COMPARATIVE ANALYSIS OF METHODS FOR MEASURING THE AIR VELOCITY AND FLOW IN MECHANICAL VENTILATION SYSTEMS – QUALITY OF METHODS FOR MEASURING VENTILATION AND AIR INFILTRATION IN BUILDINGS, 2014

Mariusz Andrzej Skwarczynski[1]

[1] *Lublin University of Technology*
Nadbystrzycka 40B
20-618 Lublin, Poland
**Corresponding author: m.skwarczynski@wis.pol.lublin.pl*

ABSTRACT

The purpose of ventilation system is to provide and remove the airflow from room in accordance with its design. Unfortunately, in practice, this basic task is very often not fulfilled, which is frequently caused by negative handling by the users of the building. The most common reason for improper operation of the mechanical ventilation system is its insufficient output in particular sections of the system. There may be a number of reasons for that: wrong calculation at the stage of designing, disregarding or bad choice of working parameters of devices used in the system or significant changes at the stage of execution works.

In case when the network is already malfunctioning or only being activated, the need to carry out measurements of output appears at a certain point. A significant parameter that should be assessed is the velocity and the amount of the air flow. Generally, such parameters are measured directly in ducts or near the air supply terminals (ATDs) or air exhaust grills. The aim of this paper is to compare available methods for measuring the size of the airflow supply in regard to the accuracy of the measurement and the analysis of the measurement results.

For the purpose of conducting the necessary measurement in the Laboratory of Air Conditioning and Ventilation of the Faculty of Environmental Engineering at the Lublin University of Technology a specially designed measurement stand was created. It is equipped with air handling unit, the network of ducts distributing the air to the ATDs as well as the measurement elements assembled directly on the ventilation ducts.

The measurements were conducted by the four air supply grills. Traditional instrumentations such as, thermo-anemometers, pitot-tubes were compare with blades, IRIS damper, and ?? air flow cones. On the basis of the results, the most appropriate measurement methods for different types of air inlet vents or different size of airflow supply were defined.

KEYWORDS

HVAC system, measurement methods for ventilation,

1 INTRODUCTION

A ventilation system is essential for the thermal comfort and good health of occupants in a living space. Without proper airflow the system and operation are compromised resulting in unsatisfactory equipment operation, customer dissatisfaction and utility waste. The airflow must first be set according to the equipment design not to the air delivered at the registers. While the design of the duct system is imperative for proper air distribution to the conditioned space, air measurements are only to be measured at the appliance for the equipment commissioning procedure.

According to Standard EN 12599 (2012), the air flow rate can be evaluated by different methods. It is usually calculated according to the air velocity and the corresponding cross section. The air velocity can be measured with the use of by means of an appropriate anemometer, Pitot Static Tube (Prandtl tube) or a pressure drop across a throttling devices. The measurement can be carried out:

- in the duct cross-section or,
- with calibrated throttle devices or,
- in the cross-section of a chamber, fan-casing or device or,
- at the air terminal devices.

If an appropriate measuring section is available, then the measurements shall be performed within the duct. If not, then cross-sections within the central unit or appliance can be used in order to determine the mean air velocity. This measurement may be used when a uniform flow and a clearly corresponding cross-section are given. Direct measurements at air terminal devices are only possible in the case of quite simple constructions (e.g. a nozzle with a known cross section). An additional measuring device is usually necessary.

The Standard EN 12599 (2012) does not define tolerances for design values itself. The results is accepted when the designed value is within the range of the uncertainty of the measurement. The permissible uncertainties of the measured values are given in Table 1.

Table 1: Permissible uncertainty of the measurement (EN 12599:2012)

Parameter	Uncertainty
Air flow rate, each individual room	± 15 %
Air flow rate, each system	± 10%
Supply air temperature	± 2 ^{o}C
Relative humidity [RH]	± 15 % RH
Air velocity in occupied zone	± 0.05 m/s
Air temperature in occupied zone	± 1.5 ^{o}C
A-weighted sound pressure level in the room	± 3 dB(A)

This paper presents a comparison of available methods for measuring the size of the airflow supply in regard to the accuracy of the measurement and the analysis of the measurement results.

2 METHODS

2.1 Experimental setup

The experiments were performed in the Laboratory of Air Conditioning and Ventilation of the Faculty of Environmental Engineering at the Lublin University of Technology. Figure 1 shows the layout of specially designed measurement stand which is equipped with air handling unit, the network od ducts, air terminal devices as well as the air flow meters. Table 2 presents the bills of materials used in the experiment setup.

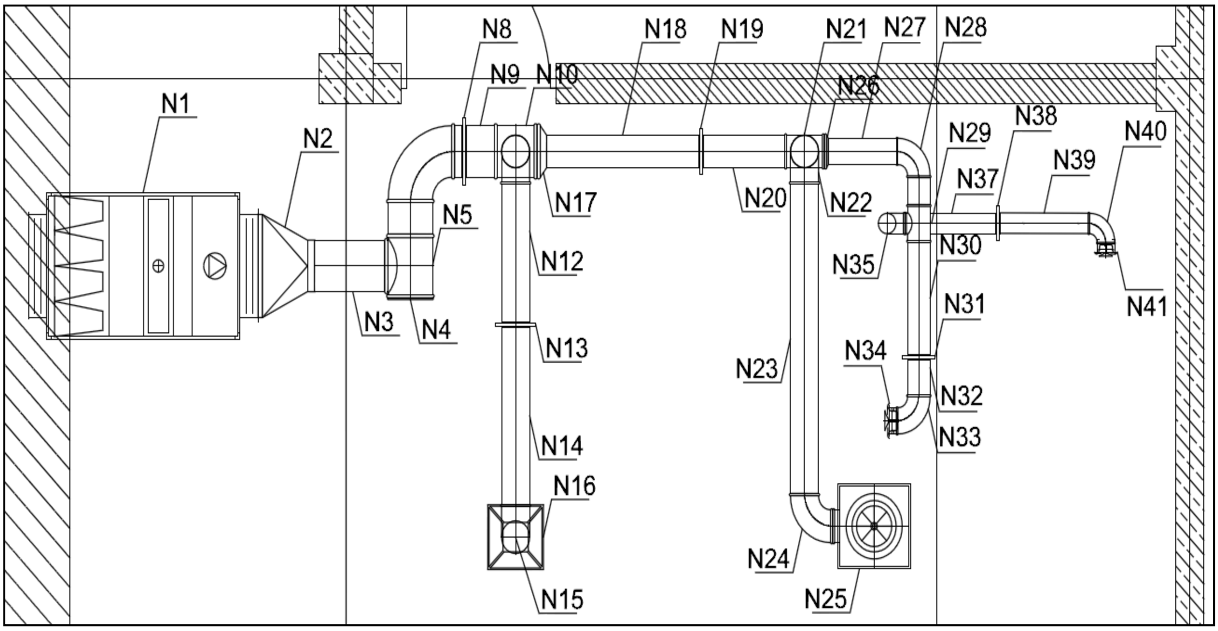


Figure 1. Scheme of experimental setup

Table 2. Bill of materials

No	Label	Description	No	Label	Description
1	N1	Air handling unit – only supply DEIMOS 0/N-5A/1-1/P made by DOSPEL	22	N22	Elbow 90^{o} DN200
2	N2	Transition rectangular/round 630x315/DN315	23	N23	Spiro duct DN200, L=1890 mm
3	N3	Spiro duct Ø315, L=500 mm	24	N24	Elbow 90^{o} DN200
4	N4	Tee DN315/DN315/DN315	25	N25	Air terminal device Konika-A-250 with plenum box PER-200-250
5	N5	End cap DN315	26	N26	Reduction DN200/DN160
6	N6	Spiro duct DN315, L=190 mm	27	N27	Spiro duct DN160, L=480 mm
7	N7	Elbow 90^{o} DN315	28	N28	Elbow 90^{o} DN160
8	N8	IRIS damper DN315	29	N29	Tee DN160/DN125/DN160
9	N9	Spiro duct DN315, L=200 mm	30	N30	Spiro duct DN160, L=700 mm
10	N10	Tee DN315/DN200/DN315	31	N31	IRIS duct DN160
11	N11	Elbow 90^{o} DN200	32	N32	Spiro duct DN160, L=300 mm
12	N12	Spiro duct DN200, L=850 mm	33	N33	Elbow 90^{o} DN160
13	N13	Air flow meter FMU 200-160	34	N34	Supply air valve KN-160
14	N14	Spiro duct DN200, L=1080 mm	35	N35	Elbow 90^{o} DN125
15	N15	Elbow 90^{o} DN200	36	N36	Elbow 90^{o} DN125
16	N16	Perforated diffuser TSO-200	37	N37	Spiro duct DN125, L=660 mm
17	N17	Reduction DN315/DN200	38	N38	IRIS damper DN125
18	N18	Spiro duct DN200, L=1080 mm	39	N39	Spiro DN125, L=630 mm
19	N19	IRIS damper DN200	40	N40	Elbow 90^{o} Ø125
20	N20	Spiro DN200, L=580 mm	41	N41	Exhaust air valve KN-125
21	N21	Tee DN200/DN200/DN200			

2.2 Measurements methods

Several measurement methods were investigated. These can be broadly divided into three groups of direct air measurement, direct air measurement with an attachment on the air intake and indirect air measurement.

Direct air measurement methods

Method 1

Pitot static tube (Prandtl Tube) or anemometer traverse in the supply duct. The number and location of the test points are specified in Standard EN 12599:2012 Annex D. The distance between the measuring section and an upstream disturbance of the duct at the measurement plane were established on the basis of 6 points as a number of measuring points for the 15% uncertainties , including an error of 5% of the measuring devices (see Figure 2). The distance was equal 0.625 m for diameter DN 125 (N41 – see Figure 1), 0.8 m for diameter DN 160 (N34 – see Figure 1) and 1.0 m for diameter DN 200 (N25 and N15 – see Figure 1). The measurement points are presented in Table 3.

Table 3. The distance from walls for different diameter

Diameter	**Number of points i**					
	1	**2**	**3**	**4**	**5**	**6**
	Distance from the duct wall y_i (mm)					
DN 125	5.5	18.3	37.0	88.0	106.7	119.5
DN 160	7.0	23.4	47.3	112.7	136.6	153.0
DN 200	8.7	29.3	59.2	140.8	170.7	191.3

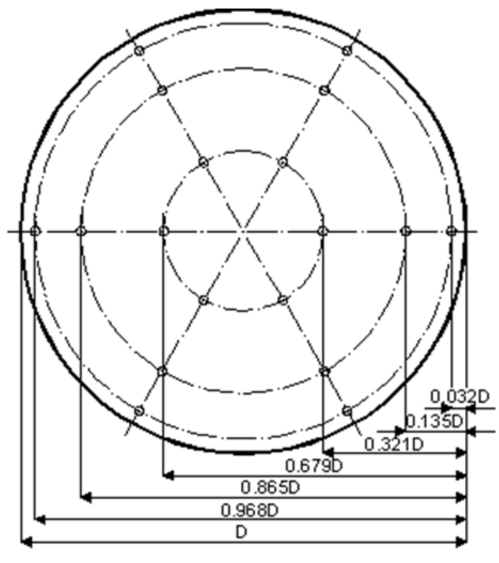


Figure 2. Position of measurement points for the circular duct cross-section

The speed for air temperature 20 °C was calculated according to the following equation:

$$V = A \cdot 1.291 \cdot \sqrt{(p_d)},\ \text{m/s} \quad (1)$$

where:

p_d – value of the dynamic pressure, Pa,
A – cross section area, m^2.

Method 2

Measurement using the effective area A_k was based on Standard EN 12238 (2001). The flow rate was calculated according to face velocity and louvre free area or a factor. Area factor or equivalent area A_k vane anemometer with a large head is recommended to integrate a large area including both louvre structure and open areas. The air flow rate q_v for a given ATD can be calculated on the basis of equation 2.

$$q_v = v_k \cdot A_k \tag{2}$$

where:
A_k – effective area of air terminal devices (see table 4), (m^2);
v_k – average air velocity (m/s).

The air velocity is measured in n values v_{ki} (i from 1 to n) in accordance with the methodology given by the manufacture. Mean value of air velocity in set number of points can be calculated on the basis of equation 3.

$$V_k = (\Sigma v_{ki}) / n \tag{3}$$

The uncertainty for the parameter A_k should be less than ± 5 % and for the parameter v_{ki} should be less than ± 10%.

Table 4. Effective area of air terminal devices

Air terminal devices	N41	N34	N25	N15
Effective area of ATD A_k (m^2)	0.00628	0.008038	0.055223	0.066248

Method 3

Measurement at the air terminal devices is presented in Figure 3. As measuring element used plenum box PER-250-200 equipped with special measurement points. The difference in pressure was measured by a pressure calibrator KAL 84. Supply air flow amount calculated according to the formula (1). The coefficient k for the plenum for supply is 27.7. This method was only used in N25 air terminal device.

Figure 3. Plenum box PER-250-200 with air flow measurement pipes (www.systemair.com, 10.02.2014)

Method 4

Pressure measurement was performed with the pressure calibrator KAL 84. The measurement was performed on a special measuring element FMU 200-160 (N13). Supply air volume was calculated according to the formula (1). The value of the correction factor k for FMU 200-160 orifice is equal to 29.4.

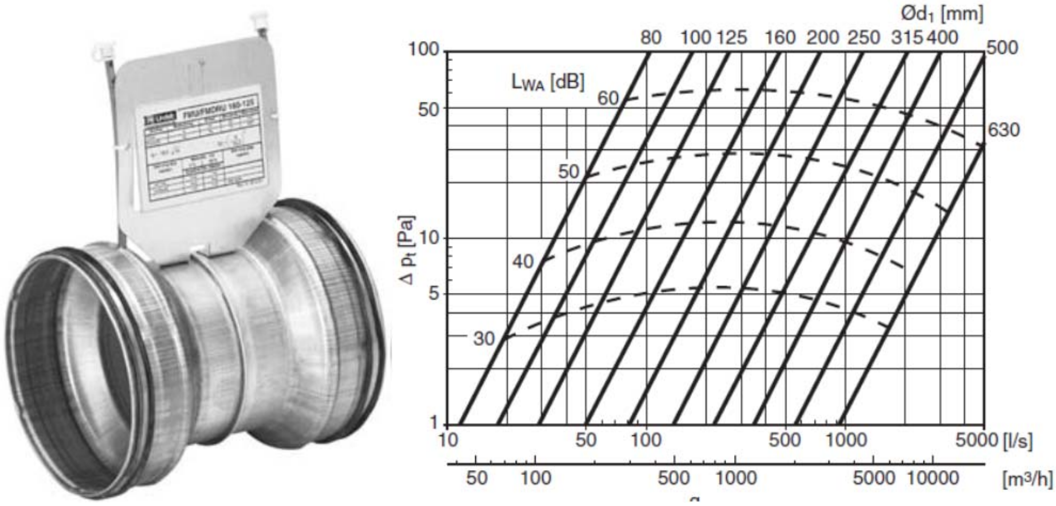
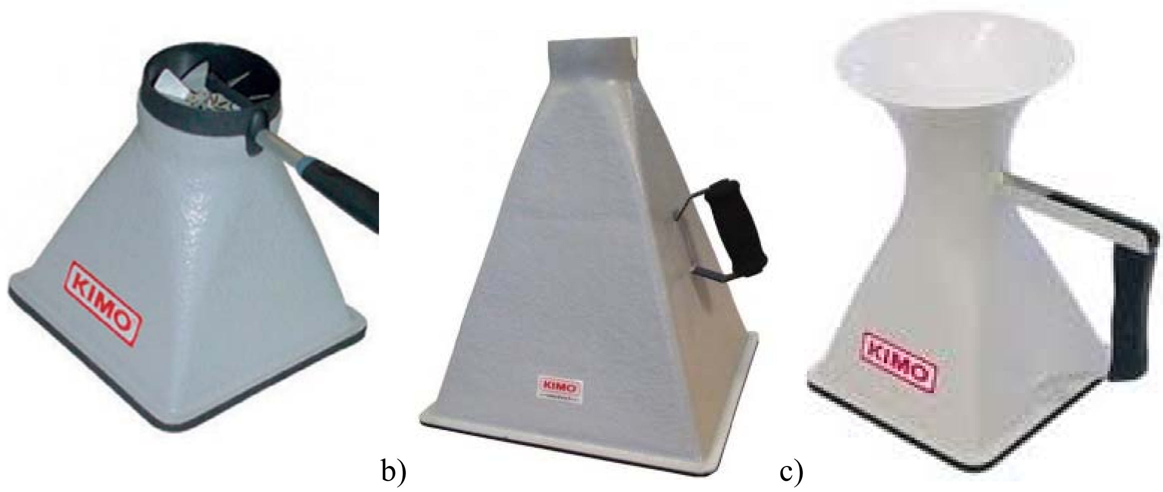


Figure 4.. Flow meter FMU (www.lindab.com, 15.02.2014)

Direct air measurement methods using an attachment on the intake

Method 5

Airflow hood fitted to the intake louvre. This technique could be applied to the air intakes of the small AHUs and the hood must be calibrated for supply or exhaust air flow measurement. This method is based on the measurement of the ventilation air velocity using a vane anemometer with probe diameter Ø100 or thermoanemometer. Measurement of the air flow takes place directly on the ventilation grilles. The probe is placed in the cones with different dimensions of measurement i.e.: model K25 (Figure 5a) is for measuring air flow from grilles surface up to 200x200 mm, model K80 (Figure 5b) up to 350x350 mm and model K120 (Figure 5c) up to 450x450 mm. First two cones are made of fiberglass and designed for the ventilation airflow ranged from 10 to 400 $m^3 h^{-1}$; and the last one is from 50 to 1200 $m^3 h^{-1}$.



a) b) c)

Figure 5. Airflow cone type a) K25 b) K80 c) K120

$$V = k \cdot w \qquad (3)$$

where:

k - coefficient factor, (-);

w - air velocity, (m/s).

According to KIMO company (www.kimo.fr, 05.02.2014), the value of the correction factor k for cones K25 and K80 has to be taken depending on the range of the air velocity. For the air velocity below 1.45 m s^{-1}, k is equal to 28.33; for air velocity in the range from 1.45 to 3.8 m s^{-1}, k is equal to 21.26; and when the air velocity is above 3.8 m s^{-1}, k factor is equal to 20.35. For cone model K120 the k factor is constant for different air velocity and is equal to 135.

Indirect air measurement methods

Method 6

Assessment damper characteristic and traverse of the total supply duct by pitot static tube (Prandtl tube). The air rate is determined on the basis of the intake damper position and the damper characteristic which are provided by the damper manufacture. Differential pressure measurement was made using the pressure calibrator KAL 84 for measuring element in the form of throttle lens IRIS-125 (see Figure 6a) and IRIS-160 (see Figure 6b). The pressure difference for each throttle setting was the basis to read the size of the air flow.

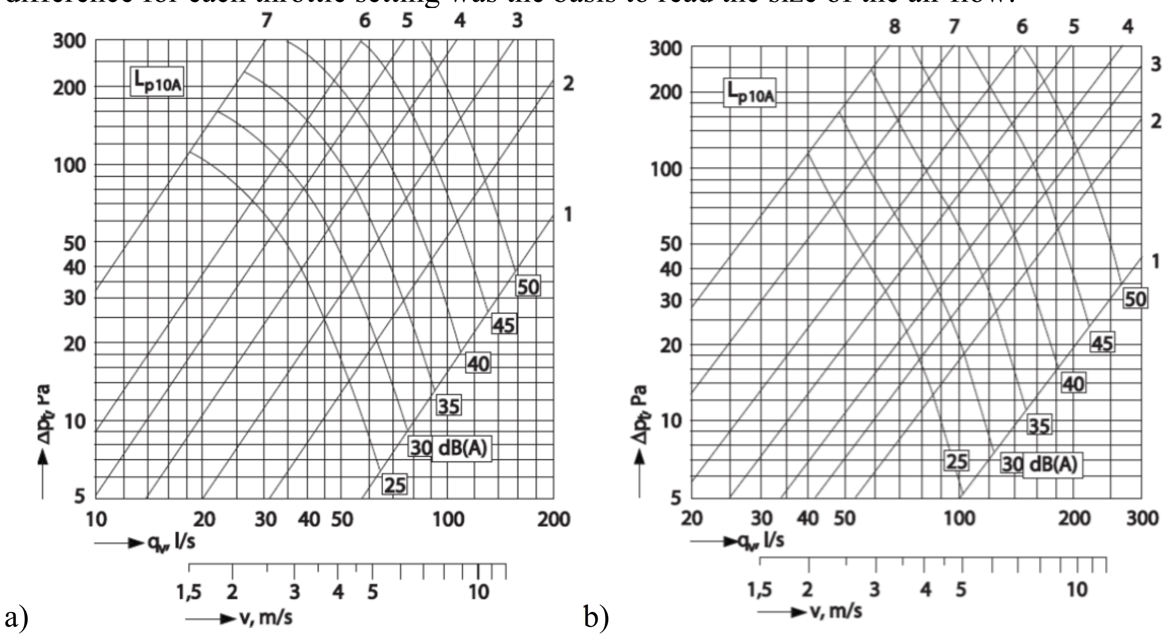


Figure 6. Air velocity and flow vs measured differential pressure on iris damper with flow meter
a) duct diameter 125 b) duct diameter 160

Table 5 consists of the list of the accuracy of instruments used in the measurement. Table 4 shows the list of air terminal devices and applied measurement technique for each model.

Table 4. Summary of measurement methods for specific ATDs

ATDs	N41	N34	N25	N15
Method 1	x	x	x	x
Method 2	x	x	x	x
Method 3	-	-	x	-
Method 4	-	-	-	x
Method 5	x	x	x	x
Method 6	x	x	-	-

Table 5. Accuracy of instruments used in airflow measurement technique

Type	Min vel.	Max vel.	Min Temp	Max Temp	Select test largest			
					Accuracy	Accuracy	Accuracy	Accuracy
	m/s or (m^3/h)	m/s or (m^3/h)	(^{o}C)	(^{o}C)	(% of reading)	(± m/s)	(% of full scale)	(± digit)
Vane 100 mm	0.20	3	-	-	2	0.06	-	-
	3.1	35	-	-	2	0.2	-	-
Hot wire	0	3	-	-	3	0.03	-	-
	3.1	30	-	-	3	0.1	-	-
Airflow hood	-	-	-	-	-	-	5	-
Prandtl tube	2	20	-	-	-	-	5	-
Manometer	0	200	-	-	1	-	-	-

3 RESULTS AND DISCUSSION

In Table 6 the results for six measurement technique for air terminal devices N41 and N34 are compared (supply air valve).

Table 6. Results for air terminal devices N41 and N34

Air terminal devices			N41			N34		
Position of damper			5	3	1	9	5	1
Method 1	Prandtl tube	dp [Pa]	*11.57*	*33.8*	*54.5*	*3.48*	*10.78*	*14.23*
Method 1	Prandtl tube	V [m^3/h]	**194.0**	**331.6**	**421.5**	**174.3**	**306.81**	**352.5**
Method 2	Free area	w [m/s]	*7.9*	*9.4*	*11.5*	*5.5*	*7.3*	*8.2*
Method 2	Free area	V [m^3/h]	**178.6**	**212.5**	**259.9**	**159.2**	**211.3**	**237.3**
Method 3	Plenum box	dp [Pa]	-			-		
Method 3	Plenum box	V [m^3/h]						
Method 4	Air flow meter	dp [Pa]	-			-		
Method 4	Air flow meter	V [m^3/h]						
Method 5	K25	w [m/s]	*9.32*	*11.38*	*12.06*	*6.62*	*8.95*	*9.88*
Method 5	K25	V [m^3/h]	**189.7**	**231.6**	**245.5**	**134.7**	**182.2**	**201**
Method 5	K80	w [m/s]	*9.84*	*12.05*	*12.96*	*6.95*	*9.53*	*10.66*
Method 5	K80	V [m^3/h]	**200.2**	**245.2**	**263.73**	**141.4**	**193.9**	**216.9**
Method 5	K120	w [m/s]	*1.65*	*2.85*	*4.41*	*1.21*	*2.29*	*2.7*
Method 5	K120	V [m^3/h]	**222.7**	**384.8**	**595.4**	**163.4**	**309.2**	**364.5**
Method 6	IRIS 125	dp [Pa]	*198.6*	*102.7*	*18.8*	-		
Method 6	IRIS 125	V [m^3/h]	**218.1**	**315.8**	**390.2**			
Method 6	IRIS 160	dp [Pa]	-			*120.59*	*49.49*	*8.8*
Method 6	IRIS 160	V [m^3/h]				**162.1**	**226.1**	**266.6**

For the supply air valve, the direct method of measurement is the most proper method for checking the air flow. The most problematic to interpret is cone air flow measurement based on vane anemometer (model K25 and K80). The measured values of velocity are much higher than 10 m/s, therefore, the calibration coefficient K for, which the proper value is estimated, is calculated according to for air velocity above 3.8 m/s. Much better results are received by cone combined with thermoanemometer. In Table 7 are shown results for two diffusers N25 and N16.

Table 7. Results for air terminal devices N25 and N16

Air terminal devices			**N25**			**N16**		
Position of damper			10%	50%	100%	30%	60%	100%
Method 1	Prandtl tube	dp [Pa]	*4.78*	*16.45*	*22.95*	*4.31*	*17.9*	*23*
		V [m^3/h]	**319.2**	**592.4**	**699.4**	**303.1**	**617.9**	**701.3**
Method 2	Free area	w [m/s]	*1.5*	*3.1*	*3.6*	*1.4*	*2.5*	*2.8*
		V [m^3/h]	**298.2**	**616.3**	**715.7**	**333.9**	**596.2**	**667.8**
Method 3	Plenum box	dp [Pa]	*16.84*	*32.78*	*51.9*	-		
		V [m^3/h]	**409.2**	**570.9**	**718.4**			
Method 4	Air flow meter	dp [Pa]	-			*12.53*	*28.5*	*30.7*
		V [m^3/h]				**374.6**	**565**	**586.3**
Method 5	K25	w [m/s]	-			-		
		V [m^3/h]						
	K80	w [m/s]	*9.24*	*13.86*	*14.48*	*11.76*	*13.38*	*13.58*
		V [m^3/h]	**188.1**	**282.1**	**294.7**	**239.3**	**272.3**	**275.9**
	K120	w [m/s]	*1.68*	*4.71*	*5.27*	*2.82*	*4.74*	*5.42*
		V [m^3/h]	**226.8**	**635.4**	**711.9**	**380.2**	**639.7**	**731.6**
Method 6	IRIS 125	dp [Pa]	-			-		
		V [m^3/h]						
	IRIS 160	dp [Pa]	-			-		
		V [m^3/h]						

The results confirm that method 1, 2, 3, and 5 (cone k120) present the similar results. The data obtained for cone K25 and K80 should not be taken into account because they are on measurement border. Only first result for this technique can be taken into consideration but their values are very low compared to another results.

4 CONCLUSIONS

As a result of measurement, it was found that:

- the results of measurements using different methods are significantly different,
- it must necessarily follow the manufacturer's recommendation contained in the technical data sheet for the devices,
- proper selection of the method of measuring the specific model of each air terminal devices is essential.

5 ACKNOWLEDGEMENTS

The work was supported by scientific grant no. N N 523 558938 from the Ministry of Science and Higher Education, Poland.

6 REFERENCES

Awbi H.B. (2003) *Ventilation of buildings*. 2nd edn. Spoon Press.

EN 12599 (2012) *Ventilation for buildings. Test procedures and measurement methods to hand over air conditioning and ventilation systems.* International Organization for Standardization.

EN ISO 5167-1 (2003) *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full General principles and requirements.* International Organization for Standardization.

EN ISO 5167-2 (2003) *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full Orifice plates*. International Organization for Standardization.

EN ISO 5167-3 (2003) *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full Nozzles and Venturi nozzles.* International Organization for Standardization.

EN ISO 5167-4 (2003) *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full Venturi tubes.* International Organization for Standardization.

ISO 7194 (2008) *Measurement of fluid flow in closed conduits. Velocity-area methods of flow measurement in swirling or asymmetric flow conditions in circular ducts by means of current-meters or Pitot statics tubes.* International Organization for Standardization.

PD ISO/TR 12767 (2007) *Measurement of fluid flow by means of pressure differential devices. Guidelines on the effect of departure from the specifications and operating conditions given in ISO 5167.* International Organization for Standardization.

Standard EN 12238 (2001) *Ventilation for buildings. Air terminal devices. Aerodynamic testing and rating for mixed flow application*. International Organization for Standardization**.**