Special edition paper

Research on Thermal Comfort Zone of Railway Stations with Air-conditioned Spaces

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There has been no previously reported research on the thermal comfort zone of air-conditioned stations from the standpoint of passengers, therefore we have had no guidelines on how much air conditioning is needed, particularly in summer when air conditioning load is high. Aiming at identifying the thermal comfort zone of stations, we carried out one-year field measurement of the thermal environment of an air-conditioned station, and we also surveyed psychological quantities perceived by passengers regarding the thermal environment per season using questionnaires. Combining with previous survey results of the Frontier Service Development Laboratory on stations without air conditioning, we have found that an index for an environment acceptable to station users in summer is a perceived temperature of SET* 32 ºC, and an index for customer comfort is SET* 29 ºC, regardless of the use of air conditioning.

●Keywords: Station, Thermal environment, Perceived temperature, Thermal comfort zone

1 Introduction

JR East has been working to reduce total CO_2 emissions from railway business as a long-term effort. In terms of stations, minimizing environmental load while improving environmental quality is an important issue. However, we have no guidelines to achieve a good balance between thermal comfort and energy conservation at stations, nor exact data and information on the actual thermal environment of air-conditioned stations. This is despite the fact that more stations have introduced air conditioning in recent years. We thus carried out measurements of thermal comfort at an air-conditioned station for three seasons with an aim of identifying the thermal comfort zone for passengers in air-conditioned stations.

2 Overview of Surveyed Station

In this research, we carried out measurement at a station located in the Kanto area. That station is a terminal station servicing both commuter lines and Shinkansen lines, and it has north and south ticket gates and an east-west over-track passage in between. There is a large-scale commercial facility (approx. 5,000 m^2) inside the south ticket gate. A major part of the passage directly connecting to the platforms on the lower levels is air-conditioned, as are all shop areas.

We divided the air-conditioned area and the non-air-conditioned passage into four zones for the measurement and survey. As the purpose was to clarify the thermal comfort characteristics as a station, we carried out the measurement and survey only in the area passengers can use as in-station passage, thus excluding inside of individual shops. Fig. 1 shows the zones.

Zone A is an air-conditioned area away from the staircases to the platforms where outside air might flow in, Zone B is an air-conditioned area adjacent to the staircases to the platforms, Zone C is a border area between air-conditioned and non-air-conditioned areas, and Zone D is a non-air-conditioned area outside of the ticket gate. We carried out three types of thermal environment measurement there.

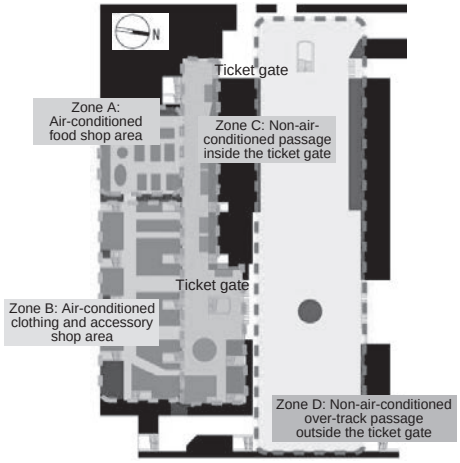

Fig. 1 Surveyed Station Plan View and Zones (Zone A to D)

Fig. 2 Photos of Individual Zones (from left to right: Zone A, B, C, D)

3 Research Flow

Fig. 3 shows the flow of this research.

First, we carried out measurement of the thermal environment of the station. Specifically, we carried out 1) Outside weather measurement, 2) Long-term in-station temperature and humidity measurement (at 37 points for nine months, Fig. 4), and 3) Intensive measurement to obtain more detailed data (at 13 points for a total of 21 days).

In the survey of the thermal comfort of customers, we carried out a touch panel questionnaire survey for the passengers in the station by using iPads to examine the psychological quantity of the situation for passengers (Fig. 5). The survey was conducted from 10:00 to 17:00, avoiding weekday peak hours, for nine

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days in summer (July to September) and six days each in autumn (October to November) and winter (December to January), for a total of 21 days. In the survey, a researcher was stationed in each of the four zones.

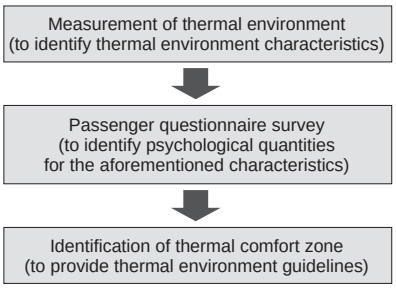

Fig. 3 Flow of Research

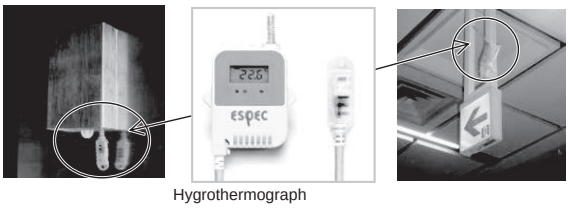

Fig. 4 Devices Installed and Used in Long-term Measurement

Fig. 5 iPad Used and Conducting Questionnaire Survey

4 Thermal Environment Measurement Results

For detailed analysis, we classified the period from July 16 to September 19, 2011 as the summer period, from September 20 to November 20, 2011 as the autumn period, and from November 21, 2011 to January 17, 2012 as the winter period. Fig. 6 shows the planar distribution of the in-station air temperature in the time from 13:00 to 13:59 on a typical day of good weather in each season period.

In the summer period, lower air temperature distribution was seen in Zone A than in other zones, temperatures being particularly lower in the shop area. In Zone B, we found that temperatures differ by around 4 ºC within the zone, with higher temperature at the staircases to the platforms. In Zone C, there also was a temperature difference around 5 ºC as in Zone B, higher at the concourse inside the ticket gate and lower at the passage. In Zone D, the air temperature was the highest in the station.

In the autumn period, the air temperature was around 22 to 26 ºC, with no remarkable difference according to the zone. However, in Zone A, the air temperature was higher than in Zone B or C. In Zones B and C, a temperature difference around 2 or 3 ºC was seen within the zone, as in the summer period.

In the winter period, we saw the largest temperature difference within the station in all the surveyed seasons—approx. 14 ºC at the maximum. The highest air temperature in the station was measured in Zone A and the lowest in Zone C. In Zone B, there temperatures differed by about 8 ºC in the north-south direction within the zone, becoming lower at the points nearer to the ticket gate. In Zone C also, temperatures differed by about 7 ºC within the zone, being lower at the concourse inside the ticket gate and higher at the passage.

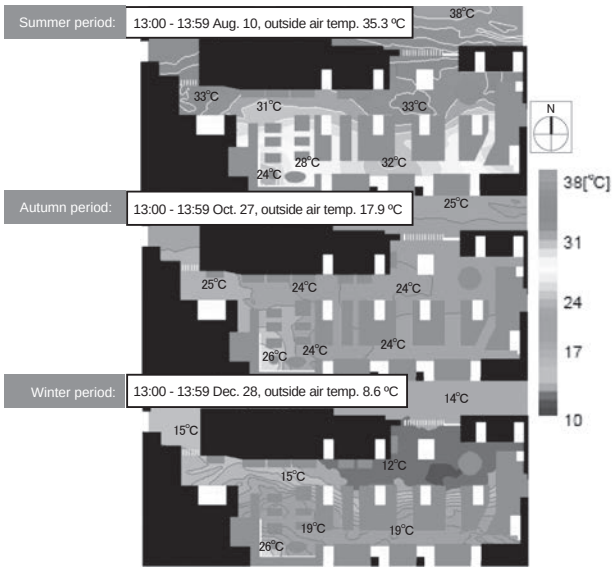

Fig. 6 Planar Distribution of the In-station Air Temperature

5 Passenger Questionnaire Survey Results

Table 1 shows the questions and response choices of the passenger questionnaire survey. The survey covered attributes of respondents, the types of use of the station and commercial facility inside the ticket gate, and the psychological quantities on personal sensation of temperature and comfort.

Table 2 shows the number of respondents of each zone in each season period. The total number of respondents in the three seasons was 1,356. By individual season, that was 823 in summer, 278 in the intermediate season, and 254 in winter. There is a seasonal difference of the total number of respondents due to the number of survey days, however the response rates per zone were similar. Female respondents accounted for a larger percentage in all three seasons—more than 60%. There was no imbalance in terms of age.

Table 1 Questions and Response Choices of Questionnaire

Questions about you	
Sex	Male/Female
Age	Under 19/ 20s/ 30s/ 40s/ 50s/ 60s/Over 70
Time in station	Q: How long have you been here? A: About 5 min./ About 10 min./About 30 min./About 1 hour/More than 1 hour
Route	Q: Where did you come here from? A: From platform/From ticket gate/From outside
Subsequent plans	Q: Will you remain here? A: Yes/No
Frequency of use	Q: How often do you use the station and the commercial facility inside the ticket gates? A: Almost everyday/A few times a week/A few times a month/Seldom or never
Type of use	Q: Why do you use the station? A: Nearest station to home/Nearest station to workplace/Transfer station/Others
Purpose of use	Q: For what purpose and when do you use the commercial facility inside the ticket gates? A: Shopping/Eating/Getting cooler or warmer/Just passing through/Do not use Before transfer/Before going home/Before commuting/Killing time/Do not use
Questions about the current environment here	
Temperature sensation	Q: How do you feel the temperature is here now? A: -3 Cold/-2 Cool/-1 Slightly cool/0 Neither hot nor cold/+1 Slightly warm/+2 Warm/+3 Hot
Temperature preference	Q: What do you want the current environment here to be? A: -1 Warmer/0 As is/+1 Cooler
Comfort	Q: What is the comfort level here now for you? A: -3 Very uncomfortable/-2 Uncomfortable/-1 Slightly uncomfortable/0 Neutral/ +1 Slightly comfortable/+2 Comfortable/+3 Very comfortable
Acceptability	Q: Do you accept the temperature here now? A: -1 Unacceptable/+1 Acceptable

Table 2 Numbers of Respondents per Zone

	Zone A	Zone B	Zone C	Zone D	Total
Summer	225	108	284	207	824
Autumn	88	38	83	69	278
Winter	67	35	85	67	254
Total	380	181	452	343	1356

Fig. 7 shows the response results on the personal sensation of temperature. In the summer period, the largest number of persons replied "slightly cool" in air-conditioned Zones A and B, while the largest number of persons replied "hot" in non-air-conditioned Zones C and D. In Zones B and C, however, responses varied by the temperature difference within each zone.

In the autumn period, compared to the responses in the summer period, the responses became neutral in general, with the responses of "slightly warm" or "neither hot nor cold" accounting for the major percentage. In Zones A and B in the winter period, more people gave responses on the warm side, even some "hot" in Zone A, with almost no responses on the cool side. In Zones C and D, the major percentage of persons gave responses on the cool side, including the largest number of responses of "cold"; however, many people gave neutral responses in both zones.

Fig. 8 shows the response results on personal preference of temperature. In the summer period, the number of people who preferred the station to be "cooler" increased in order from Zones A to D, with around 10% in Zone A and more than 70% in Zone D. In the winter period, the number of people who preferred the station to be "warmer" increased in order from Zones A to D again. A comparison of the response rate of "cooler" in the summer period and that of "warmer" in the winter period tells that the rate of people who wanted environmental control was higher in summer.

Fig. 9 shows the response results on personal sensation of comfort. In the summer period, a larger number of people gave responses on the comfortable side in air-conditioned Zones A and B, with a higher response rate of "slightly uncomfortable" in Zone B. In Zone C, the most chosen response was "neutral"; however, there were responses both on the comfortable side and on the discomfort side due to the temperature variation within the zone, as seen in the summer period. In the autumn period, the response of "slightly comfortable" accounted for the largest percentage, at approx. 40% in all zones. Compared to the summer period, the rate of people who gave responses on the uncomfortable side in Zones C and D sharply dropped, moving to the comfortable side.

In the winter period, the responses "comfortable" and "slightly comfortable" were in the majority in Zone A, while responses on the comfortable side decreased in Zone B despite it being an air-conditioned zone like Zone A. In Zones C and D, the responses of "slightly comfortable" and "slightly uncomfortable" followed the response of "neutral". Compared to the summer period, when the responses on the uncomfortable side were predominant, Zones C and D were found to be more comfortable in winter.

Fig. 10 shows the response results on personal acceptability. In the summer and winter periods, in Zones C and D particularly, the rate of people who replied "unacceptable" was slightly higher. However, in all zones and periods, that rate was less than 20%.

Those questionnaire survey results lead to the following conclusions. Air-conditioned Zone A was the most comfortable zone in the station. In Zone B that was air-conditioned but easily affected by outside air, many passengers felt uncomfortable. In Zone C, the border zone, there was quite a large temperature difference within the zone, thus causing the difference in responses. Non-air-conditioned Zone D could be judged the most uncomfortable zone in the station in terms of thermal comfort, both in summer and winter.

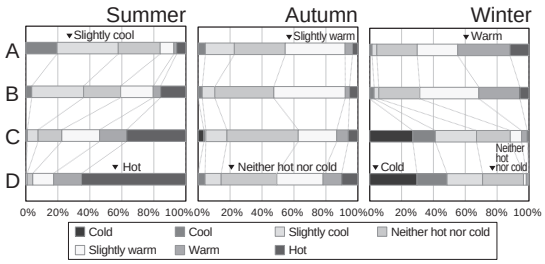

Fig. 7 Response Results on Personal Sensation of Temperature

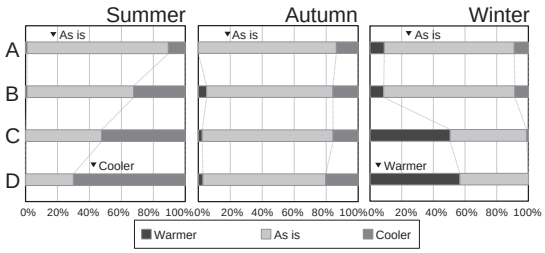

Fig. 8 Response Results on Personal Preference of Temperature

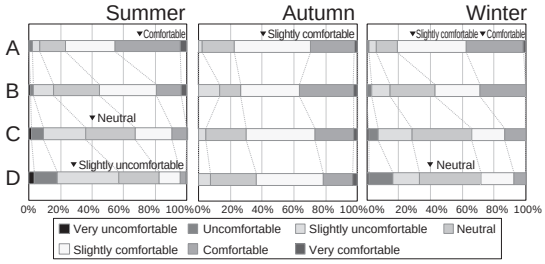

Fig. 9 Response Results on Personal Sensation of Comfort

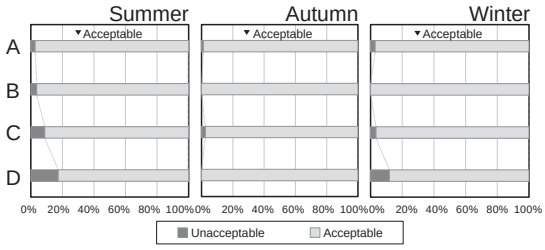

Fig. 10 Response Results on Personal Acceptability

6 Understanding of the Thermal Comfort Zone

We conducted research to understand the thermal comfort zone at a station with air conditioning this time. We had also worked on stations without air conditioning in the past. We thus compared the cases to see how much the thermal comfort zone differs.

Specifically, we investigated the correlation between the thermal environment and the psychological quantities users replied (responses on personal sensation of temperature, personal preference of temperature, personal sensation of comfort, and personal acceptability of temperature) for both the surveyed air-conditioned station and the non-air-conditioned station

researched in the past. For the surveyed station, we dealt with the responses in air-conditioned Zones A and B and in border Zone C affected by air conditioning to analyze the characteristics of an air-conditioned station. As the typical value of the thermal environment areas occupied by people, we used SET* (see note), the effective temperature for each respondent.

Fig. 11 shows the rate of the respondents who wanted temperature higher/lower than SET*. For both cases of a non-air-conditioned station and the surveyed station, the curves of people who "preferred higher temperature" and people who "preferred lower temperature" cross at approx. SET* 25 ºC, where the rate of the persons who replied the temperature was not preferable was lowest. In other words, this is the point where many users feel neither hot nor cold.

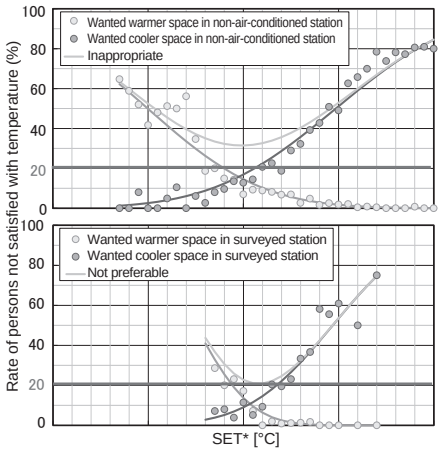

Fig. 11 Regression Curve of Rate of Persons Who Wanted Warmer/Cooler Space

Fig. 12 shows the rate of the respondents who wanted temperature higher/lower than SET* and also replied "slightly uncomfortable," "uncomfortable," or "very uncomfortable" in the choice of personal sensation of comfort. In the zone of SET* 19 - 29 ºC of the non-air-conditioned station, that rate was less than 20%. As the comfort zone of an ordinary room is SET* 23 - 28 ºC, we can say that passengers' comfort zone of the non-air-conditioned station is broader than in an ordinary room. On the other hand, the thermal comfort zone of the surveyed station was SET* 23 - 29 ºC, and its lower limit was higher than in that of a non-air-conditioned station, corresponding with the lower limit of an ordinary room. Although we had predicted that the upper limit of the thermal comfort zone of the surveyed station would be lower than that of a non-air-conditioned station, those actually corresponded to each other at SET* 29 ºC. As the summer survey period at the surveyed station happened to be in the enhanced energy conservation period after the 2011 Tohoku Earthquake and Tsunami, that might have had some effect on passengers' state of consciousness.

Fig. 13 shows the rate of the respondents who wanted temperature higher/lower than the SET* and also replied "unacceptable" in the choice of personal acceptability of temperature. For the case of a non-air-conditioned station, that rate was less than 20% (the general guideline value for setting the threshold) in the zone of SET* 19 - 32 ºC, indicating that users will accept the thermal environment of that zone. In contrast, for the case of the surveyed station in winter, the in-station air temperature was kept higher than the outside air temperature; so, the rate of the respondents who replied "want higher temperature" and "unacceptable" was quite low, never over 20%. The regression curve for the rate of the responses of "want lower temperature" and "unacceptable" of the surveyed station in summer exceeds 20% at around 32 ºC, as was the case for a non-air-conditioned station. This revealed that the upper limit of the thermal acceptability zone is SET* 32 ºC for the both stations.

(Note) SET* is the perceived temperature (in ºC) based on the new standard effective temperature theory. SET* is represented by the value (temperature) in the standard thermal environment converted from the effect of the six factors of the thermal environment: temperature (ºC), mean radiant temperature (ºC), relative humidity (%), wind speed (m/s), amount of clothing (clo) and workload (MET).

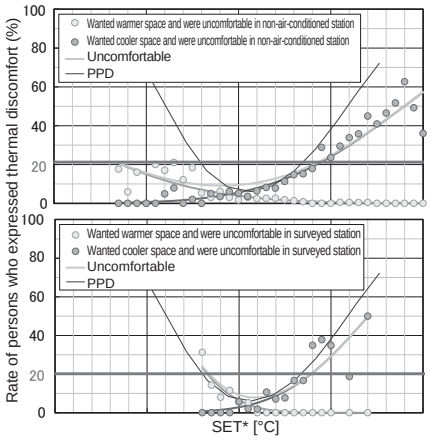

Fig. 12 Regression Curve of Rate of the Persons Who Wanted Warmer/Cooler Space and Were Uncomfortable (PPD in in the diagram is the curve of the rate of people who express thermal discomfort in an ordinary building)

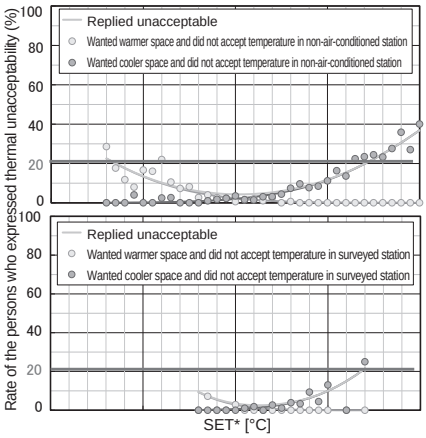

Fig. 13 Regression Curve of Rate of the Persons Who Wanted Warmer/Cooler Space and Did Not Accept the Temperature

7 Conclusion

As shown above, the upper limit of the acceptable zone of the thermal environment was SET* 32 ºC both in air-conditioned and non-air-conditioned stations. The comfort zone was SET* 19 - 29 ºC in non-air-conditioned stations and SET* 23 - 29 ºC in air-conditioned stations, again with the same upper limit. Based on those results, we have concluded that the guideline to secure an environment in a station in summer that passengers accept is SET* 32 ºC, and the guideline to secure a more comfortable environment is SET* 29 ºC.