Diffuse ceiling ventilation

Diffuse ceiling ventilation is a novel ventilation concept where the fresh air is supplied into occupied zone through perforations or slots in the suspended ceiling panels. The large opening area of diffuse ceiling inlet enables the system to supply low temperature air without causing draught. This system has a great potential to make full use of the natural cooling resource of outdoor air, especially in cold and dry climates, such as in Central or Northern Europe. Even though the interest in applying diffuse ceiling ventilation has been growing rapidly, the technical experience in designing the system is still very limited. This article aims to provide an overview of this novel ventilation system in terms of ventilation principle and system characteristics, benefit and limitation, critical design parameters and their impact. Recommendations on designing a diffuse ceiling ventilation system are given at the end.

Keywords: Diffuse ceiling ventilation, Design guide, Thermal comfort, Energy saving


CHEN ZHANG
Department of Civil Engineering, Aalborg University, Aalborg
cz@civil.aau.dk

PER HEISELBERG
Department of Civil Engineering, Aalborg University, Aalborg
ph@civil.aau.dk

Ventilation is one of the most important approaches to control the indoor environment. Besides the basic requirement on ensuring acceptable indoor air quality, more and more attention is paid to design of the ventilation systems to be more energy efficient and with a high level of thermal comfort. Diffuse ceiling ventilation is a very promising system, showing superior performance on both of these aspects (energy and thermal comfort) compared to conventional ventilation systems.

The principle of diffuse ceiling ventilation is to supply fresh air to the occupied zone from perforations or slots in the suspended ceiling panels, see **Figure 1** [1]. Due to the large opening area of the supply inlet, the air enters the occupied zone with very low velocity and no fixed direction, therefore given the name of 'diffuse'. Due to the low momentum supply, the system can directly supply air with very low temperature without causing draught. It has a great potential to make full use of the natural cooling resource of outdoor air, especially in cold and dry climates, such as in Central or Northern Europe.

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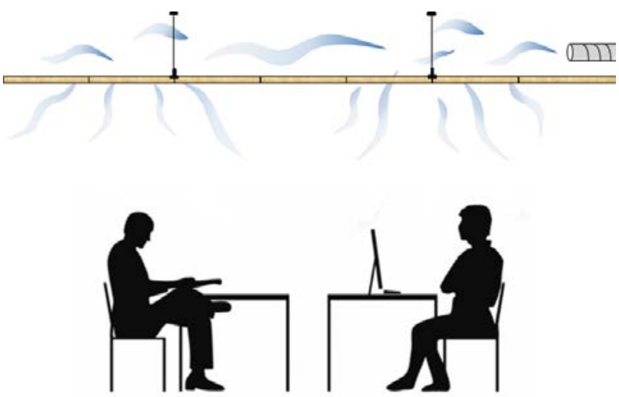

Figure 1. Illustration of the diffuse ceiling ventilation system. [1]

Air distribution principle and different types of diffuse ceiling inlet and their characteristics

Depending on air change rate the air distribution patterns in rooms with diffuse ceiling inlet can either be controlled by buoyancy force from heat sources or by momentum force from the air supply. To control the air distribution pattern by momentum force, a high air change rate is needed (50 – 100 h^{-1}), where a piston-flow takes place in the room. This air distribution principle is often applied in clean rooms, where very high ventilation effectiveness is expected. Low return openings are required in this case. When the air change rate is lower than 10 h^{-1}, air distribution will be controlled by buoyancy forces, and the ventilation effectiveness will be close to 1, which can be regarded as similar to a mixing flow. There is no strict requirement for the location of the return opening in this case.

In this article, special attention is paid to systems with a buoyancy-controlled air distribution pattern. This diffuse ceiling air distribution principle is suitable for buildings with a high cooling load and with high requirements to thermal comfort, like in offices or classrooms.

The supply inlet of diffuse ceiling ventilation can generally be divided into three types based on their airflow path through the ceiling [3]. As shown in **Figure 2**, Type A is made of ceiling panels which are impenetrable to air. The supply air enters the room through the slots between the panels and with relatively high velocity. These micro-jets below the slots generate high local entrainment and might cause draught problems at the occupant head level in the room with low floor to ceiling height. Type B is made of perforated ceiling panels, the air is supplied through both ceiling panels and the slots in between. Type C is made of porous materials instead of composed by ceiling panels. Compared with the first two types, this type of inlet has a relatively large pressure drop. **Figure 3** illustrates the pressure drop across different types of diffuse ceiling inlets, as a function of the airflow rate.

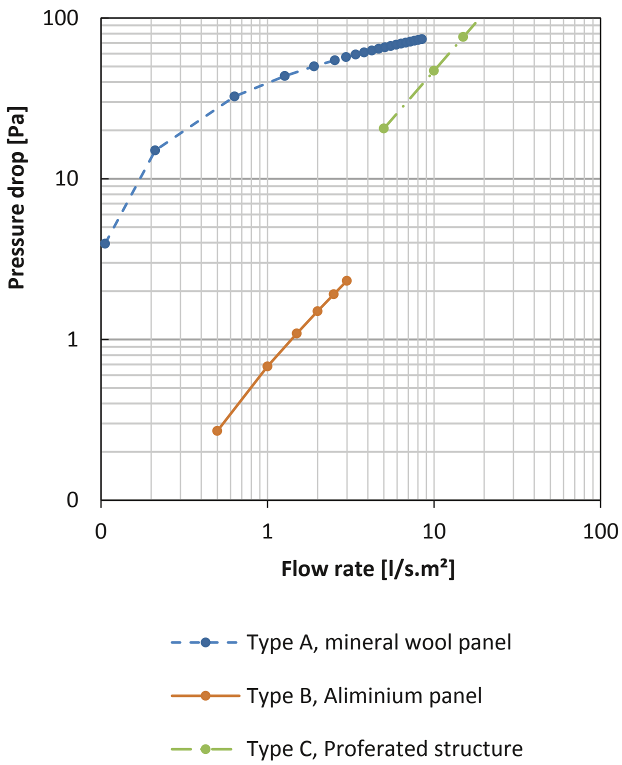

Figure 3. Pressure drop across the diffuse ceiling as function of airflow rate. [1]

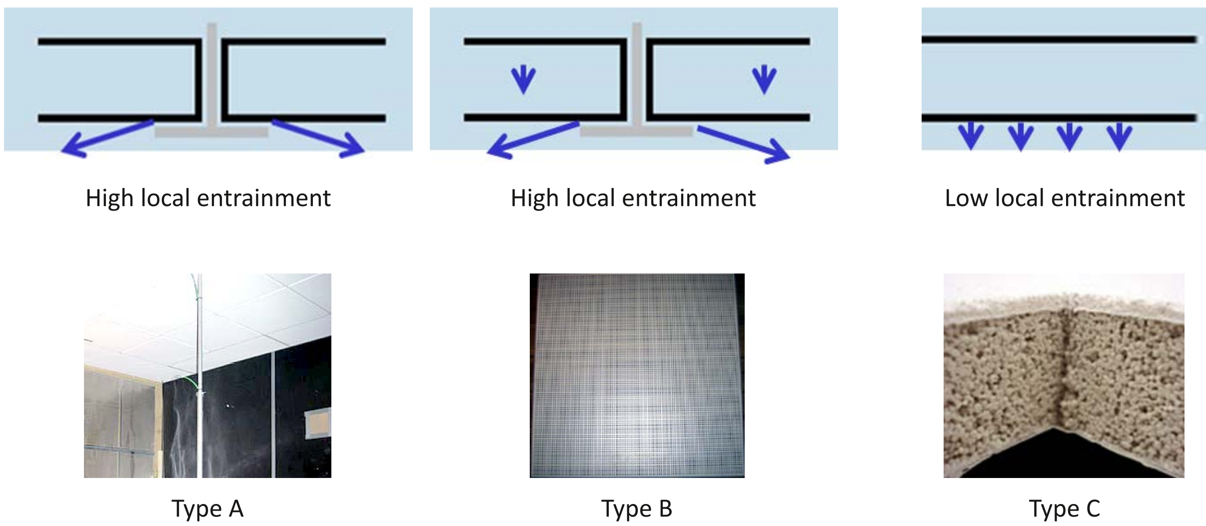

Figure 2. Three types of diffuse ceiling inlet based on air path and related product examples. [3]

Thermal comfort and indoor air quality

One of the most important features of diffuse ceiling ventilation is the high thermal comfort level. The low momentum supply enables the system to provide a draught free environment, even without preheating the cold outdoor air in the winter season. Experimental results indicate that no significant draught is experienced even with supply air temperatures down to 0°C [4]. In addition, diffuse ceiling ventilation creates a uniform temperature distribution in the occupied zone and a vertical temperature gradient less than 1 K/m can be expected under cooling conditions. A temperature stratification may occur if the system is used to warm up spaces. However, heating by ventilation is normally only required during unoccupied hours to preheat the space before occupants show up.

The airflow pattern in the room with diffuse ceiling ventilation is comparable to mixing ventilation, even though the driven force is different for these two ventilation principles. The ventilation effectiveness by diffuse ceiling ventilation is close to 1 (one meaning perfect mixing). The previous studies also indicate that no stagnant zones or shortcut of air circulation occurs in the room [5].

System capacity

In **Figure 4**, the system capacity of diffuse ceiling ventilation is compared with five other ventilation systems use a design chart method. The design chart can be expressed as a $q_0 - \Delta T_0$ chart, which encloses an area that supplies sufficient fresh air and ensures draught-free air movement in the occupied zone. This method makes it possible to compare different systems under the same boundary conditions (same room geometry and heat loads) [6]. The five other ventilation systems include the most commonly applied systems in office buildings or classrooms, they are mixing ventilation from a wall-mounted terminal, mixing ventilation from a ceiling-mounted diffuser, mixing ventilation from a ceiling-mounted diffuser with a swirling flow, displacement ventilation from a wall-mounted low-velocity diffuser and vertical ventilation from a ceiling-mounted textile inlet. It is shown in **Figure 4**, that the diffuse ceiling inlet is able to handle the highest heat load of 72 W/m² without compromising thermal comfort, while the cooling capacity of the other ventilation systems is between 36 ~ 53 W/m². The system does not have clear limits on the ventilation rate and temperature difference between supply and return. However, the limit of cooling capacity is caused by the air velocities created by convection flows generated by the heat

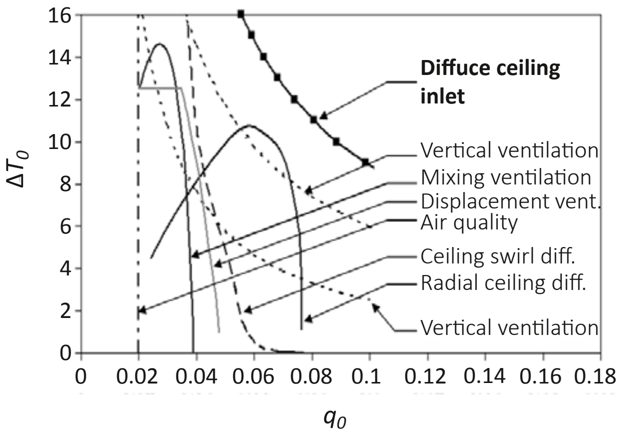

Figure 4. Design chart for diffuse ceiling inlet and five other air supply systems, q_0 is airflow rate [m³/s] and ΔT_0 is temperature difference between supply and exhaust air [°C]. **Note:** Design chart can only be applied under certain boundary conditions. [6]

sources in the room. The diffuse ceiling inlet could supply cold outdoor air (down to 0°C) to the room without creating draught. This means that preheating will often not be required and a high cooling capacity of the air can be maintained. Diffuse ceiling ventilation is especially preferable in the climate like Northern Europe or Central Europe, where a large natural cooling resource is available almost all year.

Energy saving potential

Diffuse ceiling ventilation presents large potentials for energy saving. First of all, the low-pressure drop of the system, associated with diffuse ceiling inlets and air distribution by a plenum (instead of ducts) as well as low ventilation rate demand (no preheating for supply air), allows a reduction in fan power and even allows the system to be driven by natural ventilation. Secondly, diffuse ceiling ventilation presents a high possibility to work together with night cooling. Because the ceiling slabs are typically exposed to the supply air pathways in the plenum, it increases the efficiency of the thermal storage and improves the pre-cooling effect.

Design parameters

It is important to emphasize that system capacity of diffuse ceiling ventilation is determined by several design parameters, such as diffuse ceiling type, opening area size and location, room geometry and plenum configuration, heat load magnitude and distribution, and that system capacity will be depended on the given conditions. The effects of different design parameters are discussed in the following.

Heat load magnitude and distribution

Buoyancy force is the dominant driven force for the air distribution in the room with diffuse ceiling ventilation. Therefore, heat sources play an important role and the magnitude and location of heat sources influence the system performance significantly. An evenly distributed heat load result in much lower air velocity and turbulence levels than a concentrated heat load at one end of the room, as shown in **Figure 5** [4][7][8]. At the same time, the system is more efficient in removing heat loads from sources with a high location, for example, light bulbs. Different heat load locations generate different flow patterns with resulting in variations in the maximum allowed heat load [1].

Room geometry and plenum design

Room geometry is another parameter that influences the performance of diffuse ceiling ventilation. In rooms with a high floor to ceiling height air velocity levels increase relatively and reduces the cooling capacity [4][7]. As mentioned earlier, the space above the suspended ceiling serves as a plenum to distribute air and the dimension of the plenum influence the supply airflow. If the maximum distance to the plenum inlet is larger than 10 m or if the plenum height is below 20 cm [1][9], it cannot be guaranteed that the supply air will be acceptably distributed in the room and which will cause draught issue in the occupied zone. In order to overcome this issue, it is recommended to install ducts in the plenum and help to uniform the air distribution throughout the ceiling area, if the plenum dimensions cannot be fulfilled [1].

Diffuse ceiling inlet properties

The inlet area of diffuse ceiling ventilation is rather flexible. The inlet can either occupy the whole ceiling area or a part of the ceiling. The relative location of heat sources and the diffuse ceiling opening areas plays an important role. The results from the previous studies indicate that air supply just above heat sources give the highest cooling capacity because the cold downward supply air meets the upward thermal plume and reaches a good mixing.

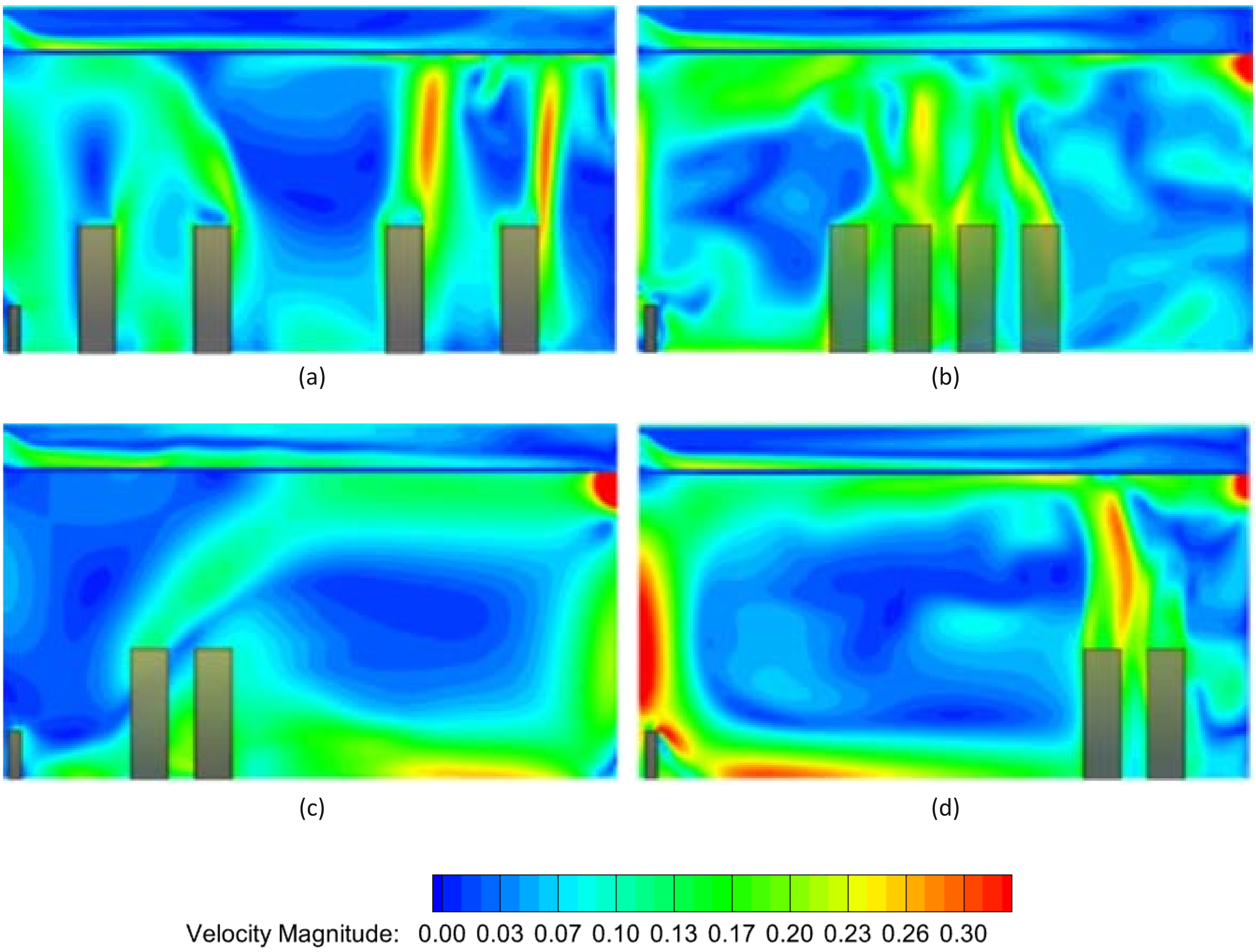

Figure 5. Velocity distribution with different heat load layouts (a) evenly distributed, (b) centered, (c) front side and (d) backside. [4]

Different from the other air distribution devices, diffuse ceiling inlet has a radiant cooling potential due to its large inlet area and low surface temperature. Instead of removing the entire heat load by convection, a part of the sensible heat load can be removed by radiation heat exchange. The surface temperature of the suspended ceiling is determined by the supply air temperature and the ceiling panel material. Ceiling panels with high thermal conductivity have a high radiant effect, for example, aluminium [9]. However, the surface temperature needs to be controlled carefully to be above the dew-point temperature of the space, in order to avoid condensation on the ceiling panels.

Condensation is a risk needs to be addressed when uses this ventilation system. Condensation on diffuse ceiling panels will affect visual perception, ventilation function and cause early failure of ceiling panels. The risk can be minimized by choosing proper diffuse ceiling panel and suspension profile. The ceiling panels with high absorptive capacity could serve as humidity buffers and give substantial stability to the indoor relative humidity, for example wood-wool cement panel with moisture capacity up to 3 kg/m². In addition, the suspension profile with high air tightness could avoid high-temperature, high-humidity room air travelling back to the plenum.

Conclusion

Recommendations on designing a diffuse ceiling ventilation system include:

- The diffuse ceiling ventilation system is primarily used for cooling. Stratification might occur when the system is used for heating. However, the system could be applied to preheat the space before occupants show up.
- The heat load distribution strongly affects the indoor thermal comfort. Avoid a concentrated location of the heat load at one side of the room.
- Avoid applying diffuse ceiling ventilation in rooms with large floor to ceiling heights. It is recommended to be applied in rooms with a room height less than 3 m and with a room width less than 10 m.
- If the plenum height is less than 20 cm or the room geometry cannot fulfil the recommendation above, it is recommended to install ducts in the plenum to uniform the air distribution.
- The diffuse ceiling inlet can either occupy the whole ceiling area or a part of the ceiling. It is more efficient to place inlet above the heat sources.
- Diffuse ceiling surface temperature needs to be carefully controlled to avoid condensation risk.

A diffuse ceiling ventilation design guide [1] has been published, which includes design procedure and case studies. Please refer to [10]. ■

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