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Air Distribution Assessment - Ventilation Systems with Different Types of Linear Diffusers

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ABSTRACT

The primary purpose of ventilation and air-conditioning system is to ensure internal comfort conditions through a continuous supply of air and maintaining the assumed indoor parameters. High air velocity in the occupied zone may result in an uncomfortable feeling of the draft, cooling effect, or local discomfort. The subjects of the study are linear diffusers, which depending on the purpose, are installed in ceilings, floors, or walls. Models may vary widely in their shape, number or size of slots/nozzles, and the length or shape of the deflector blades. The selection of the specific solution is possible only by comparing the operation of individual diffusers with each other. It could be very difficult for the average user because the datasheets often present results for different reference values or only at certain points. This work presents a comparison of the three different linear diffusers. Tests were to determine under the isothermal condition the airflow characteristics of different diffuser types by measuring velocities within the air stream at various distances away from the supply air terminal device. Measurements for each of the proposed solutions were carried out under the same ambient conditions. The supply airflow characteristics are investigated at various volumetric flow rates. The experimental tests were carried out in the thermal technology laboratory at the AGH University of Science and Technology in Cracow. The air velocity was measured at selected points using thermal anemometers. The measuring grid was prepared based on smoke tests. The collected data was used to prepare the velocity field and charts of the air throw lengths with a terminal velocity of 0.2 m/s (39 fpm) depending on the air flow rate in the selected measurement plane. The research presents the influence of air distribution systems on indoor environmental quality assessment. The fundamental aim of the paper is to present differences between systems equipped with linear diffusers of various designs. The analysis showed the design of the diffuser has an impact on the shape and range of the air stream. The vertical range for tested diffusers is significantly different. At a volume flow of 120 m^3/h (4 237 ft^3/h), it ranges from over 2.50 m (8.20 ft) to below 1.60 m (5.25 ft).

INTRODUCTION

Nowadays, designers must meet the increasing users' demands and expectations of better conditions in the rooms. A correctly designed and working ventilation system is necessary to ensure thermal comfort. Thermal comfort is affected by air temperature, humidity, air velocity, and average radiation temperature, as well as environmental factors such as clothing, gender, age, and physical activity (ASHRAE, 2010). The selection and the arrangement of the supply and exhaust elements are crucial during the ventilation system design process. Depending on the diffusers' design, they operate in different ways, which affect the shape of the airstream. Inappropriate selection or arrangement of the diffusers may cause

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discomfort for users. Proper air distribution requires the appropriate data on how they work.

The research methodology of the air inlet measurements is often provided based on standard EN 12238: 2001 (EN 12238). This standard specifies three parameters that define the characteristics of the isothermal air discharge from an air terminal device: throw, drop and spread. To obtain the complete performance parameters should be determined at least four values of volume flow. During the measurements, for isothermal testing, the temperature of the inner surfaces of the test room should not differ by more than 2K. Similarly, the temperature in the supply duct and at the exhaust terminal device should not differ from each other by more than 2K. Velocity should be measured within the airstream at a various distance away from the supply air terminal device. Measurements should be carried out in the main air stream direction. The standard includes guidelines for the location of measuring points for the approximate determination of the envelope around the diffuser, where the air velocity will be 0.5 m/s (98 fpm). Measurement points should be located along the axis of the moving air, and the distances between individual points may be different, but it is advisable to concentrate them near the maximum speed. Air velocity should be measured with meters meeting the requirements of EN 13182: 2001 (EN 13182). As reported by the ASHRAE Fundamentals Handbook for measured should be used omnidirectional sensor with a short response time. The mean air velocity in the room should be measured over a suitable period, typically 360 s. A standard deviation of the air velocity or turbulence intensity can be given for the fluctuation airflow. Smoke tests could be used to identify the flow direction.

Diffusers are the subject of many studies. Li et al. (Li et al. 2017) performed laboratory experiments to study the performance of swirl diffuser mounted on the floor. Measurements were obtained by 2D-PIV experimental system under isothermal conditions. Research on swirl diffusers was also carried out by other scientists, both using experimental research (Jaszczur et al. 2016; Borowski et al. 2019) and numerical simulations (Liu et al. 2018; Sajadi et al. 2011; Yau et al. 2018). Awwad A. et al. (Awwad et al. 2017) studied numerically the airflow movement from louver face ceiling diffusers. The effects of diffuser blade angle, lip angle, and the return air inlet locations on air distribution throughout the room were investigated. Linear diffusers are a particular type of ceiling diffuser. There are not many studies in the literature that focus on these kinds of elements. Cao et al. (Cao et al. 2017) analyzed nine cases covering different aspect ratios of the diffusers. Ceiling slot diffusers were measured under isothermal conditions in two test rooms. On this basis, a two-dimensional model used to predict the maximum velocity decay with slot diffusers was proposed. A slot-ventilated model room (single, or cellular office) was investigated experimentally by Both et al. (Both et al. 2017). The authors investigated the influence of the inlet aspect ratio on the room's draught comfort. Slot diffusers were also investigated by Yu et al. (Yu et al. 2003). The main aim of this study was to investigate experimentally airflow characteristics that are helpful to predict an isothermal wall-jet performance that occurred in a ceiling slot-ventilated enclosure. Slot linear diffusers and air curtains in the operating room were the subjects of the paper by Keshtkar and Nafteh (Keshtkar and Nafteh, 2016). By presenting CFD simulations, the authors assessed the effectiveness of the system. The results showed that the use of such a solution enables the maintenance of comfort conditions even in rooms with such high requirements as operating rooms.

There are many types of the air diffusers available on the market. Depending on the design, diffusers offered by various manufacturers, despite similar appearance, may differ significantly. The different forms of the presentation of the diffuser performance and differences in the adopted method of the measurement result in difficulty to compare various elements. Therefore, the selection of the air diffusers is a demanding task. Due to the small number of papers about linear diffusers, the authors decided to select this type of air terminal device for research. The publication focuses on the comparison of the characteristics for three linear diffusers. Elements have been selected by the authors as representative types of design for this type of diffuser. The decision has been made based on the analysis of the available linear diffusers' construction on the market. The tests for each of the elements were carried out in the same conditions. Therefore, the assessment and comparison of diffusers were possible.

EXPERIMENTAL SETUP

Three types of linear diffusers have been tested. Each of the elements was 0.82 m (2.69 ft) in length and had the same panel width. The differences are in the design of the outlet openings. Figure 1 shows the geometries of the tested diffusers.

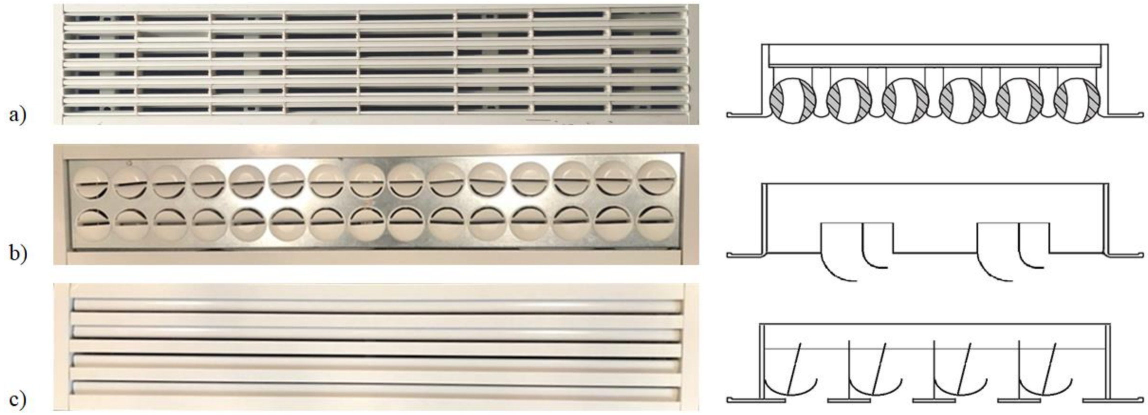

Figure 1 Diffusers geometry (a) no. 1 - with rollers (b) no. 2 - with nozzles, and (c). no. 3 - with linear slot.

The diffuser marked as no. 1 has six air supply slots fitted with movable, circular blades/rollers. Each of the individually adjustable rollers is 0.10 m in length and allows outflow at any angle, from the complete closing of the airflow up to the vertical air outflow. Diffuser no. 2 is characterized by two rows of fifteen round individually adjustable rotating nozzles. Directional nozzles have a two-slot air path that deflects the air streams. The supply air pattern can be directed by rotating the nozzles. The diffuser no. 3 has four linear slots, without modules dividing the diffuser blades. Supply air is supplied through the linear slots of the diffuser, either vertically into the occupied zone or horizontally along the ceiling surface. The air pattern can be changed by manually adjusting the flow deflection blades. The number and size of the slots of individual diffusers for testing were selected so that the devices had a similar dimension and volume flow rate range. The analysis of airflow from individual types of diffusers was carried out based on measurements made in the thermal technology laboratory of the AGH University of Science and Technology. The dimensions of the room, including the height of the adjustable ceiling, shows the figure 2.

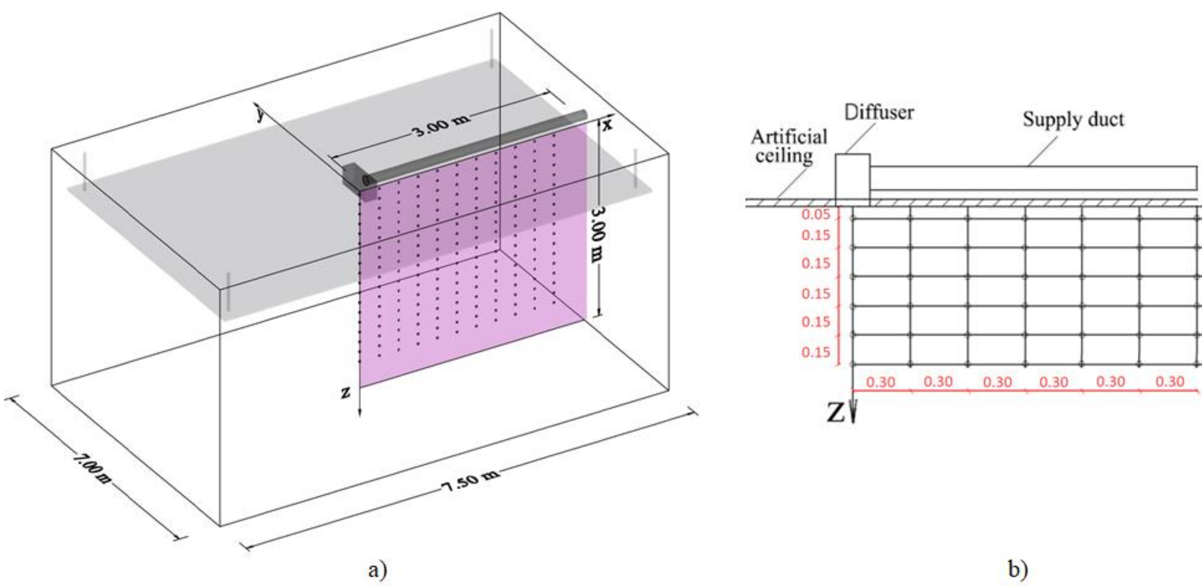

Figure 2 (a) Schematic diagram of the experimental set-up (b) The measuring grid in the X-Z plane.

The diffusers used for the study were tested with the same plenum box. The diameter of the connection stub was 0.16 m (0.52 ft). The use of the same box for each variant of the diffuser was dictated by the limitation of the impact of additional variables that could affect the operating characteristics of the devices. The air was supplied to the plenum box with a duct 0.16 m (0.52 ft) in diameter and 3.00 m (9.84 ft) in length. The air movement was forced by a radial fan equipped with a regulator enabling the change of rotational speed. During the tests, the airflow through the diffuser was adjusted by changing the fan's rotational speed. The volume of the flowing air was measured using a measuring orifice located on the suction side of the fan. The installation operated in a closed circuit, the fan forcing air into the test installation sucked in air from the test room. The measurements were carried out for four supply air streams 120 (4 237), 240 (8 474), 360 (12 712) and 480 (16 949) m^3/h (ft^3/h). The article focuses on the presentation of the results for the minimum and maximum flow used in the tests i.e., 120 (4 237) and 480 (16 949) m^3/h (ft^3/h). The measurement configurations included setting the regulating elements in two positions: outflow parallel to the ceiling with all rows in one direction (horizontal air discharge) and perpendicular to the supply openings (vertical air discharge).

The first stage of measurements was to determine the main direction of air distribution for each of the three variants of diffusers for both positions of the blades. This test was used to determine the grid of measurement points of the air velocity flowing out of the tested elements. Based on the conducted smoke tests, a measuring grid was established. The distance between the measuring points was 0.30 m (0.98 ft) horizontally and 0.15 m (0.49 ft) vertically. The exact arrangement of measuring points is shown in figure 2. The second stage of the tests was to determine the field of air velocity flowing out of structures of linear diffusers. The air velocity was measured using the measuring system consisting of four transducers with measuring probes. The measuring device has a measuring range from 0.05 m/s (98 fpm) to 5 m/s (984 fpm) and accuracy in the range of ± 0.02 m/s (4 fpm) ± 1.5% of indication, the measuring kit also includes a transducer for measuring and automatic compensation of the impact barometric pressure on the indications of thermoanemometric sensors. Results from thermoanemometers were recorded using the Air Distribution program. The average value of the 360 s measurement period was taken for processing the results. The system determines the average speed, the standard deviation of the air velocity, and turbulence intensity from the duration of the measurement.

RESULTS

The preliminary analysis was based on the observations made during smoke tests. Data obtained during measurements with thermoanemometers were entered into the software Statistica (StatSoft, 2021) and on their basis the stream shape and speed range 0.2 m/s (39 fpm) – L0.2 were plotted.

Smoke test

Smoke tests were carried out to verify the symmetry of the outflowing stream, to estimate its shape and range, before proceeding with actual tests. Figure 3 presents photos of the air flow flowing out of each of the tested diffusers as a horizontal air discharge. All posted photos were taken during the stream flow – 480 m^3/h (16 949 ft^3/h) in the X-Z plane. The directional elements are in a first setting, where the airstream is directed parallel to the ceiling.

Figure 3 Smoke test of the diffuser, with horizontal air discharge: (a) diffuser no.1, (b) diffuser no.2 and, (c) diffuser no.3.

Similarly, Figure 4 shows the operation of the diffuser with the setting of the blades for vertical air discharge at the flow of 480 m^3/h (16 949 ft^3/h). Each diffuser is initially characterized by a narrow stream, which expands as it falls.

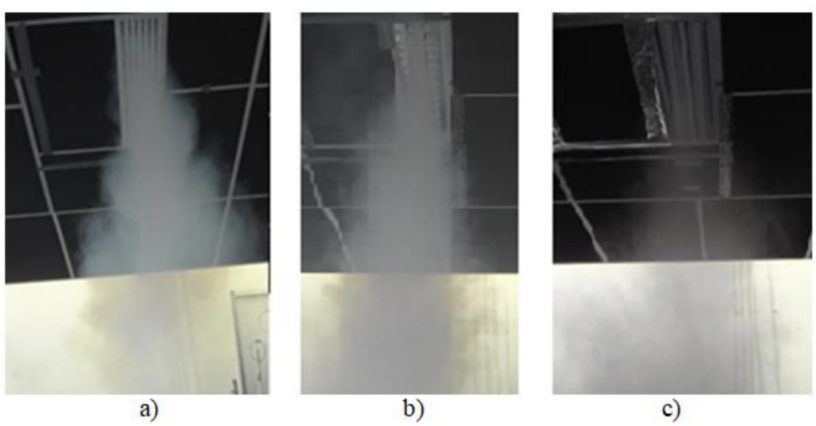

Figure 4 Smoke test of the diffuser, with vertical air discharge: (a) diffuser no.1, (b) diffuser no.2 and, (c) diffuser no.3.

The velocity fields and air throw lengths

Based on the collected data velocity fields were prepared. The velocity isolines allowed for the qualitative assessment of the airflow direction and the shape of the airflow formed by the different diffuser. Figure 5 shows the velocity field for horizontal air discharge for airflow 120 m^3/h (4 237 ft^3/h). It is noticeable that diffuser no. 2 directs the airstream along with the ceiling which allows for increasing the throw lengths. In the case of diffuser no. 1 and no. 3 stream of air bends and falls towards the occupied zone. This will be relevant for low rooms.

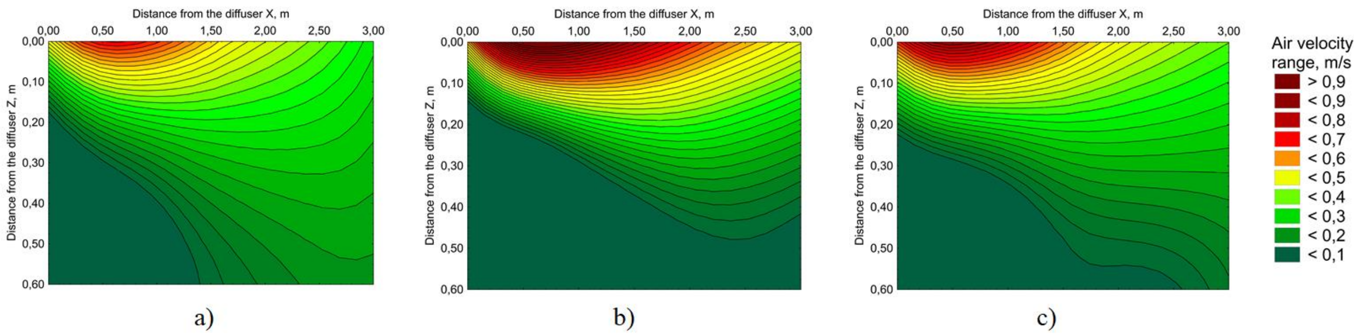

Figure 5 The velocity field for horizontal air discharge at a volume flow of 120 m^3/h (4 237 ft^3/h) for: (a) diffuser no. 1, (b) diffuser no. 2 and, (c) diffuser no. 3.

According to the results presented above, the shape of the velocity field for various structures is similar, but there is a difference in basic variables characterized the diffusers: throw, drop and spread of the airstream. The highest velocity of the air near the diffuser were recorded for the diffuser marked as 2, while the lowest velocity was notice near the diffuser marked as no. 1. Then the data was used to plot averaged and smoothed L0.2 throw length for airflow 120 m^3/h (4 237 ft^3/h) and 480 m^3/h (16 949 ft^3/h) (Figure 6). Throw length L0.2 is reported as the greatest distance from the centre of a supply air diffuser to the velocity isoline of 0.2 m/s (39 fpm) in isothermal air discharge.

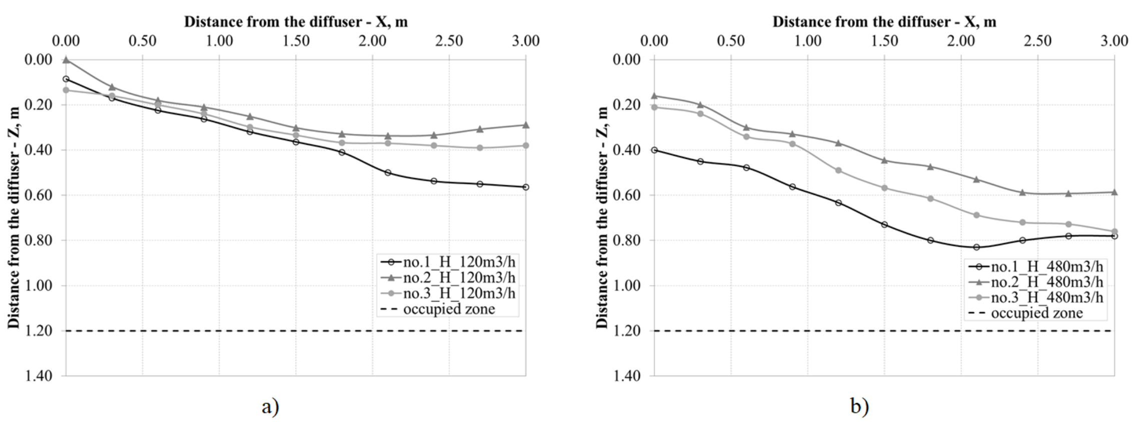

Figure 6 Throw length with terminal velocity 0.2 m/s (39 fpm) for horizontal air discharge at a volume flow rate of: (a) 120 m^3/h (4 237 ft^3/h), (b) 480 m^3/h (16 949 ft^3/h).

For horizontal air discharge the velocity in the the occupied zone (test room height 3.00 m (9.84 ft)) did not exceed the speed of 0.2 m/s (39 fpm). The differences between the analyzed diffusers are more visible with the increase of the volumetric flow, but the trend remains unchanged. Of course, the ranges of the airstream in both directions lengthen with the increase of the volume flow. As noted for each stream, the diffuser no.1 had the highest ranges and element no.2

the smallest. Diffuser with six rows of rollers (no.1) is characterized by the largest distance along the Z-axis, where the velocity of the air stream is reduced to value 0.2 m/s (drop length). For this diffuser, a velocity of 0.2 m/s (39 fpm) at a volume flow of 480 m^3/h (16 949 ft^3/h) is achieved for Z = 0.83 m (2.72 ft). The diffuser with two rows of nozzles (no.2) directs the air mass closest to the ceiling surface. Such airflow is related to the profiling of the outlet nozzles. In isothermal conditions, this diffuser is suitable for rooms where the diffuser is near the occupied zone. In the area close to the inlet, the diffuser with four slots (no.3) operates similarly to element no. 2. However, at higher flow volumes, it also tends to spread the stream more widely (similarly to element no. 1). It is particularly noticeable by increasing the distance from the diffuser along the X-axis.

The analysis also includes the vertical air discharge. In this configuration, the blades, rollers, or nozzles were adjusted to achieve vertical outflow. Figure 7 presents the velocity field for the volume flow of 120 m^3/h (4 237 ft^3/h). As in the case of horizontal air discharge, the highest velocity near the diffusers was measured for element no.2. The lowest velocity was observed for diffusers equipped with the rollers (no.1).

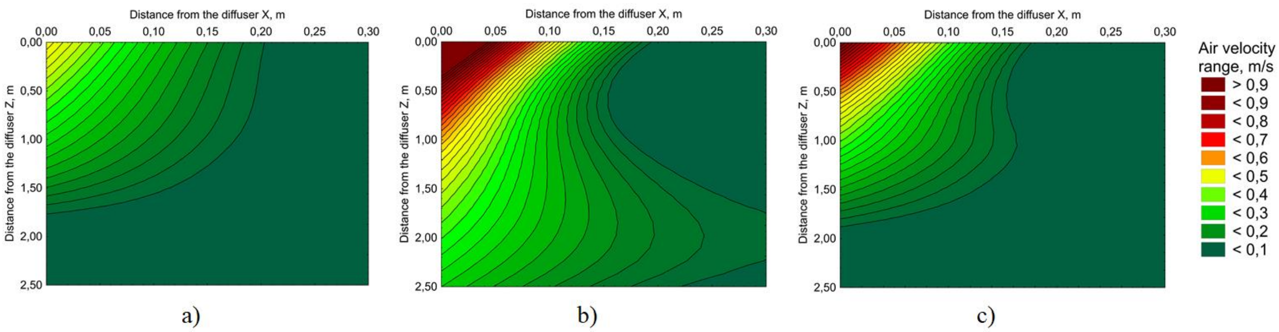

Figure 7 The velocity field for vertical air discharge at a volume flow of 120 m^3/h (4 237 ft^3/h) for: (a) diffuser no. 1, (b) diffuser no. 2 and, (c) diffuser no. 3.

Two airflow volume rates for the vertical setting were analyzed: 120 (4 237) and 480 (16 949) m^3/h (ft^3/h). For the flow volume rate of 480 m^3/h (16 949 ft^3/h), the dimensions of the test room did not allow to capture of the limit range for the velocity of 0.2 m/s. Figure 8 shows the throw length L0.2 for the analyzed diffusers in the vertical air discharge setting.

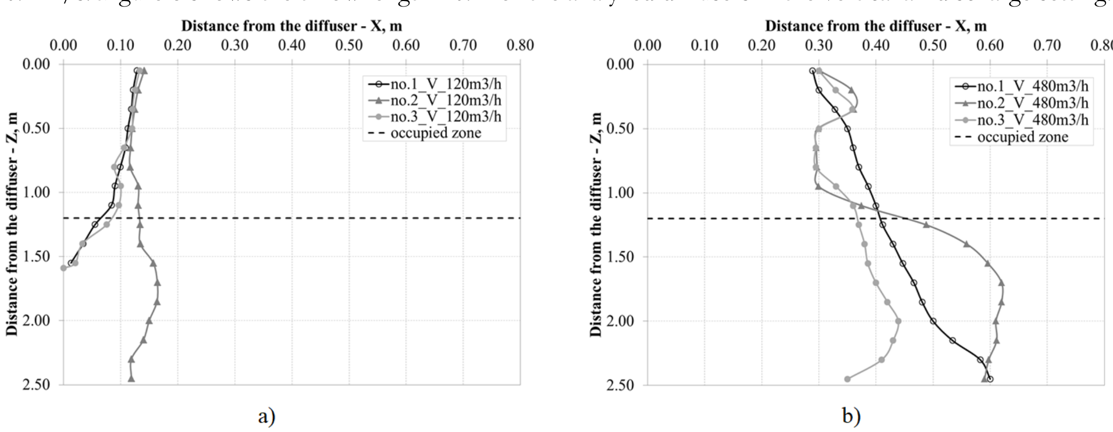

Figure 8 Throw length with terminal velocity 0.2 m/s (39 fpm) for vertical air discharge at a volume flow rate of: (a) 120 m^3/h (4 237 ft^3/h), (b) 480 m^3/h (16 949 ft^3/h).

The air inlet equipped with nozzles has the longest throw distance. Thus, with such a positioning of the blades, it could be a great solution in a high room. Additionally, this type of diffuser is suitable for heating-mode operation when the warm air must be supplied vertically downward to achieve efficient and quick heating. At the same time, it should be mentioned that if this type of diffuser is poorly located, the air may reach the occupied zone with excessive velocity, which may cause users' discomfort. Diffuser no.1 and no.3 at a volume flow of 120 m^3/h (4 237 ft^3/h) have very similar characteristics. These two diffusers with such a position of the blades can be appropriate for rooms of low height.

CONCLUSION

A properly designed and functioning ventilation system supplies adequate amounts of fresh air and provides thermal comfort. One of the aspects to consider is the velocity field of the air flowing out of the supply elements. Excessive speed in users' occupied zone can cause discomfort associated with the phenomenon of the draft. This article presents the results of experimental research for three linear diffusers of different designs with considerations of two airflow volumes.

The applied method of smoke tests allows the preliminary evaluation of the performance of the diffuser. On this basis, it is possible to determine the planes representative of the type of diffuser. Measurements on this plane allow determine the air diffusion and the throw, drop, or spread of the air stream. Comparative tests of various types of diffusers allow obtaining quantitative and qualitative information on the shape of the air stream produced by the diffuser. Only actual measurements with the use of high accuracy devices and the appropriate methodology provide reliable characteristics of the diffusers, and therefore their proper selection.

As the analysis showed, the design of the diffuser has an impact on the shape and range of the outgoing air stream. Simplified methods of the diffusers selection are not sufficient and can result in discomfort for users. The type of the diffusers or their external dimensions are just some of the key parameters. It is, therefore, necessary to consider the specific characteristics of the air diffusion as well as the function and dimensions of the ventilated spaces. The diffuser equipped with steering rollers (no. 1) has the lowest velocity in the measured plane, and the stream flowing along the ceiling drops the fastest (vertical range is the largest). In the case of vertical air discharge, the difference between diffuser with nozzles (no. 2) and other analyzed elements is particularly apparent. The vertical range for this diffuser at a volume flow of 120 m^3/h (4 237 ft^3/h) is over 2.50 m (8.20 ft), while for others, this range does not exceed 1.60 m (5.25 ft). Each of the analyzed models is characterized by an individual stream shape and throw length. Knowledge about the diffuser's performance should be used during the selection of supply elements.

REFERENCES

ASHRAE. 2010. ASHRAE/ANSI Standard 55-2010 Thermal environmental conditions for human occupancy. Atlanta: ASHRAE.

ASHRAE. 2017. *ASHRAE Handbook—Fundamentals*. Atlanta: ASHRAE.

Awwad, A., Mohamed, M.H., and M. Fatouh. 2017. Optimal design of a louver face ceiling diffuser using CFD to improve occupant's thermal comfort. *J. Build. Eng.* 11:134-157.

Borowski, M., Karch, M., Łuczak, R., Życzkowski, P., and M. Jaszczur. 2019. Numerical and experimental analysis of the velocity field of air flowing through swirl diffusers. *E3S Web Conf.* 128:1-6.

Both, B., Szánthó, Z., and R. Goda. 2017. Evaluation of air diffuser flow modelling methods experiments and computational fluid dynamics simulations. *Energy Procedia* 112:352-359.

Cao, G., Ruponen, M., Hagström, K and J. Kurnitski. 2011. Experimental Studies on Air Distribution Using Ceiling Slot Diffusers in a Room. International Journal of Ventilation. 9:4, 385-392.

EN 12238:2001 Ventilation for buildings - Air terminal devices - Aerodynamic testing and rating for mixed flow application. EN 13182:2002 Ventilation for buildings. Instrumentation requirements for air velocity measurements in ventilated spaces. Jaszczur, M., Branny, M., Karch, M., and M. Borowski. 2016. Experimental analysis of the velocity field of the air flowing through the swirl diffusers. *J. Phys.: Conf. Ser.* 745:1-9.

Keshtkar, M. M. and M. Nafteh. 2016. Investigation of influence of linear diffuser in the ventilation of operating rooms Advances in Energy Research, Vol. 4, No. 3 239-253.

Li, A., Yang, C., Ren, T., Bao, X., Qin, E., and R. Gao. 2017. PIV experiment and evaluation of air flow performance of swirldiffuser mounted on the floor. *Energy and Buildings* 156:58–69.

Liu, Z., Li, Q., and T. Ishihara. 2018. Numerical investigation of a swirl diffuser with a novel design using large eddy simulations. *Building and Environment* 135:124-141.

Sajadi, B., Saidi, M.H., and A. Mohebbian. 2011. Numerical investigation of the swirling air diffuser: Parametric study and optimization. *Energy and Buildings* 43:1329-1333.

StatSoft. STATISTICA (Data Analysis Software System); StatSoft, Inc.: Tulsa, OK, USA. Available online: www.statsoft.com (accessed on 10 May 2020).

Yau, Y.H., Poh, K.S., and A. Badarudin. 2018. A numerical airflow pattern study of a floor swirl diffuser for UFAD system. *Energy and Buildings* 158:525-535.

Yu, H., Liao, C-M., and H-M. Liang. 2003. Scale model study of airflow performance in a ceiling slot-ventilated enclosure: isothermal condition. *Building and Environment* 38:1271-1279.