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Passive Control Strategy For Mixing Ventilation In Heating And Cooling Modes Using Lobed Inserts

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Abstract

Mixing ventilation is commonly used to control thermal comfort in a room by means of air jets. The jet diffusers should distribute the fresh air and energy, for heating or cooling, in the entire occupied zone. Therefore, the design of the diffusers must aim, beyond aesthetic aspect, the ability to provide a good mixing between the jet and the ambient air. Enhancement of jet mixing with the ambient air by means of lobed inserts into a diffuser, was recently proposed in an European patent, as a promising and low-cost solution for improving the performance of HVAC systems. In this paper, an experimental investigation on thermal comfort generated by a classical multi-cone ceiling-mounted diffuser is proposed. Its performance is compared with the same diffuser equipped with lobed inserts. A simplified heated manikin simulates the presence of a human body in the test room. Thermal comfort was analyzed based on traditional pointwise measuring probes and on the standard ISO 7730. It is revealed that the thermal comfort was significantly improved using the lobed diffuser compared to the conventional one, without increase of pressure drop and sound pressure levels.

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Keywords: Mixing ventilation; Multi-cone ceiling diffuser; Lobed inserts, Thermal comfort

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Nomenclature

A_{eff}	diffuser effective area, (m)	T_a	ambient temperature, (°C)
A_n	diffuser neck area ($A_n = \pi D^2/4$), (m²)	$\overline{T}_{air}$	mean air temperature, (°C)
A_r	Archimedes number, $Ar = g\sqrt{A_n}\Delta T / T_a W_n^2$	T_{op}	operative temperature, (°C)
C_p	specific heat, (J. kg^{-1}.°C)	T_p	wall temperature, (°C)
D	neck-diameter upstream the diffuser, (m)	T_r	mean radiant temperature, (°C)
g	gravitational acceleration, (m.s^{-2})	$\overline{V}_{air}$	mean air speed, (m.s^{-1})
Q_0	initial flow rate, (m^3.s^{-1})	W_n	diffuser neck air velocity ($W_n = Q_0/A_n$), (m.s^{-1})
Q_t	room load, (W.m^{-2})	W_0	initial air velocity, (m.s^{-1})
Re	Reynolds number ($\mathrm{Re} = W_n\sqrt{A_n}/\nu$)	X, Y, Z	Cartesian coordinates, (m)
S_f	Floor surface, (m²)	ν	kinematic viscosity, (m^2.s^{-1})
T_0	initial air temperature, (°C)	ρ	air density, (kg.m^{-3})

1. Introduction

The main purpose of ventilation systems is to satisfy the need for thermal comfort and air quality for the occupants. This objective however has to be accompanied by the lowest possible energy consumption. The three design criteria must be considered as they are fundamental to the thermal environment and energy performance. For mixing ventilation purpose, a high induction level is required because it allows an optimal mix of the ventilating jet with its ambient air such that occupants will be satisfied in terms of thermal comfort and air quality.

Ceiling diffusers have gained popularity since the sixties, and nowadays they are the most used terminal devices in commercial and office buildings. As described in ASHRAE Fundamental handbook [1], the airflow pattern in cooling mode from such a ceiling diffuser is projected downward to the floor and follows it, producing a stagnant region near the ceiling. In heating mode, the airflow reaches the floor and folds back toward the ceiling. If the downward air does not reach the floor, a stagnant zone appears near the floor. Based on these features, modern commercial multi-cone diffusers were developed to mechanically adjust the inner cones, to switch from vertical flow pattern in heating mode, to horizontal flow pattern in cooling mode. The adjustment of the cones could be automatic or manual.

Considering that the efficiency of mixing ventilation systems relies on a better mix between ventilating jets and the ambient air, some studies were conducted to find suitable diffusers geometries with high induction features. The vortex diffusers were studied for that purpose, because they produce jet flows with a high degree of spin, allowing an increase in jet induction. The spin is generated by guide vanes placed inside the diffuser. Chuah et al. [2] conducted in isothermal conditions, a comparative study of a ceiling vortex diffuser to two multi-cone ceiling diffusers and were interested in their induction performances. Shakerin and Miller [3] have conducted a similar study, by comparing under isothermal conditions three vortex diffusers to a conventional circular multi-cone diffuser. In the two studies the authors came to the same conclusion, i.e., the vortex diffusers have better induction performance than the multi-cone diffusers. They observed, however, that the vortex diffusers required higher static pressure than the multi-cone diffuser. Vortex diffusers have other limitations related to the long throw that is provided. They are suitable for rooms where the ceiling is rather high. The innovative concept of lobed diffuser to achieve high induction in mixing ventilation of buildings was proposed for the first time by Meslem et al. and Nastase et al. in [4, 5]. Lobed geometry was defined either by lobed fins integrated into a rectangular grille diffuser [5] or by lobed orifices integrated into a perforated panel diffuser [4]. The proposed concept of lobed diffuser relies on the idea of relatively inexpensive and simple modification of the exit boundary geometry of a conventional diffuser. That idea is inspired by other domains i.e., combustion and aeronautic [6, 7]. In mixing ventilation it was shown that entrainment of the jet issued from the lobed diffuser is in average two times higher than the one of the jet from the standard diffuser. Furthermore, the geometry of the lobed diffuser was not found to generate supplementary noise and pressure losses were found to have similar values for innovative and standard grilles.

This paper presents an experimental investigation of thermal comfort in steady-state conditions, generated inside a climate chamber by a vertical jet in heating mode and a radial jet in cooling, produced by a flush-mounted multi-cone diffuser. The impact on thermal comfort of inserted lobes [8] into the multi-cone diffuser is evaluated.

2. Materials and method

2.1. Test chamber, thermal manikin and jet diffusers

The experiments were carried out in a cubic Laboratory chamber of an edge length of 3470 mm, coupled to an air diffusion circuit including an air handling unit (Fig. 1 a). The six inside faces are thermally controlled, using a hydraulic circuit composed of capillary tubes inserted in the walls and connected to a heat pump. To simulate a standard volume of residential or office building, a dropped ceiling was installed at height 2500 mm. The mean ambient temperature (T_a) at the extraction (see Fig. 1 a) is controlled with the hydraulic circuit. The jet flow is generated by the air handling unit equipped with a fan, a heater and a chillier, followed by a plenum box insuring a uniform velocity profile and low turbulence upstream the diffuser. The diffuser is installed at the extremity of the plenum box. The initial flow rate (Q_0) and the air temperature (T_0) are controlled with sensors placed between the handling unit and the plenum box, and again measured at the jet exit using a bolometer from ACIN (Flow finder mk2). The accuracy in flow rate measurement is ±3% of the reading.

A three-cone circular ceiling-mounted diffuser (Fig. 2 a-c) having adjustable cones was chosen and will be designated by "conventional diffuser" (CD). The two inner cones can be adjusted manually (Fig. 2 c1) to switch from vertical jet behavior (Fig. 2 c2) for heating mode to radial jet behavior (Fig. 2 c3) for cooling mode. When equipped by inserted lobes as shown in Fig. 2 d-e, the diffuser is designated by "lobed diffuser" (LD). The concept of inserted lobes [8] is its ease of implementation relative to the "built-in lobed diffuser" considered by Nastase et al. [5]. With this new concept, the process of diffuser manufacturing is not changed. The passive control of the jet is obtained by vortex promoters introduced into the conventional diffuser without intrinsic changes of its geometry.

The geometric parameters of the inserted lobes are given in Fig.2 f-g. We have used two pair of inserted lobes, one pair for heating mode (vertical jet generation) and another pair in cooling mode (radial jet generation). Lobed inserts were made of resin material and were built by a 3D printer. The obstruction ratio is about 10 % of the diffuser effective area A_{eff}, estimated to be around 0.036 m^2 at the position of the lobes (Fig. 2 e). This area corresponds to the sum of areas of inner and outer slots at the location of inserted lobes, of thickness S (Fig. 2 c4) and perimeter pt, which is equal to inserted lobe perimeter (see Fig. 2 g).

A simplified seated manikin [9] of 8 heated parts (Fig. 3 b) and total power of 81W, was used to simulate an occupant located at the center of the room (Fig. 3 a). The manikin was designed to have a mean skin temperature of 32 °C in a room with ambient temperature at 26 °C and with still air.

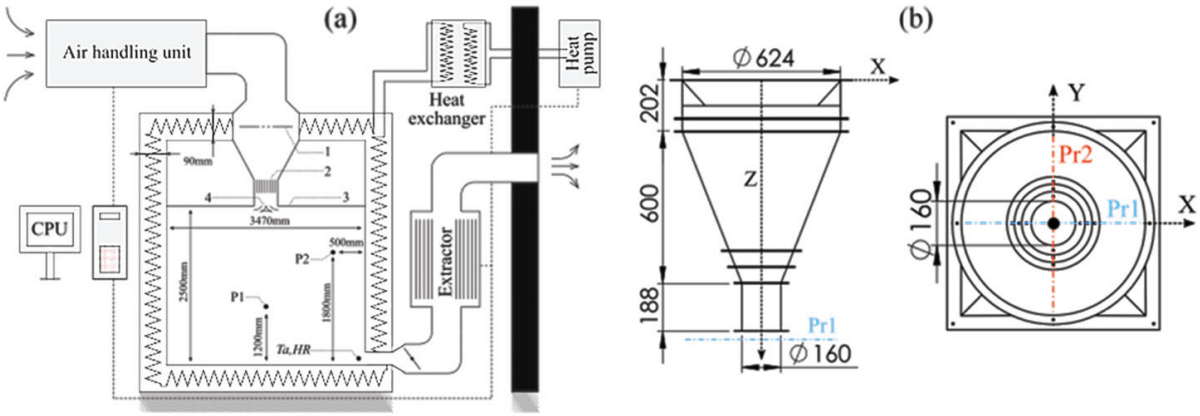
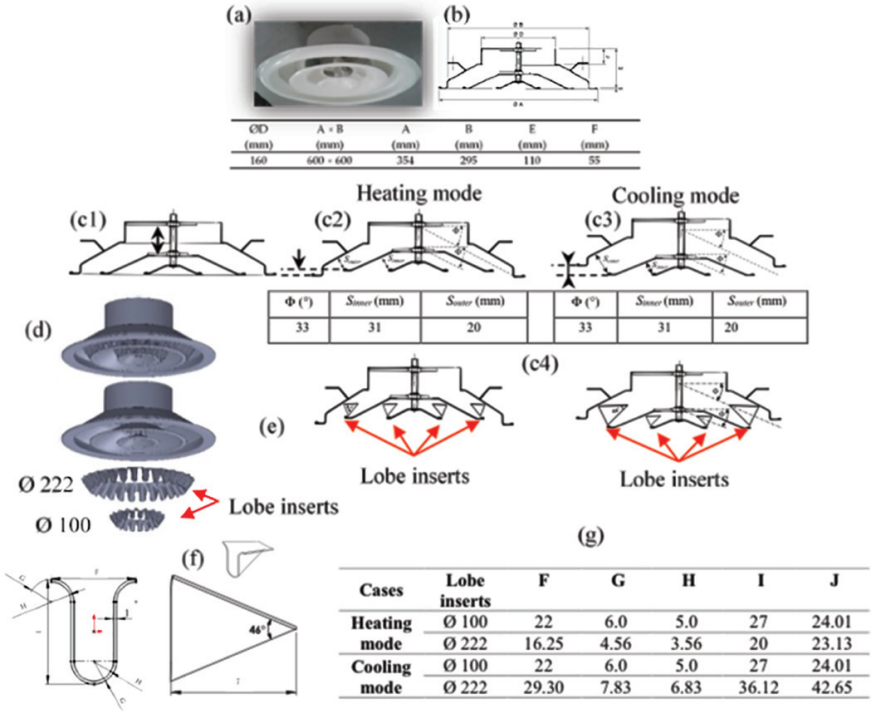


Fig. 1 (a) Sketch of the climate chamber – 1 perforated plate, 2 honeycomb, 3 diffuser, 4 dropped ceiling, P1 and P2 acoustic measurement points; (b) Details of the plenum box

To evaluate the thermal discomfort, standards ISO 7730 [10] and ASHRAE 55 [11] have adopted the PMV-PPD model (Predicted Mean Vote-Predicted Percentage of Dissatisfied) and the DR index (Draft Rate), proposed by Fanger [12, 13]. This model is used to express the thermal sensation and the corresponding percentage of people dissatisfied by the thermal environment where they are exposed. According to Fanger [12] and Awbi [14], for a uniform thermal environment, a single value of PMV-PPD indices is sufficient to express the thermal discomfort in the occupied zone. For non-uniform thermal environment, the authors proposed that measurements should be carried out at various points in the occupied zone and these are then used to calculate the distribution of PMV-PPD indices throughout the zone [14].

The DR index is a local discomfort model which characterizes draft effect on the neck of an occupant and may be extended to other body regions [14]. Nastase et al. [5], Chow and Wong [15], and Tomasi et al. [16] have used this index to study experimentally the thermal comfort generated by mixing ventilation diffusers.

In the present study, standards ISO 7730 [10] and ASHRAE 55 [11] were adopted for thermal discomfort and local discomfort evaluation. Air temperature and air speed were measured using thermocouples (type K, accuracy of ±0.3 °C) and hot-sphere anemometers (TSI 8475, accuracy of ±3 % of the reading). The occupied zone was meshed with 16 vertical canes (Fig. 3 a), each including 4 sensors located at 0.1 m, 0.6 m, 1.2 m and 1.8 m relatively to the floor. These positions correspond to the levels of ankles, waist, head of a seated occupant and head of a standing occupant [11], respectively. Wall-surface temperatures (T_p) measurements were also performed. Each wall including the floor and the ceiling is divided into 4 subzones of equal dimensions, each one equipped with a thermocouple located in its center. For mean radiant temperature ($\overline{T}_r$) calculation, the method described in ISO 7726 [17] based on wall-surface temperatures of the 6 faces and a seated manikin with unknown azimuthal angle is applied. For each experiment, the duration to achieve steady-state conditions is about 6 hours. After this period, thermal comfort measurements were carried out for a minimum duration of 8 hours with a sampling time of 1 minute.



Cases	Lobe inserts	F	G	H	I	J
Heating mode	Ø 100	22	6.0	5.0	27	24.01
	Ø 222	16.25	4.56	3.56	20	23.13
Cooling mode	Ø 100	22	6.0	5.0	27	24.01
	Ø 222	29.30	7.83	6.83	36.12	42.65

Fig. 2. (a, b) Conventional diffuser (CD) and its dimensions; (c) Control-setting of jet behavior - double-headed arrow (left) indicates the movement up/down of the inner cones, the two arrows (right) indicate the position of inner cones for heating or cooling mode jet generation; (d, e) Mounting of the inserted lobes into the CD, (f, g) Geometry details of the inserted lobes

2.2. Static pressure and sound pressure level measurements

The total pressure loss was measured for the two diffusers according to EN 12238 standard [18] using a KIMO MP110 micro-manometer. One pressure tap is installed at 1.5 *D* upstream the diffuser (where *D* in the neck diameter, see Fig. 1 b) and the second in the occupied zone outside the jet region.
Sound pressure levels were recorded using a handheld type 2250 Sound Level Meter of Class 1 Precision (Tolerance of ± 0.7 dB) from Bruel & Kjaer. According to ISO 10052 [19], a diffuser is considered as a technical equipment, and Leq (dBA) must be measured. Leq is the time average equivalent sound pressure level with A-weighting. The averaging time is 6 s as specified in [20] and measurements were performed as recommended in [19] at two locations P1 and P2 (see Fig. 1 a).These positions are corresponding respectively to the nearest position to the diffuser located in the occupied zone of the room, and the limit of the occupied zone in the case where people are seated. Three cases were considered: in the first one the measurements were performed without any diffuser mounted on the plenum, and the other two cases correspond to the operation of the system with CD and LD, respectively. This way, the sound pressure levels of the diffusers themselves were extracted. As recommended by ISO 10052 standard [19], mean values of pressure levels were calculated as a representative values of global noise generated in the occupied zone. The mean value is an average weighted by the coefficients 2/3 and 1/3 of sound pressure levels in P1 and P2, respectively.

2.3. Tested configurations

The multi-cone diffuser considered (Fig. 2 a) is recommended for flow rates ranging from 200 to 400 m^3/h. The air handling unit equipped with its plenum box (Fig. 1) and the multi-cone diffuser, provides flow-rates in the range 15 to 300 m^3/h in heating mode (vertical jet generation), and in the range of 15 to 325 m^3/h in cooling mode (radial jet generation). In this study the volumetric flow-rate was set to Q_0 =200 m^3/h and Q_0 =275 m^3/h in heating mode, and
Q_0 = 200 m^3/h and Q_0 = 300 m^3/h in cooling mode. The operating conditions are summarized in Table 1. Thermal comfort measurements were carried out considering the diffuser in heating mode (HM) and in cooling mode (CM), with an absolute difference between ambient air temperature (T_a) and supply air temperature (T_0) around 10 °C. Comfort evaluations were performed with respectively CD and LD (Fig. 2) in the presence of the heated manikin. In this study, the operative temperature (T_{op}) was introduced and estimated (Table 1) as the mean value of the mean air temperature ($\overline{T}_{air}$) and the mean radiant temperature ($\overline{T}_r$), under the specified condition of mean air speed ($\overline{V}_{air}$ < 0.2 m/s, see ISO 7726 standard [17]). Comparison of the calculated values to the measured values using a black globe thermometer (Fig. 3 a) is satisfactory. According to ISO 7730 standard [10] and ASHRAE 55 standard [11] for an individual office with one occupant having a sedentary activity, the recommended value of T_{op} for optimal thermal comfort is 24.5 °C in summer conditions and 22 °C in winter conditions. The obtained values (Table 1) are close to recommended values.

The jet Reynolds number, *Re*, and the jet Archimedes number, *Ar*, are given in Table 1 along with the load, $Q_t = \rho C_p Q_0 \Delta T / S_f$, defined as the thermal energy to be bring in the room in heating mode, and that must be removed from the room in cooling mode, in order to maintain the desired comfort conditions.

Table 1. Experimental conditions for thermal comfort evaluation

Cases	Experimental conditions (*)									
	Q_0 [m^3/h]	T_0 [°C]	T_a [°C]	$\overline{T}_r$ [°C]	T_{op} [°C]	$\overline{T}_p$ [°C]	*RH* [%]	Q_t [W/m²]	*Ar*	*Re*
CD_HM	200	34.9	21.6	18.3	21.6	18.1	46	74.2	0.0091	25000
	275	31.0	22.2	18.0	20.8	17.6	41	67.5	0.0033	34400
LD_HM	200	34.9	21.9	18.4	21.3	18.2	46	72.5	0.0089	25000
	275	31.0	22.4	18.1	21.0	17.7	41	67.0	0.0032	34400
CD_CM	200	13.4	23.4	24.3	23.8	24.7	42	55.8	0.0054	25000
	300	13.4	22.3	23.2	22.4	22.7	48	74.5	0.0046	37600
LD_CM	200	13.4	23.8	25.6	25.1	26.0	42	58.0	0.0055	25000
	300	13.4	22.3	23.2	22.3	22.8	48	74.5	0.0047	37600

(*) Data are given as the mean value ± standard deviation

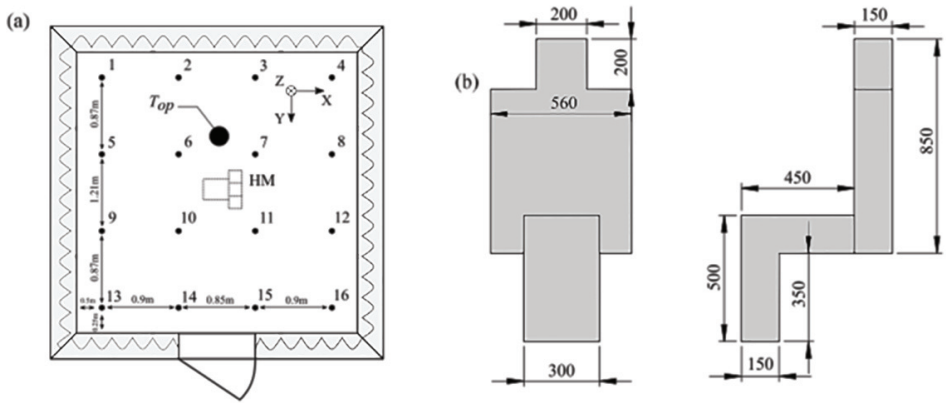


Fig. 3 (a) Positions in the horizontal plane of the room of the heated manikin (HM), of the 16 vertical canes of hot-sphere anemometers and thermocouples, and of the black globe thermometer; (b) Geometry details of the heated manikin – the dimensions are in mm

3. Results and discussion

The DR index includes the turbulence intensity which is not accessible using a hot-sphere anemometer. The standard ISO 7730 [10] recommends in this case a value of 40%. A maximum difference of 0.1% in DR distributions is recorded, using respectively this recommended value and turbulence intensity (ranging from 9 to 12 %) measured by Particle Image Velocimetry in the occupied zone. Hence, the value of 40 % has been adopted in all cases.

For the PMV-PPD model, metabolic rate, mechanical work and clothing insulation were fixed within the range recommended in [10, 11], at 1.2 met, 0 W/m² and 1 clo for heating conditions, and at 1.2 met, 0 W/m² and 0.7 clo for cooling conditions. Fig. 4 shows the statistic distribution of the 64 nodes in terms of thermal comfort levels (A, B, C) provided in ISO 7730 standard [10]. These levels fix minimum values of PPD and DR indices (Fig. 4 e).

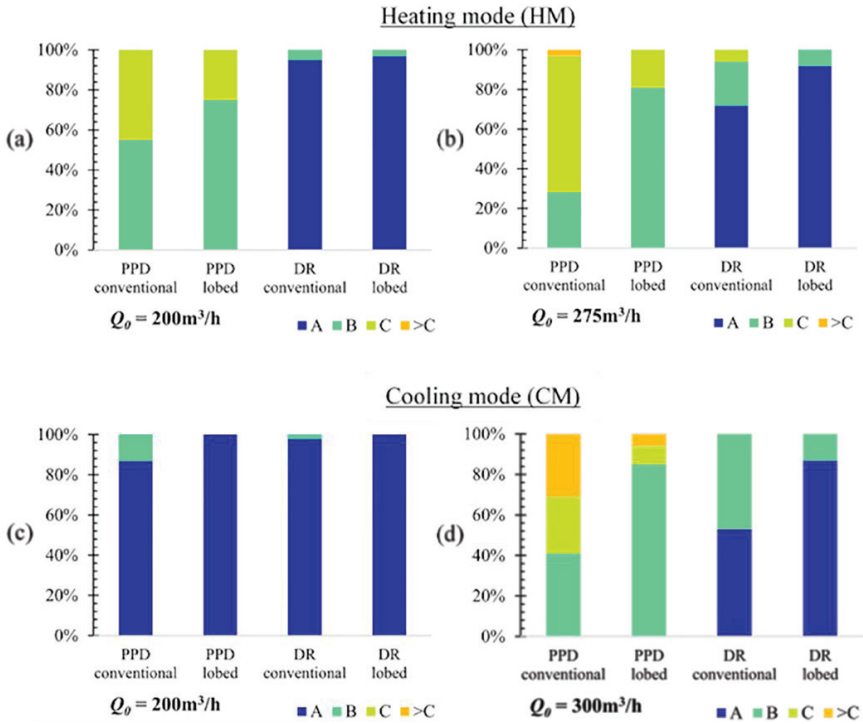
Based on the obtained distributions, the higher thermal comfort level in both heating and cooling modes, is achieved using the LD. In heating mode, for Q_0 =200 m^3/h (Fig. 4 a), in terms of the PPD index, 55% of the data falls in the category B and 45% in the category C for CD. For LD, 10% of data moves in the category A, 84% falls in the category B and only 6% falls in the category C. In terms of the DR index, almost all the points fall in the category A for the two diffusers (95% for CD and 97% for LD). For Q_0 = 275 m^3/h (Fig. 4 b), the indices show a slight degradation of the thermal comfort compared to Q_0 =200 m^3/h. However, the LD performance relative to the reference CD is more significant in this case. In terms of DR index, 92% of data falls in the category A for LD compared to 72% for CD. The improvement is more significant in terms of PPD index, with 81%, 19% and 0% of data falling in the category B, C, and > C for LD, compared to 28%, 69% and 3% for CD.

In cooling mode for Q_0 = 200 m^3/h (Fig. 4 c), all points have reached using LD the higher level A in terms of PPD and DR indices. For Q_0 = 300 m^3/h (Fig. 4 d), the indices show a marked degradation of the thermal comfort. However, the LD performance relative to CD is more visible in this case. In terms of DR index, for LD 87% of data falls into the category A, compared to 53% for CD. The PPD index is also improved using inserted lobes, with 6% of data falling outside the range A-C in LD compared to 31% in CD. Furthermore, 85% of data falls into the range A-B for LD compared to 41% in CD.

Fig. 5, a presents Mean global sound pressure levels generated by the diffusers CD and LD as a function of the initial volumetric flow rate Q_0, in heating mode (HM) and cooling mode (CM), respectively. In heating mode, there is no significant difference between the two diffusers in terms of noise generation. In cooling mode, for Q_0 = 200 m^3/h one could notice a slight difference in the mean value of Leq with an advantage for LD. For Q_0 >200 m^3/h, the

supplementary noise generated by the presence of inserted lobes is in average of 2 dB(A). The sound pressure levels in the occupied zone with each diffuser are under 45 dB(A) which is acceptable for office spaces, according to national legislations and building codes in most of European countries [21].

Fig. 5 b, shows total pressure losses for CD and LD, measured following EN 12238 standard [18], as a function of the inlet volumetric flow rate Q_0. The two diffusers display similar values of the pressure losses, with differences less than the accuracy of the pressure sensor (±2Pa), in both heating and cooling modes.



(e)

Comfort level	PPD (%)	PMV	DR (%)
A (high standing)	< 6	-0.2 < PMV < +0.2	< 10
B (mean)	< 10	-0.5 < PMV < +0.5	< 20
C (acceptable)	< 15	-0.7 < PMV < +0.7	< 30
D (unacceptable)	≥ 15	| PMV | ≥ 0.7	≥ 30

Fig. 4: (a-d) Statistic distribution of PPD and DR indices for the two diffusers in heating and cooling modes; (c, (e) Categories of thermal comfort according to ISO 7730

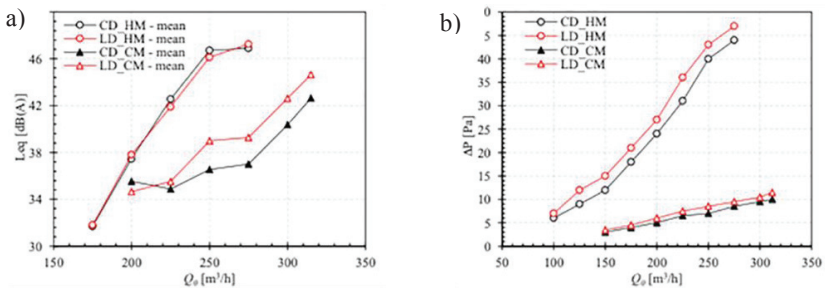


Fig.5 (a) Mean global sound pressure level of the diffusers; (b) Total pressure loss of the diffusers

4. Conclusion

In this study, thermal comfort and noise generation were analyzed in a full-scale model room in mixing ventilation, in heating mode and mode cooling, respectively. An occupant has been simulated using a seated simplified shape heated manikin positioned at the center of the room.

The ventilating jet is generated from a multi-cone diffuser (CD), flush-mounted in the center of the ceiling, operating in vertical jet generation in heating mode, and in radial jet generation in cooling mode. The effect of inserted lobes introduced into the diffuser being LD has been evaluated.

Thermal comfort analysis based on both ASHRAE 55 and ISO 7730 standards, reveals significant improvement of thermal comfort in the presence of lobed inserts into the diffuser whether in cooling or heating modes. This is achieved without significant increase in pressure drop and noise.

Beyond the performance ensured by the concept of lobed inserts, it is easy to integrate in manufacturing process relative to the built-in lobed diffuser. For all these reasons, the concept of inserted lobes is a promising low-cost solution to enhance the performance of HVAC systems.

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References

[1] ASHRAE, *Space air diffusion*, in *ASHRAE Handbook: Fundamentals*, ASHRAE, Editor. 2009.
[2] Chuah, Y.K., Hu, S.C., and Barber, J.M., *Airflow Characteristics of Circular Ceiling Diffusers.* International Journal on Architectural Science, 2000. **1**: p. 59-67.
[3] Shakerin, S. and Miller, P.L. *Experimental study of Vortex Diffusers*. in *1996 Annual Conference*. 1996. San Antonio, TX.
[4] Meslem, A., Nastase, I., and Allard, F., *Passive mixing control for innovative air diffusion terminal devices for buildings.* Building and Environment, 2010. **45**: p. 2679-2688.
[5] Nastase, I., Meslem, A., Vlad, I., and Colda, I., *Lobed grilles for high mixing ventilation – An experimental analysis in a full scale model room.* Building and Environment, 2011. **46**(3): p. 547-555.
[6] Mitchell, M., Smith, L., Karagozian, A., and Smith, O., *Emissions measurements from a lobed fuel injector/burner*, in *36th AIAA Aerospace Sciences Meeting and Exhibit*. 1998, American Institute of Aeronautics and Astronautics.
[7] Hunter, C., Presz, W., and Reynolds, G., *Thrust augmentation with mixer/ejector systems*, in *40th AIAA Aerospace Sciences Meeting & Exhibit*. 2002, American Institute of Aeronautics and Astronautics.
[8] Vialle, P.J., Leroy, E., and Meslem, A., *Diffusion device with lobe inserts and fan coil comprising such a device*, in *European Patent Office*. EP2933575. October 2015.
[9] Dogeanu, A., Iatan, A., Bode, F., Croitoru, C., and Nastase, I., *Conception of a simplified seated thermal manikin for CFD validation purposes.* Romanian Journal of Civil Engineering, 2014. **5**.
[10] ISO, *Ergonomics of the thermal environment -- Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria*, in *ISO 7730*. 2005.
[11] ANSI/ASHRAE, *Thermal environmental conditions for human occupancy*, in *Standard 55-2013*. 2013.
[12] Fanger, P.O., *Thermal Comfort, Analysis and Applications in Environmental Engineering*. 1970: Mc Graw Hill Book Company.
[13] Fanger, P.O., Melikov, A.K., Hanzawa, H., and Ring, J., *Air turbulence and sensation of draught.* Energy and Buildings, 1988. **12**(1): p. 21-39.
[14] Awbi, H.B., *Ventilation of Buildings*. Second edition ed. 2003, London, U.K.: SPON. 522.
[15] Chow, W.K. and Wong, L.T., *Experimental studies on air diffusion of a linear diffuser and associated thermal comfort indices in an air-conditioned space.* Building and Environment, 1994. **29**(4): p. 523-530.
[16] Tomasi, R., Krajčík, M., Simone, A., and Olesen, B.W., *Experimental evaluation of air distribution in mechanically ventilated residential rooms: Thermal comfort and ventilation effectiveness.* Energy and Buildings, 2013. **60**: p. 28-37.
[17] ISO, *Ergonomics of the thermal environment -- Instruments for measuring physical quantities*, in *ISO 7726*. 1998.
[18] AFNOR, *Ventilation des bâtiments - Bouches d'air - Essais aérodynamiques et caractérisation pour applications en diffusion à mélange*, in *NF EN 12238*. 2001.
[19] ISO, *Acoustique -- Mesurages in situ de l'isolement aux bruits aériens et de la transmission des bruits de choc ainsi que du bruit des équipements -- Méthode de contrôle*, in *ISO 10052*. 2004.
[20] Ministère de l'Écologie du Développement durable et de l'Énergie Ministère du Logement et de l'Égalité des territoires, *Guide de Mesures Acoustiques.* 2014.
[21] Brelih, N., *Thermal and acoustic comfort requirements in European standards and national regulations.* REHVA Journal, 2013.