United States Patent [19]

Horneff et al.

[11] **3,824,909**

[45] **July 23, 1974**

[54] **DISTRIBUTION SYSTEM FOR CLEAN ROOMS**

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[73] Assignee: **CGT Corp.**, West Conshohocken, Pa.

[22] Filed: **Nov. 24, 1972**

[21] Appl. No.: **309,267**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 26,584, April 8, 1970, abandoned.

[52] **U.S. Cl.** ..... **98/40 C**, 98/40 D

[51] **Int. Cl.** **F24f 13/08**

[58] **Field of Search** ..... 98/40 D, 40 K, 40 C, 32, 98/33 R, 115; 55/DIG. 29

[56] **References Cited**

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2,291,220	7/1942	Germonprez	98/33 R
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FOREIGN PATENTS OR APPLICATIONS

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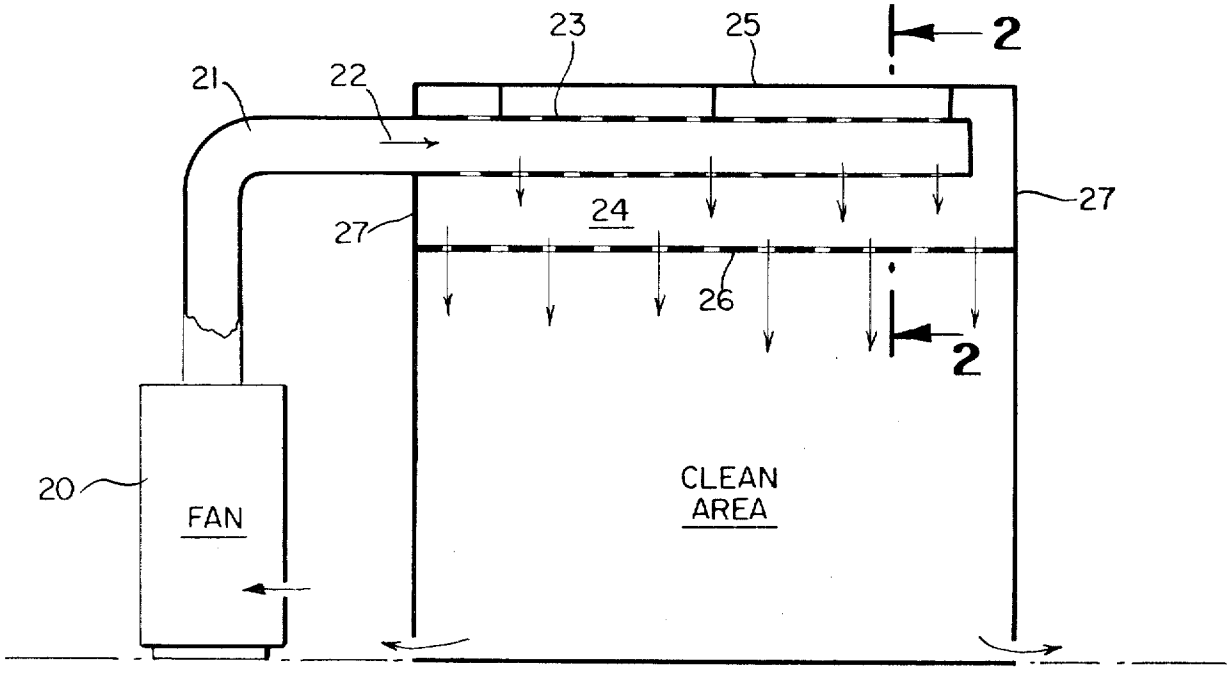
[57] **ABSTRACT**

A system for providing a uniform mass air displacement, commonly called laminar flow, at high flow rates to occupied rooms is disclosed comprising a rigid plenum chamber located at the top of a room, having a rigid perforated bottom enclosing side of the plenum forming the ceiling of the rooms, and a plurality of distribution ducts into which air is introduced from an external fan and which provide a first stage of conversion from velocity pressure to static pressure. The distribution ducts may be singular ducts or a combination of one duct within another, the ducts being perforated in varying degrees.

14 Claims, 11 Drawing Figures



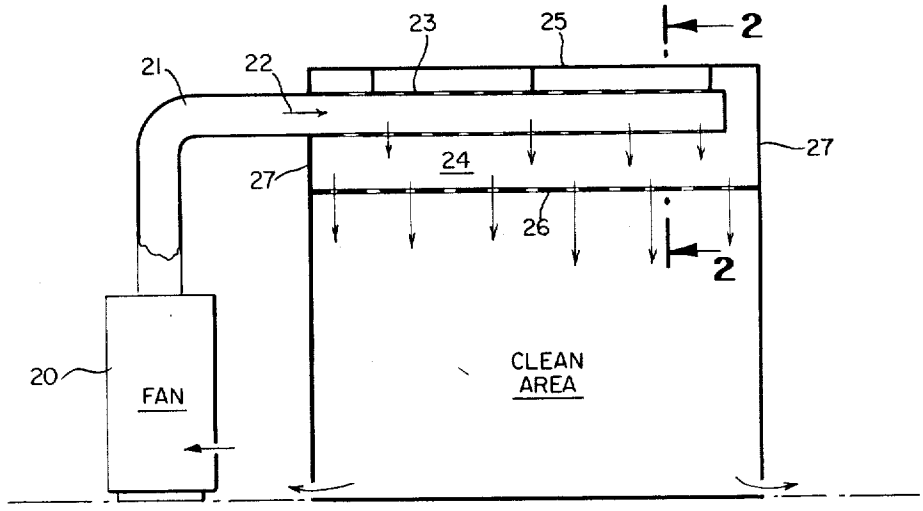


Fig. 1

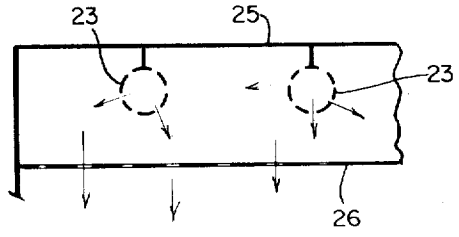


Fig. 2

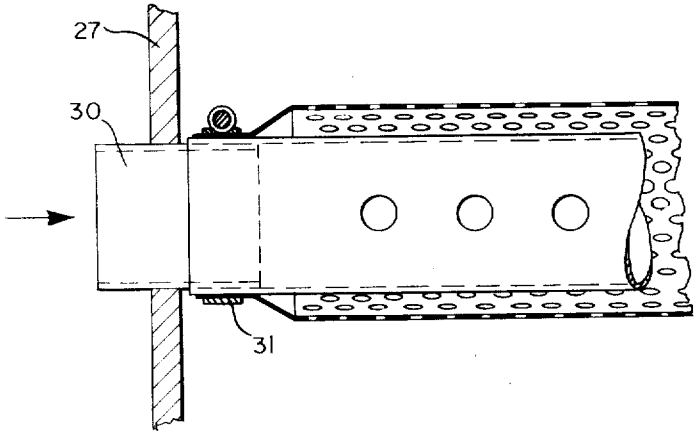


Fig. 4

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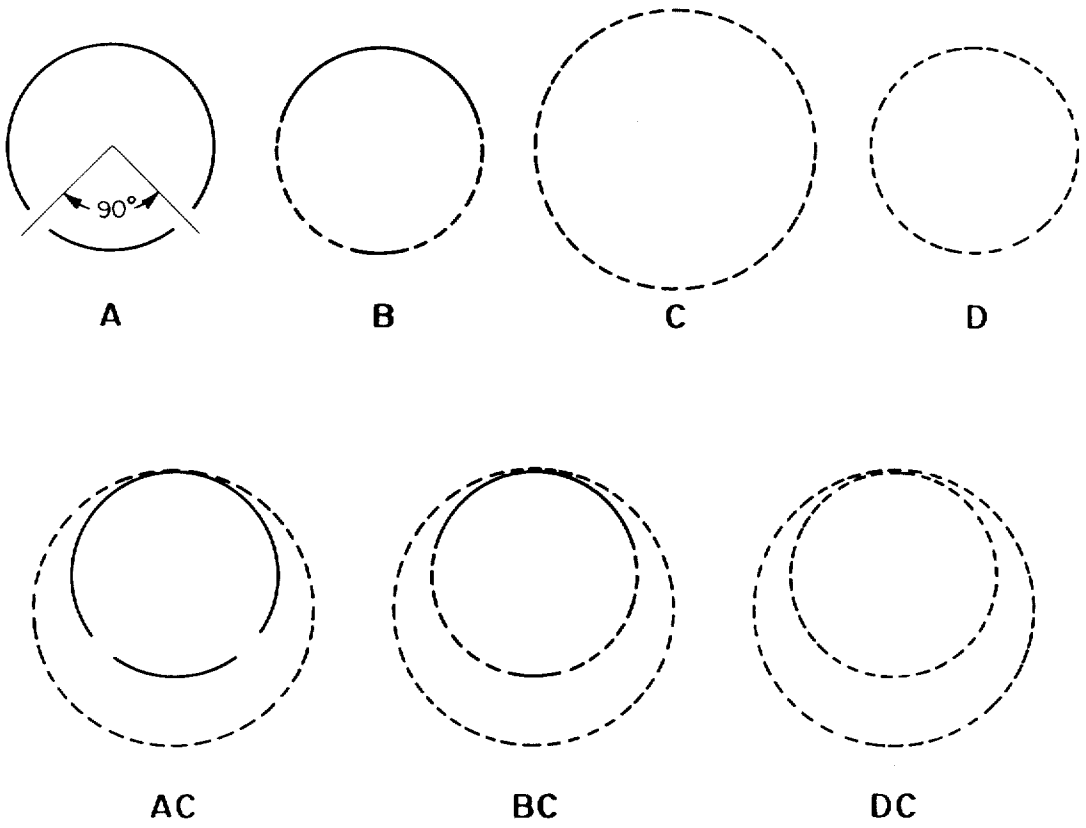

Fig. 3

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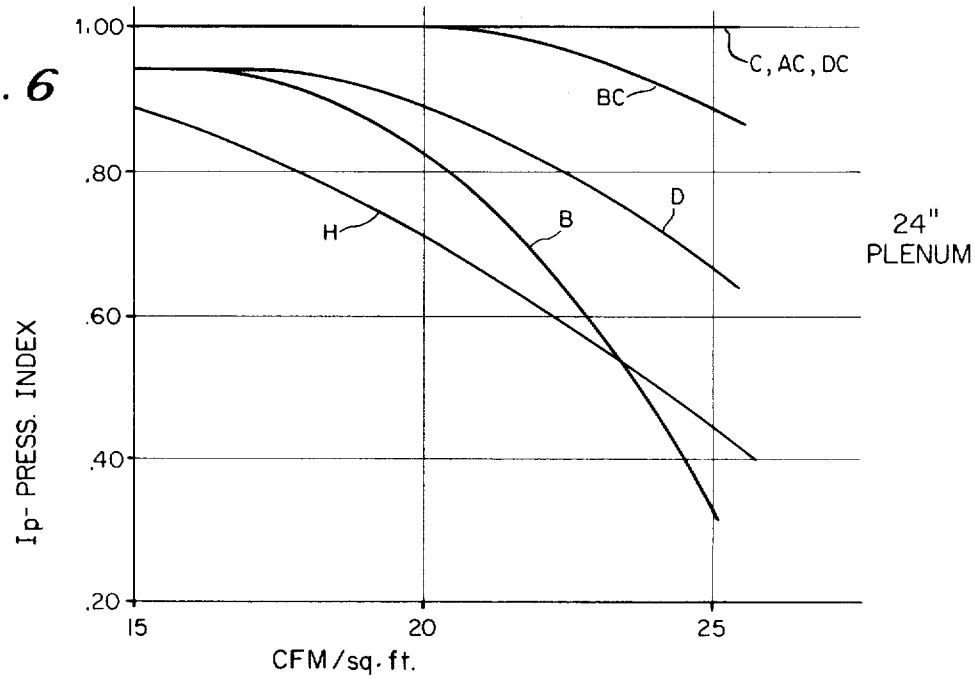
Fig. 6



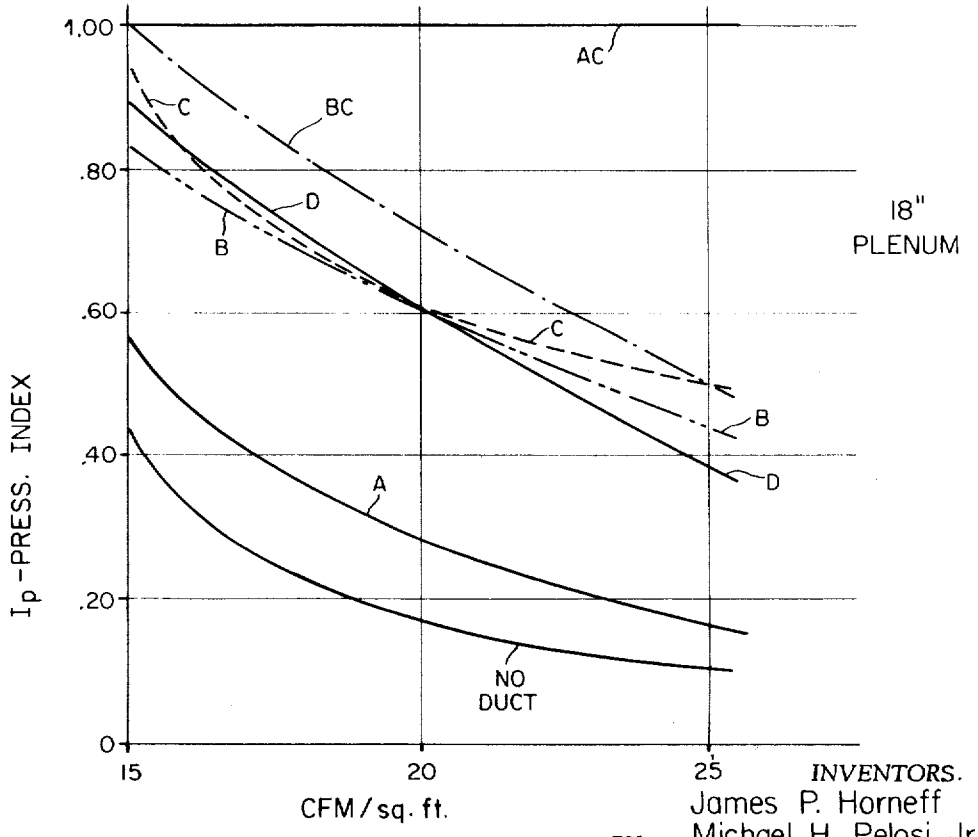


Fig. 5

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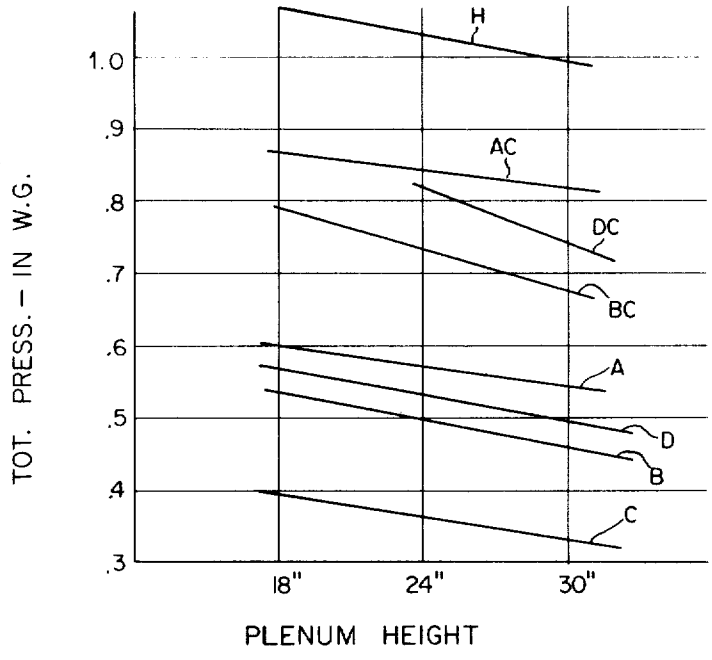

Fig. 8

20 CFM / sq. ft.

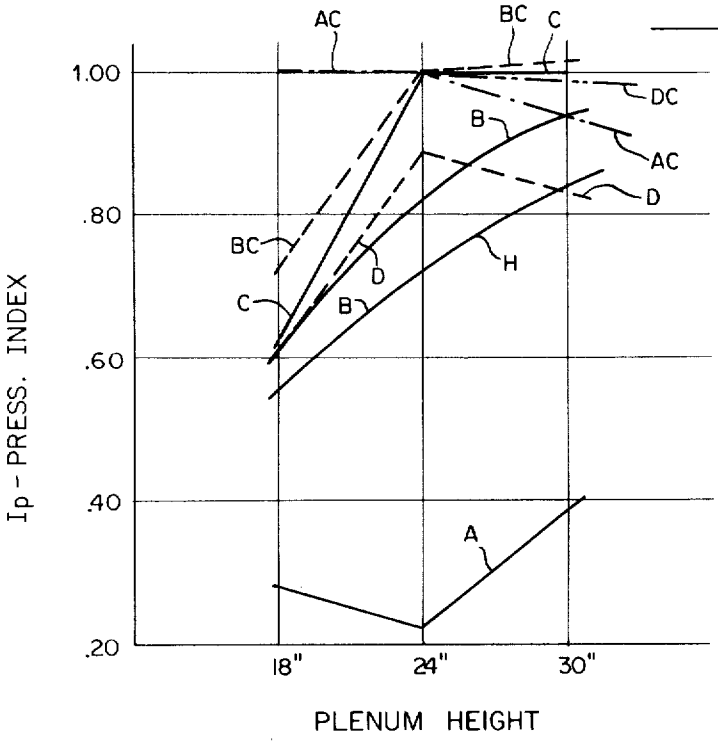

Fig. 7

20 CFM / sq. ft.

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Fig. 9

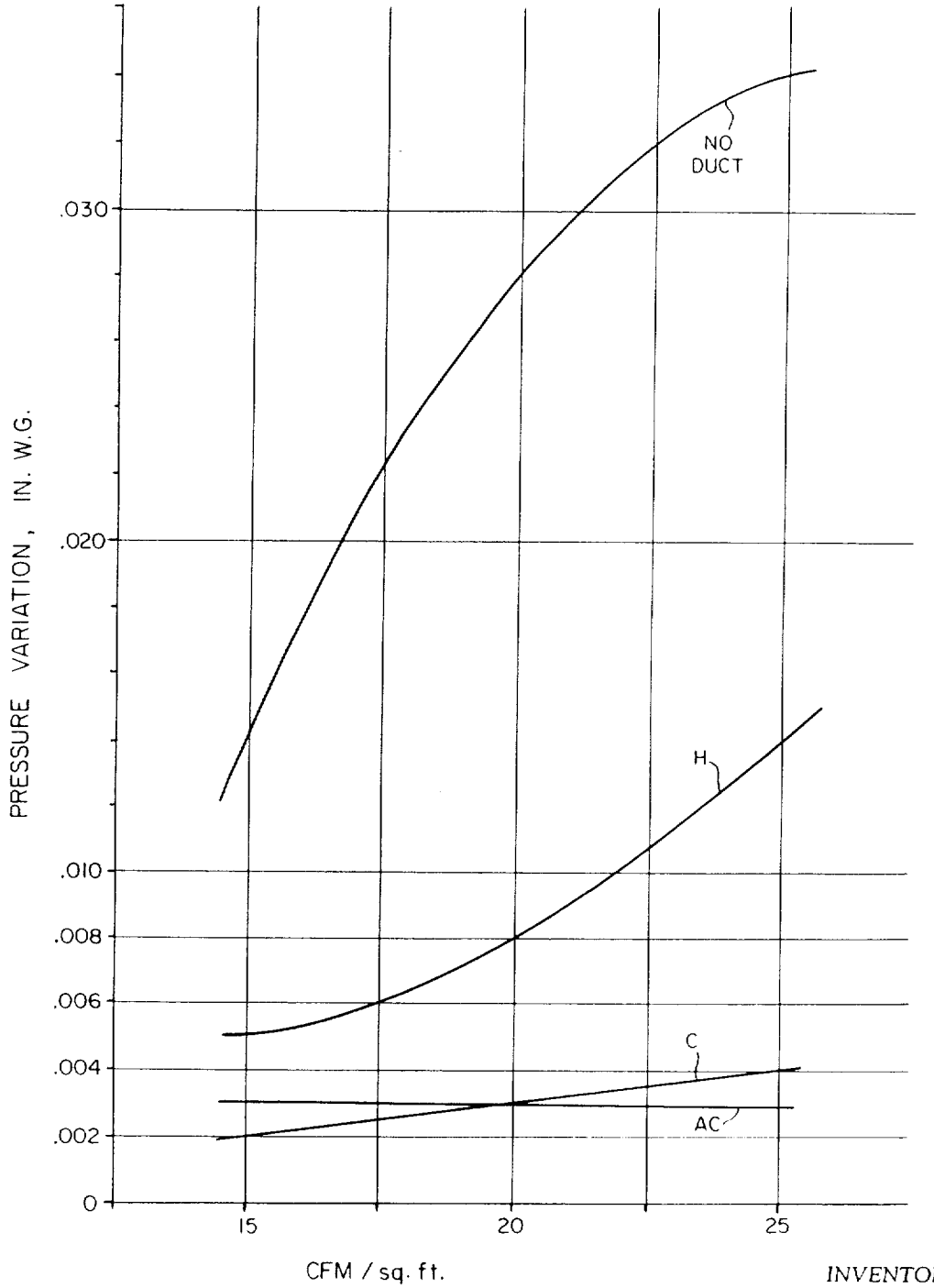

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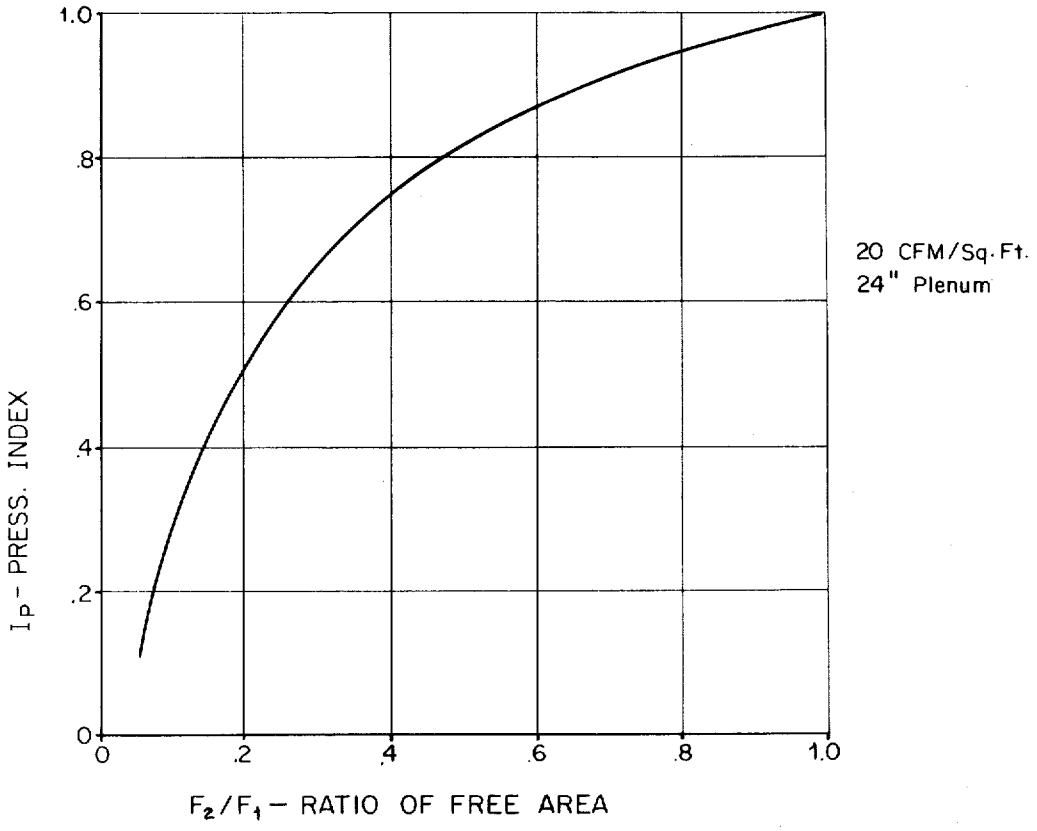
Fig. 10



F_2 = Free Area of Distribution Duct
F_1 = Free Area of Ceiling Panel

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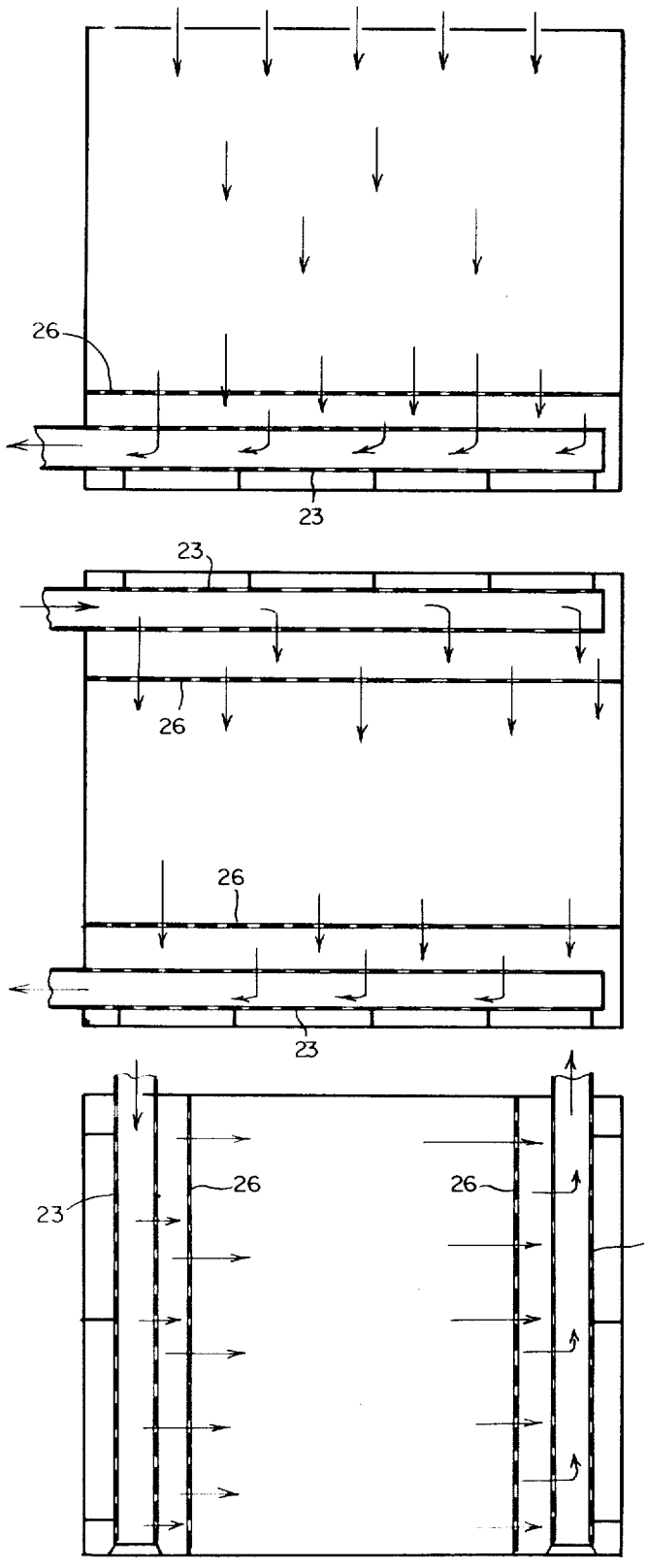

Fig. II

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DISTRIBUTION SYSTEM FOR CLEAN ROOMS

CROSS-REFERENCES TO RELATED APPLICATIONS

This application is a continuation-in-part of our co-pending application Ser. No. 26,584, filed Apr. 8, 1970, now abandoned, for DISTRIBUTION SYSTEM FOR CLEAN ROOMS.

BACKGROUND OF THE INVENTION

This invention lies in the field of clean room distribution systems and, more particularly, low velocity high flow rate clean room systems wherein the velocity pressure of air incoming to the room is largely transformed into static pressure and uniformly distributed across the room.

Clean room systems are coming into increasing use to meet the demand of today's technology. In most of these systems, and particularly in those adapted for hospital use, a primary objective of the system is to obtain uniform flow of air through the room. This is generally achieved by one of two distinct types of design used for clean rooms. The most common system uses a bank of HEPA filters placed in the ceiling, the filters acting as a distribution device and an air outlet into the clean room. Although this design has many basic advantages, it carries the disadvantage of loss of uniform flow caused by the requirement of having separate filter units, each having a different initial pressure drop, and differing loading characteristics. It is not uncommon for such a system to have non-uniform flow because some of the filters in the bank are loaded more rapidly than others, thus producing an imbalance in the flow through the ceiling.

The other type of design, of which the system of this invention is an example, may be referred to as the remote filter clean room, in which design the HEPA filters are located within or near the air supply unit, and the uniformity of flow is dependent upon the apparatus provided for distribution of air directly into the clean room. The simplest and least desirable of such remote filter systems comprises a simple box plenum, wherein the ceiling of the clean room is fed from an open box-like plenum chamber which delivers air into the clean room through a perforated ceiling, the air having been supplied directly into the plenum from an outside duct. The simple box plenum is characterized by variations in the velocity and pressure components of the air within the plenum and accordingly there is an uneven flow through the perforated ceiling into the clean room below. Indeed, it is not infrequently the case that some sections of the ceilings have negative pressure and aspirate air into the plenum rather than discharging it down into the room.

An improvement over the simple box plenum structure is the type of system shown in the U.S. Pat. to Horneff, No. 3,363,532. The pressure chamber of this system provides an improvement by delivering air at more uniform pressures to a completely perforated ceiling, resulting in a better conversion from velocity to static pressure, and a more uniform laminar flow. However, the method employed there of introducing air directly downward into the distribution chamber leads to an inefficiency of transformation of velocity to static pressure, which inefficiency prevents the system from attaining the high degree of uniform flow desired.

SUMMARY OF THE INVENTION

It is an object of this invention to provide a clean room distribution system to evenly and uniformly supply air to clean rooms with a minimum of turbulence in the clean space.

It is a further object of this invention to supply a uniform flow of air into a clean room with no aspiration of room air into the distribution plenum.

It is a further object of this invention to provide an inexpensive and efficient system for supplying uniform air flow to a clean room which is convenient, easy to install, and provides improved performance characteristics over other existing systems.

It is a further object of this invention to provide a surface across the entirety of which a uniform pressure is maintained, said pressure to be either positive or negative.

Accordingly, the clean room system of this invention comprises a rigid plenum chamber arranged at the top of a clean room, the plenum chamber having a rigid perforated bottom member separating the plenum from the clean area below, and which serves as the ceiling of the clean room area, an air supply providing clean air into such plenum chamber, and at least one air distribution duct which distributes the air throughout the plenum chamber, and which converts much of the velocity pressure of the incoming air supply to static pressure. Further transformation of velocity pressure to static pressure is achieved by the perforated ceiling, thereby supplying air uniformly into the clean room with no aspiration of room air into the plenum. In practice, the distribution ducts are cylindrical in form, preferably fabricated of flexible plastic cloth with perforations for air distribution. The distribution ducts may be single cylindrical ducts or dual ducts comprising an inner perforated duct placed within a second, or outer duct, and are suspended from the ceiling of the plenum chamber.

Other objects of the present invention will become apparent upon reading the following specification and referring to the accompanying drawings, which form a material part of this disclosure.

The invention accordingly consists in the features of construction, combinations of elements, and arrangements of parts, which will be exemplified in the construction hereinafter described, and of which the scope will be indicated by the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagrammatic side view of the system.

FIG. **2** is a side view taken along lines **2—2** as shown in FIG. **1**, illustrating the arrangement of a plurality of distribution ducts in the plenum chamber.

FIG. **3** shows diagrammatic views of cross sections of seven alternate distribution ducts.

FIG. **4** is a detailed view showing the connection of a dual distribution duct to the side wall of the plenum chamber.

FIG. **5** is a series of curves showing the pressure index versus flow rate for an 18 inch plenum.

FIG. **6** is a series of curves showing the pressure index versus flow rate for a 24 inch plenum.

FIG. **7** is a series of curves showing the pressure index versus plenum height for a constant flow rate.

FIG. **8** is a series of curves showing total load pressure versus plenum height for a given flow rate.

FIG. 9 is a series of curves showing pressure variation versus flow rate for different air distribution systems.

FIG. 10 is a curve showing pressure index versus ratio of distributor free area to ceiling free area.

FIG. 11*a* is a diagrammatic view of an embodiment with the plenum under the floor of a clean room; FIG. 11*b* is a diagrammatic view of a clean room with a plenum above the ceiling and a plenum below the floor; FIG. 11*c* is a diagrammatic view showing plenums within opposing lateral walls of a clean room.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. 1, a diagrammatic view is shown of the primary elements of the distribution system of this invention. A fan 20 supplies air through a supply duct 21 to an inlet 22 of distribution duct 23. The duct 23 is suspended from the top of a plenum 24 which is bounded on the top by ceiling 25 and the bottom by a perforated clean room ceiling 26, and by side walls 27 which laterally enclose it. The air is circulated from the fan through duct 21 into perforated distribution duct 23, from which it is passed through perforations, or openings, into plenum 24 and thence through ceiling 26 into the clean area below. It is then recirculated by conventional duct means not shown back to fan system 20. Typically, one distribution duct 23 will serve a section of ceiling approximately 4 feet wide and of a length of about 20 feet. Consequently, for rooms of average area, a number of distribution ducts will be aligned in parallel, as shown in FIG. 2, and each be longitudinally substantially coextensive with the plenum, as in FIG. 1. The precise determination of the number of ducts for any given room will be a design consideration subject to the particular application.

The preferred clean room ceiling 26 may consists of a plurality of molded plastic panels, typically of a size 24 × 24 inches × ⅛ inch. The panels are perforated, and panel hole sizes may vary from 0.040 inch diameter to about 0.125 inch diameter, and the total free or open area of the perforations may vary from 1 percent to about 10 percent. The percentage of free area of the perforated ceiling affects the pressure drop caused by the ceiling, the greater the percentage of free area the smaller the pressure drop. The ceiling panels may be suspended from the top 25 of the plenum with conventional wire and T-bar support members. Other types of perforated ceilings may, or course, be adopted for given applications. By making the ceiling panels of a translucent material and installing fluorescent fixtures in the plenum, the ceiling may provide lighting by the well known luminous ceiling method.

Referring now to FIG. 3, seven typical configurations of distribution ducts are shown, indicated A, B, C, D, AC, BC and DC. The ducts are of a "single" type, as with A, B, C and D, or of a "dual" type, as with AC, BC and DC. Configuration A is a cylinder of nominal diameter, e.g., 12 inches, having two rows of spaced openings, the rows running longitudinally with the cylindrical duct, and located at approximately a 90° angle. In practice, this angle may vary from about 90° to 270°. Configuration B comprises a cylindrical duct having perforations extending through angular ranges of approximately 45° to 165° to 315°. Configuration C comprises a cylinder of larger diameter than A or B, e.g., 16 inches, having perforations around the entire circumference of the cylinder. Configuration D is the same as C, but with the smaller diameter cylinder. Configuration AC is seen to be a combination of ducts A and C, with the smaller duct A being placed within the C duct, the two ducts joined together tangentially at the top. Similarly, configuration BC is a combination of the B duct and the C duct, and configuration DC is a combination of the D duct and the C duct. Other configurations may of course be used, these particular configurations being used to illustrate preferred embodiments, but without limiting the scope of the invention.

Although the configurations illustrated are all of cylindrical cross section, any cross section may be utilized which permits distribution of air or gas throughout the plenum. The cross sectional size of the ducts will, in general, be a function of plenum height, as discussed further later in this specification.

The distribution ducts are preferably fabricated from a flexible plastic cloth, such as a nylon reinforced vinyl laminate, which has the attributes of low cost, ease of handling, non-shedding and non-corroding. The ducts, either single or dual type, are connected to one wall of the plenum as shown in FIG. 4. The fabric of the cylinder or cylinders is connected to a round stainless steel duct collar 30 in the side wall 27 of the plenum, using a band clamp 31. It is to be noted that alternate materials, such as sheet metal, may be used in the ducts. In practice, highly advantageous results have been obtained using duct apertures or perforations of between 0.04 inch and 0.25 inch.

Generally, the ratio of the free area of the openings in the outer cylinder of the distribution duct to the free area of the perforated ceiling served by the duct may vary from 0.08 to 1.00 or more, but best performance is obtained when this ratio is between 0.50 and 1.00. As seen in FIG. 10, discussed below, pressure uniformity is at least 80 percent of the optimum attainable for ratios between 0.50 and 1.00.

In operation, the air supply which is provided through opening 22 into distribution duct 23 has considerably velocity pressure, the velocity pressure having been generated by fan 20 and being necessary to move the air from the location of the fan to the clean room plenum. In order to obtain the desired uniform flow in the clean room area, the system of this invention must effectively and efficiently convert this velocity pressure into static pressure which is applied uniformly across the top of the room. The distribution duct, due to the radial location of the openings, distributes the air at a plurality of angles with respect to the horizontal and thereby spreads it out over ceiling 26, achieving a first conversion from velocity to static pressure. Perforated ceiling 26 contributes a further conversion, the air emerging through it downward into the clean area being reduced in velocity pressure and quite uniform across the entire ceiling. Results of tests on the system of this invention are summarized quantitatively in FIGS. 5, 6, 7, 8, 9 and 10 showing performance characteristics for the various configurations, and comparing such configurations with the system shown in the reference patent to Horneff. In the drawings, each configuration tested is referred to by its letter designation as shown in FIG. 3, and the system of the Horneff patent is referred to by the letter H. Configurations A, B and D were 12 inches in diameter, and configuration C was 16 inches in diameter.

In practice highly advantageous results have been obtained with the distribution ducts 23 as high as possible

in the plenum, say within 1 inch of the top **25**, and spaced at least five inches over the ceiling **26.**

Referring now to FIGS. **5, 6** and **7,** graphs are shown of the pressure index of the differing configurations subject to several variables. The performance of the system, i.e., the uniformity of the flow, is judged by measuring the variation in static pressure in the plenum just above the perforated ceiling **26.** For this purpose, an index of pressure uniformity, I_p, is utilized, being a quantitative expression of the uniformity of the static pressure. To measure the index of pressure uniformity, static pressure is measured one inch above the ceiling **26** at the centers of 16 inch squares across the entire ceiling. I_p, for purposes of this specification, is defined as the fraction of such measured points which do not deviate more than 0.002 inch water gage from the arithmetical means of the total of such pressure readings. Thus, a system with a perfect I_p of 1.0 is one in which the highest static pressure does not exceed 0.002 inch more than the overall average and the lowest pressure is not more than 0.002 inch less than the overall average. The tolerance figure of 0.002 inch was chosen since a test showed that there is a human error of ±0.001 inch in making visual readings on a micrometer hook gage with a sensitivity of 0.0005 inch.

Referring now to FIG. **5,** I_p is plotted with respect to CFM/Sq. Ft. for a plenum having a depth of 18 inches. The bottom curve, marked "no duct", represents the situation where no distribution duct is employed, and the plenum alone is available to convert the air supply from velocity to static pressure. Each of the configurations tested, A, B, C, D and BC show a considerable improvement over the "no duct" arrangement. In FIG. **6,** I_p is again plotted with respect to CFM/Sq. Ft. for a 24 inch plenum. The performance of configurations B, C, D, AC, BC and DC is seen in comparison to the performance of the prior art Horneff system, curve H. All of the configurations of this invention show a definite improvement over the Horneff system. It is also seen that using the same ducts with a 24 inch plenum constitutes a considerable improvement over the case where an 18 inch plenum was used, resulting in an index of pressure uniformity which is appreciably 1.0 for configurations C, AC, and DC.

Referring now to FIG. 7, I_p is plotted against a varying plenum height, for a steady flow rate. All of the configurations tested except configuration A again show a marked improvement in pressure uniformity over the Horneff system.

In practice highly advantageous results have been obtained with distribution ducts of between 12 inches and 18 inches diameter, and with plenum heights of between 21 inches and 30 inches.

FIG. **8** represents a different set of performance curves, wherein the total pressure in inches water gage at the opening **22** into distribution duct **23** is plotted as a function of plenum height, for a constant flow rate of 20 CFM/Sq. Ft. The total pressure at such point is a direct indication of the loading on the fan system. It is seen that all of the configurations shown in FIG. **3** yield an improvement over the Horneff configuration, which demonstrates the increased efficiency of the configurations of this invention. One basic reason for the improvement over the prior Horneff configuration is that in the present invention the air is introduced only at the end opening of the distribution duct, allowing for static pressure build-up within the distribution duct which causes all the air to change direction and to pass out of the duct substantially uniformly at all angles normal to the duct. By contrast, in the Horneff configuration air is passed from the upper duct along the length thereof directly downwardly into the distribution duct along the length of the latter, with the result that much of the air follows a substantially vertical path straight on through to the clean area below, preventing uniform distribution.

FIG. **9** shows another illustration of the improvement provided by the configurations of this invention. There, pressure variation in inches water gage measured over the ceiling as set forth above is plotted as a function of flow rate, for configurations C and AC, as well as the Horneff system, and the box plenum (no duct) system. It is seen that the variation in pressure as a function of flow rate is minimized considerably by the C and AC configurations of this invention, with substantially no increase in variation as flow rate is raised from 15 to 25 CFM/Sq. Ft., whereas in both the Horneff and the "no duct" systems there is experienced a considerable rise in variation for the higher flow rates.

FIG. **10** plots the index of pressure uniformity against the ratio of free area of the distribution duct to the free area of the perforated ceiling is varied. It is seen that best performance is obtained when this ratio is between approximately 0.50 and 1.00.

Consistent with the foregoing it has been found that the advantageous results of the instant invention require a total plenum size, including the contained distribution duct, of between 1.5 and 3.0 Cu. Ft./Sq. Ft. of ceiling. Optimum results are obtained with between 2.1 and 2.7 cu. ft. of plenum per sq. ft. of ceiling.

From the above, it is seen that the configurations of this system provide a substantial improvement in achieving a uniform supply of air at high flow rates to occupied rooms, with a minimum of turbulence in the space, and with better efficiencies than prior systems. Although flow rates in the range of 15 to 50 CFM/Sq. Ft. are generally used, the flow rate may extend to as low as 1 CFM/Sq. Ft. and as high as 100 CFM/Sq. Ft. The systems of this invention may be used for conventional air conditioning systems with flow rates between 1 and 5 CFM/Sq. Ft., where it is desirable to avoid drafts to occupants. In such latter cases it is not necessary that the entire ceiling **26** be perforated. As little as 20 percent of the total ceiling area may be perforated in such cases, in contrast to the clean room applications where the entire ceiling must be perforated.

Another advantage in the system of this invention resides in the fact that it can be adapted to an existing room with a maximum of alteration. Construction of the plenum involves only installing the perforated member **26.**

It is to be noted that the invention of this system has been described in terms of the distribution of air. While this will be the primary use, the system may distribute gases in general, and it is understood that the term "air" as used in the claims incorporates gases and gaseous liquids as well as what is commonly considered air.

While the preferred embodiment of the system of this invention is utilized to supply air uniformly into a room, and from a ceiling of such room, it is recognized that the system could be used to accomplish uniform removal of air from a room, or to move air uniformly across a room between any two opposite walls. Refer-

ring to FIG. 11*a*, it is seen that the plenum and distribution ducts may be placed in the floor of the clean room, utilizing rigid ducts and a negative pressure to uniformly draw air from the room. FIG. 11*b* shows a system utilizing a positive pressure plenum forcing air out of the ceiling, in combination with a negative pressure plenum drawing it in at the floor, in a tandem or push-pull like operation. FIG. 11*c* shows a similar system with the two plenums placed on side walls. Thus, as these figures illustrate, the system of this invention may be used in many configurations to provide a uniform flow of air within an enclosed space, or to provide, for any purpose, a surface having a substantially uniform air pressure thereacross.

Although the present invention has been described in some detail by way of illustration and example for purposes of clarity of understanding, it is understood that certain changes and modifications may be made within the spirit of the invention.

What is claimed is:

1. A distribution system for a clean space within a building and comprising:

a. a plenum having a perforated plenum inner wall communicating with said clean space, the plenum outer wall being defined by a wall of the building;

b. distribution duct means substantially entirely within said plenum in spaced relation therein and comprising at least one distribution duct substantially coextensive in its length with one dimension of said plenum and having one open end for receiving air endwise, said duct having its axis substantially parallel to said plenum inner wall and having air outlet openings of between 0.040 inch and 0.250 inch diameter in the outer periphery thereof, for passing air into said plenum substantially normal to said axis and at a plurality of angles with respect to each other substantially completely along said one plenum dimension, the ratio of the free outer periphery area to the free plenum inner wall area being between 0.50 and 1.00;

c. air supply means for supplying air into said distribution duct means; and,

d. inlet means connecting said distribution duct means and said air supply means for introducing air at said open end of each of said at least one distribution duct, the air diffusing throughout said duct under pressure provided by said air supply means.

2. The system as disclosed in claim **1** wherein said distribution duct comprises a single cylinder having two rows of spaced apart openings, said rows being displaced at an angle within the range of 90° to 270°.

3. The system as disclosed in claim **1** wherein said distribution duct comprises a single cylinder having openings at angles within 45° to 165° and 195° to 315°.

4. A distribution system for a clean space within a building and comprising:

a. a plenum having a perforated plenum inner wall communicating with said clean space, the plenum outer wall being defined by a wall of the building;

b. distribution duct means substantially entirely within said plenum in spaced relation therein and comprising at least one distribution duct substantially coextensive in its length with one dimension of said plenum and having one open end for receiving air endwise, said duct having its axis substantially parallel to said plenum inner wall and having air outlet openings of between 0.040 inch and 0.250 inch diameter in the outer periphery thereof, for passing air into said plenum substantially normal to said axis and at a plurality of angles with respect to each other substantially completely along said one plenum dimension, said distribution duct comprising a single cylinder having openings around the entire periphery thereof and located in the upper plenum region spaced at least five inches from said plenum inner wall;

c. air supply means for supplying air into said distribution duct means; and,

d. inlet means connecting said distribution duct means and said air supply means for introducing air at said open end of each of said at least one distribution duct, the air diffusing throughout said duct under pressure provided by said air supply means.

5. The system as disclosed in claim **4** wherein said distribution duct comprises a second cylinder of smaller diameter than said single cylinder and having two rows of spaced apart openings, said second cylinder attached tangentially to and entirely within said single cylinder.

6. The system as disclosed in claim **4** wherein said distribution duct comprises a second cylinder of smaller diameter than said single cylinder and having openings at angles within 45° to 165° and 195° to 315°, said second cylinder being attached tangentially to and within said single cylinder.

7. The system as disclosed in claim **4,** said plenum having a volume of between 1.5 and 3.0 Cu. Ft./Sq. Ft. of said inner wall.

8. The system as disclosed in claim **4** wherein the ratio of free area of said outer periphery to the free area of said perforated plenum floor is between 0.50 and 1.00.

9. A distribution system for space in a building providing a uniform air pressure across a surface area, comprising:

a. a plenum having a perforated inner plenum wall defining said surface area, the plenum outer wall being defined by a wall of the building;

b. at least one distribution duct having one open end for receiving air, positioned in spaced relation entirely within and substantially coextensive in one direction with said plenum, and having an axis substantially parallel to said inner plenum wall, said duct having openings of between 0.040 inch and 0.250 inch diameter in its periphery; and,

c. the ratio of free area of said periphery to the free area of said perforated plenum wall being between 0.50 and 1.0.

10. The distribution system as disclosed in claim **9** wherein said duct comprises an inner cylindrical perforated duct attached within and tangentially to an outer cylindrical perforated duct.

11. The system as disclosed in claim **8** wherein said distribution duct comprises a second cylinder of smaller diameter than said single cylinder and having openings around the entire periphery thereof, said second cylinder being attached tangentially to and within said single cylinder.

12. The system as disclosed in claim 8 wherein said distribution duct comprises a single cylinder composed of flexible material, having openings around the entire periphery, and having a diameter of between 12 inches and 18 inches, spaced at least 5 inches from the inner plenum wall and in a plenum of between 21 inches and 30 inches in depth.

13. The distribution system as disclosed in claim 8 wherein said distribution duct comprises a cylindrical duct about 16 inches in diameter and having openings around the entire periphery thereof such that about 2.5 percent of said periphery is free area, said plenum having a depth of about 24 inches and said perforated plenum wall having about 2.5 percent free area.

14. A distribution system for a clean space within a building and comprising:

a. a plenum having a perforated plenum inner wall communicating with said clean space, the plenum outer wall being defined by a wall of the building;

b. distribution duct means substantially entirely within said plenum in spaced relation therein and comprising at least one distribution duct substantially coextensive in its length with one dimension of said plenum and having one open end for receiving air endwise, said duct having its axis substantially parallel to said plenum inner wall and having air outlet openings of between 0.040 inch and 0.250 inch diameter in the outer periphery thereof, for passing air into said plenum substantially normal to said axis and at a plurality of angles with respect to each other substantially completely along said one plenum dimension, said distribution duct comprising a single cylinder composed of flexible material, having openings around the entire periphery, and having a diameter of between 12 inches and 18 inches, spaced at least 5 inches from the inner plenum wall and in a plenum of between 21 inches and 30 inches depth;

c. air supply means for supplying air into said distribution duct means; and,

d. inlet means connecting said distribution duct means and said air supply means for introducing air at said open end of each of said at least one distribution duct, the air diffusing throughout said duct under pressure provided by said air supply means.

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