulation**

**Results**

Figure 9 shows the horizontal distribution of air temperature at a height of 1 m at 12 a.m., and Figure 10 shows the vertical distribution of air temperature across the target street and building with an open-entrance shop. In Case-1, in which air conditioning is not used, the air temperature in the street space increases due to the high-temperature ground surface being heated by solar radiation. In contrast, for Case-2 to Case-7, which use air conditioning, the air temperatures in the space are lower than that of Case-1. The accumulation range of cold air was concentrated on the spaces close to the shop entrances. In Case-4, the awning tent contributes to a decrease in the ground surface temperature, and cold air accumulates near the ground. In Case-6, outdoor shelves provide a shield against the surrounding airflow and cold air accumulation occurs around the shelves. In Case-7, which applies all techniques, including water-retentive pavement, the air temperature of the street is the lowest as compared to all other comparison cases.

Figure 11 shows the results of turbulent heat flux on an open entrance between the indoor and outdoor spaces. In Case-2, the turbulent heat flux from the outdoor to indoor space is over 0.2 [mK/s]; this means that hot air flows into the indoor space and cold air escapes to the street space outside. In contrast, the turbulent heat flux is very small in Case-7; this means that the accumulation of cold air in the street space restricts the heat exchange between the indoor and outdoor spaces. It is clarified that the architectural and passive techniques used to cool outdoor spaces contribute to decreases in the cold air release from open-entrance shops, and reduce the building cooling load.
CONCLUSION
Field measurements show that the air temperature of the target street with
open-entrance shops was much lower than that of the comparison street with closed-entrance shops, and the cold air accumulated near the ground during the summer. The effect of cold air release from the open-entrance shops on the microclimate of the outside street space was clearly confirmed. The numerical simulation shows that the accumulation range of cold air concentrated on the spaces close to the shop entrances, and that the waste cold air release from the shops decreased when ground surface temperature decreased by applying a water-retentive pavement and awning, and also when outside shelves provided a shield against the surrounding air flow. These architectural and passive techniques are useful for the creation of cool spots in the street space, and can reduce the cooling load of open-entrance shops.

REFERENCES