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DISPLACEMENT VENTILATION SYSTEM

BACKGROUND OF THE INVENTION

5 1. FIELD OF THE INVENTION

The present invention relates to a displacement ventilation system.

2. DESCRIPTION OF THE RELATED ART

A displacement ventilation system is well known as an air-conditioning system capable of reducing pollutant concentration of an occupied zone in an air-conditioned space and keeping a comfortable environment even when temperature of cooling supply air is relatively high. In this displacement ventilation system, air at a temperature slightly lower than room temperature is supplied at low velocity to the occupied zone formed in a lower part in the air-conditioned space, and pollutant such as dirt and gas produced in the air-conditioned space is carried to an upper part of the air-conditioned space by a rising airflow that is generated when the supply air is heated by a heat source (for example, a human body) existing in the occupied zone. It is recommended in a reference (Yuan, X., Chen, Q., and Glicksman, L.K.: Performance Evaluation and Design Guideline for Displacement Ventilation, ASHRAE Trans., 105(1999), pp. 308) that velocity of supply air in this displacement ventilation system should be regulated to 0.2 m/s or lower from the viewpoints of reducing uncomfortable draft and preventing the heated rising airflow generated in the occupied zone from being stirred. The displacement ventilation system ventilates the inside of the air-conditioned space by discharging pollutant together with the heated air from an exhaust port provided in a ceiling or the like.

With such a displacement ventilation system, a zone at high temperature and with high pollutant concentration is formed in the upper part in the air-conditioned space. Nevertheless, air in this zone is continuously pushed out by the low-temperature air supplied into the air-conditioned space, so that the high-temperature air with high pollutant concentration is not stirred but exhausted. Thus, the displacement ventilation system is



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beneficial in that the occupied zone located in the lower part in the air-conditioned space is maintained in a clean environment and the occupied zone can be kept in a comfortable temperature range even if the temperature of the supply air is not lowered. Thus, the displacement ventilation system is
5 expected as an air conditioning system capable of realizing energy saving and operating with high ventilation efficiency.

This displacement ventilation system ensures comfortability by regulating a difference between foot-level temperature and head-level temperature to, for example, 3°C or less (ISO, ASHRAE comfort standard),
10 and therefore, it has to operate with a large quantity of air under a reduced temperature difference between supply air and exhaust air. Therefore, many large air supply units have to be disposed in the air-conditioned space, and it is sometimes difficult to secure a place for installing the air-supply units. Moreover, when the pollutant is produced from a place with a heat source or
15 its vicinity, the pollutant is discharged from the occupied zone to the ceiling by the heated rising airflow, so that the pollutant concentration of the occupied zone can be kept low. However, when the pollutant is not associated with a heat source, an effect of carrying and diluting pollutant is small, so that an occupant may possibly suffer the exposure to the highly
20 polluted air.

Under such circumstances, with the aims of realizing a more compact air supply unit for securing its installation place, reduced temperature gradient of an occupied zone, and an improved effect of diluting pollutant in the occupied zone, a displacement ventilation system has been proposed that
25 includes a plurality of guide fins for giving rotating components to blowout air to increase an induced volume of air in the vicinity of the air supply unit, thereby improving a diffusing property of supply air (Japanese Patent Application Laid-open No. 2002-372268).

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SUMMARY OF THE INVENTION

A displacement ventilation system diffuses supply air, to thereby

enabling not only reduction in uncomfortable draft but also reduction in a vertical temperature difference in an occupied zone, without any increase in facility cost. The present invention provides a displacement ventilation system with further improvement. That is, it is an object of the present invention to provide a displacement ventilation system which is capable of giving a larger number of rotating components to supply air to induce a larger volume of air by the rotated air than in conventional systems and which has an improved airflow attenuating property.

According to the present invention, provided is a displacement ventilation system that performs ventilation by supplying low-temperature air into an air-conditioned space and exhausting heated air that has been heated and has risen in the air-conditioned space, the displacement ventilation system including: a plurality of guide fins that are attached in an air supply port of the low-temperature air to give a rotating component to the low-temperature air which is to be blown out into the air-conditioned space, the plural guide fins being arranged radially around an axis of the air supply port and slanted at an equal angle relative to a plane perpendicular to the axis of the air supply port; and a cylindrical inner wall disposed coaxially with the air supply port to surround a periphery of the plural guide fins.

Preferably, a length of the inner wall in an axial direction of the air supply port is equal to or larger than a half of a width of the guide fin in the axial direction of the air supply port. The inner wall may be made of an acoustic material. Further, the air supply ports may be arranged in plurality, each provided with the plural guide fins for giving the rotating component to the low-temperature air and each provided with the cylindrical inner wall surrounding the periphery of the plural guide fins, and the guide fins in the adjacent air supply ports may be slanted in opposite directions. Further, a perforated plate may be disposed in front of the air supply port. In this case, an open area ratio of the perforated plate is preferably 40% or higher. Preferably, a diameter D of an opening of the air supply port and a distance M from the air supply port to the perforated plate are set to satisfy a relation of $M/D \geq 0.07$.

According to the present invention, the cylindrical inner wall is formed to surround the periphery of the guide fins, so that a larger number of the rotating components can be given to the low-temperature air which is to be blown out into the air-conditioned space, compared with a case where no cylindrical inner wall is provided. Accordingly, a volume of air in the air-conditioned space induced by a flow of the blowout low-temperature air (entrainment ratio) can be made still larger, so that velocity of the low-temperature air blown into the air-conditioned space can be quickly lowered and its temperature can be quickly raised. This makes it possible to further reduce a vertical temperature difference in the air-conditioned space. In addition, pollutant, even if not discharged to a ceiling from the occupied zone by a heated rising airflow, can be diluted. The present invention is beneficial over conventional displacement ventilation systems in that the air supply unit can be made more compact.

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BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic block diagram to describe a displacement ventilation system according to an embodiment of the present invention;

20 FIG. 2 is a front view of an air supply unit;

FIG. 3 is an enlarged cross-sectional view taken along the Z-Z line in FIG. 2;

FIG. 4 is a perspective view of an air supply port in which guide fins are attached so as to give rotating components in an anticlockwise direction to low-temperature air when viewed from an indoor side of an air-conditioned space;

FIG. 5 is a perspective view of an air supply port in which guide fins are attached so as to give rotating components in a clockwise direction to the low-temperature air when viewed from the indoor side of the air-conditioned space;

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FIG. 6 is an explanatory view of air supply ports, the rotating components of the low-temperature air blown out from the adjacent air

supply ports being in opposite rotation directions;

FIG. 7 is an explanatory view of air supply ports, the rotating components of the low-temperature air blown out from the adjacent air supply ports being in the same rotation direction;

5 FIG. 8 is an explanatory view of air supply ports, the rotating components of the low-temperature air blown out from the vertically adjacent air supply ports and the laterally adjacent air supply ports both being in opposite rotation directions;

10 FIG. 9 is a graph showing how the maximum air velocity changes in correlation to the distance from the air supply unit in the displacement ventilation system of the present invention in which a cylinder surrounds a periphery of the guide fins and in a conventional displacement ventilation system without such a cylinder;

15 FIG. 10 is a graph showing how foot-level temperature, which is made dimensionless with a temperature difference between supply air and exhaust air, changes in correlation to the distance from the air supply unit in the displacement ventilation system of the present invention in which the cylinder surrounds the periphery of the guide fins and in the conventional displacement ventilation system without such a cylinder;

20 FIG. 11 is a graph showing the correlation between the length of a cylindrical inner wall (cylinder) surrounding the periphery of the guide fins and average airflow velocity when the flow rate of the low-temperature air is $90 \text{ m}^3/\text{h}$;

25 FIG. 12 is a graph showing the correlation between the length of the cylindrical inner wall (cylinder) surrounding the periphery of the guide fins and average airflow velocity when the flow rate of the low-temperature air is $150 \text{ m}^3/\text{h}$;

FIG. 13 is a graph showing the result obtained when noise generation is compared, with a material of the cylinder being varied;

30 FIG. 14 is an explanatory view of an embodiment of the present invention where a perforated plate having a large number of ventilation holes is disposed in front of a front face of the air supply unit to be parallel to the

front face;

FIG. 15 is a graph showing the correlation between an open area ratio (an area of the ventilation holes) of the perforated plate and the maximum velocity of the low-temperature air;

5 FIG. 16 is a graph showing the correlation between the distance from the air supply port to the perforated plate and the maximum velocity of the low-temperature air;

FIG. 17 is an explanatory view of an embodiment in which the cylinder is not provided when the front face of the air supply unit has a
10 sufficient thickness;

FIG. 18 is a perspective view of guide fins that are formed by punching out a circular flat plate;

FIG. 19 is a plane view of an air-conditioned space according to an example of the present invention and comparative examples 1, 2, and shows
15 the arrangement of machines and so on;

FIG. 20 is a table showing states of air-conditioning operation when the example of the present invention and the comparative examples 1, 2 are compared;

FIG. 21 is a graph showing results of comparing the example of the
20 present invention and the comparative examples 1, 2 regarding vertical temperature distributions at a D point;

FIG. 22 is a graph showing air velocity distribution at an A point;

FIG. 23 is a graph showing air velocity distribution at a B point;

FIG. 24 is a graph showing air velocity distribution at a C point;

25 FIG. 25 is a graph showing air velocity distribution at the D point;

FIG. 26 is a graph showing results of comparison regarding PMV and SET* at a place 1 m above the floor at the D point;

FIG. 27 is a graph showing concentration distribution of tracer gas, which is made dimensionless with concentration at an exhaust port, at the A
30 point when the tracer gas is discharged from a machine H3 as a heat source;

FIG. 28 is a graph showing concentration distribution of tracer gas, which is made dimensionless with concentration at the exhaust port, at the C

point when the tracer gas is discharged from the machine H3 as the heat source;

FIG. 29 is a graph showing concentration distribution of tracer gas, which is made dimensionless with concentration at the exhaust port, at the D point when the tracer gas is discharged from the machine H3 as the heat source;

FIG. 30 is a graph showing concentration distribution of tracer gas, which is made dimensionless with concentration at the exhaust port, at the A point when the tracer gas is discharged from a place 1 m above the floor at the B point where no heat source exists;

FIG. 31 is a graph showing concentration distribution of tracer gas, which is made dimensionless with concentration at the exhaust port, at the C point when the tracer gas is discharged from the place 1 m above the floor at the B point where no heat source exists;

FIG. 32 is a graph showing concentration distribution of tracer gas, which is made dimensionless with concentration at the exhaust port, at the D point when the tracer gas is discharged from the place 1 m above the floor at the B point where no heat source exists; and

FIG. 33 is a graph showing comparison results on vertical temperature distribution measured at the D point when supply air temperature is set to 30°C and a flow rate of air conditioning air is set to 4000 m³/h in heating operation under outdoor temperature of 10°.

DETAILED DESCRIPTION OF THE INVENTION

Hereinafter, preferred embodiments of the present invention will be described with reference to the drawings. FIG. 1 is a schematic block diagram to describe a displacement ventilation system 1 according to an embodiment of the present invention.

An air-conditioned space 10 is, for example, an office room, a computer room, a guest room, a banquet hall, a game hall, a printing room, a hospital room, a lavatory, a kitchen, a machine room, a boiler room, a factory,

or the like, and is demarcated by a ceiling, a floor, and sidewalls. In the example shown in FIG. 1, there is, for example, a person 12 as a heat source in an occupied zone 11 formed in a lower part in the air-conditioned space 10. Air supply ports 15 are provided in a lower part of one sidewall (right side of the air-conditioned space 10 in the drawing) 17 in the air-conditioned space 10, and similarly, an exhaust port 16 is provided in an upper part of the sidewall 17 in the air-conditioned space 10. The structure of the air supply ports 15 will be described in detail later. An air supply unit 20 is provided on a rear face side in the lower part of the sidewall 17 of the air-conditioned space 10, with a front face 21 thereof being exposed to the lower part of the sidewall 17 of the air-conditioned space 10.

As shown in FIG. 2, in the front face 21 of the air supply unit 20 thus exposed to the lower part of the sidewall 17 of the air-conditioned space 10, the plural circular air supply ports 15 are arranged laterally and vertically. Low-temperature air SA produced from outdoor air OA taken into an air-conditioner 22 is supplied to the air supply unit 20 via an air supply duct 23. With this structure, the low-temperature air SA is supplied from the plural air supply ports 15, which is formed in the front face 21 of the air supply unit 20, toward the occupied zone 11 in the lower part in the air-conditioned space 10. The air-conditioner 22 includes: a cooler 25 and a filter (not shown) for cooling the outdoor air OA to produce the low-temperature air SA; an air supply fan 27 sending the produced low-temperature air SA into the air-conditioned space 10 through the air supply duct 23 and the air supply unit 20; and so on.

As shown in FIG. 3, a plurality of guide fins 30 for giving rotating components to the low-temperature air SA which is to be blown out into the air-conditioned space 10 are fixed in each of the air supply ports 15. A supporting member 31 is disposed on an axis 15' of each of the air supply ports 15, and the plural guide fins 30 are attached to the supporting member 31 at substantially equal intervals, so that the plural guide fins 30 are radially arranged around the axis 15' of the air supply port 15.

The plural guide fins 30 are slanted at an equal angle relative to a

plane (for example, the front face 21 of the air supply unit 20) perpendicular to the axis 15' of the air supply port 15. FIG. 4 and FIG. 5 are explanatory views of the slanting angles of the guide fins 30, and the slanting direction of the guide fins 30 in FIG. 4 and that in FIG. 5 are opposite to each other.

5 Specifically, in FIG. 4, the guide fins 30 are slanted so that rotating components in an anticlockwise direction are given to the low-temperature air SA which is to be blown out from the air supply port 15 into the air-conditioned space 10, when the front face 21 of the air supply unit 20 is viewed from an indoor side of the air-conditioned space 10. In FIG. 5, on

10 the other hand, the guide fins 30 are slanted so that rotating components in a clockwise direction are given to the low-temperature air SA which is to be blown out from the air supply port 15 into the air-conditioned space 10, when the front face 21 of the air supply unit 20 is viewed from the indoor side of the air-conditioned space 10.

15 The slanted guide fins 30 are thus radially attached around the supporting member 31 in each of the air supply ports 15, so that the low-temperature air SA blown from the inside of the air supply unit 20 toward the air supply ports 15 can be forced to flow along surfaces of the guide fins 30 when passing through the air supply ports 15. In this manner, the rotating

20 components in the clockwise direction or the anticlockwise direction around the axis 15' are given to the low-temperature air SA which is to be blown out from the air supply ports 15 toward the air-conditioned space 10.

As previously described, the plural air supply ports 15 are laterally and vertically arranged in the front face (the indoor side face forming the air-

25 conditioned space 10) 21 of the air supply unit 20, and the rotating components given to the low-temperature air SA which is to be blown out from the adjacent air supply ports 15 are in opposite rotation directions. To explain this, vertically arranged four air supply ports 15a, 15b, 15c, 15d as shown in, for instance, FIG. 6 will be taken as an example. The guide fins

30 30 in the top air supply port 15a and the third air supply port 15c from the top are slanted in the direction as described in FIG. 4. This means that, when the front face 21 of the air supply unit 20 is viewed from the indoor side of

the air-conditioned space 10, the low-temperature air SA given the rotating components in the anticlockwise direction is blown out from these air supply ports 15a, 15c. On the other hand, the guide fins 30 in the second air supply port 15b from the top and the fourth air supply port 15d from the top are
5 slanted in the direction as described in FIG. 5. This means that, when the front face 21 of the air supply unit 20 is viewed from the indoor side of the air-conditioned space 10, the low-temperature air SA given the rotating components in the clockwise direction is blown out from these air supply ports 15b, 15d. Thus, the adjacent air supply ports 15a, 15b blow out the
10 low-temperature air SA given the rotating components in opposite rotation directions. The same applies to the adjacent air supply ports 15b, 15c and to the adjacent air supply ports 15c, 15d.

Specifically, if vertically arranged four air supply ports 15a', 15b', 15c', 15d' all blow out the low-temperature air SA given the rotating
15 components in the same rotation direction as shown in FIG. 7 (they all blow out the low-temperature air SA given the rotating components in the anticlockwise direction in the example shown in FIG. 7), the low-temperature air SA is blown out in such directions that the low-temperature air SA is offset between the air supply port 15a' and the air supply port 15b',
20 between the air supply port 15b' and the air supply port 15c', and between the air supply port 15c' and the air supply port 15d'. Consequently, the rotating components of the low-temperature air SA blown out from the air supply ports 15a', 15b', 15c', 15d' are offset by one another.

On the other hand, when the rotating components of the low-
25 temperature air SA which is to be blown out from the air supply ports 15a, 15b, 15c, 15d are alternately in opposite rotation directions as described in FIG. 6, the blown out low-temperature air SA is in the same direction between the air supply port 15a and the air supply port 15b, between the air supply port 15b and the air supply port 15c, and between the air supply port
30 15c and the air supply port 15d, so that the rotating components of the low-temperature air SA blown out from the air supply ports 15a, 15b, 15c, 15d are not offset by one another but mutually promote rotating motions thereof.

The relation among the vertically arranged air supply ports 15 is described in FIG. 6. However, as previously described in FIG. 2, the plural air supply ports 15 are vertically and laterally arranged in the front face 21 of the air supply unit 20. In this embodiment shown in the drawing, the slanting directions of the guide fins 30 provided in the respective air supply ports 15 are set so that the rotating components of the low-temperature air SA blown out from the vertically adjacent air supply ports 15 are in the opposite rotation directions as shown in FIG. 8. On the other, the slanting directions of the guide fins 30 provided in the respective air supply ports 15 are set so that the rotating components of the low-temperature air SA blown out from the laterally adjacent air supply ports 15 are in the same rotation direction

As shown in FIG. 3, a cylinder 32 is fixed to surround a periphery of the plural guide fins 30 attached in each of the air supply ports 15. The cylinder 32 is attached in each of the air supply ports 15, with an axis of the cylinder 32 matching the axis 15' of the air supply port 15. The inside diameter of the cylinder 32 is set substantially equal to the outside diameter of the plural guide fins 30 attached in each of the air supply ports 15. Accordingly, in each of the air supply ports 15, the outer periphery of the plural guide fins 30 is surrounded by an inner wall 33 (cylindrical inner wall 33 with the axis thereof matching the axis 15' of the air supply port 15) of the cylinder 32. Therefore, as shown in FIG. 4 and FIG. 5, the low-temperature air SA to be blown out into the air-conditioned space 10 from the inside of the air supply unit 20 through the air supply ports 15 passes in the cylinders 32 attached in the respective air supply ports 15. At this time, the low-temperature air SA flows along the surfaces of the guide fins 30 in each of the cylinders 32, so that the low-temperature air SA is forcibly given the rotating components in the clockwise direction or the anticlockwise direction.

Here, as shown in FIG. 3, in each of the air supply ports 15, a length L of the cylinder 32 in the direction along the axis 15' of the air supply port 15 is set equal to or larger than a half of a width l of the guide fin 30 also in the direction along the axis 15' of the air supply port 15. Accordingly, the

periphery of at least a half portion or more of the width l of the guide fins 30 in the direction along the axis 15' of the air supply port 15 is surrounded by the inner wall 33 of the cylinder 32. Note that in the example shown in FIG. 3, the length L of the cylinder 32 is set still longer than the width l of the guide fins 30, and thus the periphery of the whole portion of the width l of the guide fins 30 in the direction along the axis 15' of the air supply port 15 is surrounded by the inner wall 33 of the cylinder 32.

As shown in FIG. 1, an exhaust duct 41 including an exhaust fan 40 is connected to the exhaust port 16 disposed in the upper part of the air-conditioned space 10. With this structure, air staying in the upper part of the air-conditioned space 10 (air heated by thermal load of a human body, OA equipment, or the like existing in the air-conditioned space 10) is exhausted as exhaust air EA through the exhaust duct 41 to the outside.

In the displacement ventilation system 1 as structured above, the air supply fan 27 operates to send the low-temperature air SA produced in the air-conditioner 22 into the air-conditioned space 10 through the air supply duct 23, the air supply unit 20, and the air supply ports 15. When passing through the air supply ports 15, the low-temperature air SA passes in the cylinder 32 attached in each of the air supply ports 15. At this time, the low-temperature air SA flows along the surfaces of the guide fins 30 inside the cylindrical inner wall 33, so that the low-temperature air SA is forcibly given the rotating components in the clockwise direction or the anticlockwise direction. In this manner, the rotating low-temperature air SA is supplied from the air supply ports 15 into the air-conditioned space 10.

In this case, the periphery of the guide fins 30 is surrounded by the cylindrical inner wall 33 in each of the air supply ports 15, so that it is ensured that the low-temperature air SA which is to be supplied from each of the air supply ports 15 into the air-conditioned space 10 is given stronger rotating components, compared with a case where the cylinder 32 (inner wall 33) is not provided.

Then, when the rotating low-temperature air SA is supplied into the air-conditioned space 10 from the air supply ports 15, an inducing action

works, so that air in the air-conditioned space 10 is induced by the low-temperature air SA blown out from the air supply ports 15 to move together. In this case, in the displacement ventilation system 1 shown in the drawing, the low-temperature air SA blown out from the air supply ports 15 has been
5 given the rotating components, and accordingly, a volume of air in the air-conditioned space 10 induced by the low-temperature air SA (entrainment ratio) increases. Consequently, based on the law of conservation of momentum, the velocity of the low-temperature air SA lowers immediately after it is blown out from the air supply ports 15.

10 Here, comparison between the case where the periphery of the guide fins 30 is surrounded by the cylindrical inner wall 33 (cylinder 32) and the case where the cylinder 21 is not provided and thus the periphery of the guide fins 30 is open has led to the following findings. Specifically, the circular air supply ports 15 each with a diameter $D = 94$ mm were provided
15 at 12 places in the front face 21 (height = 0.9 m, width = 0.3 m) of the air supply unit 20, and the guide fins 30 were attached in each of the air supply ports 15. This structure with the cylinder 32 surrounding the periphery of the guide fins 30 and that without the cylinder 32 were compared, regarding how airflow velocity (the maximum air velocity in the air-conditioned space
20 10 at a position a given distance apart from the front face 21 of the air supply unit 20) changes in correlation to the distance from the front face 21 of the air supply unit 20. The results shown in FIG. 9 were obtained from the comparison. Further, the same structures were compared regarding a difference between the minimum air temperature and supply air temperature,
25 which was made dimensionless with a temperature difference between supply air and exhaust air, in correlation to the distance from the front face 21 of the air supply unit 20. The results shown in FIG. 10 were obtained from the comparison. Note that the minimum dimensionless air temperature which is taken on the vertical axis in FIG. 10 can be expressed by the
30 following equation.

$$\text{minimum dimensionless air temperature } T_F^* = (T_F - T_S) / (T_E - T_S)$$

T_F : minimum foot-level temperature, T_S : supply air temperature, T_E :

exhaust air temperature

It has been confirmed that when the periphery of the guide fins 30 is surrounded by the cylindrical inner wall 33 as in the present invention, the airflow velocity of the low-temperature air SA blown out from the air supply ports immediately becomes lower and the temperature of the low-temperature air SA supplied to the occupied zone 11 quickly rises. On the other hand, when the cylinder 32 is not provided, due to the open structure of the periphery of the guide fins 30, air (the low-temperature air in the air supply unit 20) around the guide fins 30 flows in from the periphery of the air supply port 15 as shown by the chain line SA' in FIG. 3. As a result, it is not possible to give sufficient rotating components to the low-temperature air SA which is to be blown out from the air supply ports 15, so that a volume of air in the air-conditioned space 10 induced by the low-temperature air SA blown out from the air supply ports 15a (entrainment ratio) is reduced. Consequently, the airflow attenuating property cannot be improved. In this respect, the present invention is capable of giving a larger number of the rotating components to the low-temperature air SA which is to be blown out from the air supply ports 15 since the cylindrical inner wall 33 surrounds the periphery of the guide fins 30 to prevent the air from entering from the periphery.

Our studies on the length of the cylindrical inner wall 33 (cylinder 32) surrounding the periphery of the guide fins 30 has led to the results as shown in FIG. 11 and FIG. 12. Specifically, the relation between the length L of the inner wall 33 (cylinder 32) and the width l of the guide fins 33 was studied when the guide fins 30 with the width $l = 16$ mm were attached in the circular air supply port 15 with the diameter $D = 160$ mm and the periphery of the guide fins 30 was surrounded by the cylindrical inner wall 33 (cylinder 32) with the inside diameter $D = 160$ mm. The length L of the inner wall 33 (cylinder 32) was varied in a length range corresponding to half to three times as large as the width l of the guide fins 30, and comparison was made on air velocity distribution at a position 200 mm distant from the front face 21 of the air supply unit 20. The case where the cylinder 32 was not provided

(the length L of the inner wall 33 = 0) was also included in the comparison. FIG. 11 shows the results when the flow rate of the low-temperature air SA blown out from the air supply port 15 is $90 \text{ m}^3/\text{h}$, and FIG. 12 shows the results when the flow rate of the low-temperature air SA blown out from the air supply port 15 is $150 \text{ m}^3/\text{h}$. In FIG. 11 and FIG. 12, the horizontal axis shows each point deviated in a diameter direction from the axis of the air supply port 15 at the position 200 mm distant from the front face 21 of the air supply unit 20. Average airflow velocity was measured at positions deviated in one (positive) direction from the axis and at positions deviated in the other (negative) direction from the axis, and the respective results were compared.

In the structure without the cylinder 32, the velocity near the axis of the air supply port 15 was higher than that in the structure with the cylinder 32. Further, from FIG. 11 and FIG. 12, which show the results of measurement under varied Reynolds numbers of blowout air when the flow rate of the low-temperature air SA was $90 \text{ m}^3/\text{h}$ and $150 \text{ m}^3/\text{h}$ respectively, it has been confirmed that the airflow velocity distribution does not greatly change even when the length of the cylinder 32 is varied. From a practical point of view, since the width l of the guide fins 30 is about 13 mm, setting the length L of the inner wall 33 (cylinder 32) to less than half of this width l would dwindle the significance of providing the inner wall 33 (cylinder 32). It can be said to be preferable to set the length L of the inner wall 33 (cylinder 32) equal to or larger than a half of the width l of the guide fins 30.

As described above, surrounding the periphery of the guide fins 30 by the cylindrical inner wall 33 makes it possible to give a larger number of the rotating components to the low-temperature air SA which is to be blown out to the occupied zone 11 in the air-conditioned space 10 than when the cylinder 32 is not provided. Accordingly, a volume of the air in the air-conditioned space 10 induced by the blown out low-temperature airflow (entrainment ratio) can be further increased, so that the velocity of the low-temperature air SA blown out into the air-conditioned space 10 can be immediately lowered and its temperature can be raised quickly. Then, the

low-temperature air SA supplied into the air-conditioned space 10 flows down to the lower part in the air-conditioned space 10 due to the temperature difference and gradually fills the occupied zone 11 in the lower part in the air-conditioned space 10 at low velocity, so that the occupied zone 11 can be maintained in a comfortable environment.

Meanwhile, in the occupied zone 11 in the air-conditioned space 10, there exists, for example, the person 12 as a heat source, so that the low-temperature air SA that is supplied to the occupied zone 11 to come into thermal contact with the person 12, other equipment with heat generation, or the like is heated in due time to slowly go up. Pollutant such as dirt and gas produced around the person 12 in the occupied zone 11 in the air-conditioned space 10 can be carried by the rising airflow to the upper part in the air-conditioned space 10.

Then, air (heated air) staying in the upper part in the air-conditioned space 10 passes through the exhaust port 16 and the exhaust duct 41 to be exhausted as the exhaust air EA to the outside of the exhaust fan 40 without being stirred, i.e., without disrupting temperature stratification in the occupied zone 11 formed in the lower part in the air-conditioned space 10. In this manner, the pollutant such as dirt and gas is discharged along with the heated air from the upper part of the air-conditioned space 10 while the low-temperature air SA is being supplied to the occupied zone 11 in the lower part of the air-conditioned space 10, so that the inside of the air-conditioned space 10 is ventilated and the occupied zone 11 in the lower part of the air-conditioned space 10 is kept in an environment of the clean low-temperature air SA.

According to the displacement ventilation system 1, the person 12 in the occupied zone 11 in the air-conditioned space 10 is allowed to scarcely feel draft. Further, a volume of induced ambient air (air in the air-conditioned space 10) whose temperature is higher than that of the low-temperature air SA blown out from the air supply ports 15 increases, and thus the temperature difference between the low-temperature air SA and the ambient air becomes smaller immediately, so that a vertical temperature

difference in the occupied zone 11 in the air-conditioned space 10 can be further reduced. This enables efficient air-conditioning of the inside of the air-conditioned space 10 with the smallest possible amount of air and enables contribution to energy savings.

5 In the foregoing, an example of the preferred embodiments of the present invention has been described, but the present invention is not limited to the embodiment shown in the drawings. For example, the cylindrical inner wall 33 surrounding the periphery of the guide fins 30 in each of the air supply ports 15 may be made of an acoustic material. In this case, the
10 cylinder 32 itself attached in each of the air supply ports 15 may be made of the acoustic material, or the acoustic material may be disposed on an inner surface of the cylinder 32.

FIG. 13 shows results of comparison on noise generation, with a material of the cylinder 32 being varied. Specifically, noise when the
15 cylinder 32 is made of foamed polyurethane high in sound absorbing property and noise when the cylinder 32 is made of plywood are compared, and the correlation between the blowout velocity of the low-temperature air SA and noise generation is shown. It has been confirmed that the noise generation is reduced when the cylinder 32 is made of the foamed
20 polyurethane high in sound absorbing effect.

Further, as shown in FIG. 14, a perforated plate 51 having a large number of ventilation holes 50 therein may be disposed in front of the front face 21 of the air supply unit 20 to be parallel to the front face 21, with a predetermined gap M provided in front of the air supply ports 15. This
25 structure can further improve the airflow attenuating property since the low-temperature air SA ejected from the air supply ports 15 further passes through the ventilation holes 50 formed in the perforated plate 51 before being supplied into the air-conditioned space 10.

The open area ratio of the perforated plate 51 (an area of the
30 ventilation holes 50) when the perforated plate 51 is thus provided in front of the air supply ports 15 was studied. The relation between the diameter D of the opening of the air supply port 15 and the distance M from the air supply

port 15 to the perforated plate 51 was also studied. An air supply unit 22 having the following structure was prepared. That is, its front face 21 has a dimension of height 600 mm × width 600 mm and in the front face 21, air supply ports 15 each with the diameter $D = 188$ mm were provided at four places, and guide fins were attached in each of the air supply ports 15. Using this air supply unit 22, warm air was supplied at a flow rate of, for example, 400 m³/h. The maximum velocity of the low-temperature air SA was measured for comparison while the open area ratio of a perforated plate 51 having ventilation holes 50 each with a 6 mm diameter was varied. The distance M between the perforated plate 51 and the air supply ports 15 was fixed to 25 mm. The correlation between the open air ratio (the area of the ventilation holes 50) of the perforated plate 51 and the maximum velocity of the low-temperature air SA was examined at each of positions whose distance X from the front surface of the perforated plate 51 was 100 mm, 400 mm, 700 mm, and 1000 mm respectively. The results shown in FIG. 15 were obtained. Note that the maximum air velocity $V_{\max}$ was made dimensionless with average blowout velocity V_0 at the position of the air supply port 15. It has been confirmed that, when the open area ratio of the perforated plate 51 is 40% or higher, the effect of the present invention is not impaired and especially at the position $X = 1$ mm, the maximum air velocity $V_{\max}$ can be most reduced when the open area ratio of the perforated plate 51 is about 60%.

With a similar structure, the correlation between the distance M from the air supply ports 15 to the perforated plate 51 and the maximum velocity of the low-temperature air SA was examined at each of positions whose distance X from the front surface of the perforated plate 51 was 100 mm, 400 mm, 700 mm, and 1000 mm respectively, with the open area ratio of the perforated plate 51 being fixed to 58% (the diameter of the hole = 6 mm) and with the distance M from the air supply ports 15 to the perforated plate 51 being varied. The results as shown in FIG. 16 were obtained. Note that the horizontal axis in FIG. 16 shows a ratio of the distance M from the air supply ports 15 to the perforated plate 51 relative to the diameter D of the opening

of the air supply port 15 (M/D). It has been confirmed that a difference in the maximum air velocity is small at the position whose distance X from the front surface of the perforated plate 51 is 1000 mm when the distance M from the air supply ports 15 to the perforated plate 51 was set to 7% or longer of the diameter D of the opening of the air supply port 15.

Incidentally, in the example described in FIG. 3 and so forth, the periphery of the guide fins 30 is surrounded by the inner wall 33 of the cylinder 32 attached in each of the air supply ports 15. However, it suffices if only the inner wall 33 surrounding the periphery of the guide fins 30 is provided, and the cylinder 32 is not necessarily essential. Specifically, the cylinder 32 need not be provided if the front face 21 of the air supply unit 20 has a sufficient thickness and the length L of the inner wall 33, which is formed in a cylindrical shape when the circular air supply port 15 is formed, is equal to or larger than a half of the width l of the guide fin 30 as shown in FIG. 17. For example, when the front face 21 of the air supply unit 20 is made of glass wool or the like excellent in the sound absorbing effect and has a sufficient thickness, not only the cylinder 32 is not required, but also the reduction in noise generation as described in FIG. 13 can be expected.

Further, in the description of FIG. 4 and FIG. 5, the plural guide fins 30 are radially attached to the supporting member 31. However, the structure of a blowout member attached in each of the air supply ports 15 is not limited to this form. For example, the structure such as a rotating airflow forming plate, which was previously disclosed in Japanese Patent Application Laid-open No. Hei 9-250803 by this applicant, may be adopted. Specifically, this structure can be easily formed in such a manner that a circular flat plate 55 is punched out, with a circular center portion thereof being left as a supporting member 31, to form fan-shaped guide fins 30 around the supporting member 31, and the guide fins 30 are bent at a predetermined angle to be slanted, as shown, for example, in FIG. 18. Either of the structures can be adopted as long as the guide fins 30 capable of giving the rotating components can be formed.

The form previously described in FIG. 8 shows the example where

the slanting directions of the guide fins 30 are set so that the rotating components of the low-temperature air SA blown out from the vertically adjacent air supply ports 15 are in opposite rotation directions, while the rotating components of the low-temperature air SA blown out from the laterally adjacent air supply ports 15 are in the same rotation direction. However, such setting of the slanting directions of the guide fins 30 provided in the air supply ports 15 is not essential. For example, the slanting directions of the guide fins 30 may be set so that the rotating components of the low-temperature air SA blown out from the laterally adjacent air supply ports 15 are in opposite rotation directions, while the rotating components of the low-temperature air SA blown out from the vertically adjacent air supply ports 15 are in the same rotation direction, though this structure is not shown. Alternatively, the slanting directions of the guide fins 30 provided in the respective air supply ports 50 may be set so that the rotating components of the low-temperature air SA blown out both from the laterally adjacent air supply ports 15 and from the vertically adjacent air supply ports 15 are in opposite rotation directions. In addition, such setting is also possible that the rotating components of the low-temperature air SA blown out from all the air supply ports 15 are in the same rotation direction. Further, such setting is also possible that the rotating components of the low-temperature air SA blown out from the air supply ports 15 are irregularly in the same rotation direction or in opposite rotation directions. The rotation directions of the rotating components of the low-temperature air SA blown out from the respective air supply ports 15 can be arbitrarily set.

Further, such a structure can be also adopted that the circular air supply ports 15 are directly formed in the air supply duct 23 to blow out the low-temperature air SA into the air-conditioned space 10, and the plural guide fins 30, which are intended for giving the rotating components to the low-temperature air SA, and the cylinder 32 are attached in each of these air supply ports 15. In this structure, the air supply unit 20 is not necessary. Another adoptable structure is that guide fins, a cylinder, and a perforated plate are attached in an architecturally constructed air supply unit and supply

air passes in this air supply unit. A wall or a double-layer floor may be utilized for installing the air supply unit.

The duct may be connected to the air supply unit at a top, a side, or a bottom of the air supply unit. Further, the supply air may pass through the inside of a double-layer floor to be sent to the air supply unit. In this case, the air supply duct up to the air supply unit is not necessary. Besides, the air supply unit may be installed around a pillar.

For example, a return duct 45 shown by the dotted line in FIG. 1 may be provided to return part of the exhaust air EA to the air-conditioner 22 for recycling. Further, instead of providing the exhaust fan 40, the heated air staying in the upper part in the air-conditioned space 10 may be continuously pushed out by the low-temperature air SA supplied to the lower part in the air-conditioned space 10. Further, the exhaust port 16 may be formed in the ceiling of the air-conditioned space 10. Moreover, the displacement ventilation system of the present invention is applicable to various air-conditioned spaces, not limited to a living room, where a person, various equipment, and the like exist as described above.

The displacement ventilation system of the present invention is structured as a system supplying low-temperature air into an air-conditioned space, but this displacement ventilation system can be utilized for heating air-conditioning in which high-temperature air is supplied into the air-conditioned space for heating.

In the displacement ventilation system of the present invention, when high-temperature air is supplied into the air-conditioned space from the air supply ports, an inducing action works so that air in the air-conditioned space is induced by the supplied high-temperature air to move together. By giving rotating components to the supplied high-temperature air by a guiding means when the high-temperature air is thus supplied from the air supply ports toward the occupied zone formed in the lower part of the air-conditioned space, it becomes possible to increase a volume of the air in the air-conditioned space induced by the high-temperature air (entrainment ratio). In accordance with such increase in the induced volume, the velocity of the

high-temperature air becomes lower immediately after it is supplied into the air-conditioned space, based on the law of conservation of momentum. This results in substantially no uncomfortable draft accompanying the supply of the high-temperature air toward the occupied zone.

5 Further, in accordance with such increase in the induced volume, low-temperature air in the occupied zone formed in the lower part in the air-conditioned space is mixed with the supplied high-temperature air, so that its temperature can rise immediately. Then, the air (mixed air) whose temperature has been raised due to the mixture of the low-temperature air in
10 the occupied zone and the high-temperature air supplied into the air-conditioned space from the air supply ports moves upward, due to its temperature rise, in the air-conditioned space immediately after the air supply, to reach the vicinity of the ceiling. Consequently, pollutant or the like produced in the occupied zone can be efficiently diluted to be carried to
15 the vicinity of the ceiling.

The air that thus moves to the vicinity of the ceiling comes into thermal contact with a wall of the air-conditioned space, so that the air is cooled by the wall whose temperature has been lowered since it has been cooled by outdoor air, and goes down again to the occupied zone. Thereafter,
20 the air is mixed with the high-temperature air supplied from the air supply ports to become at high temperature again and move up to the vicinity of the ceiling. The air in the occupied zone in the air-conditioned space and the air in the vicinity of the ceiling thus circulate, so that the air in the occupied zone is continuously displaced with fresh air moving down from the vicinity
25 of the ceiling. This enables heating of the occupied zone without causing any occurrence of uncomfortable draft.

Further, while the air in the occupied zone in the air-conditioned space and the air in the vicinity of the ceiling are thus being circulated, the air in the air-conditioned space is exhausted from the exhaust port, so that
30 indoor air is continuously displaced with the fresh high-temperature air supplied from the air supply ports. Consequently, it is possible to remove pollutant or the like produced in the occupied zone and so on to avoid

deterioration of the indoor air. As described above, the displacement ventilation system of the present invention is suitably applicable to heating air-conditioning for heating the occupied zone in the air-conditioned space by a displacement ventilation method.

5

Example

An air-conditioned space 10 (machining room) with a 190 m² floor area and a 10 m ceiling height was air-conditioned, using an air supply unit and a nozzle disposed in the air-conditioned space 10. As shown in FIG. 19, in a plane view, the air-conditioned space 10 has a 15 m × 16 m floor, and a 7.1 m × 7.2 m partition (non-air-conditioned space) is disposed in part thereof. The nozzle has a 500 mm diameter and it blows out supply air horizontally at a 4 m height position. As the air supply unit, two kinds of air supply units were prepared for comparison. One of them (an example of the present invention) was structured such that air supply ports were formed in its front face whose dimension was a 0.6 m width by a 2.1 m height, a plurality of guide fins for giving rotating components to low-temperature air SA were attached in each of the air supply ports, and the periphery of the guide fins was surrounded by a cylinder. The other one as a conventional air supply unit (comparative example 1) was structured such that air supply ports were formed in its front face with a dimension of a 1 m width by a 2.1 m height and only a plurality of guide fins for giving rotating components to low-temperature air SA were provided in each of the air supply ports. Further, as a comparative example 2, low-temperature air SA was supplied horizontally from a nozzle installed at a 4 m height position.

As shown in FIG. 19, in the air-conditioned space 10, machine tools H1 to H8 are disposed, and thermal load by these machine tools H1 to H8 and a mercury lamp disposed on the ceiling is generated in the air-conditioned space 10. The thermal load by these machine tools H1 to H8 and mercury lamp is equivalent to about 80 W/m². Temperature distribution, air velocity distribution, and pollutant spatial distribution were examined at each of A to F points shown in FIG. 19, and the respective resultant values

were compared. The A point is a position close to and directly in front of the air supply unit, the B point is a position in front of the air supply unit and more distant therefrom than the A point, and the C point is a position in front of the air supply unit and still more distant therefrom. The D point is not a position in front of the air supply unit but is a position across the partition. The E and F points are both positions on a surface of an inner wall of the air-conditioned space 10. At the B point and the position of the machine tool H3, tracer gas as pollutant was supplied.

States of the air-conditioning operation when the example of the present invention and the comparative examples 1, 2 were compared are shown in FIG. 20 (Table 1). A pressure fan installed in the ceiling was used for exhaust, and a flow rate of exhaust air was adjusted so as to be equal to a flow rate of supply air. The comparison was made when outdoor temperature was 30°C, with a flow rate of air-conditioning air being adjusted to 4000 m³/h, and supply air temperature being adjusted to 18°C. As the tracer gas as simulation of pollutant, mixed gas of SF₆ and He was used, with its density being adjusted equal to that in the air. The tracer gas was discharged at a fixed flow rate from immediately above the machine tool (H3) as a heat source or from a place where no heat source exists (1 mm above the floor at the B point), and its concentration spatial distribution was measured in each of the cases of the example of the present invention and the comparative examples 1, 2.

FIG. 21 shows vertical temperature distribution at the D point surrounded by the machine tools H2 to H6 as heat sources, the D point being distant from the air supply ports. It can be confirmed that in the example of the present invention and the comparative example 1, air temperature of the occupied zone is lower and air temperature in the ceiling which is not an occupied zone is higher, compared with the case where the nozzle, which is a mixed type, (comparative example 2) is operated. The vertical temperature difference in the example of the present invention is smaller than that in the comparative example 1, which is indicative of a state where more comfortable environment is maintained.

FIG. 22 to FIG. 25 show air velocity distributions at the A to D points, respectively. Even though the blowout air velocity in the operation of the comparison example 1 (0.3 m/s) was lower than that in the operation of the example of the present invention, it can be confirmed that the foot-level air velocity at each of the A to C points in the comparative example 1 is higher than that of the example of the present invention. Further, at the D point distant from the air supply unit, the occupied-zone air velocity in the example of the present invention is higher as a whole than that in the comparative example 1. It can be said that in the example of the present invention, due to a larger volume induced by the supply air than that in the comparative example 1, an apparent flow rate of the supply air reaching a distant place becomes higher.

FIG. 26 shows results of comparison on PMV and SET* at a height position 1 m above the floor at the D point. In the comparison, it was assumed that a metabolic rate was 1.2 met and clothing insulation was 0.6 clo. It is seen that among the three methods, the example of the present invention can achieve the greatest improvement in warm comfort at the most distant point.

FIG. 27 to FIG. 29 show concentration distribution of the tracer gas, which is made dimensionless with concentration at an exhaust port, at each of the A, C, and D points when the tracer gas is discharged from the machine tool H3 as a heat source. It can be confirmed that the comparative example 1 can achieve the lowest concentration at a place 1 m above the floor, which is the occupied zone, but the concentration at the occupied zone in the example of the present invention is about half that of the case where the nozzle is used.

FIG. 30 to FIG. 32 shows concentration distribution of the tracer gas, which is made dimensionless with the concentration at the exhaust port, at each of the A, C, and D points when the tracer gas is discharged from a place 1 m above the floor at the B point where no heat source exists. It is seen that the example of the present invention can achieve the lowest average concentration in the occupied zone 1 mm above the floor. In the

comparative example 1, the indoor air becomes active only at the foot level where the supply air is advected and at a place where a thermal rising airflow is generated by heat generation. Therefore, when pollutant is produced from a place where no buoyancy is generated, the pollutant is not diluted, so that a high-concentration part occurs in the occupied zone. In the example of the present invention that induces the air in the occupied zone by the rotating airflow, the flow of the air in the occupied zone is generated, enabling efficient dilution of the pollutant.

FIG. 33 shows comparison results on vertical temperature distribution measured at the D point when supply air temperature was set to 30°C and a flow rate of air-conditioning air was set to 4000 m³/h in heating operation under outdoor temperature of 10°. During the heating operation, the supply air goes up to the ceiling by buoyancy and is cooled by the wall to go down. In the example of the present invention, the air in the occupied zone is induced by the rotating airflow, so that the air in the vicinity of the ceiling and the air in the occupied zone are mixed more during the heating. Therefore, in the example of the present invention, owing to the induction by the rotating airflow from the air supply ports installed in the occupied zone, the foot-level temperature at a place 0.1 m above the floor is raised by about 2°C to reduce the vertical temperature difference in the occupied zone, compared with the comparative examples 1, 2 where the vertical temperature difference in the occupied zone is large. Moreover, in the example of the present invention, temperature of the occupied zone 1 m above the floor is higher by about 1°C than that in the comparative examples 1, 2. The comparison of the three types can lead to the confirmation that the example of the present invention achieves the most efficient heating.

WHAT IS CLAIMED IS:

1. A displacement ventilation system that performs ventilation by supplying low-temperature air into an air-conditioned space and exhausting heated air that has been heated and has risen in the air-conditioned space, the displacement ventilation system comprising:

a plurality of guide fins that are attached in an air supply port from which the low-temperature air is supplied toward an occupied zone located in a lower part in the air-conditioned space, to give a rotating component to the low-temperature air which is to be blown out into the air-conditioned space, said plural guide fins being arranged radially around an axis of the air supply port and slanted at an equal angle relative to a plane perpendicular to the axis of the air supply port; and

a cylindrical inner wall disposed coaxially with the air supply port to surround a periphery of said plural guide fins.

2. A displacement ventilation system that performs ventilation by supplying low-temperature air into an air-conditioned space and exhausting heated air that has been heated and has risen in the air-conditioned space, the displacement ventilation system comprising:

a plurality of guide fins that are attached in an air supply port from which the low-temperature air is supplied toward an occupied zone located in a lower part in the air-conditioned space, to give a rotating component to the low-temperature air which is to be blown out into the air-conditioned space, said plural guide fins being arranged radially around an axis of the air supply port and slanted at an equal angle relative to a plane perpendicular to the axis of the air supply port; and

a cylindrical inner wall disposed coaxially with the air supply port to

surround a periphery of said plural guide fins, wherein a length of the inner wall in an axial direction of the air supply port is equal to or larger than a half of a width of the guide fin in the axial direction of the air supply port.

3. The displacement ventilation system according to claim 1, wherein the inner wall is made of an acoustic material.

4. A displacement ventilation system that performs ventilation by supplying low-temperature air into an air-conditioned space and exhausting heated air that has been heated and has risen in the air-conditioned space, the displacement ventilation system comprising:

a plurality of guide fins that are attached in an air supply port from which the low-temperature air is supplied toward an occupied zone located in a lower part in the air-conditioned space, to give a rotating component to the low-temperature air which is to be blown out into the air-conditioned space, said plural guide fins being arranged radially around an axis of the air supply port and slanted at an equal angle relative to a plane perpendicular to the axis of the air supply port; and

a cylindrical inner wall disposed coaxially with the air supply port to surround a periphery of said plural guide fins,

wherein the air supply ports are arranged in plurality, each provided with the plural guide fins for giving the rotating component to the low-temperature air and each provided with the cylindrical inner wall surrounding the periphery of said plural guide fins, and

wherein said guide fins in the adjacent air supply ports are slanted in opposite directions.

5. A displacement ventilation system that performs ventilation by supplying low-temperature air into an air-conditioned space and exhausting heated air that has been heated and has risen in the air-conditioned space, the displacement ventilation system comprising:

a plurality of guide fins that are attached in an air supply port from which the low-temperature air is supplied toward an occupied zone located in a lower part in the air-conditioned space, to give a rotating component to the low-temperature air which is to be blown out into the air-conditioned space, said plural guide fins being arranged radially around an axis of the air supply port and slanted at an equal angle relative to a plane perpendicular to the axis of the air supply port; and

a cylindrical inner wall disposed coaxially with the air supply port to surround a periphery of said plural guide fins and

a perforated plate disposed in front of the air supply port, an open area ratio of said perforated plate being 40% or higher.

6. A displacement ventilation system that performs ventilation by supplying low-temperature air into an air-conditioned space and exhausting heated air that has been heated and has risen in the air-conditioned space, the displacement ventilation system comprising:

a plurality of guide fins that are attached in an air supply port from which the low-temperature air is supplied toward an occupied zone located in a lower part in the air-conditioned space, to give a rotating component to the low-temperature air which is to be blown out into the air-conditioned space, said plural guide fins being arranged radially around an axis of the air supply port and slanted at an equal angle relative to a plane perpendicular to

the axis of the air supply port; and

a cylindrical inner wall disposed coaxially with the air supply port to surround a periphery of said plural guide fins,

wherein a diameter D of an opening of the air supply port and a distance M from the air supply port to said perforated plate are set to satisfy a relation of $M/D \geq 0.07$.