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Swirl Diffuser Design and Performance Characteristics for Air Flow in Air Conditioning of an Automobile-A Review

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Abstract:
An air diffuser is the mechanical device that is designed to control the characteristics of a fluid at the entrance to a thermodynamic open system. Diffusers are used to slow the fluid's velocity and to enhance its mixing into the surrounding fluid.
Swirl diffusers can create better air mixing to enhance indoor air quality and help achieve compliance through Air Change Effectiveness measure. Swirling vanes are used in air diffusers to create swirling outflow jet, so that more rapid mixing with ambient air can be achieved. The Air Change Effectiveness calculation depends strongly on the flow characteristics produced by the diffuser outlet that vary considerably between different modelling set ups. Proper calibration and correct definition of performance related parameters are important to affect the radially diffusing flow pattern.
This study demonstrates the common approaches, identifies the critical design parameters, analyses and discusses the differing outcomes in terms of flow pattern, air distribution.
Frictional effects may sometimes be important, but usually they are neglected. However, the external work transfer is always assumed to be zero. It is also assumed that changes in thermal energy are significantly greater than changes in potential energy and therefore the latter can usually be neglected for the purpose of analysis. We are designing three different models of swirl diffuser on pro-E software and then analyse its performance experimentally.

1. Introduction

Air diffusers are used widely in air-conditioning systems and the air diffusion is very much influenced by the characteristics of different diffuser designs. For air supply systems in automobiles, swirling diffusers are most popular. The method of modeling the diffuser is critical as it has an important impact on the accuracy of the predicted airflow pattern in the car. Swirl diffusers are modular devices that are designed to mount into an access front panel space and “plug” into the air handling space. Diffusers are installed within an access front panel and can be relocated at any point on the base plate. This device delivers conditioned air to the space and allows the occupant to manually control both the volume and direction of the air. The diffuser is constructed of a durable, high impact, polycarbonate material available in black or gray finish. Delivering air from the front offers added benefits, beyond rearrangement flexibility. Cool, clean air is delivered directly into the occupied zone of the space, so heat and pollutants are not continually circulated within the space as they are with an overhead system. The result is a space that has stratification of heat and pollutants, with concentrations in the lower levels of the space less than those at the upper levels of the space. Ventilation is accomplished through displacement as opposed to dilution. Commercial office spaces are progressively more reliant to new designs of Heating Ventilation and Air Conditioning (HVAC) equipment to achieve better indoor conditions measured against current industry standards. One of the most telling indoor air quality parameters when it comes to air distribution system and fresh air delivery is Air Change Effectiveness (ACE). ACE is commonly used as a measure for effective delivery of outside air by a ventilation system to the occupied space in a building.

1.1. Air Swirl Diffuser

Air swirl diffuser used for distribution of air in automobiles provides complete flexibility, better indoor air quality, and greater personal comfort while reducing energy consumption. Constant volume diffusers provide greater personal comfort control by allowing the occupant the ability to control the volume and direction of airflow in their space. Thermostatically controlled VAV diffusers are available for use in areas where loads change quickly and inconsistently such as a meeting room or private office.

1.2. Air Change Effectiveness and Indoor Air Quality

Commercial office spaces are progressively more reliant to new designs of HVAC equipment to achieve better indoor conditions measured against current industry standards such as Green star and NABERS. One of the most telling indoor air quality parameters when it comes to air distribution system and fresh air delivery is Air Change Effectiveness (ACE). ACE is commonly used as a measure for effective delivery of outside air by a ventilation system to the occupied space in a building.

According to ANSI/ASHRAE 129-1997, the ACE of a building is measured by comparing the age of air in the occupied space at the occupant breathing level (1 meter from floor) to the age of air of the space if the indoor air were perfectly mixed. The age of air in this context is the average time for air to travel from an inlet to a particular point in an indoor space. ACE is strongly governed by the air flow patterns within a room. Factors affecting it include ventilation system design and operation, outside air and supply air flow rates, mixing coefficient, air distribution system and configuration that determine the type of flow, locations of supply inlets and return outlets, air conditioning operation mode etc.

An effective outside air delivery with complete mixing gives an ACE value of 1. On a broad category, entrainment flow air distribution systems that create a flow pattern by entrainment of room air into a jet typically has ACE less than 1. Displacement flow systems that sweep the air through the room from one end to the other could have ACE as high as 1.2. Typical office air distribution systems with ceiling supply of cool air should be designed to achieve ACE of 1.0. Floor supply of cool air and ceiling return typical of displacement ventilation with low velocity providing unidirectional flow and thermal stratification could achieve 1.2 whereas systems with makeup supply drawn in on the opposite side of the room from the exhaust/return may get only 0.8 and make up supply drawn in near to the exhaust and/return location could get as low as 0.5.

1.3. Modeling of Swirl Diffuser

Swirl diffusers are designed to provide effective indoor air diffusion through specially designed swirl deflection blades to produce a highly turbulent radial air flow pattern that will induce better mixing of room air. This also results in fast temperature equalisation to give stable room conditions with minimum temperature gradients. The excellent qualities of air distribution from high performing diffusers enable designers to aim for a high value of ACE. Swirl diffusers have recently become very popular because they generate radially high induction swirl air flow by drawing room air up into the supply air pattern to induce superior air mixing. Better mixing means better ACE.

Generally, diffusers come with a set of performance data derived from experimental results. For swirl diffusers, the most important parameters other than flow rate are the throw distances at specific terminal velocities (Vt normally measured at 0.75, 0.5 and 0.25 m/s) and the effective area. In order to reflect these performance data accurately, it is imperative to understand how to model the swirl diffuser correctly. This involves proper representation of its physical characteristics, correct definition of its performance data as well as other derivative parameters to ensure attainment of its performance characteristics as described in its specifications.

1.4. The Different Modelling Approaches and the Resulting Flow Characteristics

In a scenario where the diffuser is represented with a fan, the parameters to be defined are fluid temperature, flow direction that can be specified as vectors or angles from the normal, flow rate, swirl which has two options i.e. magnitude or RPM and the turbulent parameters if the two-equation or RNG model has been selected to model turbulence. Specific to swirl that controls the flow direction in relation to the direction of blade revolution, it can be defined as a swirl magnitude that takes the ratios of fan's radial coordinate to the outer radius of the fan and the tangential to axial velocities or more easily as a factor to the fan's RPM with a certain assumption on how much of the tangential velocity is transferred to the fluid.

The vortex diffuser representation for swirl diffusers takes a more involved procedure to include performance data in the form of a set of terminal velocities at specified throw distances. Room supply conditions that contain flow rate, temperature, species, and turbulence and swirl angle are to be specified as well. The swirl angle determines how much off the normal direction to the supply inlet surface the flow direction takes. The last step is to specify the modelling method of the diffuser from two options i.e. momentum or box method with the former more suited for vortex diffusers.

For proper representation of diffuser performance, the simulation requires that the airflow from the diffuser enters the room with momentum corresponding to the initial jet velocity instead of the typical velocity calculated from the volumetric flow rate and the geometric cross-sectional area that the diffuser occupies. A momentum source that accounts for the initial jet velocity is added to the diffuser to reproduce diffuser performance in the simulation in a much similar way with the approach used for linear jets. The implementation for ceiling diffusers (circular, square, and vortex) however, maintains the radial or lateral jet characteristic of the diffuser by modelling the circumferential distance of the diffuser and extruding it in the direction normal to the floor.

1.5. Factors Affecting Diffuser Performance

1.5.1. Swirling Blades Angle

The effect of blades angle on the diffuser performance is shown in Fig. As depicted in the figure, the evacuation time is minimized at the angle of 32◦ and the diffuser shows the best performance, consequently. In addition, the sensitivity of the evacuation time to the blades angle is surprisingly significant in the range of 30–35◦. The diffuser maximum discharge velocity is also illustrated in Fig. 1. As shown in the figure, with an increase in the blades angle, the maximum velocity decreases continuously due to increment of the effective outlet area. As a major conclusion, the optimum blades angle has no meaningful relationship with the diffuser discharge velocity. To describe the effect of swirling blades on the resultant airflow pattern, three cases are assessed in details:

1. Diffuser with no swirling blade;
2. Diffuser with blades angle of 32◦;
3. Diffuser with blades angle of 40◦.

The indoor airflow distribution in three cases is shown in Fig. 2.

As depicted in Fig. 2a, when the diffuser has no blade, air enters the room without any rotation just like a jet which may reduce the diffuser entrainment effect considerably. As a result, the presence of swirling blades has a key role in making the air to rotate and in improving the diffuser mixing effect. The airflow patterns through the room are also illustrated in Fig. 3b and c. at the blades angle of 32◦ and 40◦, respectively.

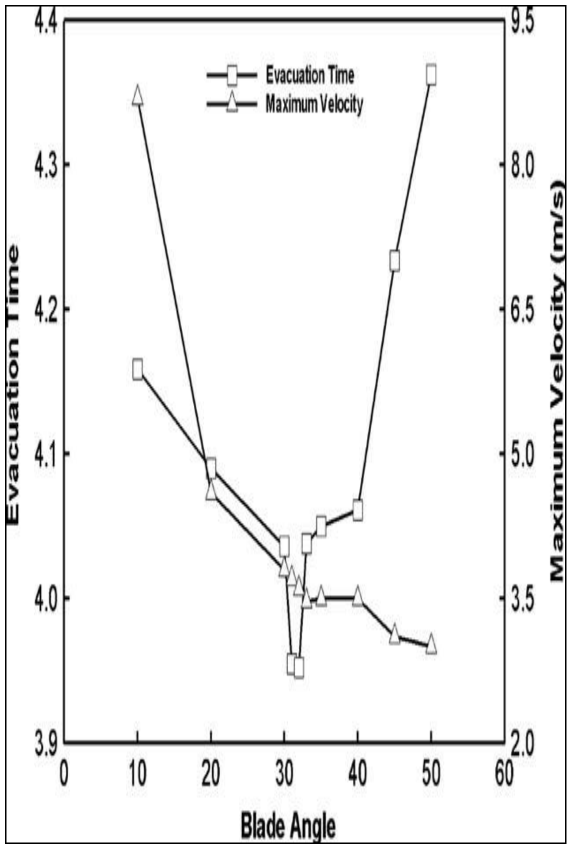

Figure 1: The effect of blades angle on the evacuation time and the maximum discharge velocity

As shown in the above mentioned figures, the velocity distribution is remarkably different from the previous case and the blades cause the flow to swirl. At the optimum blades angle, namely 32◦, the discharge air is well attached to the ceiling due to Coanda effect and distributed through the room almost uniformly. Such a well distributed pattern caused by an impressive Coanda effect, improves the indoor air mixing and the resultant induction effect. At the same time, the air velocity does not go over 0.25 m/s through the room, except near the diffuser where is not important for the residents comfort. With an improper blades angle, Coanda effect becomes weak and the airflow distribution is not perfect, despite some rotation and mixing in the diffuser discharge air. As a consequence, at the non-optimum blade angle, the diffuser operation is not perfect which leads to not only the evacuation time increment but also increase of the indoor air velocity to more than 0.25 m/s at 1.5mabove the floor. Such a draught effect may bother residents and increase comfort complaints.

1.5.2. Slots Geometry

Fig. 3 shows the effect of slots geometry on the diffuser evacuation time and its maximum discharge velocity. As illustrated in the figure, the diffuser performance is weakly depends on the slots geometry in a relatively wide range. When the angle of slots is less than 25◦ or their aspect ratio is less than 3, the indoor airflow pattern is almost the same as Fig. 2a or c and air enters the room with no or insufficient rotation, despite presence of the swirling blades. As a result, the slot geometry also plays a vital role in making the discharge air to swirl, although its effect is not as critical as the blades angle. It must be noted that although Fig. 3 shows an inverse relationship between the evacuation time and the diffuser discharge velocity, it seems that improvement in diffuser performance at high slots angles and aspect ratios is not directly due to increase of the discharge velocity. In fact, at the non-optimum slots geometry – angle of less than 25◦ and aspect ratio of less

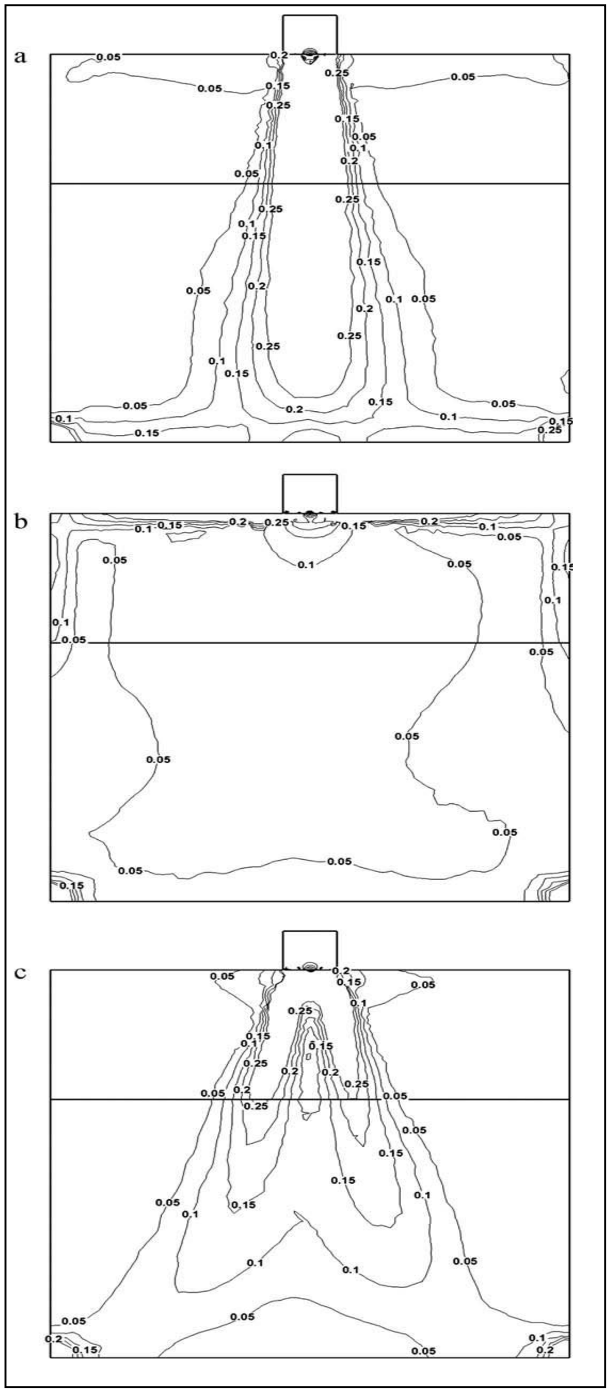

Figure 2: the effect of blades angle on the air velocity distribution through the room:

(a) No swirling blade; (b) blades angle of 32◦; (c) blades angle of 40◦. than 3 – Coanda effect is weakened due to reduction of discharge air rotation which causes the airflow to detach from the ceiling and makes the uniform indoor air distribution to break down.

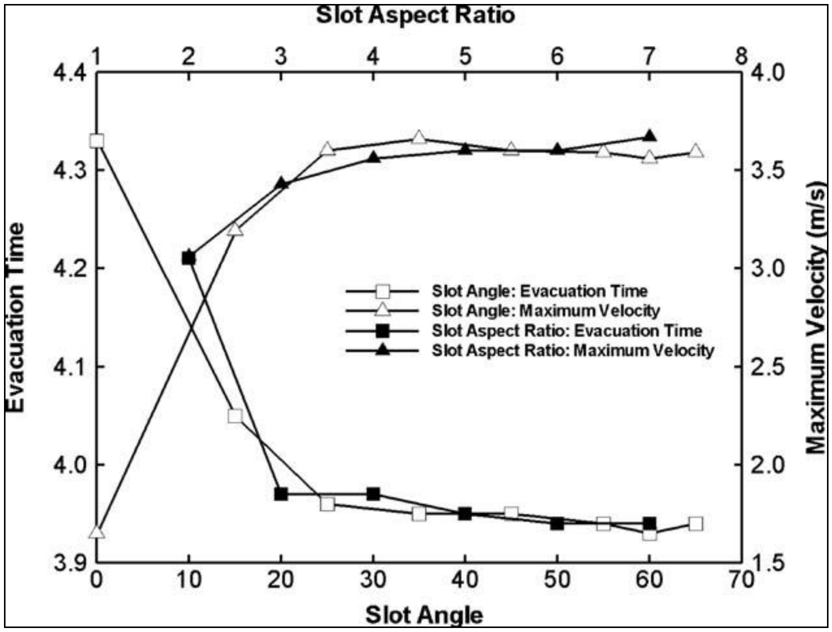

Figure 3: The effect of slots geometry on the evacuation time and the maximum discharge velocity

1.5.3. Airflow Rate

It is almost well known that with an increase in the airflow rate, the evacuation time decreases and its acceptable range is dictated mainly by the required air throw and noise criteria. However, the effect of airflow rate on the diffuser optimum geometry may be still a question. As shown in Fig. 4, the optimum swirling blades angle is surprisingly independent of the diffuser airflow rate. As this angle is the main geometric parameter of a swirling diffuser and the slots geometry has almost no effect in a relatively wide range, the airflow rate seems to have no major effect on the diffuser optimum geometry.

1.5.4. Diffuser Jet Indexes

The swirling jet performance may be characterized by an index, namely jet decay coefficient, which is introduced by Hu [11] as:

$$K = \frac{V_x}{V_o}\frac{x + x_p}{\sqrt{A_o}}$$

where K is the jet decay coefficient, Vx is the centerline velocity at the distance x. Vo and Ao are the effective outlet velocity and area, respectively and xp is the distance between the jet virtual origin and the diffuser centreline.

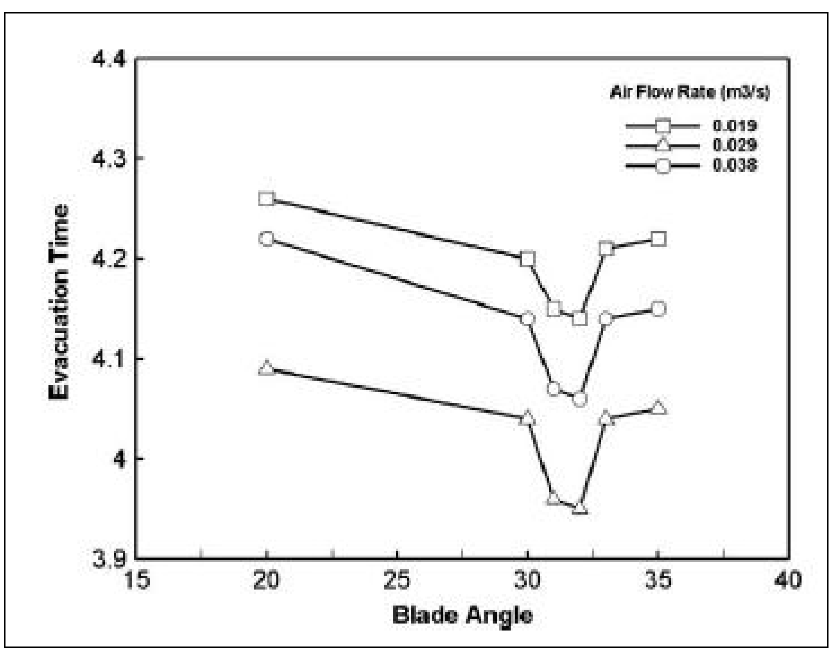

Figure 4: The effect of diffuser airflow rate on the optimum swirling blades angle

1.6. Different Model of Swirl Diffuser

1.6.1. Floor "Swirl" Diffuser

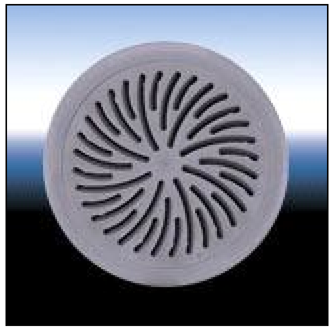

Figure 5

Floor "Swirl" Diffusers are designed for use in raised access floor air distribution systems, where the floor cavity is used as a pressurized supply air plenum. The NFD core design produces a low velocity helical "swirl" discharge air pattern. The design achieves high induction rates of room air which optimizes mixing for maximum comfort conditions.
An architecturally appealing face design compliments any contemporary decor and is available as standard in a gray or black finish as well as a wide variety of custom colors. Allowing extreme flexibility in space planning, the diffuser, once installed in the access floor panel, can be quickly relocated to accommodate changing conditions and floor layouts.

1.6.2. Aluminum Floor "Swirl" Diffuser

Figure 6

Aluminium Floor "Swirl" Diffusers are designed for use in raised access floor air distribution systems, where the floor cavity is used as a pressurized supply air plenum. The specially designed ANFD core produces a low velocity helical "swirl" air pattern. This design achieves high induction rates of room air which optimizes mixing for maximum comfort conditions.
An architecturally appealing face design compliments any contemporary decor and is available as standard in a gray or black textured finish as well as a wide variety of custom colors. Allowing extreme flexibility in space planning, the diffuser, once installed in the access floor panel, can be quickly relocated to accommodate changing conditions and floor layouts.

1.6.3. VAV Floor "Swirl" Diffuser with Actuator

Figure 7

Floor "Swirl" Diffusers with actuators are designed for use in raised access floor air distribution systems, where the floor cavity is used as a pressurized supply air plenum. An integral modulating actuator provides variable air volume control in cooling applications for precise zone temperature control. The NFD-VAV core design produces a low velocity helical "swirl" discharge air pattern. The design achieves high induction rates of room air, which optimizes mixing for maximum comfort conditions.
An architecturally appealing face design compliments any contemporary decor and is available as standard in a gray or black finish as well as a wide variety of custom colors.
Allowing extreme flexibility in space planning, the diffuser, once installed in the access floor panel, can be quickly relocated to accommodate changing conditions and floor layouts.

1.6.4. VAV Aluminium Floor "Swirl" Diffuser with Actuator

Figure 8

Aluminium Floor "Swirl" Diffusers with actuators are designed for use in raised access floor air distribution systems, where the floor cavity is used as pressurized supply air plenum. An integral modulating actuator provides variable air volume control in cooling applications for precise zone temperature control. The core design produces a low velocity helical "swirl" discharge air pattern. The design achieves high induction rates of room air, which optimizes mixing for maximum comfort conditions. An architecturally appealing face design compliments any contemporary decor and is available as standard in a gray or black textured finish as well as a wide variety of custom colors.

Figure 9: Smoke visualization of the airflow pattern from the swirl diffuser

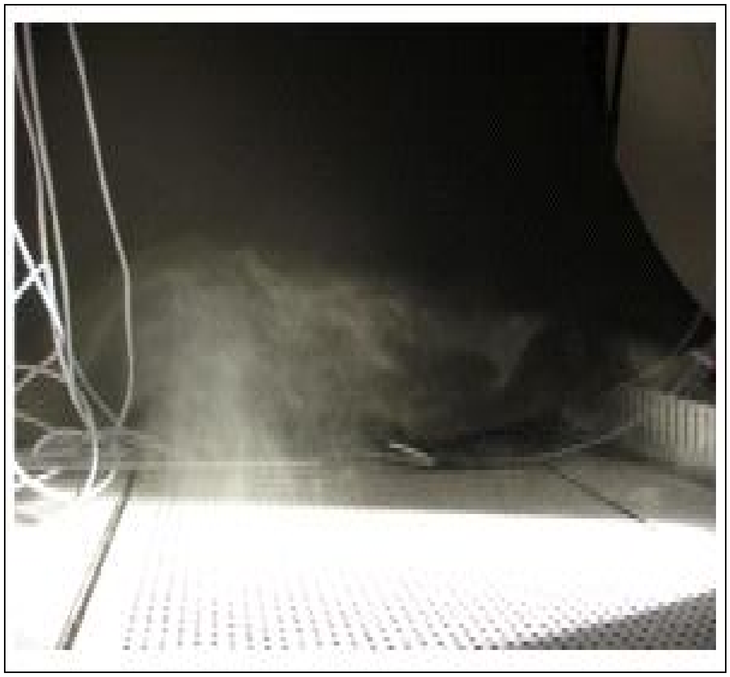

Figure 10: Smoke visualization of the airflow pattern the perforated panel

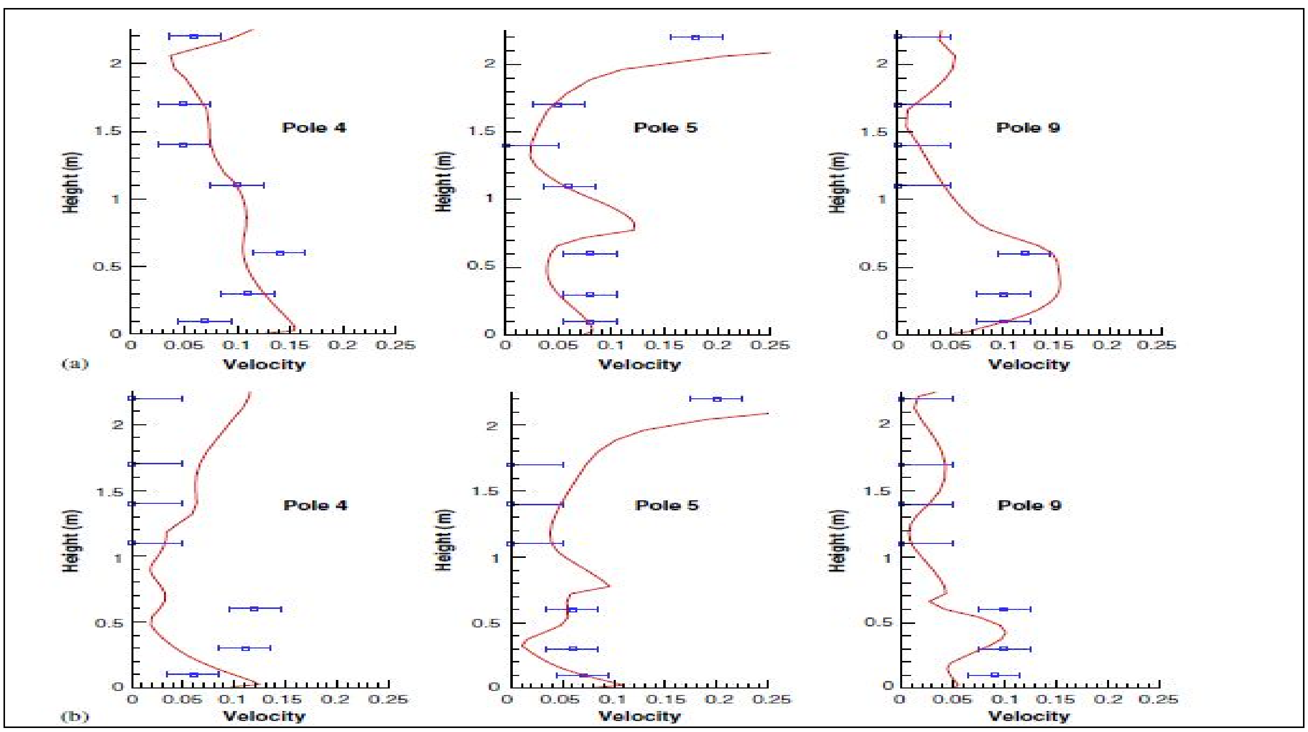

Figure 9 (a) Comparison of the vertical velocity profiles of Workshop-1with swirl diffusers: units—m/s, symbols—measurement, lines—computation. (b) Comparison of the vertical velocity profiles of Workshop-2 with perforated panels. Units—m/s, symbols—measurement, lines—computation.

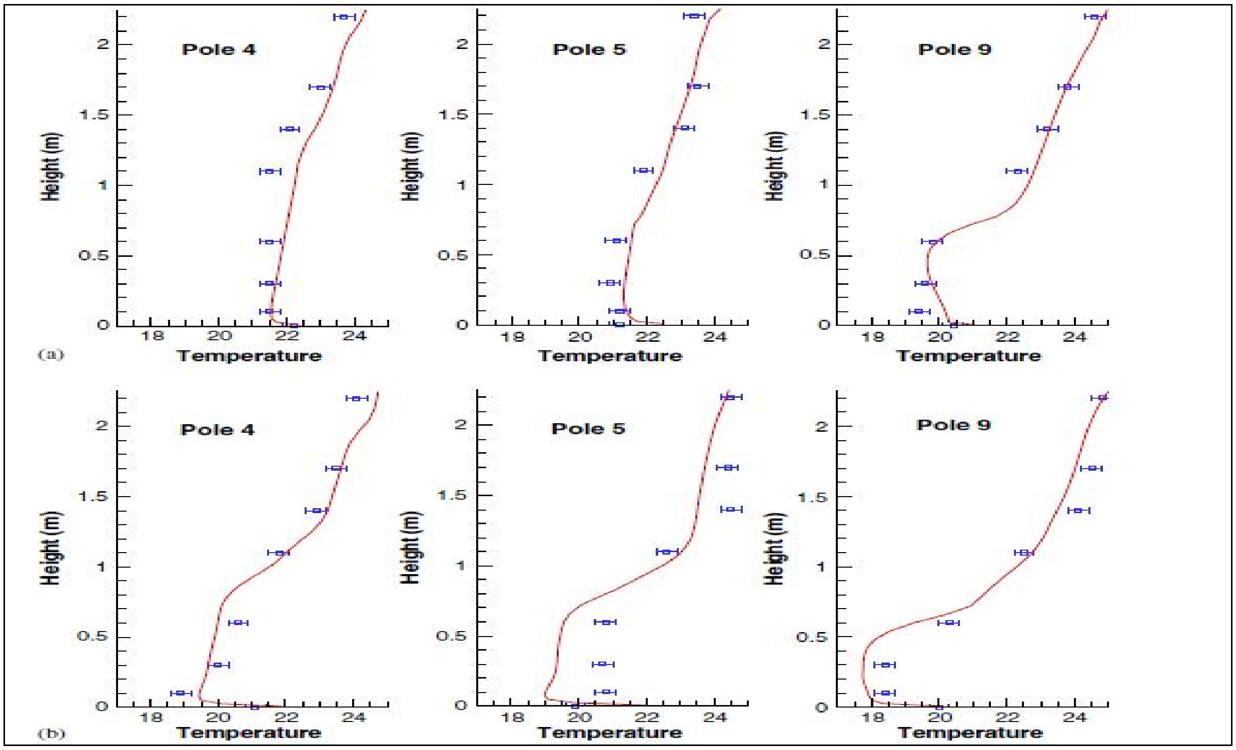

Figure 10 (a) Comparison of the vertical temperature profiles of Workshop-1with swirl diffusers: units—OC, symbols—measurement, lines—computation. (b) Comparison of the vertical temperature profiles of Workshop-2 with perforated panels units—OC, symbols—measurement, lines—computation.

2. Conclusions

The results from this study show that an air distribution from swirl diffusers in an automobile can improve indoor air quality because the contaminant concentration in the breathing zone is lower than that of mixing system. Since a more unidirectional flow was created, the slow recirculation at the occupant zone was eliminated with both swirl diffusers and perforated panels, and the risk of cross contamination can be effectively reduced. The system with the swirl diffusers can provide a better comfort level than that with the perforated panels due to the mixing by the diffusers.

This study helps in designing different models of swirl diffuser for air conditioning in automobiles under different operating conditions. We can improve the ACE and human comfort by varying the slot angle of diffuser. It will results in better mixing of air inside the automobiles and the variation in temperature of air inside the vehicle will be reduced.

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