 #5868

CORRELATION OF RESIDUAL VELOCITY WITH THROW AND TERMINAL VELOCITY FROM A LOUVER-FACED UNIDIRECTIONAL DIFFUSER

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ABSTRACT

The central thesis of this paper is the stated importance of predicting the residual air velocity in the microenvironment of an occupant served by a ceiling-mounted air diffuser obtaining horizontal airflow along the ceiling. Experimental data are presented for a unidirectional, louver-faced, ceiling-mounted diffuser supplying air to a room under isothermal test conditions. Test data correlating residual air velocity with terminal air velocity are given for five different arrangements of furnishings in the zone of occupancy that correspond to typical conditions encountered in practice.

The correlation of residual air velocity with terminal air velocity corresponds with a new definition of throw. *Throw is defined as the horizontal distance from the ceiling diffuser to a wall that intercepts the air trajectory, wherein the terminal air velocity is measured at the wall 5 feet (1.52 m) above the floor.*

At any specified value of residual velocity in the zone of occupancy, it is demonstrated that the corresponding value of terminal velocity is a variable with respect to the throw of the diffuser. For a relatively short throw, such as 5 ft (1.52 m), the allowable terminal velocity is in excess of 100 fpm (0.51 m/s) and approaches 200 fpm (1.02 m/s), depending upon the arrangement of furnishings in the room. At throw values in excess of 20 ft (6.1 m), the allowable terminal velocity is only marginally greater than the specified value of residual velocity in the zone of occupancy.

Should diffuser throw versus terminal velocity on the wall be available, the data presented in this paper would enable a designer of room air distribution systems to quantify residual air motion in the occupied zone. A predictable residual air velocity could enhance the purging of bioemissions and control of the temperature field in the microenvironment. In a variable-air-volume system, the lower limit of air supply could, effectively, be specified.

INTRODUCTION

Overview

One of the purposes of room air distribution is to cause air movement about the occupant so as to purge bioemissions and to offset sensible and latent heat loads emanating in the microenvironmemt of the occupant.

If the direct flow of conditioned air to the microenvironment of an occupant effects less than the above-stated ideal, one can postulate situations wherein the occupant would be in a region characterized by large-scale eddies or with no air movement at all. These two unacceptable conditions often arise in variable-air-volume (VAV) systems of air distribution. VAV, by definition, is a process wherein the rate of air delivery is reduced from a design/maximum value in response to a diminished thermal load. We may, therefore, define a marginal rate of air delivery as one that produces unacceptable conditions in the microenvironment of an occupant at the reduced flow.

This paper addresses the need to characterize in a quantifiable way adequate, marginal, or unacceptable air conditions utilizing residual air velocity or speed in the microenvironment.

Residual Air Velocity, *Vr*

Residual air velocity is the air velocity at any defined location in the zone of occupancy. The specification of an upper limit for residual air velocity is given as 50 fpm (0.25 m/s) in ASHRAE (1989) and as high as 70 fpm (0.36 m/s) in evaluating the air diffusion performance index (ADPI) (ADC 1984; ASHRAE 1990). It is important to note that the specification on an upper value for residual air velocity is a *limiting* condition and any specific value lower than the upper limiting value is not specified.

Critical Subzones

A critical subzone would be a location in the microenvironment of an occupant where a high residual air velocity would be characterized as a draft or where a low, prescribed value of residual air velocity would be required.

In defining a critical subzone, it has been assumed that room air distribution would be effected by a ceiling-mounted diffuser wherein both the flow of the original, primary, air supply and the entrained air supply would maintain contact with the ceiling. Should a sufficient quantity of air be supplied to maintain flow along the

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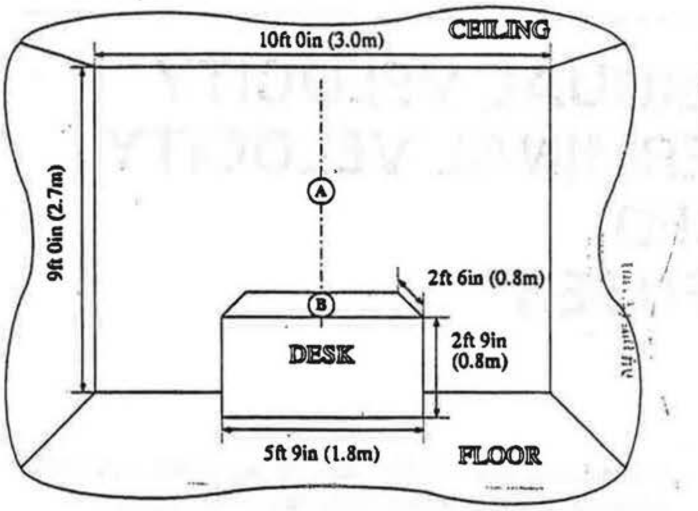

Figure 1 *Case No. I, desk centered and flush against far wall; Ⓐ 5 ft (1.52 m) above floor on far wall where maximum terminal velocity is found, Ⓑ on top-front of desk in line with Ⓐ.*

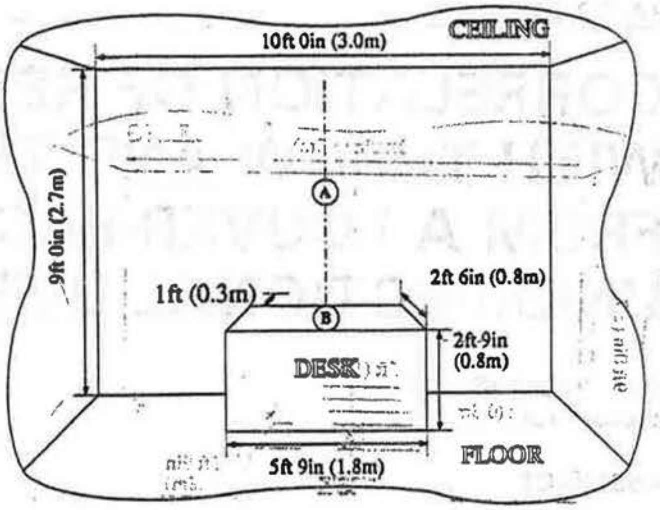

Figure 2 *Case No. II, desk centered on far wall, 1 ft (0.3 m) from wall; Ⓐ 5 ft (1.52 m) above floor on far wall where maximum terminal velocity is found, Ⓑ on top-front of desk in line with Ⓐ.*

ceiling, the airstream will then continue along the surface of any intercepting barrier, such as a wall. This phenomenon is well recognized and reported extensively in the technical literature (Koestel and Tuve 1955; Reinmann et al. 1959) and confirmed in the exercises in mathematical modeling (Nielsen et al. 1978; Fang and Grot 1990).

Estimating a range of residual air velocity in the microenvironment would be, in the author's opinion, a more reliable quantifier of room air distribution than reliance on common "rules of thumb," such as rates of air change, flow rate per unit of floor area, etc.

A specific, critical, subzone in the microenvironment, point B, may be designated as indicated in Figures 1 through 5, thus defining the critical subzone where an upper and lower limit of the value of the residual velocity (*Vr*) could be specified for the microenvironment. Point B in Figures 1 through 5 defines the location of the critical subzone in Cases I through V, respectively.

Terminal Air Velocity, *Vt*

After many decades of research on air jets and ceiling diffusers, culminating in *ASHRAE Standard 70-72* (ASHRAE 1972) and the ADC test code (ADC 1984), throw and terminal velocity (typically at the ceiling) have become the parameters used to characterize diffuser performance. In this paper, the maximum velocity of the air supplied at a location 5-ft above the floor is the reference velocity shown in Figure 6 and is defined by the parameters indicated therein. Typically, the maximum value of *Vt* occurs within 1 in. (2.5 cm) of the surface of the wall.

METHODOLOGY

Basis of Correlating *Vr* vs. *Vt*

In an earlier investigation (Yousoufian 1992) independent of the present effort, it was established that an

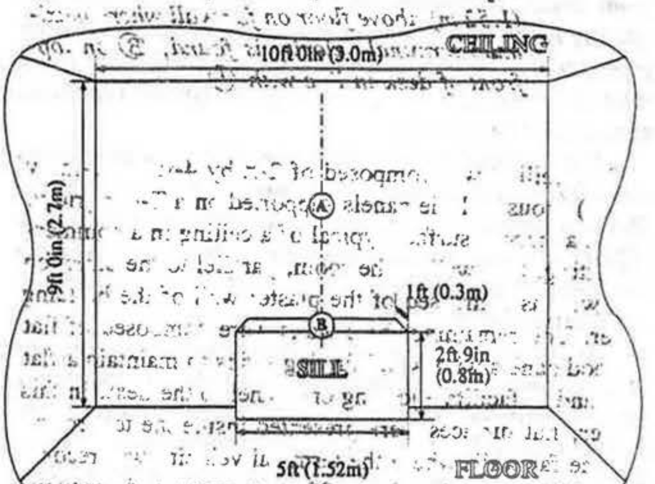

Figure 3 *Case No. III, window sill centered on far wall; Ⓐ 5 ft (1.52 m) above floor on far wall where maximum terminal velocity is found, Ⓑ on top-front of sill in line with Ⓐ.*

empirical correlation of *Vt* existed, as defined in Figure 6, as a function of the rate of airflow from a louver-faced diffuser. It was assumed that a value of *Vr* over a range of 50 fpm to 75 fpm (0.25 m/s to 0.38 m/s) would need to be correlated with a corresponding value of *Vt*, which would be of greater magnitude yet to be determined. It was left to the results of the experimental investigation to ascertain the physical parameters that would affect the correlation of *Vt* vs. *Vr*.

Test Room

The room into which air was introduced from a ceiling diffuser to record a terminal velocity on the far wall is shown schematically in Figure 6.

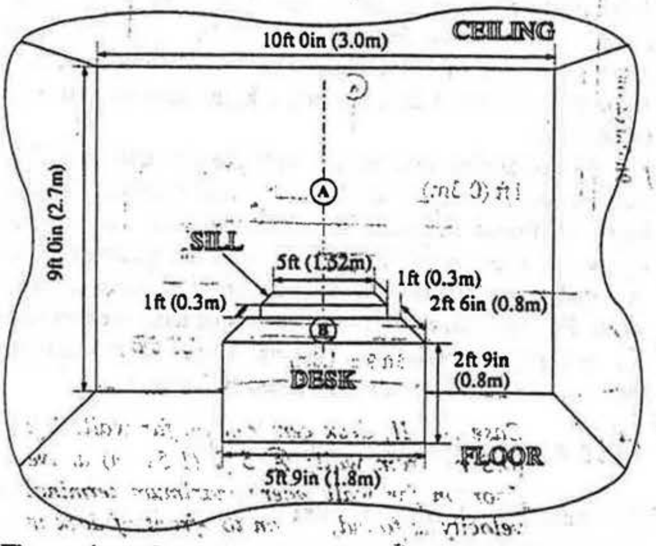

Figure 4 *Case No. IV, desk and window sill centered on far wall, desk 1 ft (0.3 m) from sill; Ⓐ 5 ft (1.52 m) above floor on far wall where maximum terminal velocity is found, Ⓑ on top-front of desk in line with Ⓐ.*

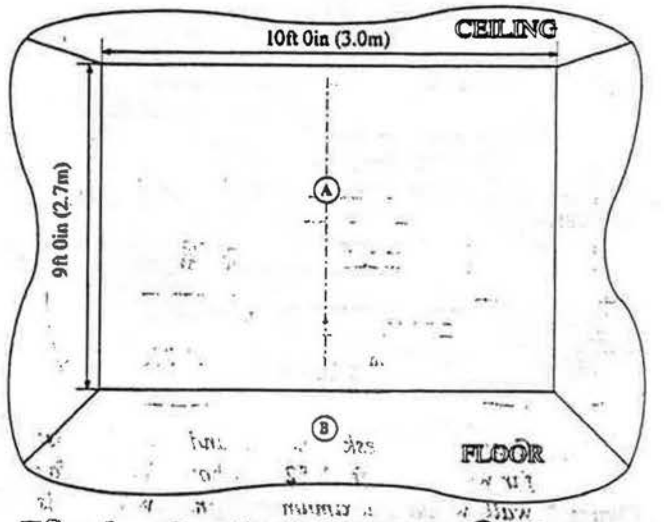

Figure 5 *Case No. V, bare room; Ⓐ 5 ft (1.52 m) above floor on far wall where maximum terminal velocity is found, Ⓑ on floor 2.5 ft (0.8 m) from far wall in line with Ⓐ.*

The ceiling was composed of 2-ft by 4-ft (0.61-m by 1.22-m) acoustical tile panels supported on a T-bar grid to present a smooth surface typical of a ceiling in a commercial setting. One wall of the room, parallel to the direction of flow, was composed of the plaster wall of the building proper. The remaining three walls were composed of flat plywood panels with wood furring strips to maintain a flat plane and to facilitate joining one panel to the next. In this manner, flat surfaces were presented inside the test room.

The far wall, where the terminal velocity was recorded, could be moved as far as 20 ft from the diffuser while maintaining the integrity of the six boundaries of the room. The various vertical and horizontal joints formed by butting the walls and ceiling against one another were not sealed. The ceiling did, however, rest securely on the walls, especially the far wall, which defined the extent of the throw. Furthermore, the ceiling-wall joint at the far wall was inspected visually and by means of a smoke gun to ensure no measurable airflow above the location of V_t. All tests were conducted in a room with a fixed ceiling height of 9 ft (2.74 m) and a width of 10 ft (3.0 m). As indicated in Figure 6, air supplied to the room was returned through an open doorway adjacent to the rear wall and near the ceiling-mounted air diffuser.

Air Diffusers and Air Supply System

The source of the primary air supply was introduced into the room through a unidirectional louver-faced ceiling diffuser. A fan, calibrated for the rate of airflow, supplied a large duct, as shown in Figure 7, from which air was issued through a louver-faced diffuser mounted flush in the ceiling.

The following diffuser sizes were employed:

Throw, ft (m)	Diffuser Size (in.)	(cm)
5 (1.52)	3x12	(7.6x30.5)
10 (3.05)	3x24	(7.6x61)
15 (4.57)	3x48	(7.x122)
	6x24	(15.2x76.2)
20 (6.10)	6x30	(15.2x61)

A major effort was devoted to equalizing the air velocity using an adjustable multiple-vaned grid to equalize the rate of airflow over the neck area of the diffuser. A hot-wire anemometer was employed to measure air velocities issuing from the louvers of the diffuser, and the vanes of the grid were adjusted to correct imbalances as they were discovered.

The rate of airflow issuing from a diffuser was controlled by a movable scroll that formed the inner boundary of the volute of the fan vent set. In this manner,

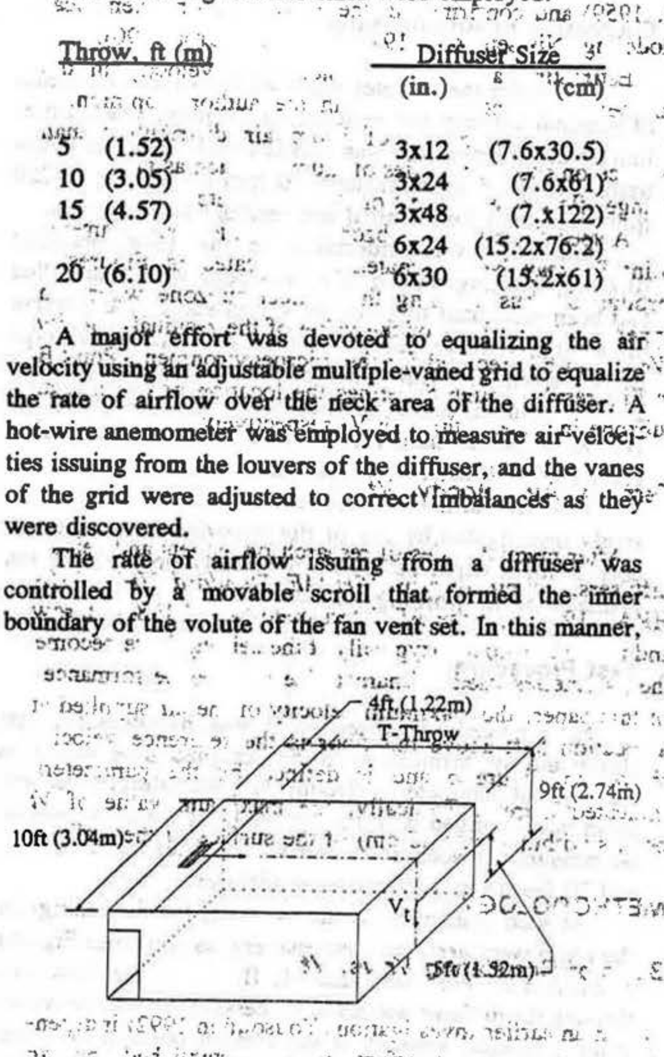

Figure 6 *Schematic design of physical model.*

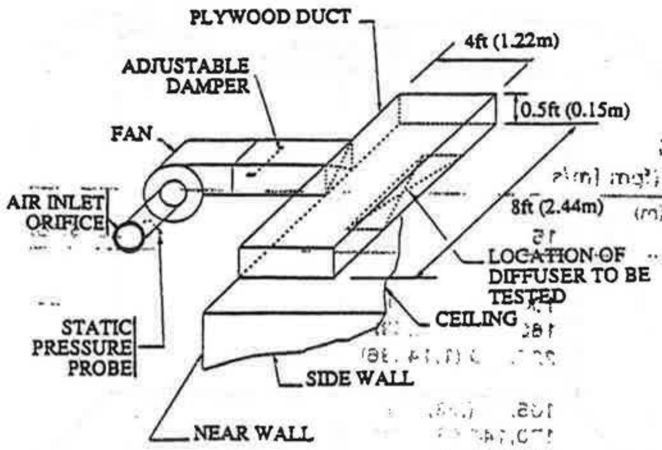

Figure 7 Fan and ductwork arrangement.

the airflow rate could be set to a low value and, if possible, at or somewhat lower than 50 fpm (0.25 m/s) at the point where the maximum residual air velocity, *Vr*, was to be recorded.

Calibration of Anemometer

A hot-wire anemometer was used for all measurements of terminal velocity and residual air velocity. The calibration of the anemometer was verified daily over the entire usable range of approximately 50 fpm (0.25 m/s) to 250 fpm (1.27 m/s) for terminal and residual air velocities.

Calibration was undertaken in the 18-in.-diameter (0.46 m) working section of a low-speed wind tunnel that had been calibrated for flow by a pitot-static tube traverse of a high-velocity section using a Prandtl, null-type micromanometer with pure methyl alcohol. Inches of alcohol column could be measured to an accuracy of 1/1000 in. (0.025 mm) for the fluid, which had a specific gravity of 0.79 to 0.80 at test conditions.

Velocity variation at the test section had been extensively investigated by use of the hot-wire anemometer to correct for a slight deviation in velocity profile over the diameter of the working section.

Test Procedure

In a preceding subsection it was hypothesized that throw and the furnishings in the occupied zone would be the physical parameters affecting *Vr*. Accordingly, the test room was arranged with the far wall, on which *Vt* was to be measured, placed at successive distances of 5, 10, 15, and 20 feet from a louver-faced diffuser.

At each placement of the far wall, the furnishings in the room were arranged successively, as shown in Figures 1 through 5. For each case (I, II, . . .) the flow rate through the diffuser was set at successive values that would yield a residual velocity at the control point at or lower than about 50 fpm (0.25 m/s) to values of *Vr* approaching 100 fpm (0.51 m/s) for each case. Values of *Vt*, *Vr*, and throw were recorded for each case (I, II, . . .). The flow rate to the neck of the diffuser was varied between a low value of 200 fpm (1.02 m/s) and a high value of 800 fpm (4.06 m/s).

As the testing progressed with the far wall at 5 feet and on, successively, to 20 feet, it became necessary to use larger diffusers in order to obtain the required longer throw. At a throw of 15 ft (4.57 m), the experiment was repeated using diffusers of two different physical dimensions. For each case there are two sets of data corresponding to a given correlation of *Vr* vs. *Vt* for 15-ft (4.51-m) throw. All of the test data are listed in Table 1.

TEST RESULTS AND CONCLUSIONS

Procedure to Normalize Test Data

The raw test data of *Vr* vs. *Vt* were plotted on rectangular coordinates for each value of throw, as shown (in normalized curves) in Figure 8. Based on the shape of the resulting curves, it was assumed to have the form

$$Vr = a\ Vt^n$$

and, accordingly, would result in a straight line on log-log graph paper. Furthermore, it is reasonable to assume that at very large values of *Vr* and *Vt*, considering the close physical proximity of *Vr* and *Vt*, the two values would be nearly the same. This is evident in Figure 11 at a throw of 30 ft (9 m), wherein *Vt* is seen to be rapidly converging to the corresponding value of *Vr*.

The actual test data had a lower limit of *Vr* of 25 to 50 fpm (0.13 to 0.25 m/s) and an upper limit of 200 fpm (1.0 m/s). Using two-cycle log-log paper, the coordinates were designated having a scale of 10 - 100 - 1,000 fpm (0.05 - 0.5 - 5.1 m/s). The coordinate *Vt* = *Vr* = 1,000 fpm (5.1 m/s) was assumed to be sufficiently large to correspond to a coincidence of *Vr* and *Vt* as postulated above. Accordingly, in the normalization of the test data, each case proceeded in the following manner:

1. On two-cycle log-log graph paper, the raw data of *Vt* vs. *Vr* were plotted and, using *Vt* = *Vr* = 1,000 fpm (5.1 m/s) as a focal point, radial lines were drawn to intercept the test data by a visual method of averages (illustrated for Case I: Figure 9).
2. Using the preceding curves generated by the test data, at successive constant values of *Vr* = 30 fpm (0.15 m/s), 50 fpm (0.25 m/s), 70 fpm (0.36 m/s), 100 fpm (0.51 m/s), and 180 fpm (0.91 m/s), values of *T* and *Vt* were noted and plotted on log-log graph paper. In drawing the family of curves, it was postulated that all values of *Vr* would converge to a common value of *T* at *Vt* = 1,000 fpm (5.1 m/s) (illustrated for Case I: Figure 10).
3. Using the curves generated in the preceding plot of log

TABLE 1
Test Data—*Vt, Vr* (fpm [m/s])

Throw—ft (m)			
5 (1.52)	10 (3.05)	15 (4.57)	20 (6.10)
CASE I			
100,25 (.51,.13) 155,60 (.79,.30)	105,55 (.53,.28) 165,100 (.84,.51) 205,125 (1.04,.64)	100,70 (.51,.36) 160,115 (.81,.58) 225,170 (1.14,.86) 105,70 (.53,.36) 170,140 (.86,.71) 215,180 (1.09,.91)	65,50 (.33,.25)
CASE II			
155,45 (.79,.23) 200,75 (1.02,.38)	100,45 (.51,.23) 165,90 (.92,.46) 225,155 (1.14,.79)	100,60 (.51,.30) 160,90 (.81,.46) 225,165 (1.14,.84) 105,60 (.53,.30) 170,130 (.86,.66) 215,165 (1.09,.84)	70,50 (.36,.25)
CASE III			
100,40 (.51,.20) 155,65 (.79,.33)	105,60 (.53,.30) 160,105 (.81,.53) 220,155 (1.12,.79)	105,75 (.53,.38) 165,130 (.84,.66) 225,175 (1.14,.89) 110,75 (.56,.38) 165,130 (.92,.66) 230,180 (1.17,.91)	60,50 (.30,.25)
CASE IV			
200,50 (1.02,.25)	105,35 (.53,.18) 160,75 (.81,.39) 225,130 (1.14,.66)	110,65 (.59,.33) 160,115 (.81,.58) 225,170 (1.14,.86) 105,60 (.53,.30) 160,115 (.81,.58) 225,170 (1.14,.86)	75,50 (.38,.25)
CASE V			
155,35 (.79,.18) 200,65 (1.02,.33)	100,40 (.51,.20) 165,70 (.84,.36) 225,125 (1.14,.64)	105,60 (.53,.30) 160,95 (.81,.48) 225,130 (1.14,.66) 100,60 (.51,.30) 155,100 (.79,.51) 225,140 (1.14,.71)	75,50 (.38,.25)
Diffuser Neck Sizes Used for Data Obtained at Each Throw, in. (cm)			
3 × 12 (7.6 × 30.5)	3 × 24 (7.6 × 61.0)	6 × 24 (15.2 × 61.0) 3 × 48 (7.6 × 121.9)	6 × 30 (15.2 × 76.2)

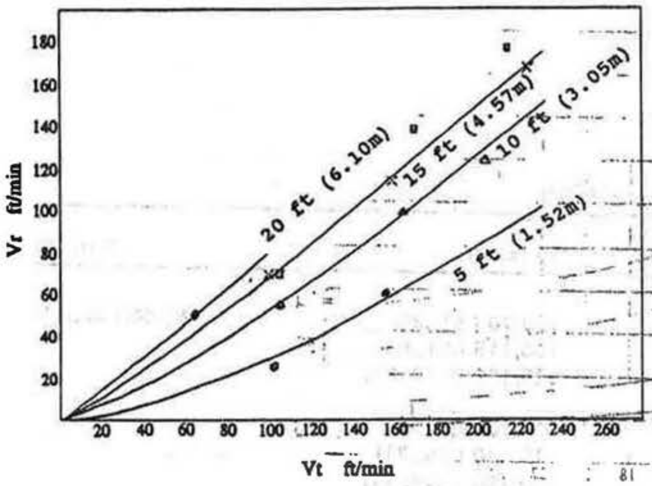

Figure 8 ***Case I.***

Vt vs. log *T* and using *Vr* = 15 (0.07), 25 (0.13), 50 (0.25), and 70 (0.36) fpm (m/s) as an independent parameter, a family of curves of *T* vs. *Vt* was generated on rectilinear coordinates. As an illustration, these curves appear in Figure 11 for Case I.

CONCLUSIONS

The final representation of the test data, in a normalized curve of *T* vs. *Vt* for each of the five cases, is shown in Figure 12. Using Case I as an example, Figure 11 contains a family of curves of *T* vs. *Vt* for various values of *Vr* to demonstrate an amplification of the test data. The contents of these two figures are discussed below:

1. It is evident (and logical in retrospect) that the allowable terminal velocity would be a *variable* with respect to throw to achieve a specific residual velocity in the microenvironment.
2. For any given value of residual velocity, the terminal velocity rapidly approaches the value of the residual velocity as the throw exceeds 30 ft (9.1 m), as seen in Figure 11.

Based on a thoughtful analysis of the data arising from these limited tests, one could postulate the following, subject to more extensive testing and/or computational analysis:

3. Having correlated *Vr* as a function of *Vt* and *T*, the empirical curves of the various cases may apply to any unidirectional louver-faced diffuser irrespective of design variations, so long as the maximum value of *Vt* coincides with both the geometric centerline of the diffuser and the actual flow path.
4. Inasmuch as *Vt* is located 5 ft (1.52 m) from the floor, if a ceiling height greater than 9 ft (2.84 m) were employed, the value of *Vt* correlated in the curves

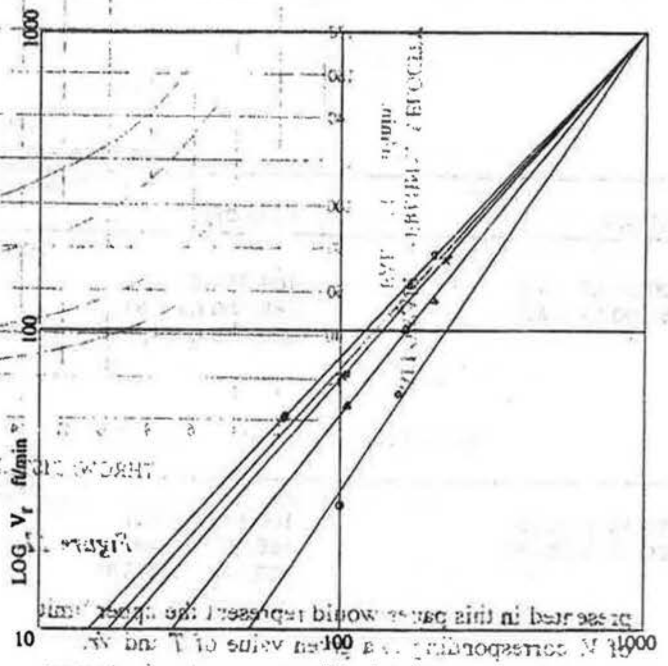

Figure 9 ***Case I.***

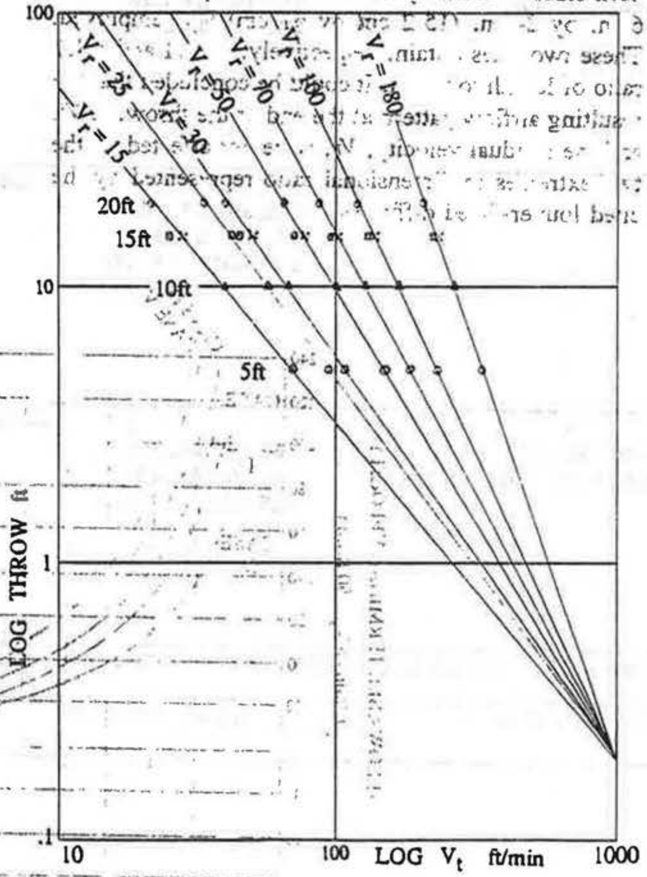

Figure 10 ***Case I.***

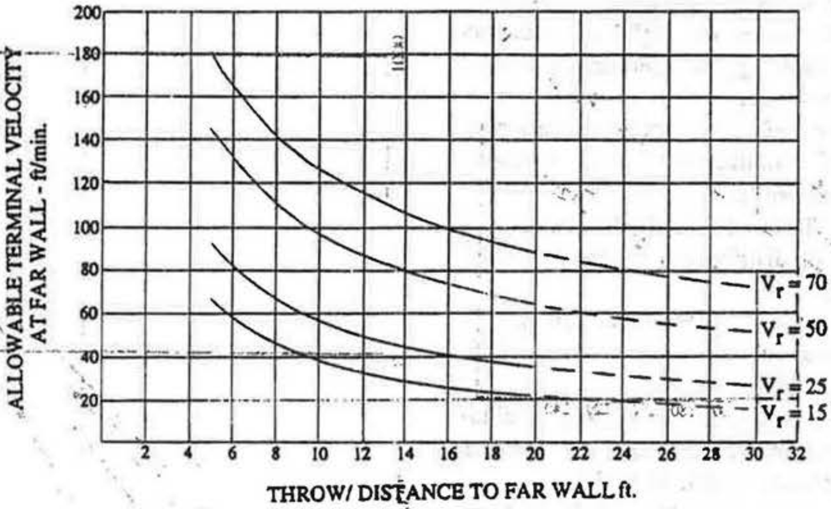

Figure 11 Case I.

presented in this paper would represent the upper limit of *Vt* corresponding to a given value of *T* and *Vr*.

5. For each case, at 15 ft (4.57 m), two sets of data were obtained wherein the identical rate of airflow was set for each pair of data. In each case, a diffuser with neck sizes of 3 in. by 48 in. (7/6 cm by 122 cm) and 6 in. by 24 in. (15.2 cm by 61 cm) was employed. These two sizes obtain, respectively, a 16:1 and a 4:1 ratio of length to width. It could be concluded that the resulting airflow pattern at the end of the throw, at *Vt*, and the residual velocity, *Vr*, were not affected by the two extremes in dimensional ratio represented by the cited louver-faced diffusers.

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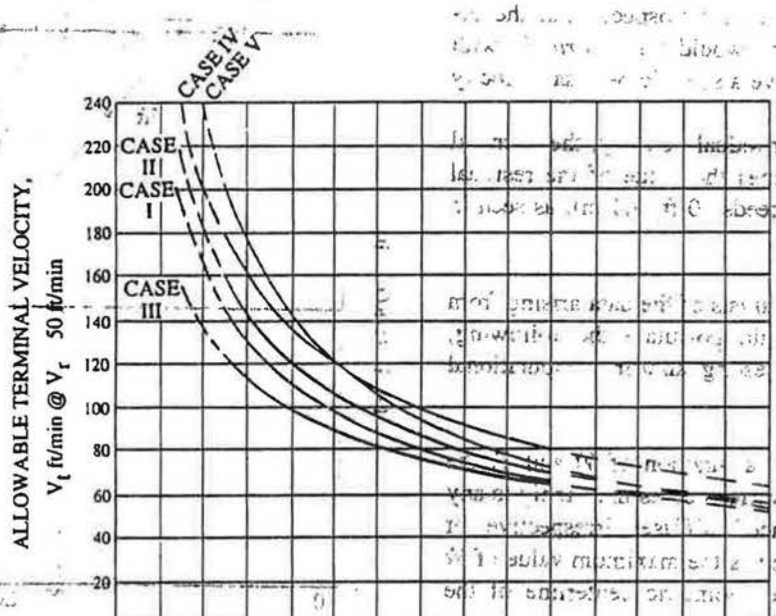

Figure 12 Cases I-V.

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