Horizontal Movements of Proscenium Curtain in Multipurpose Hall Caused by Temperature Difference between Stage and Front Seat Zones

Yuichi Takemasa [1], Satoshi Togari [1], and Shin Hayaka

[1] Kajima Technical Research Institute, Tokyo, JAPA

ABSTRACT

It is well known that a proscenium curtain in a multipurpose hall or an auditorium tends to move horizontally during the heating period as a result of the difference in air temperatures between the two zones divided by a proscenium curtain, the stage zone and the front seat zone. However, no reports have described this curtain movement quantitatively. The present paper describes the results of field measurements of the movement of a proscenium curtain in an existing multipurpose hall during the winter. An analytical airflow network model is used to reproduce the pressure difference between the two zones.

The results of measurements show that horizontal movement of a proscenium curtain is strongly affected by the difference in air temperatures between the two zones. The analytical network model can reproduce these phenomena very well and can be used in the design process. The influence of curtain weight is also discussed. The results strongly suggest the importance of architectural planning as well as HVAC design.

KEYWORDS

Multipurpose halls, proscenium curtains, measuring techniques, air conditioning, temperature gradient, modeling.

INTRODUCTION

In the design of a multipurpose hall or an auditorium, the horizontal movement of a proscenium curtain during the heating period and cold drafts in the front seat zone caused by the temperature difference between the stage zone and the front seat zone tend to be problems (Nomura 1977). Some reports describe the cold drafts and the thermal environment around proscenium curtains (Terasawa et al. 1994; Kawaoka et al. 1994). However, curtain movement has not been discussed quantitatively.

Recently, the authors had a chance to measure pressure differences between the two zones divided by a proscenium curtain and the resulting movement of the curtain in an existing multipurpose hall in the winter. The present report focuses on temperature differences between the front seat zone and the stage zone, which are thought to be the main cause of the pressure differences between the two zones. Measurements were made under various conditions by changing the target temperatures of HVAC (Heating, Ventilating, and Air-Conditioning) systems. An analytical airflow network model is applied to reproduce the pressure differences between the two zones. The applicability of the model is also discussed. Some design suggestions are summarized at the end of the paper.

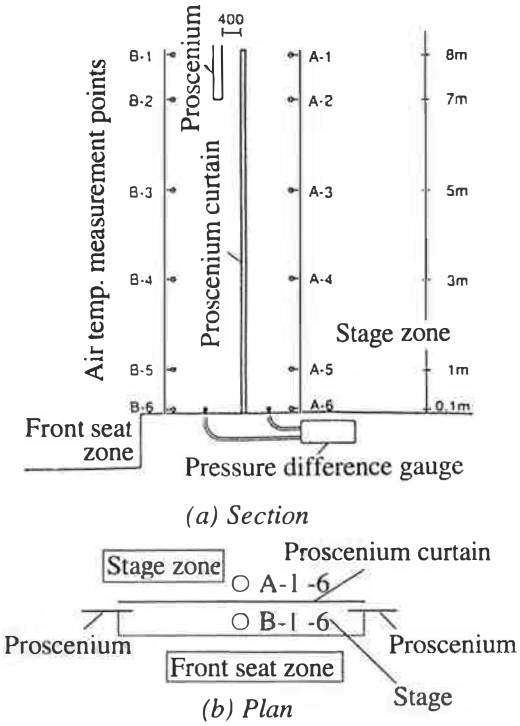

Figure 1 Outline of measurements.

MEASUREMENT METHODS

The hall measured is a multipurpose hall located in Tokyo, Japan. The hall has a seating capacity of 500. Its stage is divided by a light movable proscenium curtain. The curtain is 8 m high. Different HVAC systems are installed for the stage zone and the seat zone.

The measurements were made with various combinations of heating and cooling conditions in the stage zone and the seat zone on a day at the beginning of December. Horizontal movement of the curtain was observed while the target temperatures of the two zones were changed. A video cassette recorder was used to record curtain movement. Curtain displacement was measured by observation.

As shown in Figure 1, the items measured were vertical temperature distributions (6 points in the vertical direction) in the two zones divided by the curtain, and the pressure difference in the region close to the stage floor (FL + 0.1 m). The pressure difference is shown as difference from the pressure in the front seat zone. All pressure differences at other heights were estimated based on the measured vertical temperature distributions and the pressure difference near the stage floor. The temperatures were measured with thermocouples, and the pressure difference near the floor was measured by an electric pressure difference gauge.

MEASUREMENT RESULTS

Figure 2 shows measured variations of air temperatures, the pressure difference

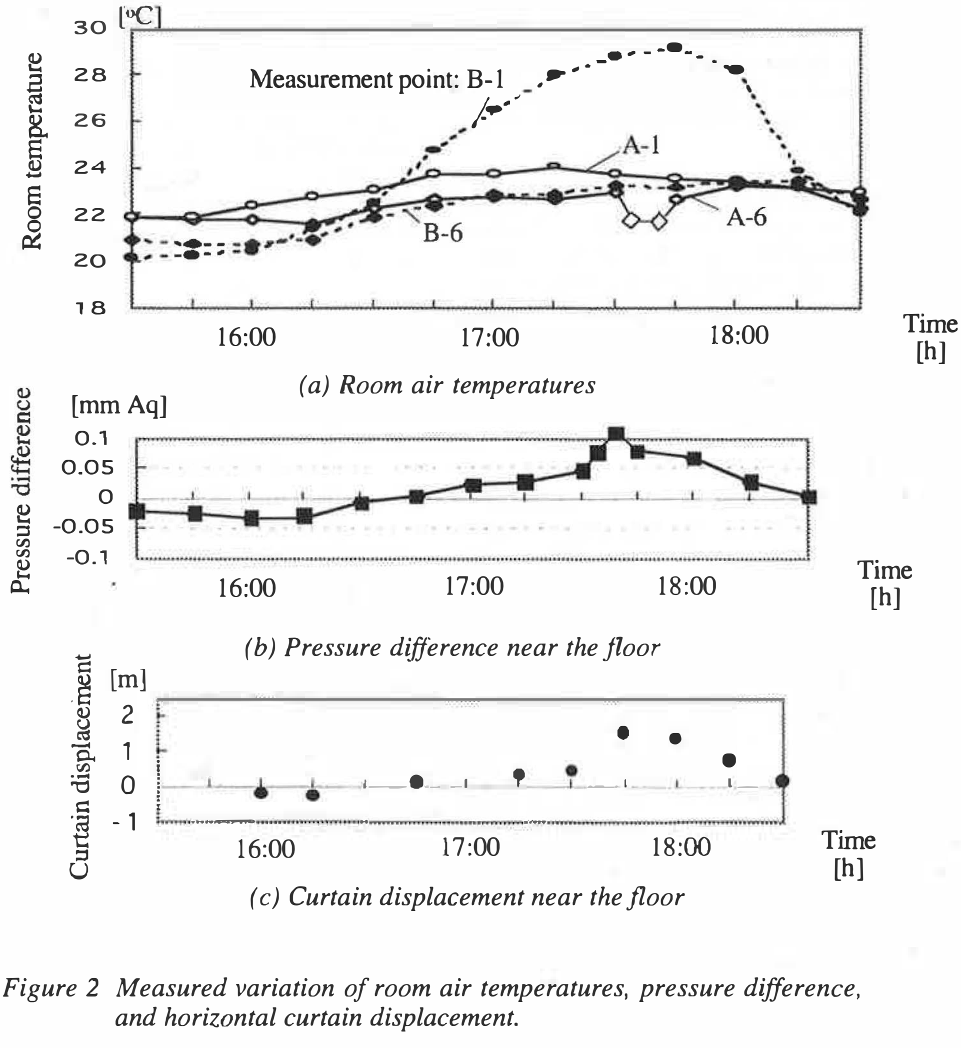

Figure 2 Measured variation of room air temperatures, pressure difference, and horizontal curtain displacement.

between the two zones near the floor, and horizontal displacement of the lowest portion of the curtain from its origin. The origin is assumed to be on the floor exactly under the curtain hanger.

The curtain moved toward the stage just before and after 16:00, when the seat zone was cooled. This was due to negative pressure in the stage zone as shown in Figure 2 (b). However, curtain displacement was relatively small, in line with the relatively small temperature differences between the two zones at the time, as is demonstrated by Figure 2 (a). Figure 3 shows a picture of curtain displacement at 16:16.

After 16:30, the target temperature in the seat zone was intentionally set to be higher in order to make the vertical temperature difference in the seat zone large. As the temperature in the upper region of the seat zone became higher, the pressure differences between the two zones also became larger and the curtain began to move toward the seat area (Figure 2 (c)).

The curtain moved dramatically further toward the seat zone at 17:34, when a door connecting the stage zone with stair areas behind the stage was opened. Figure 4 is a picture demonstrating this phenomenon at 17:35. The area of the door is about 4 m^2. The stairs are connected through a passage to a back entrance, which has only one automatic door. Curtain displacement reached its maximum of about 2 m around 17:43. This drastic movement is thought to have been caused by a large mass of cold air that moved from the stair regions into the stage zone after the door was opened. The cold air caused a sudden drop in the air temperature in the lower region of the stage (Figure 2 (a)), and then led to a sharp rise in positive pressure in the stage zone (Figure 2 (b)). The air moved through a newly created small slot between the inclined curtain and the stage floor (Figure 4). This phenomenon will be discussed in more detail later in the paper.

The curtain started to move back to the stage zone after 17:44, when the door behind the stage was shut again. However, movement was very slow.

The observed results suggest strongly the importance of architectural planning, including areas behind the stage, as well as design of HVAC systems.

CALCULATION METHODS

It would be useful to predict the movement of a proscenium curtain in the design process when such risks are expected. The authors attempt to estimate curtain movement using an analytical airflow network model, and to evaluate the model. Assuming that comprehensive temperature distributions are provided by various simulation tools, the focus is on predicting pressure differences between the two zones on the basis of measured temperature distributions. It is assumed that there is no infiltration in the hall and that air balances due to HVAC systems are sufficient. A normal steady-state airflow network model making use of Bernoulli's theory was applied. Curtain displacement can then be derived from a simple theory of dynamics by dividing the curtain vertically into some mass

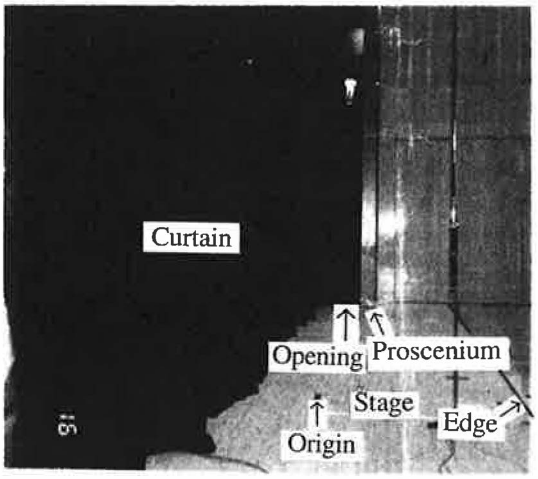

Figure 3 Displacement of the proscenium curtain (at 16:16).

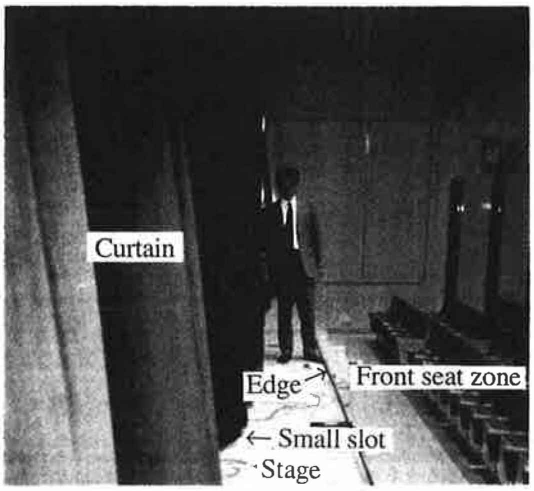

Figure 4 Displacement of the proscenium curtain (at 17:35).

points (for example 80 points) and solving the force balance equations concerning outer force caused by pressure differences, the tension force of the curtain, and the force of gravity at each point.

CALCULATION RESULTS

Figures 5 and 6 demonstrate calculated vertical distributions of pressure differences and measured vertical temperature distributions. Measured pressure differences are also shown in these figures. In this calculation, it is also assumed that the opening between the curtain and the adjacent proscenium is a simple opening.

'Calculation 1' in these figures shows the results when the size of the opening is assumed not to change due to curtain movement. The calculated results correspond well with the measured results at 16:15 (Figure 5) but there are some discrepancies at 17:34, when the curtain moved dramatically (Figure 6). This indicates that the model must be modified to account for curtain movement changing the size of the opening along the edge of the curtain.

As nearly half the opening between the two zones is located over the upper region of the curtain, in the example multipurpose hall, the neutral pressure line is relatively high from the stage floor. When the curtain moves dramatically toward the seat zone, the opening along the side of the curtain becomes smaller. This leads to a

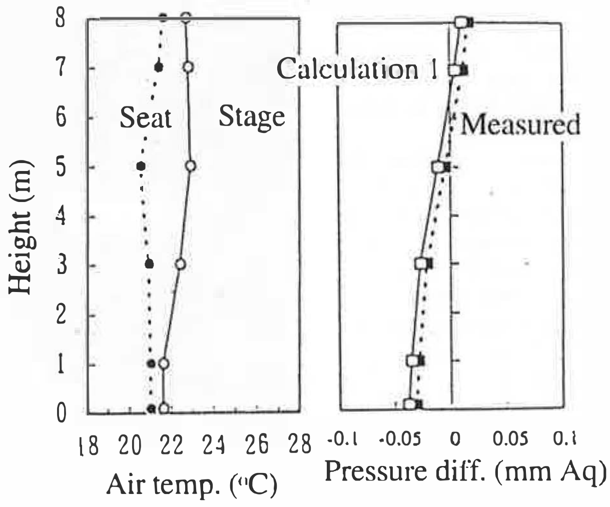

Figure 5 Profiles of measured temperature and pressure difference distributions (at 16:15).

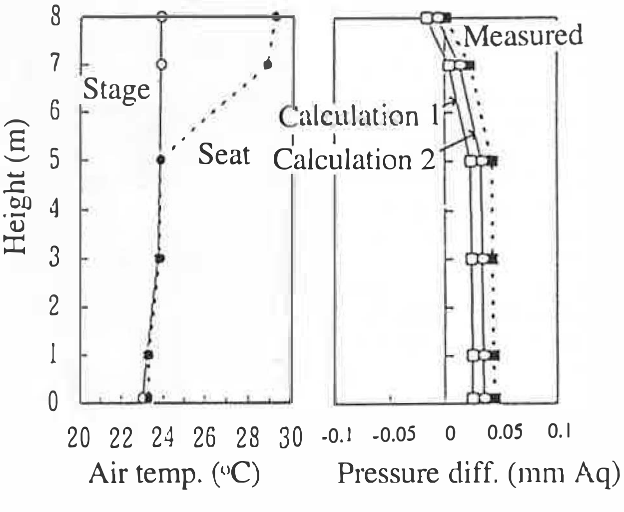

Figure 6 Profiles of measured temperature and pressure difference distributions (at 17:34).

higher neutral pressure line and much greater movement of the curtain toward the seat zone. The calculation should reflect this process.

'Calculation 2' in Figure 6 is a revised version of 'Calculation 1' and includes the effects of the decreased opening adjacent to the proscenium. The opening itself is not calculated; measured size of the opening is used in this study. The effect of the small slot created between the curtain and the stage floor at that time is neglected in the calculation. As shown in Figure 6, a calculation method that takes into account changes in the size of the opening produces more satisfactory results.

Conversely, the opening at the side becomes larger when the air temperature in the stage zone is higher than in the seat zone. The larger opening lowers the height of the neutral pressure line and prevents the curtain from moving toward the seat zone. In this case, how the size of the opening changes is not so critical for estimating curtain movement (Figure 5).

DISCUSSIONS

After the door connecting the stage area and the stair zones was opened (after 17:34 in Figure 2), the curtain moved dramatically. This movement closed the side opening adjacent to the proscenium completely and the air moved through the small slot between the inclined curtain and the stage floor. At that time, the measured pressure difference near the stage floor was larger than the estimates based on measured temperature profiles. Note that no infiltration in the hall and sufficient air balances due to HVAC systems are assumed and that the small slot under the curtain is neglected in the calculation. Therefore, the authors deduce that a large amount of air was introduced into the stage region by way of the stairs and the open door. This deduction is not completely supported by the measured results, because such a phenomenon was not observed in the presence of other conditions during the measured period, including when the door behind the stage was opened. However this result suggests the importance of architectural planning such as with respect to doors behind the stage zone opening to the outside by way of stairs, passages, and entrances.

The door was closed again after 10 minutes, but the curtain did not soon return to its former position and moved very slowly. This unlinear 'sticking effect' was partly because of friction between the curtain and the stage floor and partly because of the relatively high neutral pressure line caused by the small side opening. This indicates that the distance between the curtain and the proscenium is important and should be carefully considered in the design process.

Curtain weight has also great influence on horizontal curtain movement. Figure 7 illustrates an example estimation of

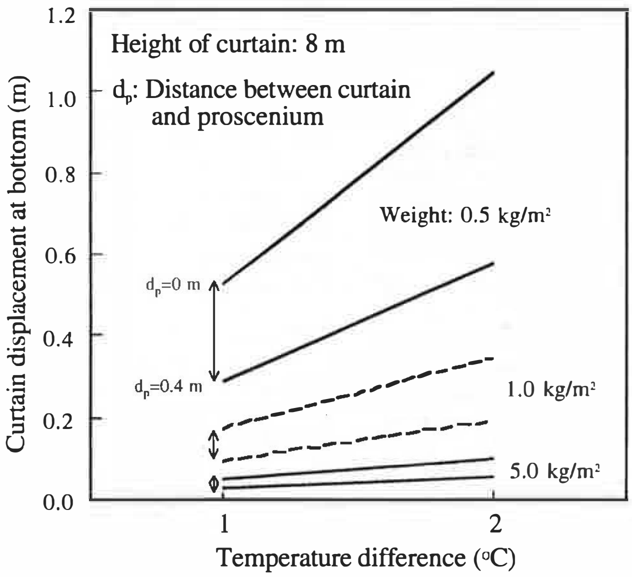

Figure 7 Temperature differences and curtain weight versus horizontal curtain displacement.

the effects of temperature differences and curtain weight on curtain displacement. This figure can be used for the design process. The smaller the distance between a curtain and a proscenium (d_p in Figure 7), the larger is the appropriate value for curtain displacement within the indicated range for each curtain weight.

DESIGN SUGGESTIONS

From the results of the present study, the following design suggestions can be derived concerning proscenium curtain movement in a multipurpose hall or an auditorium.

1. Temperature differences between front seat zones and stage zones have a large influence on curtain movement. Appropriate HVAC systems are required for both seat and stage zones. The systems must meet heating and cooling demands. Diffusers, nozzles, and exhaust outlets should be installed so as to prevent excessively large vertical temperature differences.

2. The air imbalance due to HVAC systems in both seat zones and stage zones should be kept as small as possible.

3. Operations of HVAC systems are quite important. Inappropriate target temperature settings may lead to large temperature differences between the two zones, which are the main cause of large curtain displacement. One should note that the air temperatures in seat zones during the heating period tend to rise suddenly after many audience members enter the hall. This can easily lead to large temperature differences between the two zones.

4. Architectural planning is also very important in order to avoid large curtain displacement. Doors opening to the outside by way of stairs, passages, and entrances should be avoided as far as possible. The movement of actors or other people during performances should be carefully considered in the design process. As indicated by Figure 7, the distance between the curtain and the proscenium is also important and should be carefully considered. When stage zones have exterior walls, appropriate insulation should be installed in order to decrease the K-values of the walls.

5. Curtain weight has a great impact on curtain movement. If curtain weight is high, curtain displacement will be small even if the temperature differences between the two zones are large. If curtain weight is less than 1.0 kg/m², small temperature differences may cause large curtain displacement (Figure 7). In that case, especially great care should be taken in terms of not only HVAC design but also architectural planning including spaces behind stage zones.

CONCLUSIONS

The effects on proscenium curtain movement of temperature differences between the two zones divided by the curtain were evaluated quantitatively through field measurements. The measured results show that horizontal movement of the curtain is strongly affected by air temperature differences between the two zones. The analytical network model used by the authors can reproduce these phenomena very well and can be used in the design process. The observed results strongly suggest the importance of architectural planning as well as HVAC design. Some design suggestions were also proposed based on the results of the study.

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