INVESTIGATING AIRFLOW PATTERNS NEAR SUPPLY AND EXHAUST VENTS OF ROOM-BASED VENTILATION UNIT USING LASER DOPPLER ANEMOMETRY

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Abstract

In this study, airflow patterns near side-to-side located supply and exhaust vents of a duct-less room-based ventilation unit with recuperative cross-flow plate heat exchanger were investigated. Airflow fields were created by measuring a grid of 550x550mm with 50mm steps on five vertical planes with a distance of 50mm between the steps. The mean velocity components were measured using two-component laser Doppler anemometry (LDA). Although the airflow patterns indicate short-circuiting of the airflows near the supply and exhaust vents, it can be considered marginal and should be accounted only at low flow rates. It is noted that the supply air jet, due to the Coanda effect, is attracted to the external wall, thus extending the throw distance of the jet. The information gathered in this experiment can be used in future research, i.e. to validate numerical CFD models used for estimating ventilation effectiveness, thermal comfort, contaminant concentration etc., and to determine the suitability of a ventilation unit in different configurations for different buildings.

Keywords: Laser doppler anemometry (LDA), velocimetry (LDV), room-based ventilation, airflow patterns

Introduction

The air supplied to rooms through various types of outlets (e.g. grilles, ceiling diffusers, perforated panels) can be distributed by turbulent air jets or in a low-velocity, unidirectional manner. The air jet discharged from an outlet is the primary factor affecting air motion in a room (Kato & Murakami, 1992). Straub, Gilman & Konzo (1956) found that little difference was observed by the changes in the location of the return intakes. Differences in the temperature of the supply air jet and ambient air temperature generate buoyancy in jets, affecting its trajectory, throw and location at which it attaches to and separates from the nearby surface. Attached jets travel at higher velocity and entrain less air than a free jet (ASHRAE, 2009). Straub et al. (1956) concluded that one of the most acceptable distributions of air is obtained from outlets located near a wall, which directs the air vertically with little spread. The latter type had acceptable performance over a wide range of flow rates and supply air velocities. In order to estimate the airflow patterns in rooms with forced ventilation, data through experiments need to be acquired.

Provision of good quality experimental data is essential for accurately validating mathematical models of airflow (Posner, Buchanan & Dunn-Rankin, 2003). Such models may be used for important applications in building services and engineering, including air tightness, ventilation, air conditioning and refrigeration. Reliable data improves confidence in the use of mathematical models, usually Computational Fluid Dynamics (CFD) models, and enables engineers to investigate the effects of installing, removing or altering the arrangement of fans, ducts and other ventilation devices, without expensive physical testing (Mayers, Mitchell, Missenden & Gilbert, 2010). Aside from the popular CFD-based models, data can be gathered by analytical, empirical, small-scale and full-scale experimental modeling and measuring (Chen, 2009). To obtain reliable and precise information on actual airflow patterns and velocity distributions, experimental measurements are a must (Sun & Zhang, 2007). Small-scale and full-scale experimental models can give more detailed information about the performance of ventilation systems than the analytical and empirical models. With small-scale models there are often scaling problems while trying to achieve flow similarity with an actual room or building (Chen et al, 2010). In case of experimental modeling, airflow characteristics must be studied.

The commonly used methods at present and the potential techniques for the near future for indoor airflow measurements include rotating vane anemometers, thermal anemometers, ultrasonic anemometers, visualization techniques, particle image velocimetry, particle tracking velocimetry, and molecular tagging velocimetry and Laser Doppler anemometry (Sun et al, 2007). In order to measure the global velocity distribution in a flow field accurately, measurement techniques have to be used which do not disturb the flow field. One of the most accurate techniques is the Laser Doppler Anemometry (LDA), also known as Laser Doppler Velocimetry (LDV), which can also accurately measure low velocity magnitude and direction without disturbance to the flow fields (Diodati, Paone, Rossi & Tomasini, 1993; Mease, Cleveland, Mattingly & Hall, 1992).

The laser Doppler technique relies on the presence of particles in the flow, which not only follow all flow velocity fluctuations but are also sufficient in number to provide the desired temporal resolution of the measured flow velocity (Adrian, 1983). Particle tracking and particle light scattering are the two most important issues involved in the choice of tracer particles. Given that the tracking ability must be fulfilled, light scattering can be influenced by the particle substance, incident laser power, collection aperture and its position and detector electronics (Albrecht, Damaschke, Borys & Tropea, 2003). The choice of the right seeding material to scatter the light from laser beams or a light sheet can be crucial to the acquisition of successful experimental data. Numerous properties of the particle material have to be taken into consideration when selecting the appropriate seeding medium for a particular measurement task. The mean particle size is only one of the parameters. Others include specific gravity, particle shape, the width of size distribution, surface characteristics and the refractive index (Meyers, 1991).

In this study full-scale measurements were conducted using a two-dimensional LDA system with 3-axis traverse to characterize airflow patterns near side-to-side located supply and exhaust vents of the room-based ventilation unit. The studied ventilation unit is a duct-less single room unit with a recuperative cross flow plate heat exchanger, used mainly in renovated residential buildings, elderly homes and educational institutions (Kõiv & Mikola, 2013).

2. Methods

2.1 The principle of measurement technique

The measurements are performed at the intersection of two laser beams, where there is an interference fringe pattern of alternating light and dark planes (Mease et al, 1992). Seeding particles scatter the light, which appears to flash, as the particles pass through the bright planes of the interference pattern. The back-scattered light is captured by the transmission/receiving optics. A photomultiplier converts the light intensity fluctuations to electrical signals, which are in turn converted to velocity information in the Burst Spectrum Analyzer (BSA) processor. The frequency of the flashing light (Doppler frequency) is proportional to the flow velocity at the measurement point. The processing results are handled by the BSA software. In this case two components of the velocity can be acquired simultaneously (Chen et al, 2010). The scheme of LDA is shown in Figure 1.

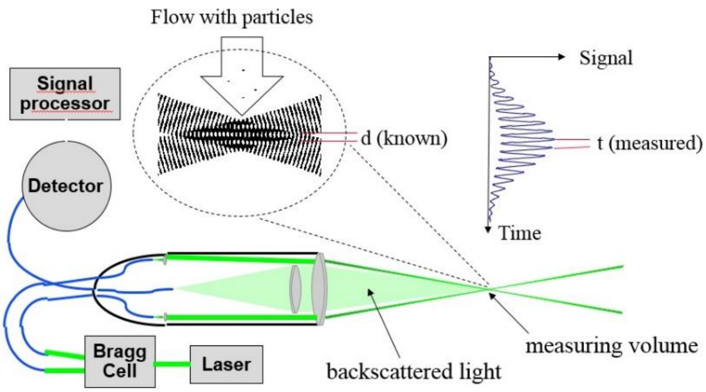

Fig. 1. The scheme of the two component LDA.

2.2 Experimental set-up

LDA measurements were performed using a compact 2D LDA system FlowExplorer 300 (produced by Dantec Dynamics). It is an integrated and accurate system that consists of a factory-aligned and calibrated optical probe, signal processor and software package for data analysis. The LDA system was equipped and integrated with a motorized 3D traversing system that was controlled by the same software. This allowed setting up a measurement grid according to a specific test. The use of a traversing system enabled to accurately re-measure single data points in a grid if needed. The range of the movement was 610 mm in all three directions with a resolution of 6.25 μm. This assured high-quality of the measurements.

The FlowExplorer 300 measures one or two velocity components simultaneously. The maximum output of the optical head is 500 mW for the first and second velocity component. The measurement distance from the optical head is fixed to 485 mm. The diameter of the measurement volume is 0.17 mm and length 2.8 mm. The maximum velocity range is ± 45 m/s and velocity fluctuations < 0.002 % of the velocity range. The wavelengths of the laser beams are λ = 532 nm and λ = 671 nm.

The duration of the measurement in a single point can be adjusted by fixing the desired number of measured particles in the horizontal and vertical direction or the time of measurement. Other set-up parameters are mean velocity and velocity span in the horizontal and vertical direction and laser sensitivity. These settings are adjusted according to a specific test and/or measurement point if needed (The default values used are described in Table 1).

Table 1. The default parameter values used in velocity components in single point measurement.

Parameter	Uy (vertical)	Ux (horizontal)
Max. samples	20000	10000
Acquisition time (s)	60	60
Velocity span (m/s)	3.17	1.33
Center velocity (m/s)	0	0
Laser sensitivity (V)	1000	1000

The experimental set-up is shown in Figure 2. The LDA probe positioning traverse system was mounted on a 1.6 m high static mount. The center of the supply and exhaust vents was measured 163 mm from the wall. The traverse system was positioned with one horizontal axis (x-axis) parallel to the wall. The traverse z-axis was defined as perpendicular to the wall with negative direction towards the wall and zero-value in the center of the vents. The y-axis was defined as the vertical axis (Figure 3). Zero position for the x- and y-axis was located 237 mm from the center of the exhaust vent. Measurements were taken on five constant z-axis values of +50 mm to -150 mm with 50 mm steps on measurement grids parallel to the wall. The measured area was 550 x 550 mm. Single point measurements were taken at every 50 mm step, 144 measurements per grid.

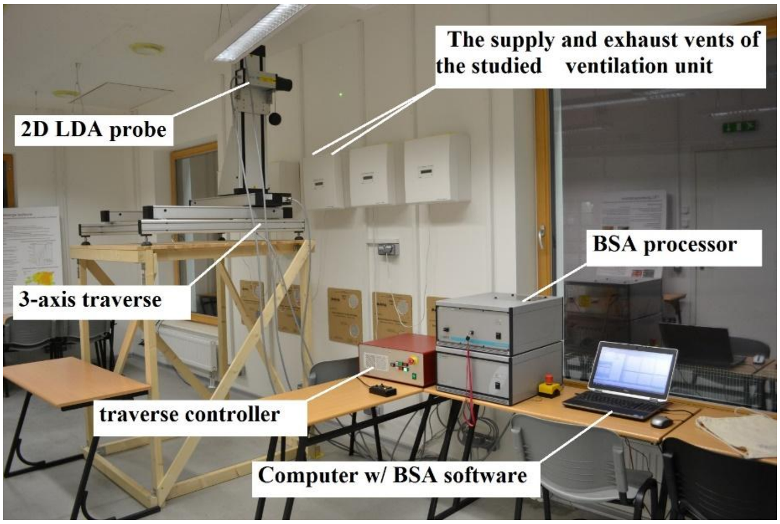

Fig. 2. Experimental set-up

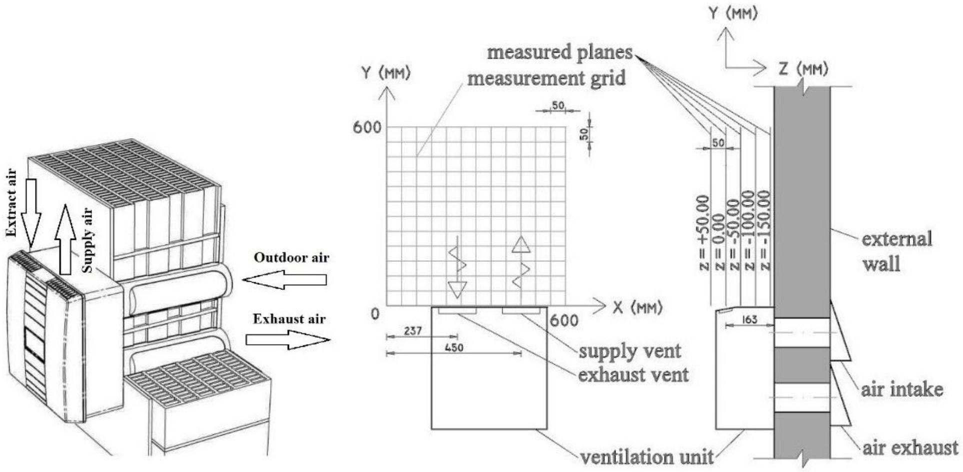

Fig. 3. Illustration of the studied ventilation unit (left), the front view of the unit with the measurement grid (center) and the cross section showing the measured planes and distances (right).

A simple version of the vaporization/condensation-type particle generator was used for seeding particle generation. The generator heats an oil/air mixture to produce hot vapor, which condenses as it cools when leaving the generator (Meyers, 1991). In this case propylene glycol-water mixture was used for its ability to accurately act as a tracer for the airflow (Figure 4). Such seeding, however, is difficult to regulate, so the delivery rate tends to be unsteady and the droplet size distribution rather wide (Melling, 1997). The aerodynamic diameter of the generated particles is <10 µm averaging at 3.5 µm (Varughese et al, 2005).

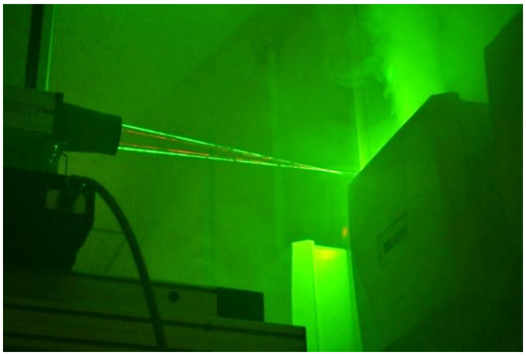

Fig. 4. Measuring airflow velocity near an exhaust vent with the two-component LDA system. Vaporized propylene glycol is used for particle seeding.

In order to achieve neutral buoyancy, well-mixed conditions and continuous, steady distribution of the seeding particles, a plastic covered wooden frame structure, used as a buffer chamber, was constructed at the external wall of the laboratory and was connected to the intake of the ventilation unit (Figure 5). The dimensions of the buffer space were 1.5 x 1.0 x 3.2 m. The particle generator was mounted inside the structure and its output was regulated by a remote control.

During the measurement period, the airflow rate of the ventilation unit was approximately 30 m^3/h, the measured supply air temperature was +17 °C and the room temperature +22°C.

Fig. 5. Buffer chamber for a constant supply of seeding particles, connected to the intake of the ventilation unit.

3. Results

With the data acquired by the LDA measurements, vector fields of air velocity were created (Figure 6). The measured average centerline velocity of the supply jet stream at the airflow rate of 30 m^3/h was 0.97 m/s. At the distance of 600 mm on the center plane, the vertical component of the velocity was decreased to 0.24 m/s. The neighboring plane (z = - 0.50) shows velocity increase in the vertical direction at the center of the jet, referring to the dispersion and deviation of the jet towards the wall. When comparing the two flow patterns at z = +50.00 mm and z = -50.00 mm either side of the plane in the center of the vents (z = 0.00), it can be seen that the air jet from the supply vent is attracted to the wall, indicating near the wall Coanda effect.

The velocity vectors between the supply and exhaust vents show air movement directly from the supply to the exhaust vent, although the effect is trivial considering the reach area of the exhaust vent and the jet magnitude. This however, can be a factor at low airflow rates.

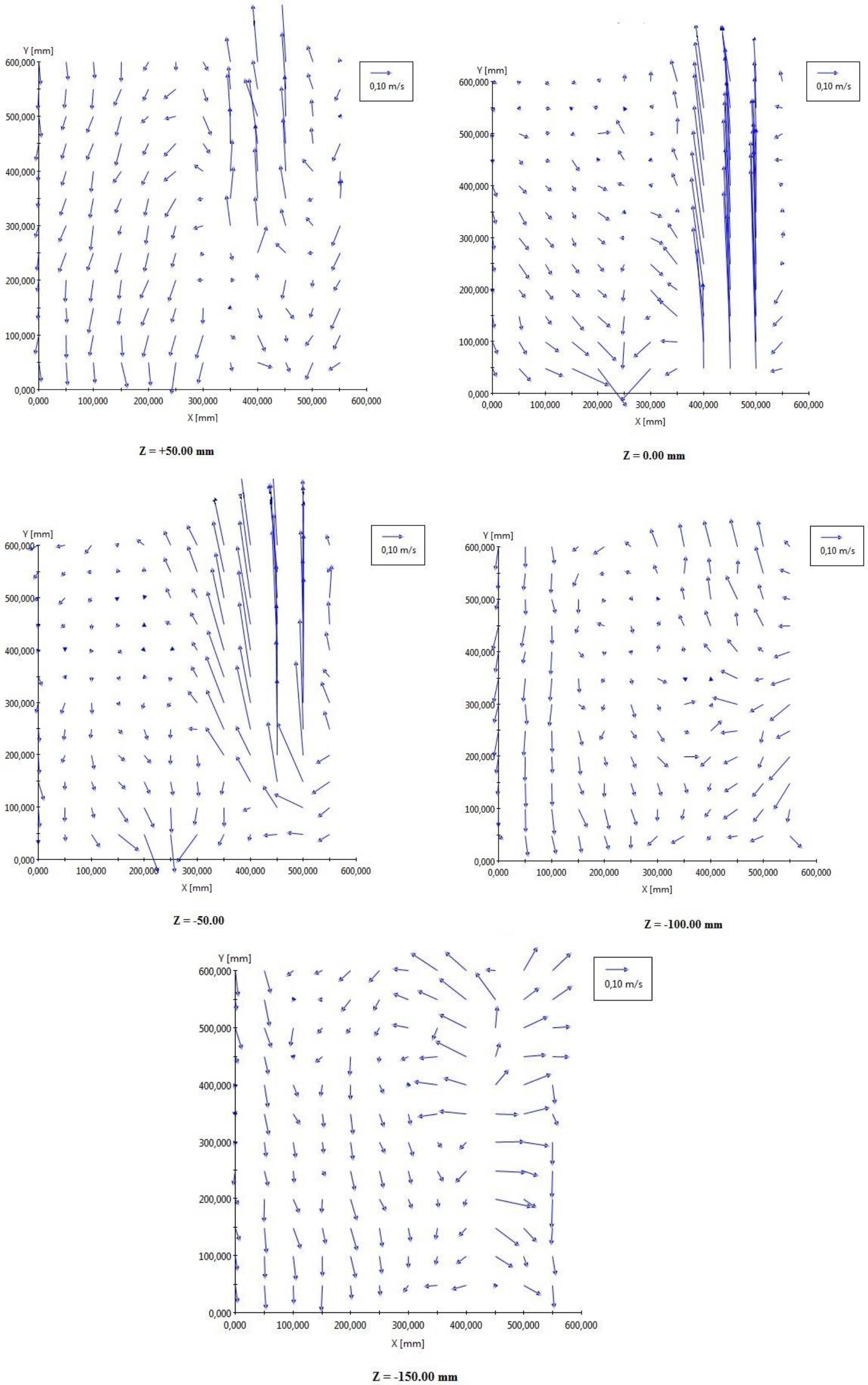

Fig. 6. Velocity vector plots near the supply and exhaust vents of the ventilation unit on parallel planes.

Conclusion

The aim of this study was to characterize airflow patterns and gather experimental data on air velocity and air movement peculiarities near side-to-side located air supply and exhaust vents. With the LDA configuration used in this experiment, it was possible to take only single point flow velocity measurements, which made the complete flow pattern scan of the studied region a very time-consuming process. Although the conducted airflow patterns indicate some short-circuiting of the airflows near the supply and exhaust vents, it can be considered marginal, since the air velocity near the exhaust intake decreases rapidly as the distance from the inlet increases. It is noted that the supply air jet is leaned towards the external wall, caused by the Coanda effect and extending the throw distance of the jet. An uneven distribution and disturbance of the velocity vector field can be seen near the sides of the jet, indicating entrainment of the room air.

The information gathered in this experiment can be used in future research, i.e. to validate numerical CFD models used for estimating ventilation effectiveness, thermal comfort, contaminant concentration etc., and to determine the suitability of a ventilation unit in different configurations for different buildings.

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