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The Performance of Diffuse Ceiling Inlet and other Room Air Distribution Systems

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SUMMARY

The paper analyses different room air distribution systems, and describes a design chart which can be used for the evaluation of variables as air quality, air velocity and temperature gradient as a function of flow rate and temperature difference in the supply system. The design chart can also be used for analysing other system parameters as e.g. system capacity and noise.

The paper addresses the diffuse ceiling inlet and five other air distribution systems, namely 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. All these systems can be used in the case of cooling of the room.

KEYWORDS

Room air distribution, Design chart, Diffuse ceiling inlet, Mixing ventilation, Displacement ventilation.

INTRODUCTION

A building requires supply of fresh air and removal of heat, gases and particulates which are emitted in the building. It is not sufficient to supply clean air with the correct temperature and flow rate to each individual room in a building, it is also necessary to design an air distribution system in the room in such a way that occupants experience high air quality and thermal comfort in the occupied zone. Therefore, it is important that the occupied zone has the optimum climate with respect to air temperature, air velocity, temperature and velocity gradients, mean radiant temperature and asymmetric radiant temperature. It is also important that the supply air reaches all parts of the occupied zone. Areas of the room lying outside the occupied zone may have higher velocity levels and higher or lower temperatures without decreasing comfort in the occupied zone.

THE DESIGN CHART

One of the aims of the design of an air distribution system is to find the limits of the diffuser regarding possible flow rates into the room and temperature differences between the supply and return temperatures, i.e. to find the limits that maintain an acceptable comfort level with small draught and low temperature gradients in the room in the case of cooling. To make the decisions more qualified, a design chart was developed; see (Nielsen, 1980 and Nielsen, 2007). This design chart has been utilized in connection with several ventilation principles used in the same test room as seen in the following sections. By use of the design chart it becomes possible to compare different systems, which enables the user to find the best system for individual demands.

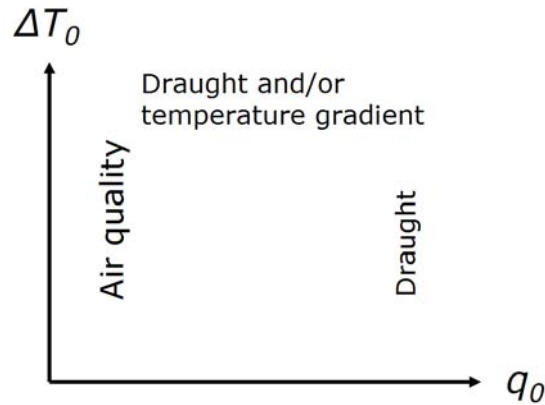


Figure 1. Design chart that indicates the restrictions on the flow rate q_o and on the temperature difference ΔT_o between return and supply.

Figure 1 describes the idea behind a design chart for air distribution in rooms. The chart is based on the minimum and maximum allowable flow rate q_o to the room, and also on the maximum temperature difference between return and supply. The figure indicates that it is necessary to have a minimum flow rate of fresh air into the room to obtain a given air quality. This flow rate is constant and independent of ΔT_o when the air distribution system generates mixing, but it can be a modest function of ΔT_o in the case of displacement ventilation. It is characteristic of air distribution systems based on the supply of momentum flow that they generate a mixing in the occupied zone, which is important for the creation of uniform conditions in the occupied zone when the heat load is high. There is a drawback to the systems, namely that this flow generates draught when the flow rate is above a certain level. Some systems, such as diffuse ceiling inlet analysed in this paper, generate a very low level of momentum flow and, therefore, they do not show a limit of q_o . Draught is in this case generated by the heat loads in the room, which limits the product of q_o and ΔT_o (thermal load).

The temperature difference ΔT_o between return and supply is also restricted as indicated in figure 1. A too high temperature difference may either cause draught in the occupied zone or create a too large temperature gradient in the room.

Figure 1 indicates an area for the variables q_o and ΔT_o , which will give a sufficient supply of fresh air, and a draught free air movement in the occupied zone, plus a restricted vertical temperature gradient. This area is considered as the design area for a given air distribution system. The limits for the design area can be related to different parameters as:

- Sufficient air supply (L/s)
- CO₂ concentration (ppm)
- Draught (m/s)
- Draught ratio (DR) (%)
- Vertical temperature gradient (K/m)
- Percentage of dissatisfied due to temperature gradient (PD_{grad}) (%)
- Percentage of dissatisfied due to asymmetric radiation (PD_{rad}) (%)
- System capacity

- Noise from system and diffusers

The limits for the design area are in this paper defined as a maximum air velocity of 0.15 m/s in the occupied zone, a maximum vertical temperature gradient of 2.5 K/m and a minimum flow rate of 10 l/s per person.

It is possible to find the limits in the design chart, even if the experiments are made under conditions different from the boundaries in the chart as explained in Figure 2. The figure shows the values for a given experiment ($q_o, \Delta T_o$). The curve corresponds to a constant value of $\Delta T_o / q_o^2$, which is also a constant Archimedes number. A normalized velocity is constant along the curve, and it is possible to find the position of the limiting flow $q_{o,lim}$ for a given reference velocity u_{max} (as indicated in the upper part of the figure)

$$u_{max} = (q_{o,lim}/a_o) \text{ const} \quad (1)$$

although no measurements have been made at this flow rate. Experiments and the similarity principles are used to express Equation (1). The similarity principles show that any non-dimensional velocity as $u/(q_o/a_o)$ can be given as a unique function of the Archimedes number if the flow in the room is a fully developed turbulent flow (high Reynolds number flow) and the non-dimensional velocity is therefore constant for a constant Archimedes number; see (Tähti and Goodfellow, 2001).

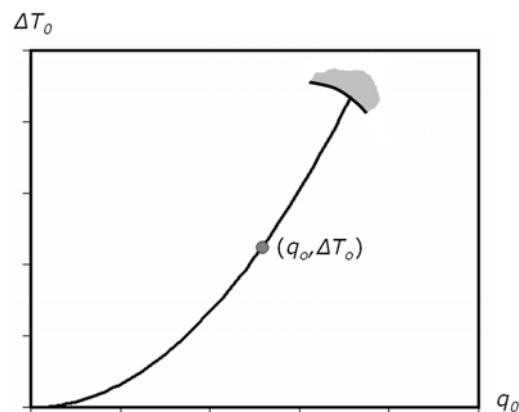


Figure 2. Experiments with constant Archimedes number in a design chart.

The draught (the design limits for the system) is not always generated by the flow from the supply openings as discussed earlier, it can also be generated mainly by the heat load in the room, which is the case with a diffuse ceiling inlet where the whole ceiling, or part of the ceiling, is the inlet. The maximum velocity can in this case be found from

$$u = \text{func}(Q) \quad (2)$$

where u is a velocity in the occupied zone and Q is the thermal load removed by the ventilation system. A reference velocity like 0.15 m/s gives the corresponding load Q_{max} .

TEST ROOM AND DIFFUSE CEILING INLET

The systems are all tested in the same full-scale room. The dimensions of the room are in accordance with the requirements of the International Energy Agency Annex 20 work

(Lemaire et al. 1993) with length, width and height equal to 4.2 m, 3.6 m and 2.5 m, respectively.

Figure 3 shows the furnishings and the heat load of the room (an office layout). The heat load consists of two PC's, two desk lamps and two manikins producing a total heat load of 480 W. The heat load is in some of the experiments increased up to 1060 W.

The thermal load is constant in all experiments, and the flow rate has been raised from 2.75 h^{-1} up to 10.45 h^{-1} with a variation in the temperature difference, ΔT_o , between 12 K and down to 3.5 K. The room temperature is close to 22.9°C in all the experiments.



Figure 3. Furnishings and heat load in the full-scale room.

The diffuse ceiling inlet is made as a standard acoustic ceiling (30 mm) mounted 150 mm below the ceiling, see Figure 4.



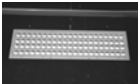



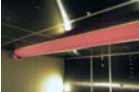
Figure 4. A: Test room with diffuse ceiling inlet. B: Location of acoustic ceiling below the ceiling. C: Supply opening to the plenum.

Tests were made with both a radial diffuser in the plenum, and with an opening without pressure loss, see Figure 4C, and it was not possible to measure any difference in the air distribution in the plenum. Pressure differences measured on an acoustic element ($1.2 \times 0.6 \times 0.03 \text{ m}$) and on the ceiling show that the main part of the supply flow passes the ceiling in the suspension system of the acoustic elements. The whole ceiling worked as supply area.

The paper compares the diffuse ceiling inlet with five other air distribution systems, namely: 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 a low impulse system based on a textile terminal. All the systems are summarised in Table 1, (Nielsen et al., 2003, 2005 and 2006). It is possible to make a direct comparison between the different air

distribution systems shown in Table 1 because the experiments are made in the same room with the same office equipment; two computers, two desk lamps and two manikins.

Table 1. Five different air distribution systems.

System	Supply	Return	
Mixing ventilation	End wall-mounted	Return opening below supply terminal	
Mixing ventilation	Ceiling swirl diffuser	End wall-mounted below ceiling	
Mixing ventilation	Radial ceiling diffuser	End wall-mounted below ceiling	
Displacement ventilation	End wall-mounted	End wall-mounted below ceiling	
Vertical ventilation	Ceiling-mounted low impulse textile terminal	End wall-mounted at floor level	

RESULTS AND DISCUSSION

It is expected that the velocities in the occupied zone are, to some extent, independent of the supply flow, because the momentum of the supply flow has a very low level. It is also expected that the velocities are dependent on the heat load in the room. Figure 5 shows the averaged velocity at the ankles (0.1 m), heads (1.1 m) of the two manikins, and at a height of 1.4 m. The figure shows that the velocities are dependent of the heat load as expressed in Equation (2). The design limits for the system are 0.15 m/s, and this level is observed at a height of 1.8 m, corresponding to the height of the occupied zone.

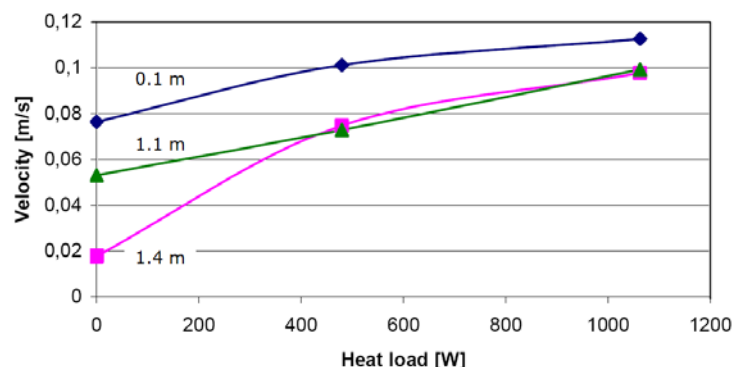


Figure 5. Velocity at the heights of 0.1 m, 1.1 m and 1.4 m versus heat load. The flow rate to the room is $0.1 \text{ m}^3/\text{s}$.

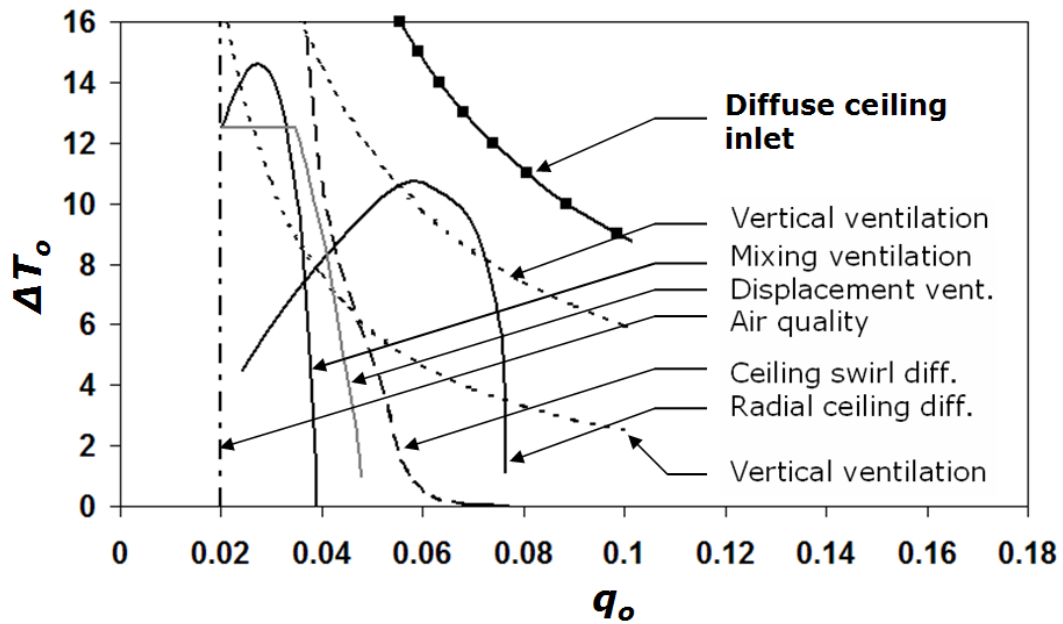


Figure 6. Design chart for a diffuse ceiling inlet and five other air distribution systems. Air quality requires in all cases that q_o is larger than $0.02 \text{ m}^3/\text{s}$.

Figure 6 shows the design chart for the diffuse ceiling inlet as well as for the five other air distribution systems. It is obvious that the diffuse ceiling inlet is able to handle the highest load compared to all the other systems. The draught limit (0.15 m/s at a height of 1.8 m) is close to a line representing a constant load, $\Delta T \cdot q_o = \text{const}$, which means that the draught in the occupied zone is independent of the flow rate to the room.

Figure 6 indicates that the room, to some extent, has the same level of comfort as regards maximum velocity and temperature gradient in the case of mixing ventilation with a wall-mounted diffuser or displacement ventilation with a wall-mounted low velocity diffuser. The figure also shows that the vertical ventilation (low impulse) systems are superior to both mixing ventilation based on a wall-mounted diffuser and to displacement ventilation (the $q_o - \Delta T_o$ curve is located to the right of the curves of the two other systems). In connection with vertical ventilation it should be noticed that the layout with two work places in a small room may result in the possibility of handling a higher load compared with the situation in a large room with vertical ventilation. (The lowest curve for vertical ventilation in Figure 6 is obtained for one manikin in the room, corresponding to two persons in a larger room).

Mixing ventilation generated by a radial ceiling-mounted diffuser is able to handle a higher heat load than any of the other five systems, but not a load as high as the diffuse ceiling inlet.

It should be emphasised that the design chart, Figure 6, is dependent on room size, room layout and layout and design of the terminal units (type, number, location, etc.).

It is possible to use the method behind the design chart in rooms larger than the test room in this paper, and in connection with other types of diffusers as well. It is necessary to work with modified flow elements (wall jet, penetration length, stratified flow, etc.) corresponding to the

actual room dimension, which results in a specific design chart for the individual room and the individual diffuser.

CONCLUSIONS

In many cases the air distribution system can be designed by a dimensional analysis method based on flow elements. Many new air distribution systems are difficult to define from a combination of flow elements and other methods must be used. It is shown that results obtained by experiments can be expressed in a $q_o - \Delta T_o$ design chart. It is possible to compare measurements on different air distribution systems in the design chart if the experiments are made in the same room with the same heat load geometry.

It is also shown that air distribution systems based on a diffuse ceiling inlet are able to handle the highest load in a ventilated room with a conventional geometry. Mixing ventilation and ceiling-mounted diffusers are able to generate comfortable conditions up to a thermal load which is slightly superior to systems with mixing ventilation from wall-mounted diffusers, displacement ventilation with a wall-mounted low velocity diffuser or vertical ventilation systems with ceiling-mounted textile terminals.

It is characteristic that a diffuse ceiling inlet is without restrictions on both temperature difference ΔT_o and flow rate q_o within the level of traditional design practice. This effect is seen in Figure 6 as a lack of limitation of ΔT_o and flow rate q_o . A similar effect can be seen for the vertical ventilation system.

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