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ACOUSTICAL PARAMETERS OF THE PROTOTYPE AIR CONTROL BLADES IN THE CEILING SWIRL DIFFUSER

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ABSTRACT

Heating, ventilation, and air-conditioning (HVAC) systems are necessary to keep indoor environments warm, cool and clear. However, for architects and designers usually consider the aerodynamical and acoustical parameters, like ventilation rate, airflow direction, sound pressure level and sound power level are important because they are connected with the appropriate selection of some elements of the system (fans, ducts, angles, air valves, silencers, diffusers, and exhaust elements). One such element is the ceiling swirl diffusers, which create a swirl to supply air to rooms where people are and allow mixing flow ventilation in the comfort zone. They are also the source of noise in these rooms. In this work the new types of blades for ceiling swirl diffusers are proposed. To check the noise level of selected blades into the square ceiling swirl diffusers, the aeroacoustic studies were performed. The influence of four prototype manually adjustable air control blades in two positions for noise of ceiling swirl diffuser was measured in the reverberation room. The objects were installed on a plenum box with a side entry without the damper. The prototype blades were made using a 3D printer. These studies were used to indicate the blade with the lowest noise parameters .

Keywords: *HVAC, noise reduction, ceiling diffuser, airfoils*

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1. INTRODUCTION

For the major part of our lives, we have to be in the indoor air for example in the work/home environments and transport vehicles [1, 2]. Clean air in a room is an essential component for a healthy indoor environment. That air is distributed by heat, ventilation and air-conditioning (HVAC) systems. Understanding the behavior of the airflow in a ventilated rooms essential for architects and designers for the correct design each element of HVAC systems. Supplying fresh air to an enclosed space to refresh/remove/replace the existing atmosphere can be accomplished by natural means (e.g., opening a window or door) or mechanical means (e.g., fans or blowers). Natural ventilation effects are uncertain, unreliable and difficult to control. Mechanical ventilation provides constant temperature, humidity and air quality within the enclosed space and is used more often in modern buildings. In mechanical systems, the control of the amount and quality of air in the human-occupied zone is necessary. This can be achieved by air diffusers of different kinds. Devices controlling the room ventilation are called ATD's (air terminal devices), what generally describe supply, exhaust or transfer diffusers and grilles. The ceiling swirl air diffusers are mechanical devices designed to control the characteristics of fluid at the entrance to an open system - rooms. Such diffusers are very common in heating, ventilating and air-conditioning systems [3-6]. There are usually connected to the HVAC systems and ventilation duct by a plenum box or sometimes directly connected to the duct. Such diffusers have got adjustable blades. The blade of the swirl diffuser influence for air diffusion into the room. Directions of air discharge depend also on altered by adjustment of the control blade settings. The connection between the different construction of swirl diffusers and their blades and aerodynamical parameters and noise generation is studied in theme literature [7]. Inside buildings fitted with HVAC systems, the majority of the noise comes from the air, i.e. caused by the movement and distribution of air between ducts and from the ducts into different areas through vents, diffusers and return grilles. Polish Standard PN-B-02151-2 [8] defines requirements on permissible sound levels in rooms designated for people's stay. For single or multi-family rooms, the permissible model sustainable sound level A is 25 dB. In school classrooms and lecture rooms the sound level A should not exceed 35 dB. For offices, this parameter should not be over 35 dB. According to this, is very important that the construction of each element of the HVAC system should provide a low level of noise.

In this work, an adjustable-blade swirl diffuser was tested taking into account his acoustical parameters. The diffuser was equipped with a plenum box and the diffuser front with 8 slits for blades. As the “base” diffuser with adjustable blades, the commercial one was taken shared by a friendly company. The four prototype blades were designed and altered in a swirl diffuser. The prototype blades were made using a 3D printer. The reverberation room was used in these studies. The measurements were made according to ISO 5135. This procedure helped the find the lowest noise swirl diffuser with a prototype blade.

2. EXPERIMENTAL STUDY

Experimental acoustical studies were made during the airflow generated by the swirl diffuser front with adjustable blades in the reverberation room Institute of Power Engineering - Fig 1. The measurements were made on a test stand built following the norm ISO 5135 [9]. The reverberation room has got a volume of 237.0 m^3, an area of 231.5 m^2 and non-parallel walls. The tested object was connected to the centrifugal fan through three absorption silencers and a noise source outside the chamber as shown in Fig. 2.This diffuser comprises a square diffuser front with 8 slots, Fig. 3. Each slit (dimension 20mm×105mm)) had blades on the inside, Fig. 1. Discharge directions of air can be altered by adjustment of the blade angle. For this study, the swirling blades were set to 45º (as a right-turned and left-turned) and oriented so as to create an external swirl and also in a horizontal position (covering a little a slit, but the outlet was around the blades). The blade seen in Fig.3. was used as the “base” - a commercially often used blade in such diffusers. The commercial blade - "base" was designed as a rectangular flat plate with chamfer edges and three semi-circular guides on the top of the blade. The underside of the blade has got one long guide in the middle directed perpendicular to the airflow.

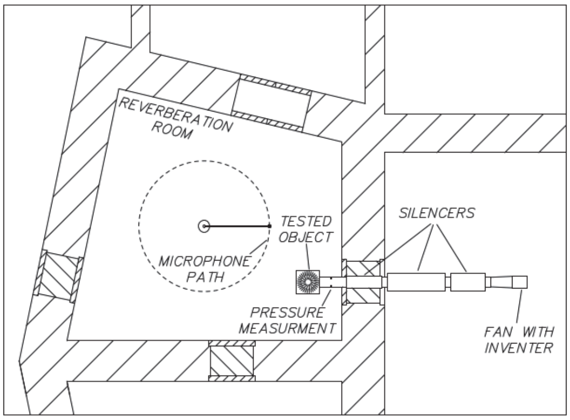


Figure 1. Scheme of reverberation room with studied object.

Figure 2. Photo of studied object in reverberation room.

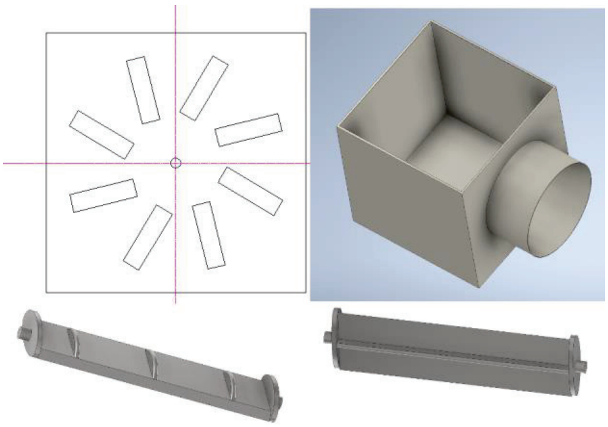


Figure 3. Diffuser in experimental setup and front panel. Under, the both side (left - top; right - down) and of commercial blade treated as a base model.

The four prototype blades were chosen from the airfoil NACA base - Fig. 4 [10]:

- two symmetrical, like NACA 0012 and MH27,
- two unsymmetrical S1012 and Prandtl.

The maximum thickness of all prototype airfoils was around 12%. The blades were made by the 3D printer from ABS. Models of airfoils were suited to slit in the front panel of the diffuser (and also to the applied fixing), so they had got the same length and width as a base blade. However, the trailing edges of the studies prototype blade were changed by cutting. When the distance between the upper and lower side was 1mm the airfoils the trailing edge was cut and rounded. This treatment caused a better a 3D print of the studied blades.

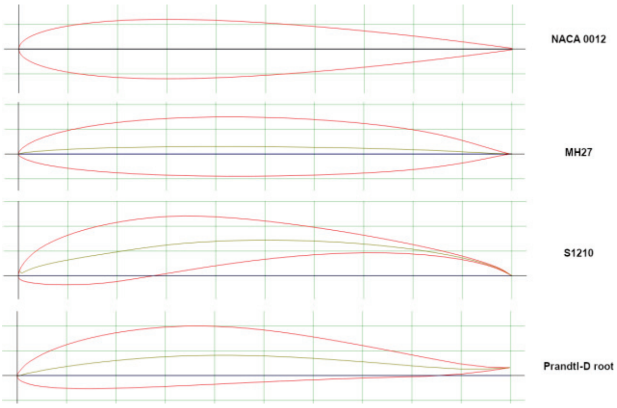


Figure 4. Prototype model of blades variant using in these studies.

The measurements were carried out for three-volume flows: 200, 300 and 400m^3/h. The volumetric flow was set by changing the rotation frequency of the fan motor. For this purpose, a three-phase inverter is connected to the motor. Flow velocity was measured using the Testo 420 balometer. The static pressure drop on the expansion box together with the front plate was measured 300 mm on the channel in front of the plenum box in four evenly located points around the circumference and the environment. A differential pressure transducer was used for this.

The three-position of blades were studied according to Fig.5. The generated noise was determined by sound power level, measured and calculated under PN-EN ISO 3741 [11]. The Nor 140 measuring set with the Nor850 software and the Nor265 rotary table were used for the measurements. The sound pressure was measured at twelve uniformly spaced points in a circle with a radius of 1.7 meters (circumference 10.7 m). Measured in 1/3 octaves in the range from 100 Hz to 10,000 Hz. The measurement time is set to 15 seconds and in the case of background measurement to 30 seconds. Reverberation was measured for four omnidirectional loudspeaker settings with three microphone settings every 120 degrees. All calculations of the sound power level were made using a previously made calculation sheet. Before and after all measurements were made, the background level was measured and calibrated using the Bruel & Kjaer 4231 calibrator. After measuring each setting, the temperature, relative humidity and atmospheric pressure necessary for calculating the sound power were recorded

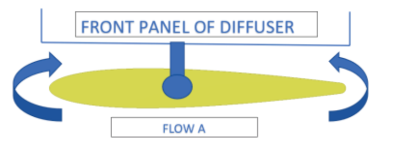
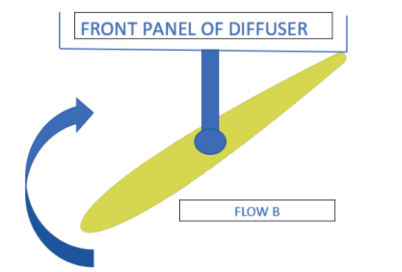
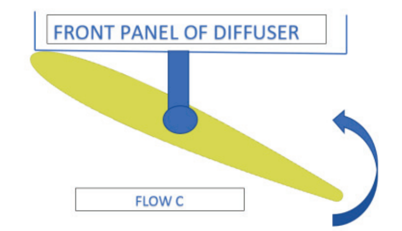
	Flow A - inflow between two side of blades
	Flow B - inflow to the leading edge of airfoil (blade)
	Flow C - inflow to the trailing edge of airfoil (blade)

Figure 5. Scheme of inflow between studied blades and front panel of the diffuser.

3. RESULTS

The example graphs for flow A for the three-volume flow are presented in Figure 6. For all studied prototype blades, noise reduction was observed. As can be seen, each prototype blade gave lower values of the acoustics spectrum in the whole studied range. The similar acoustic spectrum for the flow B and flow C were observed. This suggests, that all studied in this work blades are "acoustical" better than commercial.

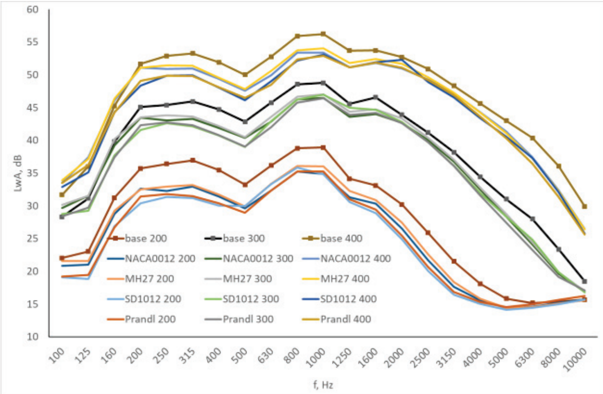


Figure 6. Sound acoustic A power level for studied blades in flow A at different volume flow.

The differences between the 1/3-octave level of sound power of the “base” blade and studied variant of blades were used to present the results of noise reduction (ΔL_w), using the equation (1).

$$\Delta L_w = L_{W"base"} - L_{W"variant"} \tag{1}$$

where $L_{W"base"}$ - the level of the sound power in the frequency band considered for the "base" blade; $L_{W"variant"}$ - the level of the sound power in the frequency band considered for the studied variant of blade. The example graphs for flow C are presented in Fig. 7, 8 and 9. The positive values of the 1/3-octave differential spectrum tell about the noise reduction by studied blade variants.

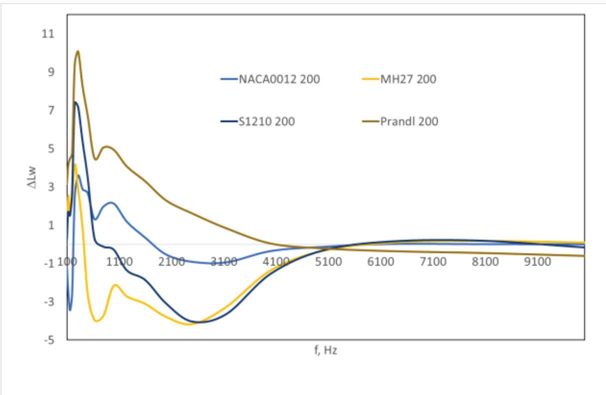


Figure 7. 1/3-octave differential spectrum between “base” and studied variants of blades at 200m^3/h, for flow C.

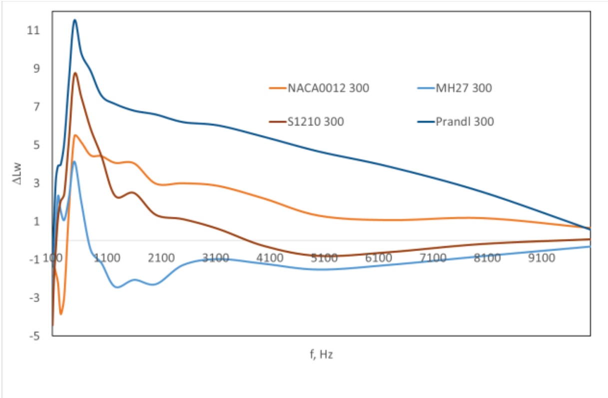


Figure 8. 1/3-octave differential spectrum between “base” and studied variants of blades at 300m^3/h, for flow C.

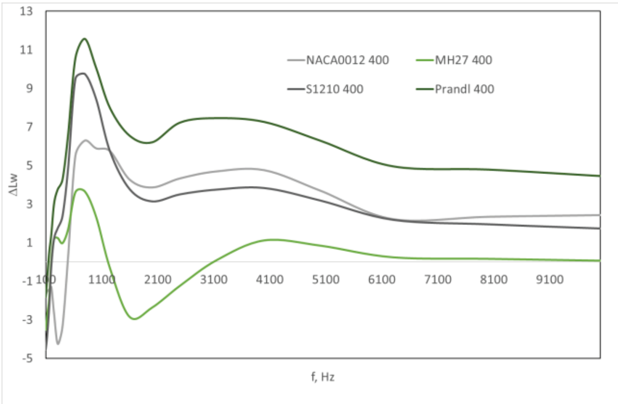


Figure 9. 1/3-octave differential spectrum between “base” and studied variants of blades at 400m^3/h, for flow C.

However, at 200m3/h, for the MH27 variant, the 1/3-octave differential spectrum has negative values above 600Hz, similar to the S1210 blade where negative values above 800Hz are observed and also for NACA 0012 - above 2000Hz. In this case, it could be said that only a Prandtl blade can reduce the noise more than the commercial blade.

MH27 blade variant gives also negative 1/3-octave differential values at 300m3/h and 400m3/h. It could be said that the barrel shape of the MH 27 airfoil is not a good solution and this blade should not be used in ceiling swirl diffusers.

From all studied blades the Prandtl type has got better parameters than the commercial blade in ceiling swirl diffuser. Regardless of the position of this blade (flow A, B, C) the lower L_{wA} values were obtained. The sound power level with A corrections for the studied damper's plate is presented in Table 1. The L_{wA} for the "base" blade is different for flow A i B (flow C is the same as B due to the construction of the blade).

As can be seen, from Tables 1 and 2 there are positives and negatives differences between the "base" blade and the studied variants of blades.

Table 1. The A-sound power level L_{wA} for the studied type of blades in different flow volumes and flow positions (A, B, C).

Type of blade	q, m³/h		
	200	300	400
	L_{wA}, dB, flow A		
Base	46.6	56.8	64.4
NACA 0012	43.0	54.6	62.3
MH 27	43.7	55.1	62.7
S1210	42.5	54.5	61.7
Prandtl	42.6	54.2	61.6
	L_{wA}, dB, flow B		
Base	41.9	53.9	62.1
NACA 0012	40.4	53.4	62.1
MH 27	42.0	56.1	63.7
S1210	40.2	52.5	59.9
Prandtl	41.0	52.2	59.7
	L_{wA}, dB, flow C		
Base	42,0	54,1	62,1
NACA 0012	42.2	54.4	61.6
MH 27	44.7	57.6	64.7
S1210	41.8	53.4	59.7
Prandtl	37.6	49.7	57.3

The maximum difference is 4,7 dB for Prandtl at 400m^3/h at flow C. The positive values can are seen at flow A, and are independent of the type of blade. So, when the blades are in this position in the ceiling swirl diffuser it would be good to replace them the another. But also in this position, the A-sound power is the biggest. When the ceiling swirl diffusers are used in a building the blades are positioned to get the appropriate flow in the room and very often flow B i C is preferred. In this positions of flow (B i C), the best acoustic parameters have got the Prandtl blade, but also the S1210 blade goes fine compared to the commercial blade. It seems that unsymmetrical profiles could be a better solution for reducing noise in outlet ventilation systems and if we change the blade construction in the swirl diffuser we could reduce the noise to around 2-4dB.

Table 2. The differences between single-number A-sound power level ΔL_{wA} for "base" commercial blade and prototype blades in different flow volumes and flow positions (A, B, C).

Type of blade	q, m³/h		
	200	300	400
	ΔL_{wA}, dB, flow A		
NACA 0012	3,6	2,2	2,1
MH 27	2,9	1,7	1,7
S1210	4,1	2,3	2,7
Prandtl	4,1	2,6	2,8
	ΔL_{wA}, dB, flow B		
NACA 0012	1,5	0,5	0,0
MH 27	-0,2	-2,2	-1,7
S1210	1,7	1,4	2,1
Prandtl	0,9	1,7	2,3
	ΔL_{wA}, dB, flow C		
NACA 0012	-0,2	-0,3	0,5
MH 27	-2,7	-3,5	-2,6
S1210	0,2	0,7	2,3
Prandtl	4,4	4,4	4,7

The values of static pressure for the studied blades are given in Table 3. The low values were obtained for the Prandtl blade at each flow position A, B and C. The results of pressure measurements also suggest that the Prandtl blade could replace the commercial blade in this type of swirl diffuser.

Table 3. The pressure differences for "base" commercial blade and prototype blades in different flow volumes and flow positions (A, B, C).

Type of blade	q, m³/h		
	200	300	400
	Δp, Pa, flow A		
Base	37,4	81,2	141,0
NACA 0012	31,7	74,1	131,0
MH 27	33,5	75,5	133,0
S1210	26,0	68,0	121,5
Prandtl	28,7	66,7	120,0
	Δp, Pa, flow B		
Base	32,9	71,3	130,8

NACA 0012	30,0	65,7	123,8
MH 27	30,0	71,9	127,0
S1210	27,5	66,7	120,2
Prandtl	25,5	65,8	115,2
	Δp, Pa, flow C		
Base	31,5	52,8	127,8
NACA 0012	32,3	75,2	129,3
MH 27	30,6	71,9	123,7
S1210	29,8	71,7	120,4
Prandtl	27,5	67,4	119,0

4. CONCLUSION

In this study, an adjustable-blade swirl diffuser with a plenum box and the diffuser front with 8 slits for blades was studied. As the “base” diffuser the commercial one was taken shared by a friendly company with adjustable blades. The four prototype blades, from the base of the airfoils and profiles, were altered in this diffuser for any potential solution to noise reduction. the acoustical parameters were measured in the three-volume flow and three positions of the blade. The 1/3-octave L_{wA} spectrum and 1/3-octave differences ΔL_w spectrum show that the two types of studied blades could be used to reduce the noise of the swirl diffuser. Thanks to this the noise power can be reduced by about 2-4dB.

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