HAL
open science

Ceiling turbulent asymmetrical air jets under interaction effects of room architectural elements - a full scale experimental characterization

Chi-Kien Nguyen, Damien David, Frederic Kuznik, Gilles Rusaouen

To cite this version:

Chi-Kien Nguyen, Damien David, Frederic Kuznik, Gilles Rusaouen. Ceiling turbulent asymmetrical air jets under interaction effects of room architectural elements - a full scale experimental characterization. Roomvent 2018, Jun 2018, Espoo, Finland. hal-02095556

HAL Id: hal-02095556

https://hal.science/hal-02095556v1

Submitted on 10 Apr 2019

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

CEILING TURBULENT ASYMMETRICAL AIR JETS UNDER INTERACTION EFFECTS OF ROOM ARCHITECTURAL ELEMENTS – A FULL-SCALE EXPERIMENTAL CHARACTERIZATION

Chi-Kien Nguyen[1,*], Damien David[1], Frédéric Kuznik[1], Gilles Rusaouën[1]

[1]Université de Lyon, CNRS, INSA de Lyon, UCBL
CETHIL UMR5008, F-69621, France
[*]*Corresponding email: chi.nguyen@insa-lyon.fr*

SUMMARY

Experimental investigation of ceiling turbulent asymmetrical air jets was conducted in a full-scale entirely controlled test room (6.2 x 3.1 x 2.5 m). Our realistic case study introduces architectural elements which make the air jet interacted with the room: a plenum box, a grille diffuser, air exhausts and a side wall near the air inlet. Deviations concerning the trajectory of the studied jet were observed and analyzed. Combined effects of room architectural elements have significantly deviated and deformed the air jet development. A method has been proposed to quantify the jet deformation based on a so-called deformation indicator. These results obtained allow for further cases studies under non-isothermal and moisture conditions with condensation. Detailed experimental data could be used as a benchmark study for CFD models evaluation for configurations with rupture of symmetry.

Keywords: asymmetrical jet, interaction, architectural elements, full-scale, deformation indicator

1 INTRODUCTION

Understanding room air distribution is essential to the buildings ventilation systems design and occupants' thermal comfort and indoor air quality controls. Indoor air distribution investigation involves two common methods: numerical simulation and full-scale measurements. Numerical simulation using CFD models is most convenient and efficient for predicting airflow distributions and for assessing ventilation performances in buildings (Chen, 2009). However, their accuracy and reliability remain a major concern, given the lack of proper and thorough validation studies, particularly from full-scale validation studies that can provide valuable and relevant data concerning room airflow characteristics, including the turbulent flow characteristics.

In the literature, in order to investigate the indoor air distribution and the air jet characteristics for evaluating mixing ventilation systems performances, numerous research have been undertaken, either by empirical methods (Grimitlyn and Pozin, 1993), (Li and al., 1993); by experiments and CFD methods (Sun et al., 2004), (Kuznik et al., 2007), (Nielsen et al., 2010), (Hurnik et al., 2015). Although configurations of non-isothermal air jets, effects of obstructions or internal heat sources have been considered, one could remarks a common problem in the location of supply and exhaust air outlets. They were all located symmetrically with respect the room geometry. This arrangement was probably made in purpose for which the air jet is believed to have a quasi-free and symmetrical distribution behavior; and thus investigations were carried out merely in the axis of the room, i.e. the median-plane. In fact, while this configuration could be sufficient for a fundamental basis study, or for simpler modeling/experiments, it does not represent a realistic configuration in which the air jet is not developed freely and symmetrically; hence the intention of this experimental study. The main objective is to characterize an asymmetrical vertical air jet issued from a ceiling grille diffuser in a full-scale room. The air jet interacts with room architecture elements and thus has its trajectory deviation and its shape deformation. Dealing with such air jets, an advanced analysis of the 3-D airflow structures is strongly recommended. Detailed measurements from full-scale experiments accompanied by well-known boundary conditions could be reliable enough to serve as benchmark test for CFD models validation, in particular for airflow configurations with rupture of symmetry.

2 EXPERIMENTAL APPARATUS AND METROLOGY

2.1 MINIBAT test room and flow configuration

Experimental investigation was conducted in a full-scale test cell entitled "MINIBAT", which its environment is entirely controllable. MINIBAT is located at the CETHIL laboratory – INSA de Lyon, France. It consists of three distinct parts: a test room, a thermal buffer zone and a climatic chamber. The test room, with dimensions L x W x H = 6.20 x 3.10 x 2.50 m, is the place where experiments are carried out (c.f. Figure 1). The South facade is a glazing, which is in contact with a climatic chamber. It acts like a weather generator, which is capable of simulating outdoor temperature. Five other facades are in contact with a thermal buffer zone that allows maintaining a stable temperature. A detailed description of the test cell was given in (Teodosiu and al., 2017).

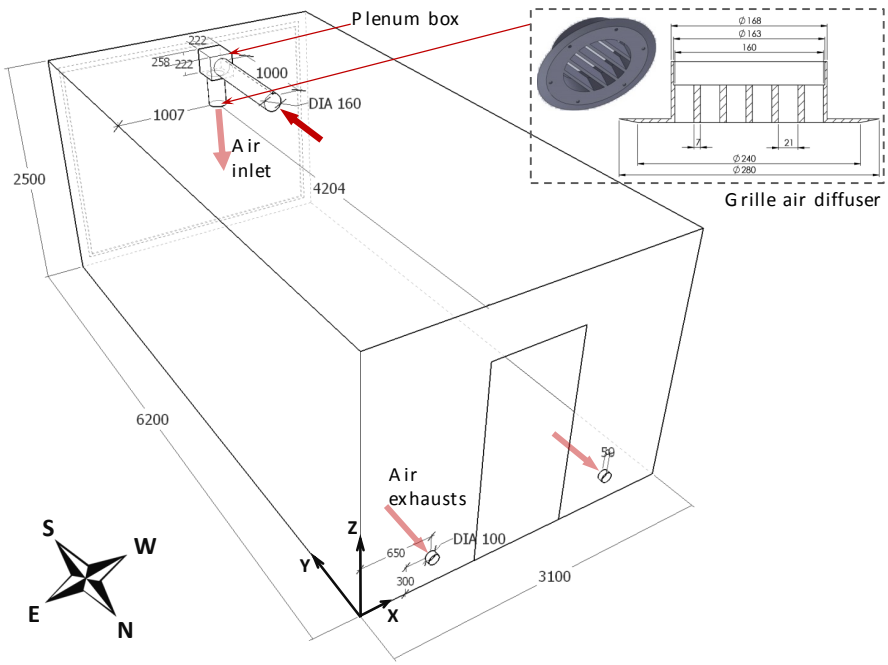

Figure 1. Scheme of MINIBAT test room with flow configuration

The indoor air is ventilated using a closed-loop air handling unit. The ceiling supply air diffuser (Ø160 mm) is located 1.0 m from the East and 4.2 m from the North walls. It is equipped with fixed grille fins, which their direction is parallel to the X-direction (effective/free area ratio of 76% (ASHRAE, 2017)). The two air exhausts (Ø100 mm) are located in the North wall, distanced by 0.3 m from the floor and 0.65 m from the adjacent vertical walls. Our configuration approaches realistic cases in buildings. Indeed, considering the space availability above a suspended ceiling, a plenum box could be installed before the air inlet. Given the room limited dimensions, the supply air inlet could be subsequently located near a vertical side wall and thus the air jet would not develop symmetrically. These architecture elements will necessarily have an impact on the jet behavior and characteristics.

2.2 Metrology and experimental protocol

For the boundary conditions, a network of 180 Pt100 probes was implemented on both external and internal sides of six walls to measure their temperature on the different test cases. The air supply flow rate and temperature were regulated using a propeller flow meter and Pt100 probes respectively. As for the indoor air metrology, we have designed and programmed a mobile robot (c.f. Figure 2) with sensors equipped. The exact position of the robot inside the room can be determined thanks to a LiDAR (laser detection and ranging) (1). The air speed was measured using hot-sphere anemometers (2) with a measuring range of [0.15 – 5] m/s and an expanded absolute accuracy of [±0.03 – ±0.15] m/s accordingly. The air temperature was measured using calibrated fast-response K-type thermocouples (3) (Ø25 µm) with an accuracy of ±0.06 °C in mean value.

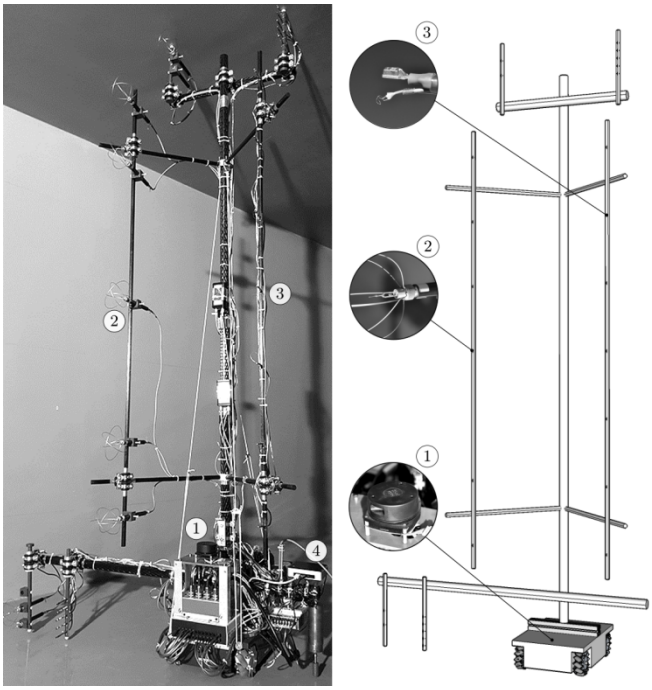

Figure 2. Mobile robot equipped with various sensors
(1) – LiDAR; (2) – Hot-sphere anemometers; (3) – Thermocouples; (4) – Remote controlled mini-PC

For each measurement campaign, three days are required in order to obtain steady state within the test room. During this stage, airflow rate, air temperature and humidity set points are fixed depending on the configuration test cases. Once the steady state reached, the mobile robot is used to examine the area of interest (1 x 1 m around the air inlet with a mesh of 0.05 m). For each robot position, air velocity and temperature are measured with an acquisition frequency of 10 Hz (100 ms between each measure). Recorded values are averaged over 2000 samples, i.e. 200 s in order to reduce fluctuations.

3 RESULTS AND DISCUSSIONS

In the present paper, the case of an isothermal jet is analyzed. The experimental conditions (wall temperatures, air supply parameters) are summarized in the Table 1. The empirical free jet model will not be described in order to not overload the paper. They were based on the publications of (Goodfellow, 2001), (Awbi, 2003) and are detailed in (Nguyen et al., 2017). Experimental results were analyzed and visualized using Python programmation and ParaView software.

Table 1. Isothermal jet case study – Experimental conditions

	Ceiling	**Floor**	**S (°C)**	**N**	**E**	**W**	**Flow rate (m^3/h)**	**U_0 (m/s)**	**Re_0 (-)**	**T_0 (°C)**
Mean value	20.7	20.9	20.9	20.6	20.5	20.5	119.99	2.1	17268	19.98
SDEV	0.2	0.2	0.1	0.2	0.2	0.2	0.75	0.01	-	0.06

3.1 Jet trajectory and maximum velocity decay

Firstly, mean air velocity data were interpolated to determine the true maximum velocity values in each of the six measured horizontal planes. A qualitative 3D visualization of the trajectory of the jet as well as the line of the maximum velocity decay is given in the Figure 3.

It is possible to observe an asymmetrical trajectory of the experimental jet. The jet develops in the North-West direction, towards the exhausts mouths (North side) and towards the far West wall. This behavior of the experimental jet is probably due to the near side wall, the exhaust mouths as well as the plenum box. One could make a first statement that the jet trajectory is deviated under the combined effects of the disturbance of the near wall and the aspiration of the two exhausts mouths.

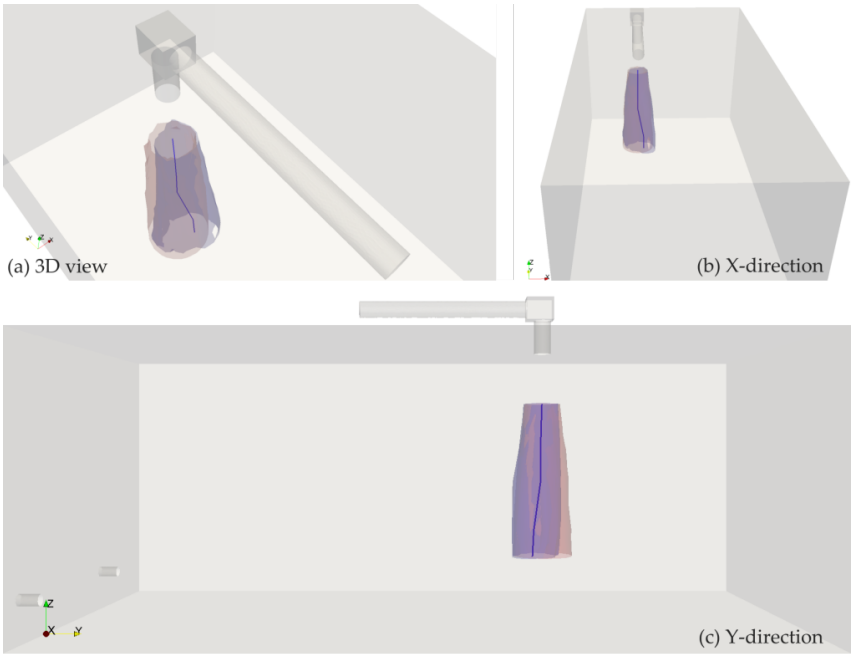

Figure 3. Jet trajectory deviation and maximum velocity decay
With: red – free jet; blue – interacted jet; value taken for contour drawing: 0.2 m/s

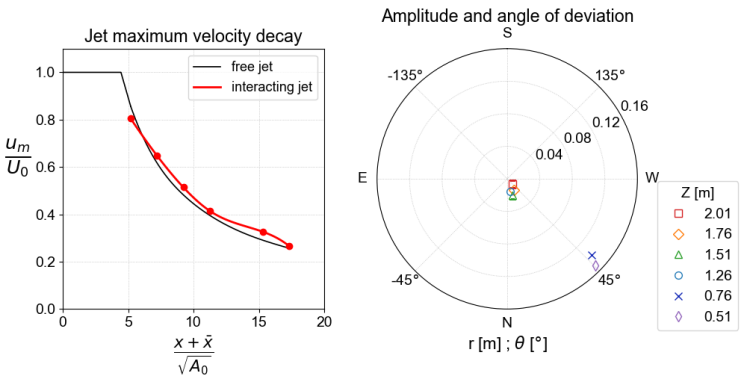

Figure 4. Jet maximum velocity decay – Amplitude and angle of deviation of the jet

The Figure 4 gives a quantitative description of the amplitude and the angle of deviation of the experimental jet. The maximum velocity decay of both the free jet and interacting jet is also presented. In the region near the diffuser, the jet does not deviate visibly, the deviation amplitude remains minimal (1 cm to 2 cm). Nevertheless, in the jet fully developed region (Z = 0.75 m and 0.5 m), the jet deviation is much more visible with an amplitude reaching 15 cm and an angle of 45°. As for the jet maximum velocity decay, despite the behavior of the air jet, the decay curve does not differ much from that of the free jet. It is therefore possible to deduct that the architectural elements might have deviated the jet trajectory but about the same max velocity values are found compared to a free jet.

3.2 Jet velocity contours and cross-section velocity distribution

In this section, one analyzes the distribution and the deformation of the velocity profiles in the jet cross-section. The air jet was spread asymmetrically, one needs a method to quantify this deformation. For this purpose, the jet mean velocity contours with air speed exceeding 0.2 m/s, according to the six measured planes, have been plotted (c.f. Figure 5). The coordinates (X, Y) = (0; 0) corresponds to the center of the grille diffuser. It is possible to notice a non-circular spread of the jet following the X-direction (East-West) in the jet flow-development region. This deformation is probably due to the fins direction of the grille. In the fully developed region, the air jet spread is clearly asymmetrical and its shape seems to rather deform upon the room geometry impacts than the grille diffuser direction.

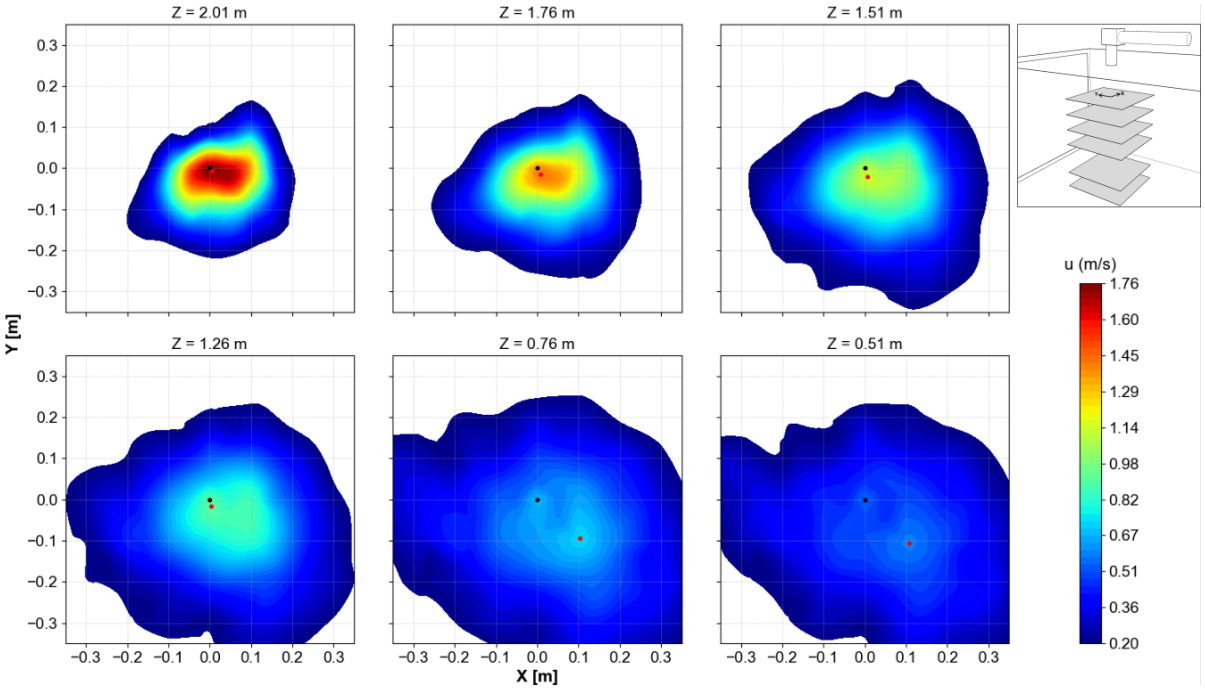

Figure 5. Jet mean velocity contours following Z

In the literature, for jet cross-sectional velocity profiles characterization, it is well known to evaluate u/u_m in terms of dimensionless coordinates $r/b(z)$, providing that the jet is totally axisymmetrical (Awbi, 2003). However, since our studied jet does not have a preferred direction with respect to the others, an analysis according to the X and Y directions is incomplete. Therefore, we define the hydraulic radius (r_h) and the disk-equivalent radius (r_{Deq}), which are given by the following formulas:

$$\boldsymbol{r_h = \frac{2S}{P}} \;;\; \boldsymbol{r_{Deq} = \sqrt{\frac{S}{\pi}}} \quad (S \text{ and } P \text{ are respectively the contour area and perimeter})$$

These formulas were applied to determine the hydraulic and disk-equivalent radius of the normalized velocity contours presented in Fig.5, i.e. for contours u/um = (0.2…1). We define the jet profiles deformation indicator (DI) as the ratio r_h/r_{Deq}. A value of DI = 1 means a circular contour.

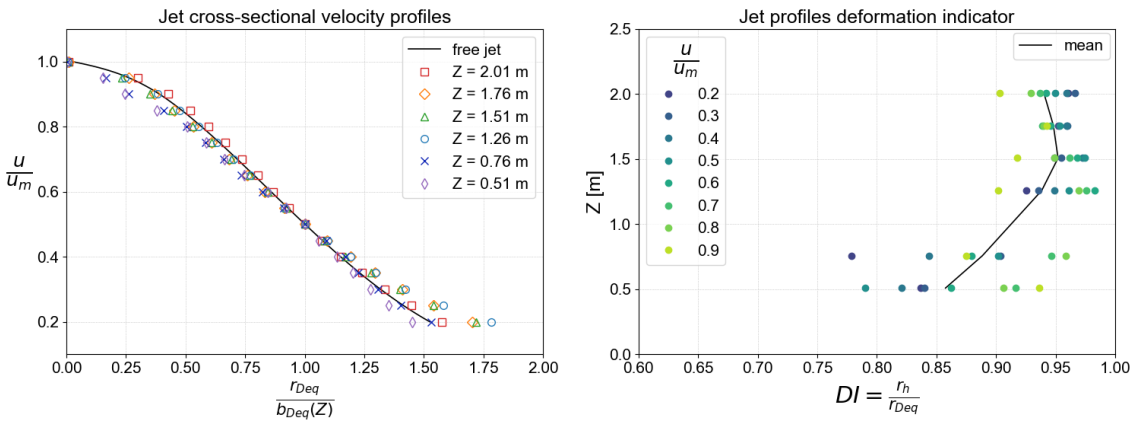

Figure 6. Velocity distribution in the jet cross-section – Deformation indicator of jet velocity profiles

The plot of velocity distribution profiles u/u_m in terms of $r_{Deq}/b_{Deq}(z)$ are given in the Figure 6. The free jet profile can be expressed by a single Gauss error-function curve. It is possible to remark the self-similarity of all the 6 jet cross-sectional profiles despite their asymmetry. It can be seen that the profiles Z = 0.76 and 0.51 show a smaller spread than the others, probably due to the momentum loss.

If the asymmetrical jet distribution profiles are about the same as the free jet, how could we quantify the jet deformation? Hence, the purpose of the deformation indicator *DI*. As shown in Fig.6, for the four planes Z = 1.25…2.00 m, their *DI*-values vary between 0.9 and 0.98. The last two planes show a greater variation: their values vary between 0.78 and 0.95. It is then possible to conclude that for a normalized velocity contour, the more the *DI*-value is smaller than 1, the greater the deformation.

4 CONCLUSIONS

- While axisymmetrical free air jets have been widely studied in the past, few studied a realistic air jet having interaction with the room. Therefore, the present paper presents a full-scale experimental characterization of an asymmetrical vertical air jet. The air jet interacts with room architecture elements and thus has its trajectory deviation and its shape deformation.
- The disturbance of the side wall near the air inlet, the aspiration of exhausts mouths, the presence of the plenum box and the grille of fins have significantly deviated the jet trajectory and deformed the shape of the jet, especially in the fully developed jet region.
- A method has been proposed to quantify the jet cross-sectional profiles and their deformation. It is a graphical-based method by using the so-called hydraulic radius and disk-equivalent radius.
- Following this study, experimental results of non-isothermal jets as well as the indoor turbulent dynamic fields are being analyzed. On the other hand, the encouraging results obtained allow for more thorough experimental test cases with the presence of moisture and the condensation on a cold wall; knowing that the experimental set-up for the latter is already in preparation.
- Detailed data issued from this study could be reliable enough to serve as benchmark test for CFD models validation, in particular for airflow configurations with rupture of symmetry.

REFERENCES

ASHRAE. (2017). Chapter 20 Space Air Diffusion. ASHRAE Handbook Fundamentals.

Awbi, H.B. (2003). Ventilation of buildings. Spon Press, London.

Chen, Q. (2009). Ventilation performance prediction for buildings: A method overview and recent applications. Building and environment, vol. 44, no 4, 848-858.

Goodfellow, H.D. (2001). Industrial ventilation design guidebook. Academic press, Chapter 7.4.

Grimitlyn, M.I., Pozin, G.M. (1993). Fundamentals of Optimizing Air Distribution in Ventilated Spaces. ASHRAE Transactions 99, 1128–1138.

Hurnik, M., Blaszczok, M., Popiolek, Z., 2015. Air distribution measurement in a room with a sidewall jet: A 3D benchmark test for CFD validation. Building and Environment 93, 319–330.

Kuznik, F., Rusaouën, G., Brau, J., 2007. Experimental and numerical study of a full scale ventilated enclosure: Comparison of four two equations closure turbulence models. Building and Environment 42, 1043–1053.

Li, Z.H., Zhang, J.S., Zhivov, A.M. and al. (1993). Characteristics of diffuser air jets and airflow in the occupied regions of mechanically ventilated rooms - a literature review. ASHRAE Transactions, n°99, 1119–1127.

Nguyen, C.-K., David, D., Kuznik, F., Rusaouën, G. (2017). Full-scale experimental study of ceiling turbulent air jets in mechanically ventilated rooms, in: 38th AIVC Conference, Nottingham, England.

Nielsen, P.V., Rong, L., Olmedo, I., 2010. The IEA Annex 20 Two-Dimensional Benchmark Test for CFD Predictions, in: Clima 2010. Presented at the 10th Rehva World Congress.

Sun, Y., Tan, Z., Zhang, Y., Zhao, L., 2004. Comparison of Six CFD Models for Room Airflow Study with PIV measurement Data, in: ASABE Paper No. 044097. ASAE.

Teodosiu, R., David, D., Teodosiu, C., Rusaouën, G., Ilie, V., Nguyen, C.-K., 2017. Experimental and Numerical Investigation of Mechanically Ventilated Rooms. Energy Procedia 112, 252–260.