International Symposium on Room Air Convection and Ventilation Effectiveness
University of Tokyo, July 22 – 24, 1992

6055

BASIC STUDY ON MULTI-CEILING-SLOTS SYSTEM FOR CONTROLLING AIR MOVEMENT IN OCCUPIED SPACE

Hideki Kubota
Professor
Muroran Institute of Technology
Muroran, Hokkaido, JAPAN

Noriyuki Yamada
Graduate Student
Muroran Institute of Technology
Muroran, Hokkaido, JAPAN

ABSTRACT

For producing better uniformity of air velocity distribution in occupied space, the basic characteristics of confined plane jets discharged from the multi ceiling slots are discussed whose system has been developed for controlling air movement in occupied space. After a series of experiments using a chamber of 240x30x80 cm with a slot on one end simulating one part of the room with unit slot, typical flow pattern by Coanda effect, which should be avoided for practice, was observed on the jets from the slots whose lengths were from 80 to 70 cm (100% to 87.5% of chamber's height of 80 cm; name it as <u>slot ratio</u>). The slot lengths of 50 to 60 cm (75% to 62% of slot ratio) were found to be recommended since the slight influence of the Coanda effect fluctuated the axes of the jets and resulted the better uniformity of air velocity distribution at the occupied space.

KEY WORDS slot, plane jet, air movement, cooling, Coanda effect

INTRODUCTION

In usual air conditioning system, air temperature and humidity are the mainly controlled factors. The air movement in occupied space, however, is not considered as a factor to be controlled but as a source of discomfort so that the velocity is managed just to maintain under the permissible level, since the air supply system is not so designed that the velocity in occupied space is controllable. In addition to that, the important effect of air movement under the permissible level is not well recognized and the only few papers are found on the effect of the air movement around the threshold value. One of the author discussed and introduced a thermal sensation of "atmosphere warmth" in his previous paper (Kubota 1989), which is defined as the sensation on the atmosphere being perceived through bare face and hands, which is described as a function of the heat flux at the forehead. The human body is proved to be very sensitive to air velocity of around threshold value; for example, the atmosphere warmth at 22 °C, 10 cm/s is nearly equal to that at 25 ℃, 25 cm/s.

The multi-ceiling-slots system has been developed for controlling the velocity at the occupied space. In the system, the jets are discharged from the slots into the room vertically; the pitch (w) of the slots is recommended to be around 1/3 of the distance from the ceiling to the upper level of the occupied space; for example, the head level of the seated occupants for offices, where the jets from the slots interact each other so that the velocity distribution becomes practically uniform. The uniformity of the velocity distribution is needed not only for creating the preferable environment but also preventing the discomfort of draft.

However, we have few data on the characteristics of the multi-plane-jets which are considered to be easily affected by the Coanda effect. If we apply the slots whose lengths are the same to that of the room, the jets from the neighbouring slots induce each other due to Coanda effect and join to form a large jet, which could provide with discomfort draft and make difficult to predict air distribution.

The present paper reports, first, about the basic characteristics of the plane jet in a confined space observed by using a chamber of 80x60x240 cm with a slot at one end which simulates one section of the room air distribution in multi ceiling slots system. In addition, a slot condition is recommended for practice, based on the results obtained using an office room of 6x4x2.7 m with multi-ceiling-slots, whose conditions are selected by referring to the results obtained at the chamber tests.

CONCEPT OF THE SYSTEM

The concept of the system is presented in Figure 1 where the air conditioner controls air temperature and humidity, and the circulating fan system with multi-ceiling-slots controls air movement in occupied space.

APPARATUS AND MEASURING TECHNIQUES

In the present study, two types of experiments; (A) and (B) were performed. For test (A), a chamber of 80x60x240 cm was applied, and for the test (B), an office room of 4x6x2.7 m were used. The chamber for test (A) with a slot at one end is a model for simulating one part of the air distribution as shown in Figure 1. In the the office room on test (B) with 6-lines of slots (60 cm pitch) of 15 mm wide were mounted on the ceiling and air circulating ceiling fan was installed on a corner of the ceiling chamber.

A schematic diagram of the apparatus for test (A) is shown in Figure 2. The width of the slot was 8.8 mm. The lengths of the slot tested were 80, 70, 60, 50, 40 and 30 cm whose ratios (name it as <u>slot ratio</u> in this paper) against the chamber's height of 80 cm were 100, 87.5, 75, 62.5, 50 and 37.5 % respectively. Outlet velocity was 2.5 m/s. The velocity profiles of jets were obtained at 14 sections of Y coordinate; at the middle level of the chamber. At the Y-Z planes parallel to the end plate at X=120 cm and 140 cm, velocity distributions were measured.

The velocity was measured by an omni-directional temperature-compensated anemometer of 0.5 mm in diameter and the data were collected over a period of three minutes at each point with 0.5 second time intervals.

RESULTS AND DISCUSSIONS

Chamber Test

Figure 3 shows the contour of equal velocity on the center X-Y plane of Z=40 cm in which the trajectories of the jets are found. When the ratio of the lengths S'/S (slot ratio; S' =slot length, S= chamber height) is 87.5% or more, the jets are forced to curve to a side wall by the pressure difference between the spaces of both sides of the jet plane, which is called as Coanda effect. When the ratio is 50% or less, the jet flows straight like free jet. In the cases described above, the flows of jets are found to be stable comparing the case of jet with 62.5% slot ratio where the contour is rather complex, indicating the axis of jet to be fluctuating since the jet is affected slightly by the weak pressure difference.

These characteristics appear in the velocity contours, shown in Figure 3, at the Y-Z section of x=120 cm where corresponds to the occupied space. For the case of 87.5% slot ratio, the lines of contour seem to be parallel to each other showing the characteristics of plane jet being remained. On the other hand, when the slot ratio is 37.5%, the circular shape of contour appears which indicates the the jet being close to the round jet due to the shortness of the slot length. In contrast to these cases, when the slot ratio is 62.5%, the contour seems to be mosaic, meaning the good uniformity of velocity distribution.

Figure 5 shows the unevenness of velocities in coefficient of variations of the velocities (=standard deviation/average x100) at the plane of x=120 cm, the minimum value is found around 70% of slot ratio.

The velocity at the axis of the jet, peak velocity, in nondimensional form, are shown in Figure 7 where the jets are divided into two groups; stable and unstable jets. The peak velocity of the jets of 75 and 62.5% slot ratios are found to decrease more rapidly than others.

Office Room Test

For the test in the office, the slot ratios of 100% and 70% (=S'/S : unit slot length(S') = 64 cm, length of area for unit slot (S) = 91.5 cm) were applied, as the typical ratios which give strong and weak (preferable) influence of the Coanda effect respectively. The velocity profiles at the 5 levels measured on the center section of the room are shown in Figure 8. The trajectories of the jets on 100% slot ratio are found being curved due to the Coanda effect. As described before, the slot ratio of 100% is not recommended because the behavior of the jets affected by the Coanda effect is not predictable. In contrast to this, for 70% slot ratio which is recommended from the results on the chamber tests, the axes of jets seems to be straight except the jets near the walls, which is considered to give miner effect on velocity distribution in occupied space.

The peak velocities in nondimensional form are shown in Figure 9 from which the following relation is obtained for 70% slot ratio.

$$(U_p/U_o)(\sqrt{W/k_p h}) = \sqrt{W/x}(1-0.035(x/W)^3) \quad (1)$$

If we apply the value of x/W around 1/3, where x is the vertical distance from ceiling to the head level for seated person, the velocity distribution at this level becomes practically uniform whose value of the velocity is presented by the value of U_P in Equation 1.

CONCLUSIONS

This paper examined about an optimum condition for the slot of multi ceiling slots system which has been developed for producing uniform air velocity distribution in occupied space. After a series of experiments using a chamber (80x60x240 cm) and an office room (4x6x2.7 m), the slot ratio (=slot length/length of area for unit slot) of around 70% is recommended for better uniformity of velocity distribution at the occupied space, since the delicate influence of the Coanda effect fluctuates the axes of the jets slightly which could make better mixing of velocities at occupied space.

ACKNOWLEDGMENTS

The authors are indebted to Messrs. Y. Isomatu, K. Obara, M. Kawaoka, T. Kondo, R. Akiyama for their help.

REFERENCES

1) Kubota, H., 1981, Basic Study on Room Air Distribution-Multi-Ceiling-Slots System-, Transactions of Architectural Institute of Japan, No.310,

2) Kubota, H., 1988, Artificially Produced Mild Breeze for a Healthy Indoor Building, Proceedings of Healthy Buildings '88,

3) Kubota, H., 1989, Effect of the room air movement on the atmospheric thermal sensation, Summaries of Technical Papers of Annual Meeting, Architectural Institute of Japan

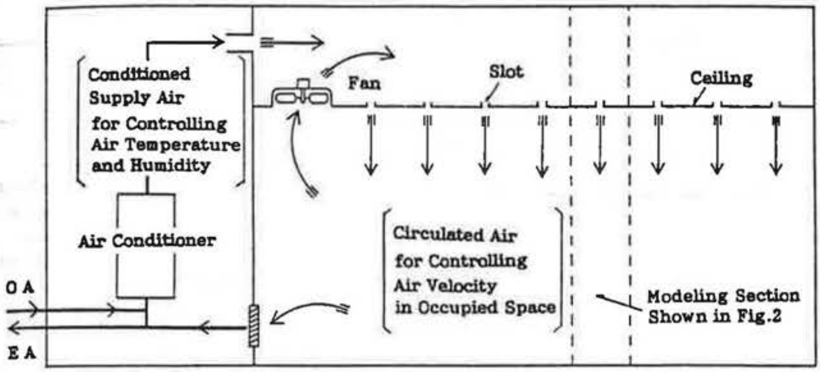

Figure 1 Conceptive View of Multi-Ceiling-Slots Air Supply System

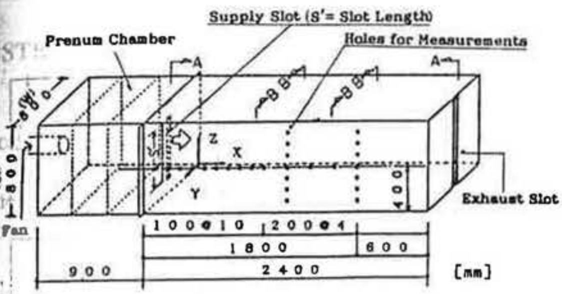

Figure 2 Model of Apparatus

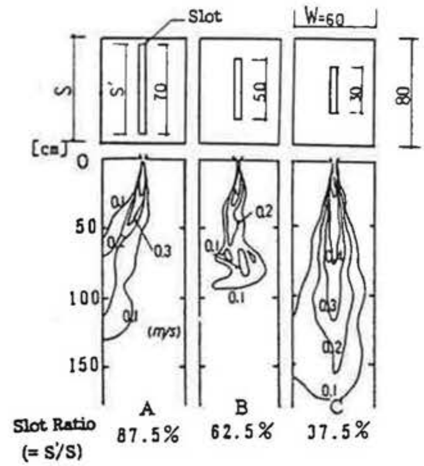

Figure 3 Velocity Contour at A-A Section(Center)

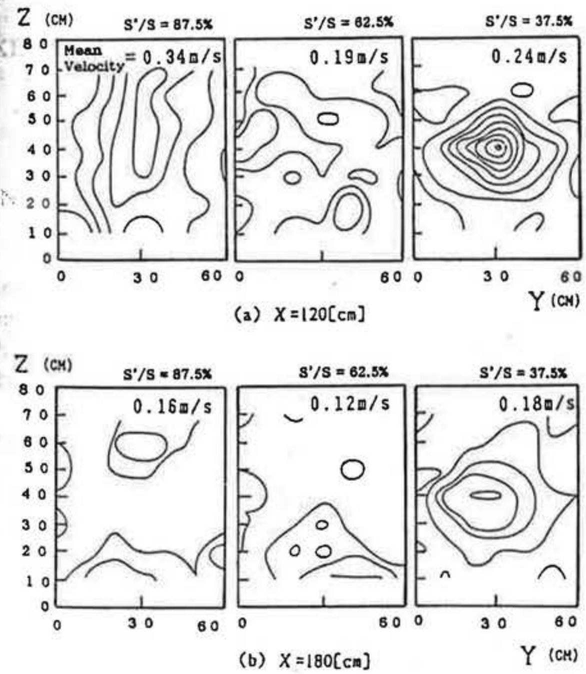

Figure 4 Velocity Contour at B-B Section

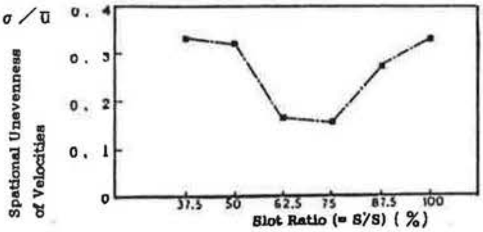

Figure 5 Slot Ratio vs Spational Unevenness of Velocities

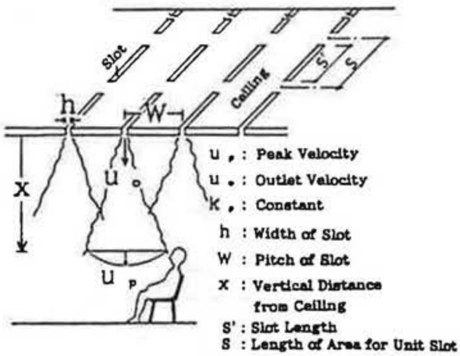

Figure 6 Nomenclature

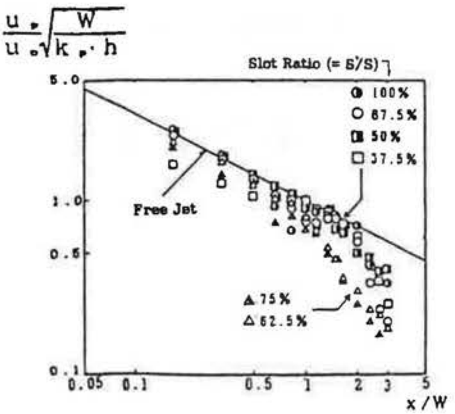

Figure 7 Decrease of Peak Velocities along Vertical Distance in Model Chamber

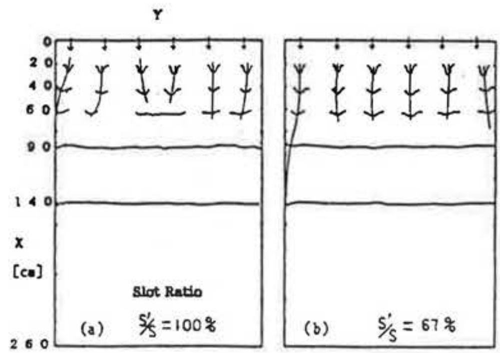

Figure 8 Trajectries of Jets (Life-Size Laboratory)

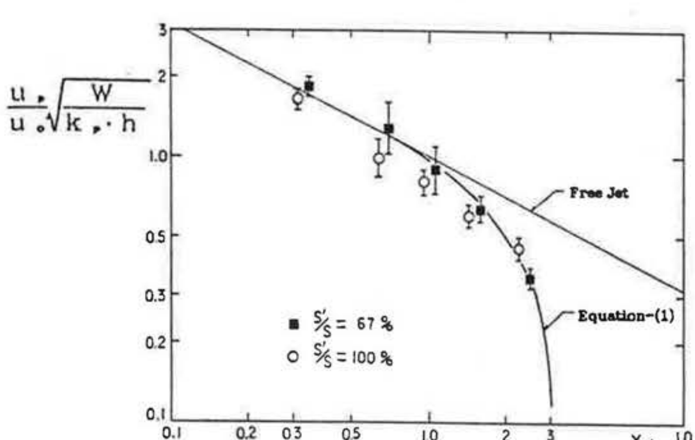

Figure 9 Decrease of Peak Velocities along Vertical Distance in Life-Size Laboratory