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Adam NYGARD
Jarosław BARTOSZEWICZ

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Evaluation efficiency of low-power fans used in the means of transport

The article presents test results on low-power fans used in the means of transport. Fans evaluation was in the context of energy efficiency. Interest in scientific topics related to low-power fans has its source in the reports of the Chief Inspector of Environmental Protection on the state of the natural environment in Poland and European Union reports assessing our natural environment. The goal of the article is to compare experimental results with Minister of Economy Regulation of March 11th, 2014, which introduces changes in accordance to European Parliament and Council Directive 2009/125/WE, with regard to ecodesign requirements for fans driven by motors with an electric input power between 125 W and 500 kW.

Key words: *fans, low-power fans, evaluation efficiency, fan efficiency, transport*

1. Introduction

This article presents the continuation of tests on low-power centrifugal fans. Its purpose is to compare the results of tests with the Resolution of the Minister of Economy of 11 March 2014 implementing the changes in the performance of Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for fans driven by motors with an electric input power between 125 W and 500 kW.

The directive was implemented to reduce electric energy consumption as a result of technology development and improvement of the design, rising the energy efficiency of fans used for gas transportation. This Directive concerns fans driven by electric motors. For the European market in 2016 energy consumption of fans described above was 344 TWh per year. With regard to the project being implemented by the European Union, requirements for fans were established. In its main part, the Directive presents information on how to calculate the minimum energy efficiency of a fan. The formula from Directive 2009/125/EC used to determine the minimum required energy efficiency that should be obtained by a fan (driven by motor with an electric input power between 125 W and 10 kW) is presented below:

$$\eta = 2.74 \cdot \ln(P_{el}) - 6.33 + N \qquad (1)$$

where: η – energy efficiency, P_{el} – input power of the fan, N – energy efficiency grade (depending on the test methodology, type of fan and the efficiency) [1].

In connection with the earlier work of the authors who researched energy boilers [2–4] and aerodynamic analysis of gas flow by recirculation [5] including the combustion chamber. The previous article [6] presents the results of testing low-power centrifugal fans, which are used in low-power boilers

In this article presents test results on low-power centrifugal fans being a source of energy in pipeline transportation used in the means of transport.

Low-power fans are used in means of transport in ventilation, air conditioning and heaters [7]. The most commonly used air conditioners in the means of transport are integrated air conditioners installed during production, which we use in passenger cars, vans and trucks and who is part of the HVAC system (Heating, Ventilation, Air Conditioning) [8]. The integrated air conditioning system allows rising and lowering the air temperature in the vehicle's working space. Low-power fans meet the functional requirements of the project including the analysis of mass transport equations in ventilation systems, without the obligation to work with high efficiency. EU regulations impose the minimum efficiency that must be achieved by compression machines whose electrical power is greater than the defined minimum threshold given by a simple algebraic formula. As a result, almost all fans used in means of transport and mobile working machines are excluded from supervision. Compression machines are used to: increase the density of the gas medium, increase the pressure of the medium, force the flow, increase the temperature of the working medium and intensify the Joule-Thomson effect. The effect of the compression machine is to increase the pressure on the discharge side of the machine relative to the suction side. The ratio of pressure on the compressor discharge side to the pressure on the suction side is called compression. When the compression is less than 1.1 in relation to the suction side, we are talking about fans.

Figures 1–3 show selected cabin fans used to supply air to the cabin. Figure 1 presents the centrifugal fan installed in VW Jetta cars with 1.4 TSI engines with 150 HP output produced from 2014.

Fig. 1. Fan installed in VW Jetta [9]

Figure 2 presents the fan used in Mercedes-Benz CLS Coupe 220 BlueTEC manufactured from 2014 with 127 kW engine power.

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Fig. 2. Fan installed in Mercedes-Benz CLS Coupe 220 BlueTEC [9]

Figure 3 shows the fan diagram installed in the BMW 3 Series (F30 and F80) 318d produced from 2014 with a 112 kW engine power.

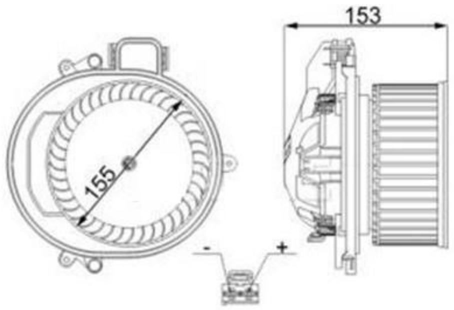

Fig. 3. Fan installed in BMW 3 Series [9]

Figures 4 and 5 show examples of fans used for cooling heat exchangers installed in various means of transport and mobile working machines. Figure 4 shows the SPAL 002-B46-02 fan, which has the following parameters:
– voltage: 24 V,
– current: 6.2 A,
– power: 148.8 W,
– air flow: 620 m³/h.

Fig. 4. Fan SPAL 002-B46-02 [10]

Figure 5 shows the SPAL 005-A45-02 fan, which has the following parameters:
– voltage: 12 V,
– current: 13.3 A,
– power: 160 W,
– air flow: 610 m³/h.

Fig. 5. Fan SPAL 005-A45-02 [10]

2. Test method

The subject of research were low-power fans used in transport, ventilation, air-conditioning and heaters. The fans were powered by electric motors. Nine fans with electric power from 10 W to 125 W were tested to verify the application of the directive for fans with less than 125 W input power.

Figure 6 presents the scheme of a measurement stand built in the Chair of Thermal Engineering of Poznan University of Technology.

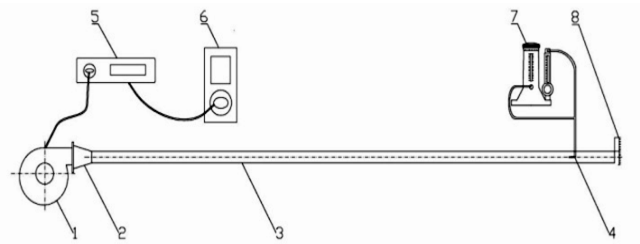

Fig. 6. Scheme of a measurement stand: 1 – fan, 2 – confusor, 3 – measuring channel, 4 – Prandtl probe, 5 – fan's operation regulator, 6 – wattmeter, 7 – compensation micro-manometer, 8 – flap valve

The measurement stand was built based on the guidelines contained in Polish standards [11, 12, 13, 14] and the directive. In the directive four measurement categories defining the arrangement of measurements and the inlet and outlet conditions of the fan were distinguished:
– "measurement category A" – the fan is measured with free inlet and outlet conditions,
– "measurement category B" – the fan is measured with free inlet and with a duct fitted to its outlet,
– "measurement category C" – the fan is measured with a duct fitted to its inlet and with free outlet conditions,
– "measurement category D" – the fan is measured with a duct fitted to its inlet and outlet.

Fans were tested using the arrangement where the fan is measured with free inlet and with a duct fitted to its outlet (measurement category B). Conducted tests allowed to measure and calculate the following quantities describing fans under tests: Δp_c – total pressure increase, P_{el} – electric power consumed by the fan, η – total efficiency of the fan, $\dot{V}$ – volume flow of the air flowing through the fan.

Based on the analysis of the measuring equipment used and the method of determining the characteristic parameters describing the operation of the fan, the relative error is for the following values:
– increase in total pressure – 1%,
– electric power consumed by the fan – 1.5%,
– air volume flow – 1%.

3. Results

Figures from 7 to 17 present characteristics of nine fans of electric power lower than 125 W.

Figures 7 and 8 present examples characteristics made for the fan F1 who were made for different values of motor speed n (100%, 72% and 45% of the maximum speed). Measurements were for relative quantities compared with the volume flow. The electric input power of the fan F1 was 37 W. The volume flow for speeds under test was as follows:

- for n = 100%, the volume flow increases from 29 m^3/h to 155 m^3/h,
- for n = 72%, the pressure decreases from 29 m^3/h to 106 m^3/h,
- for n = 45%, the pressure decreases from 20 m^3/h to 89 m^3/h.

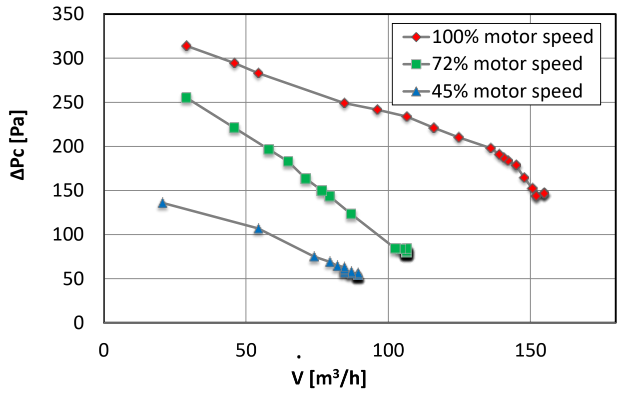

Fig. 7. Characteristics of ΔPc for fan F1

In Figure 7 we may notice the decrease of pressure with the increase of air volume flow. This dependence repeats for all motor speeds. For subsequent motor speeds, the pressure decrease was as follows:

- for n = 100% the pressure decreased from 314 Pa to 147 Pa,
- for n = 72% the pressure decreased from 255 Pa to 80 Pa,
- for n = 45% the pressure decreased from 136 Pa to 54 Pa.

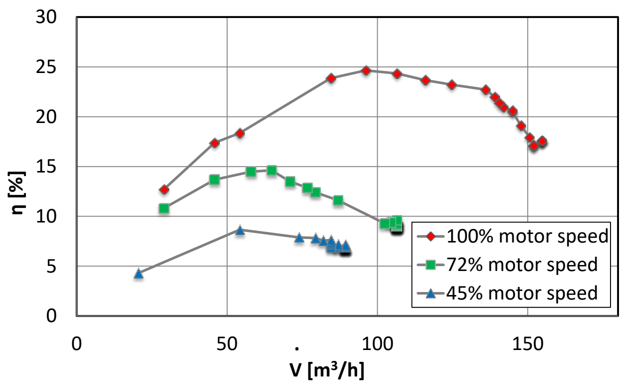

Fig. 8. Characteristics of η for fan F1

Figure 8 presents the efficiency characteristics. The fan had the highest efficiency during testing at maximum motor speed. Efficiency for motor speed n = 100% increases with the volume flow from 13% to 25% and for the volume flow equal to 155 m^3/h, it starts to decrease to 18%. Efficiency for motor speed n = 72% increases with the volume flow from 11% to 15% and for the volume flow equal to 65 m^3/h, it starts to decrease to 9%. Efficiency for motor speed n = 45% increases with the volume flow from 4% to 9% and for the volume flow equal to 54 m^3/h, it starts to decrease to 7%.

Figures from 9 to 17 present characteristics of total pressure increase, efficiency and power varying in a function of air volume flow. Graphs show the increase in the input electric power and the decrease in total pressure increase with the volume flow increase.

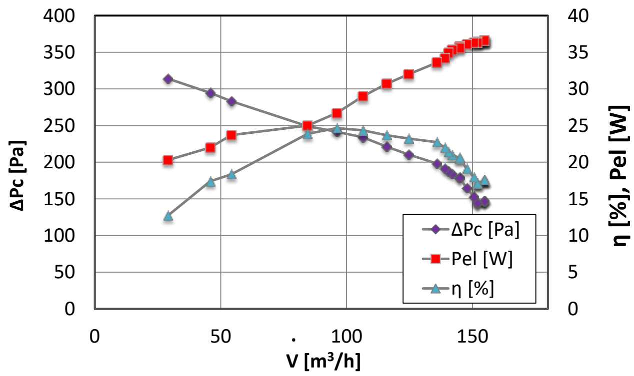

Fig. 9. Characteristics of fan F1 for 100% motor speed

Figure 9 presents the characteristics of fan F1 for 100% motor speed. The volume flow ranges from 29 m^3/h to 155 m^3/h. With its increase, the pressure decreases from 314 Pa to 147 Pa and the power consumption increases from 20 W to 37 W. With the increase of volume flow, the efficiency increases from 13% to 25% and for the volume flow equal to 155 m^3/h, it starts to decrease to 18%.

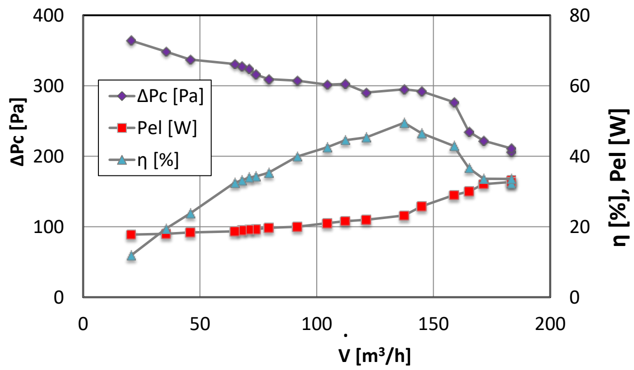

Fig. 10. Characteristics of fan F2 for 100% motor speed

Figure 10 presents the characteristics of fan F2 for 100% motor speed. The volume flow ranges from 20 m^3/h to 183 m^3/h. With its increase, the pressure decreases from 364 Pa to 206 Pa and the power consumption increases from 18 W to 33 W. With the increase of volume flow, the efficiency increases from 12% to 50% and for the volume flow equal to 137 m^3/h, it starts to decrease to 32%.

Figure 11 presents the characteristics of fan F3 for 100% motor speed. The volume flow ranges from 20 m^3/h to 171 m^3/h. With its increase, the pressure decreases from 325 Pa to 183 Pa and the power consumption increases from 18 W to 33 W. With the increase of volume flow, the efficiency increases from 11% to 34% and for the volume flow equal to 130 m^3/h, it starts to decrease to 27%.

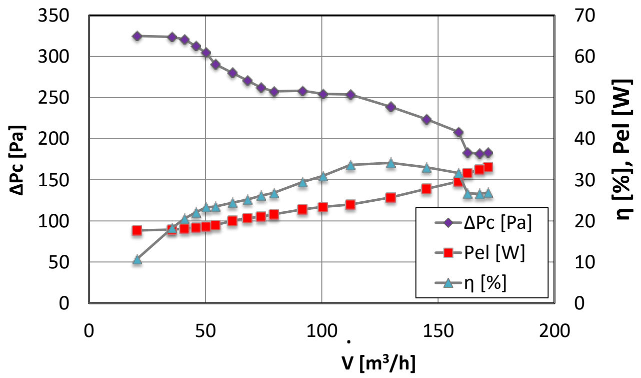

Fig. 11. Characteristics of fan F3 for 100% motor speed

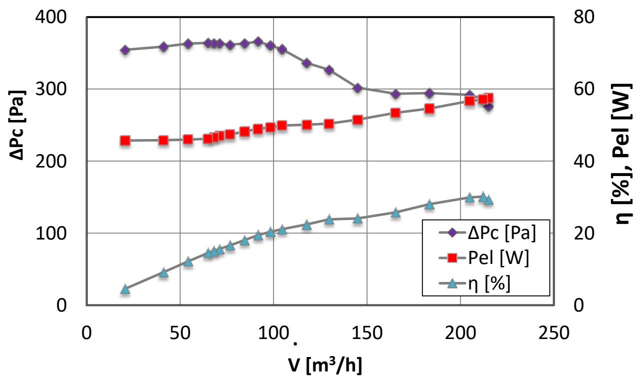

Fig. 12. Characteristics of fan F4 for 100% motor speed

Figure 12 presents the characteristics of fan F4 for 100% motor speed. The volume flow ranges from 20 m^3/h to 215 m^3/h. With its increase, the pressure decreases from 354 Pa to 276 Pa and the power consumption increases from 46 W to 58 W. With the increase of volume flow, the efficiency increases from 11% to 34%.

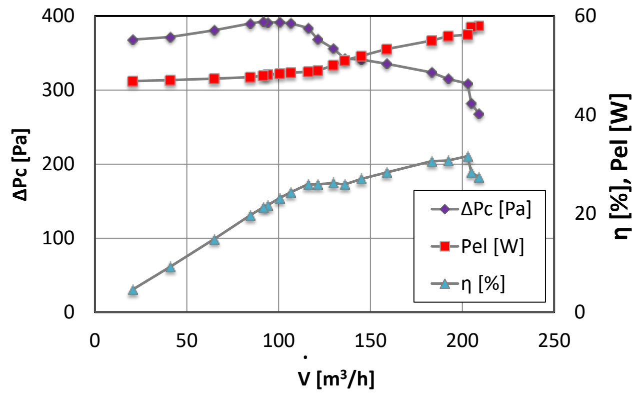

Fig. 13. Characteristics of fan F5 for 100% motor speed

Figure 13 presents the characteristics of fan F5 for 100% motor speed. The volume flow ranges from 20 m^3/h to 209 m^3/h. With its increase, the pressure decreases from 368 Pa to 268 Pa and the power consumption increases from 47 W to 58 W. With the increase of volume flow, the efficiency increases from 5% to 32%.

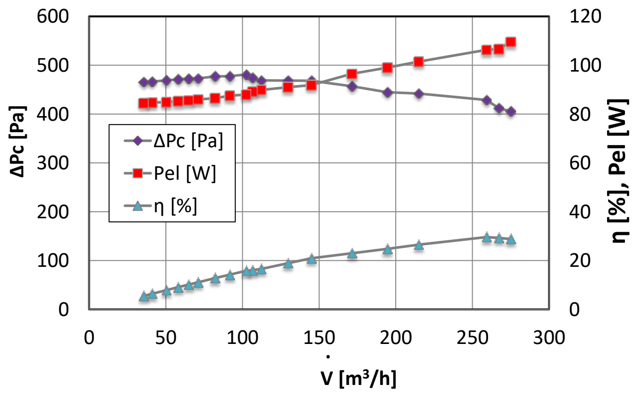

Fig. 14. Characteristics of fan F6 for 100% motor speed

Figure 14 presents the characteristics of fan F6 for 100% motor speed. The volume flow ranges from 35 m^3/h to 275 m^3/h. With its increase, the pressure decreases from 466 Pa to 406 Pa and the power consumption increases from 85 W to 110 W. With the increase of volume flow, the efficiency increases from 6% to 30%.

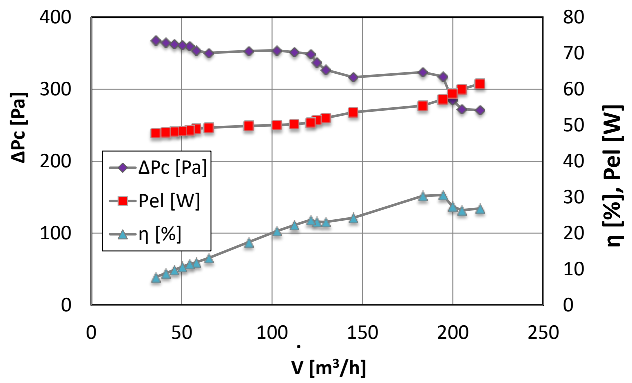

Fig. 15. Characteristics of fan F7 for 100% motor speed

Figure 15 presents the characteristics of fan F7 for 100% motor speed. The volume flow ranges from 35 m^3/h to 215 m^3/h. With its increase, the pressure decreases from 368 Pa to 271 Pa and the power consumption increases from 48 W to 62 W. With the increase of volume flow, the efficiency increases from 8% to 31% and for the volume flow equal to 194 m^3/h, it starts to decrease to 26%.

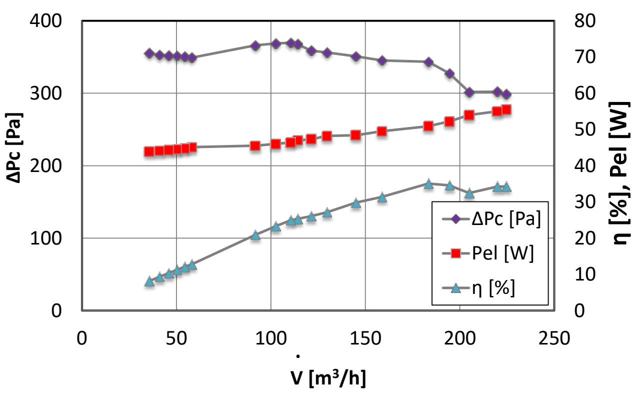

Fig. 16. Characteristics of fan F8 for 100% motor speed

Figure 16 presents the characteristics of fan F8 for 100% motor speed. The volume flow ranges from 35 m^3/h to 224 m^3/h. With its increase, the pressure decreases from 355 Pa to 299 Pa and the power consumption increases from 44 W to 56 W. With the increase of volume flow, the efficiency increases from 8% to 34%

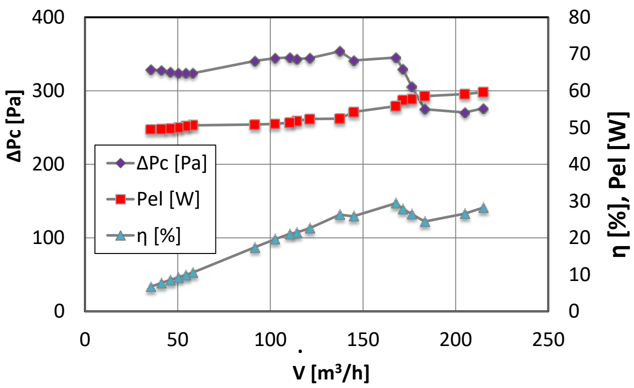

Fig. 17. Characteristics of fan F9 for 100% motor speed

Figure 17 presents the characteristics of fan F9 for 100% motor speed. The volume flow ranges from 35 m^3/h to 215 m^3/h. With its increase, the pressure decreases from 329 Pa to 276 Pa and the power consumption increases from 50 W to 60 W. With the increase of volume flow, the efficiency increases from 7% to 29%.

4. Conclusions

Table 1 presents a comparison of the following technical parameters fans: electric power consumed by the fan, total pressure increase, volume flow of the air flowing through the fan, total efficiency of the fan.

Table 1. Comparison of technical parameters fans

Fan symbol	Electric power P_{el} [W]	Total pressure increase ΔPc [Pa]	Volume flow of the air $\dot{V}$ [m^3/h]	Efficiency η [%]
F1	37	314	155	25
F2	33	364	183	50
F3	33	325	171	34
F4	58	366	215	30
F5	58	392	209	32
F6	110	481	275	30
F7	62	368	215	31
F8	56	370	224	35
F9	60	354	215	29

Table 2 presents a summary of the results for electrical power and fan efficiency.

Figure 18 shows a comparison of the efficiency obtained as a result of test measurements and the efficiency calculated on the basis of the formula in the directive.

Table 2. Summary of results for fans' efficiencies

Fan symbol	Electric power P_{el} [W]	Efficiency obtained in test η_1 [%]	Efficiency calculated based on the Directive η_2 [%]
F1	37	25	46
F2	33	50	45
F3	33	34	45
F4	58	30	47
F5	58	32	47
F6	110	30	49
F7	62	31	47
F8	56	35	47
F9	60	29	47

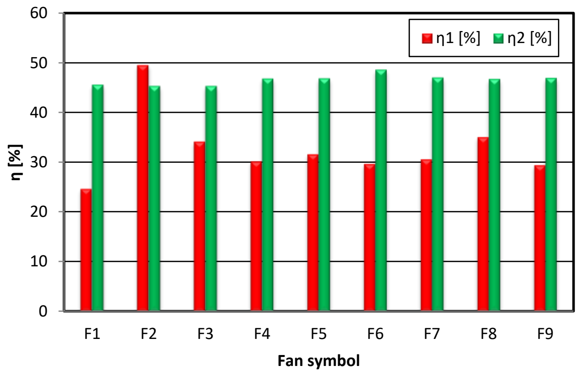

Fig. 18. Comparison results of the evaluation of efficiency

The purpose of the continuation of research in this article was to compare the results of research on nine centrifugal fans used in means of transport in terms of efficiency achieved and the requirements of the Regulation of the Minister of Economy of 11 March 2014 introducing changes in performance Directive 2009/125/EC of the European Parliament and of the Council [1] regarding ecodesign requirements for fans driven by motor with an electrical input between 125 W and 500 kW. After testing the nine fans, we can see that only one fan with the F2 symbol would meet the minimum energy efficiency requirements described in the directive. The other eight do not meet the requirements. Therefore, an appropriate resolution should be prepared covering the requirements for fans of this class, based on the results of tests on already existing fans, and it is justified to formulate an application to the Polish Committee for Standardization in order to verify the above-mentioned resolution. The results obtained indicate that there is a need to develop new guidelines. They should relate to the performance of low power fans with less than 125 W input power that is not covered by European Parliament Directive 2009/125/EC.

Acknowledgements

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Nomenclature

η	energy efficiency
P_{el}	input power of the fan
N	energy efficiency grade
ΔPc	total pressure increase
$\dot{V}$	volume flow of the air

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Adam Nygard, MEng. – Institute of Thermal Energy, Poznan University of Technology.

e-mail: *adam.nygard@put.poznan.pl*

Prof. Jarosław Bartoszewicz, DSc., DEng. – Institute of Thermal Energy, Poznan University of Technology.

e-mail: *jaroslaw.bartoszewicz@put.poznan.pl*