Experimental investigation of a new supply diffuser in an office room

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ABSTRACT

Full-scale measurements were carried out for investigation of thermal comfort in an office room for a new supply air diffuser. Results of the measurements were performed with both whole- field measuring and traditional point measuring techniques. Experimental results were carried out for supply Archimedes numbers varying from 0.04 to 0.16 and two cooling loads, i.e. 55 and 70 W/m^2. Characteristics of indoor environment and occupants' comfort were explored and analyzed. It was concluded that the airflow pattern and thermal comfort from the investigated low-velocity diffuser were in good agreement with standard ISO 7730.

INTRODUCTION

Ventilation systems are the core of indoor climate production and energy usage in buildings, so the ventilation flow-rate should satisfy the need for thermal comfort and air quality for the inhabitants as well as reduced energy usage. Research objectives have been made to decrease pollutant expansion and increase ventilation efficiency with the additional aim of decreasing the use of energy. These three factors must be considered in the design of a ventilation system for a room or a building as they are fundamental to the thermal environment and energy performance. The aim of the present paper is to explore the basic features of ventilation performance and characteristics of envelope flows. For this reason the experimental investigation was focused on thermal comfort of a new proposed supply diffuser for an office room. The newly proposed supply air diffuser can be described as a number of free circular jets issuing from different apertures at the inlet of the supply device which is covered by convex perforate plate. The present paper reports the result of experiments from point measurements in the occupied zone, as well as the impact of the boundary conditions on the airflow field. Both instantaneous and average values of the velocity were measured by the use of hot-wire and thermistor anemometers. Different indexes of thermal comfort, such as PMV, PPD and DR were presented with measuring operative temperature, air temperature, air velocity, relative humidity and turbulence intensity. For qualitative evaluation, infrared camera was utilized to capture the overall thermal and flow characteristics close to the supply diffuser.

METHODOLOGY AND EXPERIMENTAL SET UP

The measurements were carried out in a well insulated test room with floor area 4.2×3.6 m^2 and a ceiling height of 2.5 m, as a mock-up of an office room, located at the laboratory of ventilation and air quality at the Center of Built Environment, University of Gävle, Sweden, see Figure 1.

The room simulates a realistic office environment, which furnished with PC- simulator (115 W), mannequin (95 W) with approximately the same area and heat load as a human body, see ref. [1], and lighting (144 W) was provided by four Fluorescent tubes. To compensate for the heat through the window due to solar radiation the whole floor was covered with an electric mat (65 W/m^2); an electric heating foil (233 W/m^2) was also used to cover 2 m^2 of the external wall simulating three artificial windows. The ventilation of the room was run by a new supply diffuser, the inlet of diffuser is located against the wall on which the artificial windows are mounted. The supply flow rate was varied between 0.02-0.04 m^3/s, and the difference temperature between the inlet and room mean air was kept at ca 5-8°C. The average room air temperature, T_r, was determined by measuring the air temperatures between floor and celing with 24 thermocouples in the middle of the room. The differences between ventilation cooling loads, heat loads and heat transmission losses is balance by cooling power from ceiling beam. Table 1 illustrates the studied cases in this study.

Table 1. Summary of the experimental cases.

Case	Q (W/m^2)	V (m^3/s)	T_{in} (°C)	T_r (°C)	Ar (0)
A	55	0.040	16.0	20.5	0.03
B	55	0.025	16.0	20.8	0.09
C	55	0.025	12.5	20.9	0.16
D	55	0.020	16.0	20.7	0.14
E	70	0.025	12.5	20.7	0.15

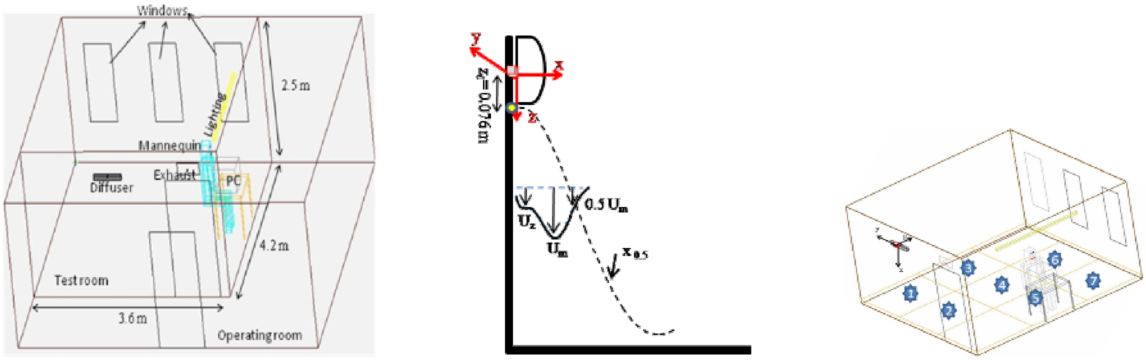
Archimedes number was calculated according to Eq. (1) for finding the supply condition.

$$Ar(0) = \frac{g\beta\Delta T\sqrt{A(0)}}{U_{in}^{2}} \qquad (1)$$

Where $A(0)$ is the free opening area, T_{in} is the supply temperature, U_{in} is the supply velocity and $\beta = 1/T_r$ is the thermal expansion of the air.

Methods of studying indoor parameters in this paper include experimental methods, the measurement results were used to quantify level of the thermal for cooling and ventilation strategy. The evaluation of these levels depends on the parameters of the measurements such as air velocity, temperature, thermal comfort and visualization of air flow in the occupied zone and near zone of the diffuser.

All the measurements were carried out under steady state condition. Thermal image was used to register the images of the general flow and temperature field close to the supply air diffuser. Infrared thermography is a technique for visualization of the relationship between air temperature distribution and air flow patterns, which can record an image of radiation emitted from the objects, see ref. [2]. A screen with emissivity 0.91 was stretched at the middle of the diffuser and parallel with airflow. A modern infrared camera which is sensitive to infrared radiation in range 7.5-13µm, a Agema S60 (FLIR system) was used with the accuracy of screen surface temperature ±0.2°C and camera resolution is quantified by 320×240 number of pixels. A large number of thermocouples type T (copper-constant) were used to measure the room surface temperatures (walls, floor, and ceiling), inlet, exhaust as well as air temperature gradient. All thermocouples were connected to a computer which controlled by a data acquisition (Agilent 34970). The thermocouple has an accuracy of ±0.1°C for temperatures from 10 to 30°C. All the thermocouples were covered with tape on the surfaces of the walls with tape for elimination of the radiation effects. The thermocouples measured the temperature with time average over 60 s.



a) b) c)

Figure1. a) Test room layout, b) flow pattern below the diffuser, c) position of the measuring points in the occupied zones.

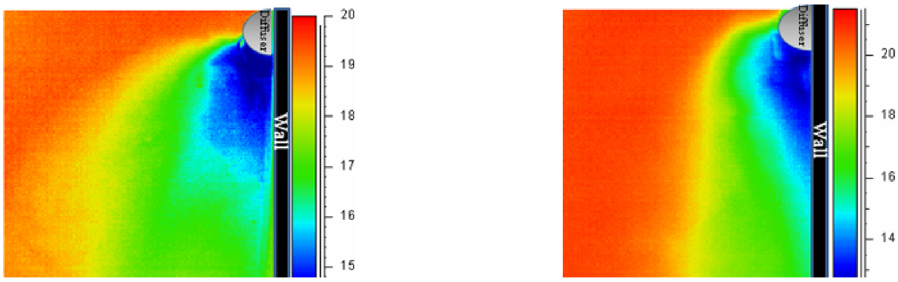
The velocities of interest have been logged at near-zone and occupied zone with one dimension hot-wire and three-dimension thermistor anemometers. Hot-wire (Dantec 55P15) and temperature thermistor were placed on a 2–D traversing system close to the diffuser which made it possible to measure velocity and temperature gradient with the same probe, in this case two probes can capture the velocity and temperature profile with minimum disturbance of the air flow from the supply level up to the floor. The hot-wire measured low air velocity with a sampling rate 100 Hz with 30000 numbers of sample. The calibration was done with wind tunnel between 0.2-4.0 m/s. 28 omnidirectional thermistor anemometers type CTA, see ref. [3] were used in order to increase measurement precision in the occupied zone. The velocity was measured at three seconds interval and the total number of samples was 100. These thermistor anemometers can be recorded the low velocity measurement with accuracy ±5% or 0.05 m/s.

The Innova temperature transducers and CTA probes have been used to investigate the thermal comfort as well as DR values according to ISO 7730 [4]. The PMV and PPD values are measured directly, on the basis of the dry heat loss, knowledge of the activity level, clothing and water vapor partial pressure of the air. The sensor which calculates the thermal comfort indexes has the same mean surface temperature as the person it means to simulate, a person with clothing of the same clo value as that set on the instrument and with heat loss corresponding to thermal comfort in the actual surrounding. The temperature transducers register the results of air and operative temperature with different accuracy ±0.2°C and ±0.3°C for range 5-40°C, respectively. The measurements were carried out for each point during 1200 s and as the same this time for changing the position of the point until the sensor reached in thermal equilibrium with its surroundings. The Innova humidity transducer measured the absolute humidity of air in the test room. The orifice plate with accuracy ±5% determined the air flow rate for different cases.

RESULTS

IR image

The flow pattern and temperature distribution were explored by means of infrared camera image. In Figure 2a and 2b, the infrared camera is a powerful tool which represents the air temperature distribution close to the supply diffuser.



a) b)

Figure 2. Infrared camera images (a) Airflow rate 0.040 m^3/s, T_{in} = 15°C, and (b) airflow rate 0.025 m^3/s, T_{in} = 12.5°C.

Near zone study

As can be seen in this part, air velocities and temperatures for the inlet centerline region and for the near wall region were recorded with the hot-wire anemometry method and thermistor. The hot-wire has measured the mean velocities and standard deviation in the near zone of the diffuser. In Figure 3a by using maximum velocity and minimum temperature, the trajectory for jet is plotted for the same supply air condition, i.e. for the Case *A*, which they explore the buoyant jet close to the supply. The jet velocity decrease quickly near the wall and the boundary of the buoyant jet becomes thick with increasing the distance in dowstream direction, *z*, from the diffuser level. The velocity remains constant for different height, $z/A^{0.5}$, at, $x/A^{0.5}$, greater than 3. The max velocity is recorded 1.2 m/s close to the wall and the lowest velocity is 0.2 m/s at 0.05 m above the floor at the near zone for Case *A*. Figure 3b show mean velocity and temperature profiles at different downstream locations from supply for Case *A*. The data has been normalized by dividing the local stream-wise velocity, U_z, by the maximum velocity at the same location, U_{max}. The distance from the wall, *x*, has been also normalized by $x_{0.5}$, i.e. the point where the velocity has fallen to half of its maximum value.

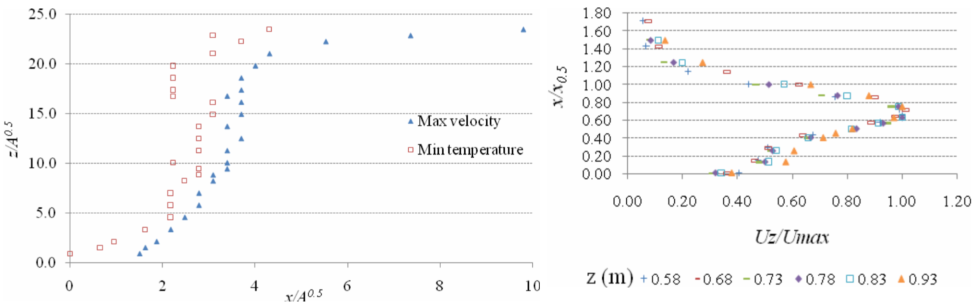


Figure 3. (a) Velocity and temperature trajectory and (b) Non-dimensional mean velocity and temperature profiles in normal direction to the wall at different down-stream locations for Case *A*.

Occupied zone

The average velocity values, u_l, are presented by velocity probes at the center of seven zones with different heights. The velocity varies in the occupied zone due to changes of airflow rate and temperature at the diffuser inlet. These measurements were made at ankle, waist and neck level for sitting and standing person, see Table 2. The air temperature at the center of all measured zones, T_l, by thermistor anemometers type CTA is included in Table 2. The relative humidity in the room has been also measured and presented in Table 2.

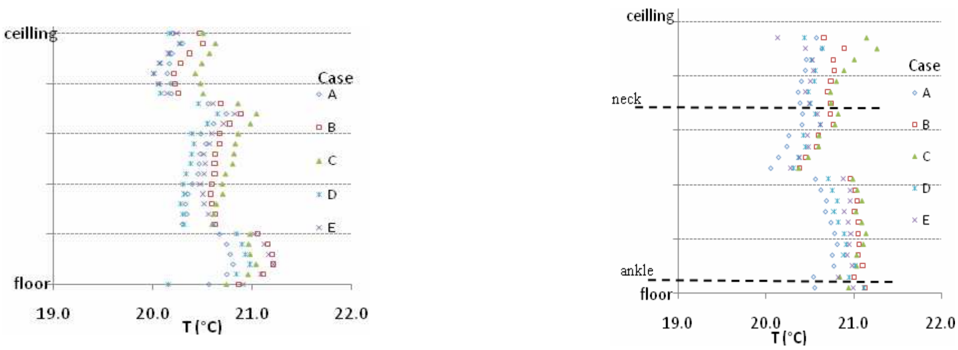
Table 2. Measured data for velocity, turbulence intensity, air temperature and relative humidity in the occupied zone.

	Point description	Case				
		A	*B*	*C*	*D*	*E*
u_l (m/s)	I*	0.18	0.15	0.15	0.17	0.14
	II*	0.1	0.1	0.06	0.1	0.1
	III*	0.07	0.08	0.06	0.08	0.08
	IV*	0.09	0.08	0.07	0.09	0.08
Tu (%)	I	29	31	31	30	30
	II	36	40	37	40	40
	III	37	39	37	41	41
	IV	34	37	34	40	39
T_l (°C)	I	20.9	21.2	20.9	20.9	21.1
	II	21.1	21.3	21.3	21.1	21.2
	III	21.1	21.3	21.4	21.1	21.2
	IV	21.1	21.2	21.3	21.0	21.1
RH (%)	Whole room	28	32	21	29	27

I ankle seated person (0.1 m), II*waist seated person (0.6 m)*
*III*neck seated person (1.1 m), IV*neck standing person (1.7 m)*

Temperature measurement

Thermocouples, which shield against thermal radiation, were used to illustrate vertical air temperature difference between ankle and neck, see Figure 4. The results are in acceptable level for a seated person at sedentary activity according to standard ISO 7730 [4]. The setting of comfort level at sedentary activity is at metabolic rate 1.2 met and clothing 0.7 clo.



a) b)

Figure 4. Temperature gradient, a) wall, b) room

Thermal comfort indexes

The thermal comfort is evaluated by measuring temperatures, relative humidity and air velocity that give rise PMV values. The PMV values were calculated at different heights for the center zone 4 in the room to illustrate the variations of different thermal climate, see Table 3. It seems there is not too much variation of PPD and PMV between Case *C* and *E*. PPD index for the waist and the neck of the seated person for different supply condition for zone 4, which has been shown in Table 4, remain in an acceptable region according to ISO 7730 and shows small difference. There is a small different for ankle position, which is probably due to heated floor, see Figure 1c for position for the zones in the room.

Table 3. Thermal comfort indexes and draught rate at different height for zone 4.

	Case C			*Case E*		
	Ankle	*Waist*	*Neck*	*Ankle*	*Waist*	*Neck*
PMV (-)	-0.4	-0.3	-0.5	-0.5	-0.3	-0.7
PPD (%)	8	7	9	10	7	14
DR (%)	14	3	5	13	9	6

Ankle = 0.1 m from the floor, Waist= 0.6 m from the floor, Neck = 1.7 m from the floor

Table 4. PMV, PPD and DR indexes as a function of Ar number for zone 4.

	Ar (0) = 0.04			Ar (0) = 0.09			Ar (0) = 0.15		
	Ankle	*Waist*	*Neck*	*Ankle*	*Waist*	*Neck*	*Ankle*	*Waist*	*Neck*
PMV (-)	-0.4	-0.3	-0.5	-0.5	-0.3	-0.5	-0.6	-0.5	-0.6
PPD (%)	9	7	10	10	7	10	12	10	13
DR (%)	17	9	7	13	9	6	17	8	8

CONCLUSIONS

Under non-isothermal conditions, the characteristics of the wall jets are experimentally investigated. The result of velocity profile in the occupied zone and thermal comfort present the airflow pattern from a low velocity diffuser in a one-desk office configuration. By near zone study, the trajectory of velocity and temperature profile of a non-isothermal jet was monitored with the point measuring technique. The air flow at the beginning was governed by jet and then mainly controlled by buoyancy. The result of thermal comfort indexes were presented as a function of Archimedes number. The evaluation of the thermal comfort was in good according to ISO 7730. The mean value of air temperature, air velocity and turbulence intensity of all 7 zones and thermal comfort indexes for zones 4 and 6 in the room show an expected behavior of the diffuser. From the results the conclusion can been drawn that velocity in the occupied zone except at ankle level is below 0.1 m/s. Explanation of higher average velocity at ankle of seated person can be due to heated floor.

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