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Published in:
CLIMA 2016 - proceedings of the 12th REHVA World Congress

Publication date:
2016

Document Version
Peer reviewed version

CLIMA 2016 - proceedings of the 12th REHVA World Congress

Heiselberg, Per Kvols

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Field Study of Diffuse Ceiling Ventilation Performance in a Landscape Office

Daria Zukowska[#1], Marie Wolsing[#], Malene Grysbæk[#], Christian Anker Hviid[#*]

[#]*Department of Civil Engineering, Technical University of Denmark,*

Brovej, Building 118, DK-2800 Kgs. Lyngby, Denmark

**Saint-Gobain Nordic*

Robert Jacobsens Vej 62A, DK-2300 Copenhagen S, Denmark

[1]dz@byg.dtu.dk

Abstract

Performance of diffuse ceiling ventilation with regard to thermal comfort and limits of the cooling capacity of the system was studied in a 97 m^2-landscape office. Seven operation scenarios were tested: two for mixing ventilation with ceiling mounted fan coils and five with diffuse ceiling ventilation. The conditions for ventilation air change rates were 1.2, 11.5 and 17.9 h^{-1}, respectively and temperature differences between supply and exhaust ranged between 5.5 and 10.6 K. The vertical room temperature distribution and the air speed in several points in the room were measured. The results show that diffuse ceiling ventilation has substantial potential for landscape office applications because it can provide important cooling capacity while maintaining an acceptable comfort level in the occupied zone. It does not generate draught in the occupied zone even at large temperature differences between supply and exhaust and great air change rates, while the same design parameters caused risk of draught in many points in the case with mixing ventilation. Good mixing in the occupied zone in case of both systems resulted in only small vertical temperature gradients. The results from the study allow extrapolating the design chart q-ΔT for diffuse ceiling ventilation systems for higher ventilation flow rates.

Keywords - diffuse ceiling ventilation; landscape office; thermal comfort; air speed; vertical temperature gradient; cooling capacity; design chart

1. Introduction

Office spaces require supply of fresh air in order to remove heat, gases and particulate matter emitted from the building and occupants, and to ensure good air quality and thermal comfort in the occupied zone. Offices with high heat load require a high ventilation airflow which can cause draught when supplied through conventional inlet diffusers [1]. Diffuse ceiling ventilation is a concept of ventilating spaces with high air change rates by supplying the air into a plenum above a suspended ceiling instead of directly to the room.

The air is distributed to the room with low velocity through the perforation and cracks in the ceiling [2]. A design chart has been developed for the maximum cooling capacity of different ventilation systems and it shows that diffuse ceiling ventilation has the ability to handle a high heat load without creating draught and large vertical temperature differences [1].

Diffuse ceiling ventilation has been proven to perform well in a number of laboratory experiments, field investigations and numerical simulations in terms of thermal comfort [1-6]. However, the performance of the system in a real office environment has not previously been reported. The present paper reports the performance of diffuse ceiling ventilation in an office with regard to thermal comfort and limitations for cooling capacity [7].

2. Methods

Facility

The measurements were performed in a landscape office of 5.9 x 16.8 x 2.6 m (width x length x height) in Kalundborg, Denmark. The office was occupied by 6 persons and during the investigation the majority of the desks was placed in one end of the room in order to concentrate the heat sources (Fig. 1). The acoustic ceiling, which consists of a suspension system with Gyptone Quattro 50 gypsum boards size 600 x 600 mm and a perforation area of 18% (perforation size 12 x 12 mm), is installed at a height of 2.6 m above the floor creating a 0.8 m high plenum above.

Fig. 1 Test office with mixing ventilation system

The office is equipped with a mixing ventilation system with 5 fan coils type LGG SK-ECM 42 mounted in the acoustic ceiling, as shown in Figs. 1 and 2 (left). The air is exhausted through 3 ceiling diffusers. The fan coils can function as ventilation units (fan level 0) or as a cooling system with recirculation of the exhaust air through the outlet in the bottom of the unit (fan levels 1-3). The original set up of the ceiling is called “baseline condition” in the paper.

The same ventilation system with fan coils was used during the investigation of diffuse ventilation, however, all fan coils were moved above the acoustic ceiling (Fig. 2 right), so that the air was supplied to the plenum above the suspended ceiling instead of directly to the room. The plenum worked as a pressure chamber and air was distributed to the room through the perforation in the gypsum plates and cracks between the plates and the suspension system. In order to prevent the airflow from the plenum to enter the room through the other leakages, the ceiling lamps and the skylights were sealed.

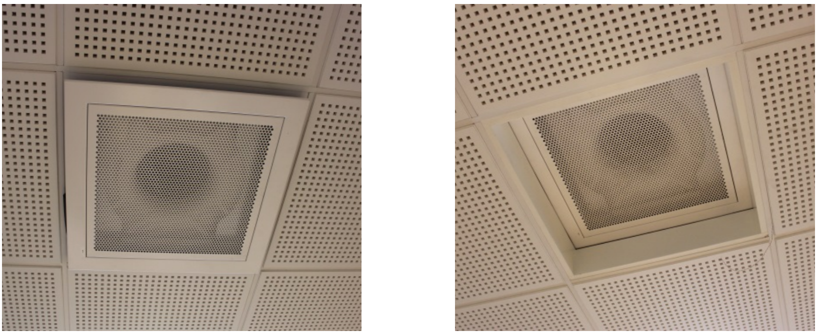

Fig. 2 Fan coil position in baseline condition (left) and in diffuse ventilation condition (right)

Investigated conditions

Seven different ventilation conditions, two baseline conditions with mixing ventilation and five conditions with diffuse ceiling ventilation, were investigated in the office comprising three different ventilation air change rates of 1.2, 11.5 and 17.9 h^{-1} (fan level 0, 1 and 3 respectively) and temperature differences between supply and exhaust between 5.5 and 10.6 K. The detailed description of the seven conditions is listed in Table 1.

Table 1. Investigated ventilation conditions

Condition	Air change rate [h^{-1}]	Temperature difference [K]	Supply air temperature [°C]	Cooling capacity [W/m^2]
Base_F3_ΔT5.5	17.9	5.5	17.8	86
Base_F1_ΔT6.6	11.5	6.6	16.6	66
Dif_F3_ΔT5.8	17.9	5.8	16.9	91
Dif_F3_ΔT7.4	17.9	7.4	19.5	116
Dif_F1_ΔT6.8	11.5	6.8	14.4	68
Dif_F0_ΔT5.8	1.2	5.8	17.2	6
Dif_F0_ΔT10.6	1.2	10.6	18.0	11

Experiments were carried out during autumn 2015 with approximately the same outdoor temperature for all scenarios and with overcast sky. The 6 employees were performing sedentary work and had the same level of clothing in all conditions. To maintain the heat balance for the room, it was ensured that the room temperature was stable during the measurements. To maintain the heat balance when testing high cooling capacities, up to three electrical radiators (900 or 1800 W each) were used and placed under the desks to minimize their influence on the air movement pattern in the room.

Measurement technique

Thermal comfort in the office in each of the investigated conditions was assessed in terms of draught risk and vertical temperature gradient.

In order to examine the risk of draught, air speed measurements were performed in 9 locations in the office for the baseline conditions (Locations 1-9, see Fig. 3) and in 17 locations for the cases with diffuse ventilation. The air speed was registered by a wireless thermoanemometer system SensoAnemo5100SF with four omnidirectional air speed sensors mounted at heights 0.15 m, 0.85 m, 1.55 m and 2.25 m. The accuracy of the measurements with the speed sensor is ±0.02 m/s.

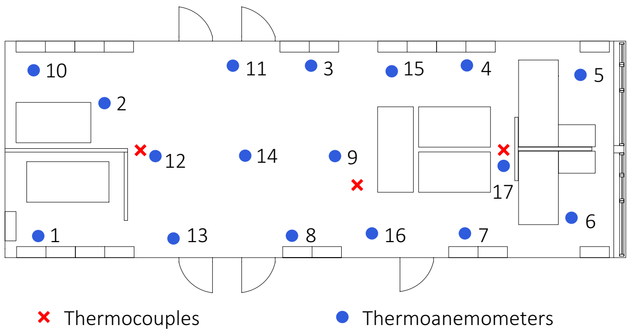

Fig. 3 Locations of air speed and room temperature measurements in office

The total recording time in one position of the anemometers was 10 minutes and logging interval was 2 seconds. The first 4 minutes was used to achieve steady state, while the highest value of the following 2 times 3-minute averages was used for further analysis.

The vertical air temperature distribution was measured in one location in the office by 7 thermocouples type T (constantan-copper) fixed on a stand at heights 0.1, 0.6, 1.1, 1.7, 2.4, 2.5 and 2.6 m (Points 1-7 in Fig. 4), while vertical air temperature distribution in plenum was measured at heights 2.7, 3.0 and 3.3 m (Points 18-20 in Fig. 4). Additionally, the room temperature was registered in two other locations in the room at height 1.3 m (Points 8 and 9 in Fig. 4). The locations of the three stands are shown as crosses in Fig. 3.

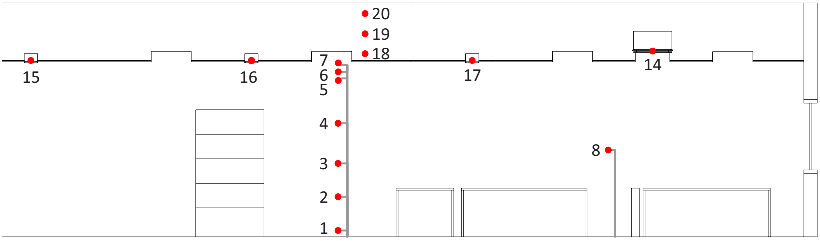

Fig. 4 Points of temperature measurements in office

The air temperature was also measured in each supply and exhaust in order to calculate the average temperature for supply and exhaust in each condition (Points 10-17 in Fig. 4).

All thermocouples were connected to a multichannel datalogger Keysight 34972A registering the temperatures with 10 s logging interval. The accuracy of the temperature measurement is ±1.0 K. The recording time for each condition was the same as the total time for the air speed measurements in all locations, and the average temperatures for these periods were analyzed.

3. Results and Discussion

Vertical temperature gradient

Vertical temperature profiles for all the investigated conditions measured in the centre of the office are presented in Fig. 5. The temperature profiles for the cases with mixing ventilation and diffuse ventilation look very similar. It is seen that in all cases only small vertical temperature gradients were obtained which indicates good mixing of the air in the occupied zone. For six of the seven conditions the temperature difference between ankle and head levels was 0.2-0.5 K. A greater temperature gradient between ankle and head equal to 1.3 K was measured for condition Dif_F0_ΔT10.6 as a result of the great temperature difference between supply and exhaust. However, all conditions fulfilled the requirements in CR 1752 [8] for thermal environment Category A according to which the temperature difference between the heights of 0.1 m and 1.1 m above the floor (corresponding to ankles and head levels of a sitting person) should be maximum 2 K.

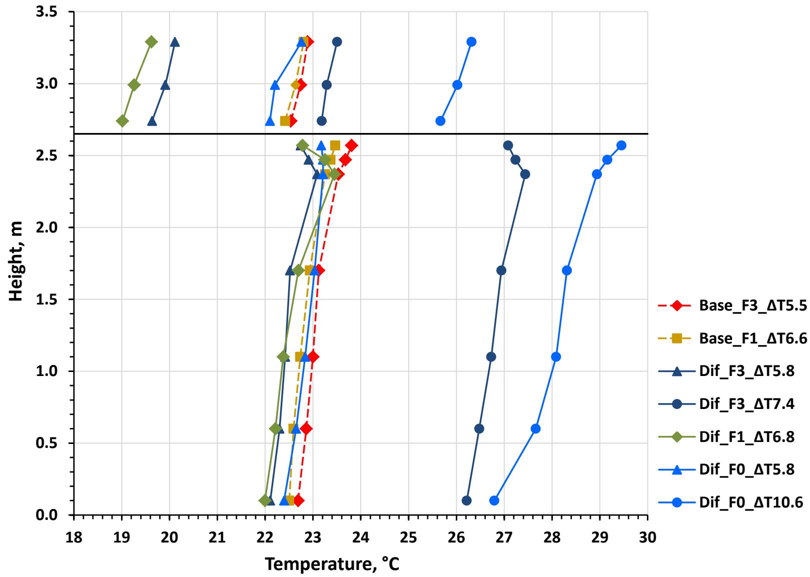

Fig. 5 Vertical temperature profiles for the seven investigated conditions

As expected in the cases with diffuse ventilation, the air temperature close to the ceiling (within 20 cm below the ceiling) was decreasing due to colder air entering the room through the perforation and cracks in the suspended ceiling (Fig. 5). In the baseline conditions the measuring points were not directly affected by the colder airflow from the fan coils located in some distance from the stand with the thermocouples.

For all cases with diffuse ventilation the temperature of the air above the plenum was a few degrees lower than the temperature in the office due to supply of the air directly to the plenum (see Fig. 5) and obviously the greater airflow, the greater temperature difference was registered.

Air speed

In order to evaluate the risk of draught in the office a maximum velocity of 0.15 m/s was used as a reference which according to CR 1752 [8] is one of the criteria for classifying a building to Category A.

The results show that diffuse ceiling ventilation generally does not cause risk of draught in the occupied zone (between the floor level and 1.8 m above the floor). Only in Location 13 at height 0.7 m a slightly higher air speed (0.16 m/s) was registered for the condition with the maximum air change rate of 17.9 h^{-1} and great temperature difference of 7.4 K (Dif_F3_ΔT7.4). Since only one point with air speed above 0.15 m/s was found, the result was neglected and not further investigated. Fig. 6 presents the results of the air speed measurements in Location 13 for two diffuse ventilation cases with maximum airflow.

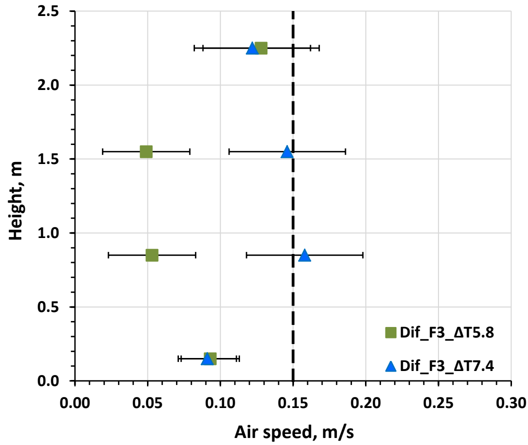

Fig. 6 Measured air speed values in Location 13 for two diffuse ventilation cases with maximum air change rate

For comparison the maximum airflow supplied directly to the occupied zone through the ceiling mounted fan coils (Base_F3_ΔT5.5) caused risk of draught in many points as indicated with red colour in Table 2. For the baseline condition with lower airflow (Base_F1_ΔT6.6) only in one point in the occupied zone (height 0.85 m in Location 5) slightly higher air speed (0.16 m/s) was measured.

Table 2. Results of air speed measurements for condition Base_F3_ΔT5.5 (air speed above 0.15 m/s is indicated in red colour in m/s)

Location/ Height (m)	1	2	3	4	5	6	7	8	9
0.15									
0.85	0.17				0.19	0.17			
1.55	0.21	0.16	0.24		0.21	0.19	0.29		
2.25				0.17		0.17	0.19	0.15	0.15

An example of the results for the conditions with maximum airflow is shown for Location 6 in Fig. 7, where it is clearly noticeable that the air speed registered for the baseline condition are much higher than the values measured for the diffuse ventilation system.

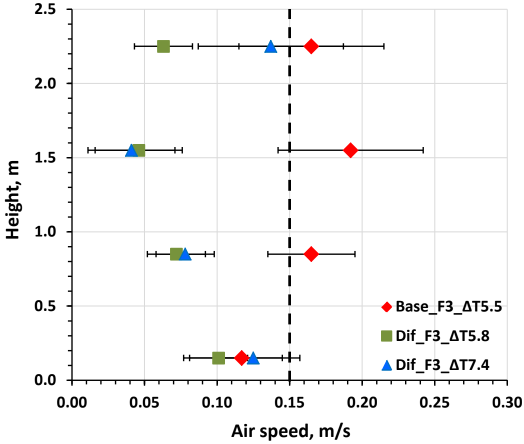

Fig. 7 Measured air speed values in Location 6 for the cases with maximum air change rate

Cooling capacity

During the whole period of the measurements in each condition, the thermal balance in the room was kept which is proved by small temperature fluctuations measured by thermocouples.

The cooling capacity $\Phi_{cooling}$ of the ventilation systems was calculated according to (1) using the flow rate q and the temperature difference ΔT between exhaust and supply air. The specific heat capacity c_p of air was set to 1005 J/(kg·K) and the density ρ to 1.2 kg/m^3. The temperature efficiency ε_T was assumed to be 1 based on the results from the vertical temperature profiles proving good air mixing in the occupied zone in all conditions (Fig. 5). Cooling capacity of the systems in W/m^2 of the floor is listed in Table 1.

$$\Phi_{cooling} = q \cdot c_p \cdot \rho \cdot \Delta T \cdot \varepsilon_T \qquad (1)$$

The results shows that the diffuse ceiling ventilation can provide great amounts of cold air without causing problems with the indoor environment and therefore it can be used to cool even up to 116 W/m^2 (Dif_F3_ΔT7.4). For comparison the mixing ventilation with fan coils can only deliver around 50% of this cooling capacity (Base_F1_ΔT6.6) within indoor environment requirements with regard to risk of draught and vertical temperature gradient.

Design chart q-ΔT

The results from the study make it possible to extrapolate the design curve for diffuse ceiling ventilation systems in the design chart q-ΔT introduced by Nielsen and Jakubowska [1] for higher ventilation flow rates as presented in Fig. 8 as a dashed curve. The q-ΔT chart shows the limitations of the cooling capacity of the diffuse and mixing ventilation due to risk of draught. The curves for mixing ventilation and diffuse ceiling ventilation show the combination of temperature difference between supply and exhaust and the airflow, which encloses the area that meets thermal comfort requirements. The two red points for the Baseline conditions are much beyond the design curve for mixing ventilation, which supports the results from the present study. In Fig. 8 it is also clearly seen that the two conditions with diffuse ceiling and air change rate of only 1.2 h^{-1} (Dif_F0_ΔT5.8 and Dif_F0_ΔT10.6) do not provide the minimum airflow of 565 m^3/h according to EN 15251 [9] for a building Category I represented in the design chart as a vertical dashed line (q_{min}).

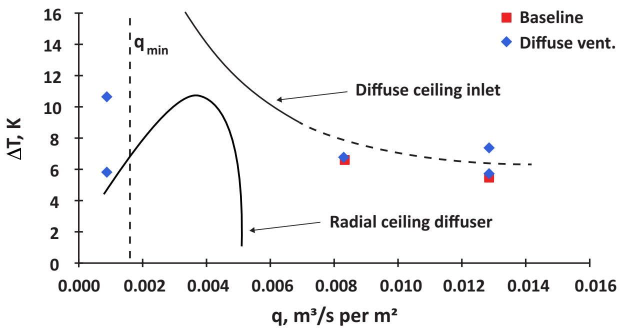

Fig. 8 Design chart q-ΔT [1] with extrapolation for diffuse ceiling ventilation based on the results from the present study

Nielsen et al. [10] reported that the cooling capacity of diffuse ceiling ventilation depends on the heat load arrangement, with the highest capacity when the heat loads are evenly distributed. In the present study the heat loads were concentrated in one end of the office, and the q-ΔT chart presented in Fig. 8 may therefore look different if the heat loads are evenly distributed.

4. Conclusions

The present investigation proves that diffuse ceiling ventilation has great potential for landscape office applications because it can provide large cooling capacity while maintaining an acceptable comfort level in the occupied zone. Both large amounts of supply air and large temperature differences between supply and exhaust did not cause risk of draught or too high vertical room temperature gradients in the occupied zone.

The study shows that mixing ventilation with fan coils cannot provide the same large cooling capacity as diffuse ceiling ventilation with air speed and room temperature gradient within the requirements for thermal environment Category A.

Based on the results from the present investigation, the existing design chart q-ΔT for diffuse ceiling ventilation was extrapolated for higher ventilation flow rates, which is useful when designing ventilation for rooms with high heat loads.

Acknowledgement

The present work has been supported by Saint-Gobain Nordic by providing the test office and financing the remodelling of the office.

References

[1] P.V. Nielsen and E. Jakubowska. The performance of diffuse ceiling inlet and other room air distribution systems. In: Proceedings of Cold Climate HVAC, Sisimiut, Greenland, 2009.

[2] C. Zhang, P. Heiselberg and P.V. Nielsen. Diffuse Ceiling Ventilation – A Review. International Journal of Ventilation 13 (2014) 49-63.

[3] C.A. Hviid and S. Svendsen. Experimental study of perforated suspended ceilings as diffuse ventilation air inlets. Energy and Buildings 56 (2013) 160-168.

[4] J. Fan, C.A. Hviid and H. Yang. Performance analysis of a new design of office diffuse ceiling ventilation system. Energy and Buildings 59 (2013) 73-81.

[5] C.A. Hviid and S. Terkildsen. Experimental study of diffuse ceiling ventilation in classroom. In: Proceedings of the 33rd AIVC Conference, Copenhagen, Denmark, 2012.

[6] P. Jacobs and B. Knoll. Diffuse ceiling ventilation for fresh classrooms. In: Proceedings of 30th AIVC Conference Trends in High Performance Buildings, Berlin, Germany, 2009.

[7] M. Wolsing and M. Grysbæk. Diffus ventilation og køling i kontorer – Luftstrømninger og kølekapacitet. Bachelor thesis. Department for Civil Engeneering, Technical University of Danmark. 2015 (in Danish).

[8] CEN Report 1752 Ventilation for buildings – Design criteria for the indoor environment. CEN/TC 156/WG 6, 1998.

[9] EN 15251 Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. CEN, Brussels, 2007.

[10] P.V. Nielsen, R.W. Vilsbøll, L. Liu and R.L. Jensen. Diffuse ceiling ventilation and the influence of room height and heat load distribution. In: Proceedings of Healthy Buildings Europe 2015, Eindhoven, The Netherlands, 2015.