Study on Saving Energy at Stations with Commercial Facilities

Abstract
The purpose of this study is to improve the indoor thermal environment and to improve the energy efficiency of HVAC (Heating, Ventilation, and Air Conditioning) systems in commercial facilities in terminal stations. In this study, measurement of temperature, humidity, and wind velocity were carried out. We also performed summer simulations for several patterns of thermal insulation levels and adjustment of openings to introduce natural ventilation. This study demonstrates the possibility of applying passive design by simulation.

Keywords: Commercial facilities, Terminal stations, Thermal insulation, Natural ventilation, Passive design

1. Introduction
Station spaces commonly have structures where they are partially open to the outdoor environment, and they are characterized by being easily affected by that environment. Particularly in summer, the impact of body heat from many passengers has been confirmed to make the interior of stations extremely hot, and improvement of the thermal environment has become an issue. Also, with the increase in commercial facilities inside stations, some stations have introduced large-scale HVAC systems. With the introduction of heaters and coolers in some areas of spaces partially open to the outdoor environment, saving energy at stations has become an issue that needs to be addressed.

In this study, we consider introduction of passive design, consider through measurement investigation and simulations the scope in which passive design can be used and feasibility of that, and aim to establish a simulation mode that contributes to planning for introducing passive design. Those are done with an aim of making large-scale stations with air-conditioned commercial facilities to be energy saving.

2. Measurement Investigation

2.1 Station Investigated
The station investigated was SG Station, a terminal station in the greater Tokyo area with commercial facilities and mixed air-conditioned and non air-conditioned spaces and where it is assumed passive design can be applied.

2.2 Measurement Investigation of Thermal Environment
In the measurement investigation, we measured in a continuous manner in summer the air temperature, humidity, and wind velocity at openings such as stairways in the station as well as outside temperature and insolation outside the station. The seven zones in Fig. 1 are classified as Zone A for the station concourse next to the north ticket gate, Zone B for the over-track passage, Zone C for the station concourse next to the south ticket gate, Zone D for the plaza for transfer to other-company lines, Zone E for commercial facilities (vaulted ceiling space), Zone F for the passageway for transfer to other-company lines, and Zone G for commercial facilities (passageway area). The hygrothermographs of

Table 1 Overview of SG Station

<table>
<thead>
<tr>
<th>Station name</th>
<th>SG Station</th>
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<tbody>
<tr>
<td>Station form</td>
<td>Over-track station</td>
</tr>
<tr>
<td>Location</td>
<td>Tokyo</td>
</tr>
<tr>
<td>Passenger volume (average)</td>
<td>Approx. 361,000 people/day</td>
</tr>
<tr>
<td>No. of platforms</td>
<td>8 platforms, 15 tracks</td>
</tr>
<tr>
<td>No. of ticket gate locations</td>
<td>2 for entry/exit, 3 for transfer</td>
</tr>
</tbody>
</table>
(1) in the table and anemometers for (2) in the table were set up at a height of approx. 3.0 m above the floor in order to not obstruct flow of passengers. Also, anemometers for (3) in the table were set up at the entrance to commercial facilities, so measurements were taken only for two days at night with anemometers set up on tripods temporarily at a height of about 0.5 m from the floor in order to avoid being affected by station users.

Table 2 Overview of Measurement Items

<table>
<thead>
<tr>
<th>Measurement item</th>
<th>Measurement location</th>
<th>Measurement period</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Temperature &amp; humidity</td>
<td>Concourse, over-track passage, commercial facilities (see Fig. 1)</td>
<td>Aug. 6 to Sept. 12, 2016</td>
</tr>
<tr>
<td>(2) Wind speed</td>
<td>Openings for stairways to platforms from concourse (see Fig. 2)</td>
<td>Aug. 6 to Aug. 9, 2016 (3 days)</td>
</tr>
<tr>
<td>(3) Wind speed</td>
<td>Openings for entrances to commercial facilities (see Fig. 2)</td>
<td>Aug. 6 to Aug. 7, 2016 (2 days)</td>
</tr>
<tr>
<td>(4) Insolation</td>
<td>Roofs of buildings surrounding station</td>
<td>Aug. 6 to Sept. 1, 2016</td>
</tr>
</tbody>
</table>

3. Measurement Investigation Results and Considerations

3.1 Air Temperature in Station

The relationship between the outside air temperature and the air temperature in the station at typical measurement points out of the temperature measurement points in Fig. 1 is shown in Fig. 3. Air temperature in the station was constantly higher than outside temperature at all points except the Zone E measurement points. In particular, air temperature in the station was confirmed to be the highest at measurement point T-3 in the over-track passage. This is assumed to be because glass is used abundantly on the walls, causing direct impact of insolation.

From measurement results of T-18 in Zone E, we found that even though daytime air temperature of the commercial facility area where air conditioning is used was kept below outside air temperature, it was higher than outside air temperature at night when air conditioning is stopped. This is the same as other areas and assumed to be due to the impact of heat radiation from shop refrigeration equipment and frames.

Fig. 4 shows the change over time of air temperature in the station on August 9, a typical clear day, and Fig. 5 shows change over time on August 28, a typical cloudy day. The air temperatures in the station shown in the figures are averages for the measurement points in each zone. From Fig. 4 and Fig. 5, we see as demonstrated above that air temperature in the station at Zone E where air conditioning operates becomes higher than outside air temperature at night when air conditioning is stopped. From this, we assume that ventilating heat by nighttime ventilation may reduce startup load for air conditioning and thereby contribute to saving energy. And while the insolation graph shows peak insolation at 12:00, the peak air temperature in the station is at about 15:00. From this, we assume that air warmed by insolation impacts air temperature in the station with a difference in time.
3.2 Indoor Air Flow Speed
For measurements by the anemometers in the station in Fig. 2, Fig. 6 shows wind speed at openings in a north-south direction and Fig. 7 shows wind speed at openings in an east-west direction. The wind speeds in the figure are measurement data obtained from August 6 to 8 averaged for the same time of each day. From that, we find that wind speeds at openings in a north-south direction are faster than those in an east-west direction. At SG Station, the north-south direction is parallel to the tracks and measurement locations at opening that are for stairways to platforms, so we confirmed that strong wind is generated intermittently in the direction parallel to the tracks.
4. Simulation Analysis

From the measurement investigation results, we assume that the air-conditioned and non-air-conditioned spaces need to be insulated because the air temperature in the station is higher than the outside air temperature and that air temperature in the station needs to be released because nighttime outside air temperature is lower than air temperature in the station.

In light of this situation, we analyzed by heat and ventilation simulation improvements to the thermal environment and the effects of reducing thermal load by insulating by changing wall specifications and releasing heat by nighttime ventilation. We also verified the scope in which passive design can be used and feasibility of that. The purpose of those is to verify the possibility of making station buildings energy efficient.

For analysis, we separate SG Station into north and south buildings at the over-track passage. At the north building with simple commercial facility layout, we confirm changes in wall thermal insulation performance. And at the south building ceiling window openings in the commercial facility area, we confirm changes by applying nighttime ventilation.

4.1 Wall Insulation Performance Verification for North Station Building

4.1.1 Overview of Verification

Walls of commercial facilities inside SG Station are of specifications for inside walls, so they have poor insulation performance. However, measurements verified that air temperature in the station is higher than temperature of outside air in the summer, so commercial facilities in stations need to be considered as being outside, not inside buildings. We therefore confirmed to what extent wall insulation performance of commercial facilities in an environment with greater thermal load that outside has on air conditioning load.

4.1.2. Simulation

Table 3 shows setting conditions for north building simulation performed this time and Table 4 shows a list of setting for consideration cases of insulation performance. The three cases verified were no, medium, and large insulation performance.

<table>
<thead>
<tr>
<th>Case</th>
<th>Insulation performance</th>
<th>Heat transmission coefficient (W/m²K)</th>
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</thead>
<tbody>
<tr>
<td>N-1</td>
<td>No insulation</td>
<td>3.456</td>
</tr>
<tr>
<td>N-2</td>
<td>Medium insulation</td>
<td>1.810</td>
</tr>
<tr>
<td>N-3</td>
<td>High insulation</td>
<td>0.385</td>
</tr>
</tbody>
</table>

4.1.3 Simulation Results

Fig. 8 shows the average air temperature in the station for the three simulation cases and measured air temperature. Measurement points express T-1 and T-2 measured at the north building shown as covered in chapter 2.2. There were places observed where measured and simulated air temperature values diverged, but they generally matched for temperature change over time. Thus, we believe that the simulation model created is valid.

Next, a graph comparing commercial facility cooler thermal load is shown in Fig. 9. Average thermal load in the cases is 40.1 kW for N-1 (no insulation), 35.9 kW for N-2 (medium insulation performance), and 29.1 kW for N-3 (high insulation performance). This means that a 27% decrease in thermal load can be obtained by changing from composition with no insulation to that with high insulation performance.
4.2 Nighttime Ventilation Effect Verification for South Station Building

4.2.1 Overview of Verification

In analysis of the south building, we looked for results in Zone E where the impact of adjustment of ventilation opening/closing was remarkable. In Zone E, there are commercial facilities with multi-layer structure spaces having open ceilings at the center and skylights. Air temperature in commercial facilities is controlled by air conditioning to be comfortable in the daytime, but it becomes higher than outside air temperature after closing and air conditioning is stopped, and that is assumed to make air conditioning load at start of air conditioning the next day greater. In this study, we confirm by simulation the changes in thermal load applied to air conditioning and changes in air temperature and humidity due to nighttime ventilation.

4.2.2 Simulation Cases

We verified the results of keeping some openings to the Zone E commercial facility area open at night. Table 5 shows simulation conditions for the south building and Table 6 shows opening and closing patterns for openings.

4.2.3 Simulation Results

Fig. 10 shows the relationship between average commercial space air temperature in Zone E for three simulation cases and outside air temperature, and Fig. 11 shows a graph comparing commercial space cooling thermal load in the individual cases. Average values for thermal load in the cases was 154 kW for S-1 (openings were closed), 148 kW for S-2 (openings other than skylights were left open), and 145 kW for S-3 (all openings, including skylights, were left open). From this, we were able to confirm that influx of outside air from leaving openings open reduced air temperature in commercial facilities up to approx. 2 ºC compared with when all openings are closed and that cooling load can be reduced by approx. 6%.

Meanwhile, from the relationship between average relative humidity in commercial facilities for the simulation cases and outside air relative humidly (Fig. 12), we confirmed that outside air is brought in from leaving openings open at...
night results in an approx. 10% increase in humidity in commercial facilities over when closed. For that reason, we believe that settings where sensible heat and latent heat are comprehensively evaluated are needed instead of just leaving openings open.

5. Conclusion

In this study, we considered introduction of passive design, conducted measurement investigation and heat/ventilation simulations for SG Station and considered the scope in which passive design can be used and feasibility of that. Those were done in order to achieve energy saving at large-scale stations with commercial spaces that use air conditioning.

From measurement investigation, we confirmed that the temperature at many areas within the station building in summer becomes higher than that of the outside air and confirmed that a substantial amount of wind is generated in north-south openings of the station (parallel to the tracks).

From analysis by simulation, we confirmed for the north building that cooling load of commercial facilities could be reduced by using wall material composition with high insulation performance. And for the south building, we confirmed that commercial facility temperature could be reduced by using nighttime ventilation and that cooling load of commercial facilities could thus be reduced. However, an effect of outside air entering by leaving openings open and causing relative humidity to increase was seen. For that reason, we believe that settings where sensible heat and latent heat are comprehensively evaluated are needed instead of just leaving openings open.