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SPECIFIC FAN POWER


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Abstract <p>The object of the work is Specific Fan Power. The first aim of the thesis was to compare SFP of two Air Handling Units with different type of control. SFP is the main value of regulating of energy consumption of the fan system. This fact indicates need of SFP controlling. The second aim of the thesis was to compare direct and indirect measurements of active power that are used for calculation of SFP. Incorrect method of measuring of active power can lead to wrong calculations of SFP.</p> <p>The first part is theoretical description of calculation of SFP value. It shows what can influence SFP. Then measurements in A-building of Mikkeli University of Applied Science were made. Active powers were measured for four fans in two AHU by means of two methods. Then SFP values were calculated and compared with requirements.</p> <p>As a main result, it was shown that direct measuring of active power do not lead to correct and reliable results. According to calculations and measurements that were done in this thesis SFP values of 3 fans are in normal range. Only one fan has poor SFP value and it is so because of belt connection that is in inappropriate condition.</p>		
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1 INTRODUCTION

Buildings are big consumers of energy. Its biggest share is needed for building engineering services that provides good indoor climate. Ventilation system is a huge part of this services that work almost all the time and use great amount of electricity. This great electricity consumption is a reason why we have to find solutions to increase energy efficiency of ventilation system. One solution is to increase fan system efficiency because fan is a main consumer of electricity in ventilation system. Another solution is to decrease resistance of the ventilation system in order to reduce demand of electric power for air transporting. It can be done by means of controlling of Specific Fan Power that is one of indicators of energy efficiency of ventilation system.

This thesis will discuss SFP. It is one of the main indicators of efficiency of ventilation system. SFP shows how much electric power is needed to move one cubic meter of air. It includes combination of system parameters that are taken into account in one complex value. Inefficient ventilation system is a problem that leads to larger consumption of electricity and the main reason of it is problems with fans. The first step is to check how efficient ventilation system is. It is made by means of measuring of properties of fans operation that will be expressed as SFP value.

The first part of the thesis discusses theoretical background of SFP. It describes calculation methods of SFP in different cases and factors that influence SFP as consumption of electricity, efficiency of fans and resistance of ventilation system. The second part of the thesis will include research in A-buildings of Mikkeli University of Applied Sciences (MUAS). SFP of different air handling units will be measured.

This thesis will show difference of SFP between constant air volume and variable air volume air handling units. Direct and indirect measurement of active power will be done in order to find out a difference. In addition, thesis will show how an older ventilation system meet with new SFP requirements and what solutions can be applied to increase efficiency.

2 THEORETICAL BACKGROUND

2.1 Definition of SFP

Specific fan power is a measure of how much electric power is required by a fan to transport a given air volume. Electric power is used by fan system and depends on flow rate, resistance of ventilation system and efficiency of fan system. These are main parameters that have influence on SFP. By stipulating a maximum SFP, it is possible to limit the power requirements for transporting air for entire building, AHUs and individual fans and thus to obligate engineers to design systems to be more efficient. SFP gives overall picture of how electric power is utilized by the system. SFP have to be defined during early design stage. In addition, SFP can be used as a method of controlling to verify that requirements have been meet at the designed conditions after installation. /1, p.464 E./

SFP can be expressed in two different values. The first value express SFP as power divided per cubic meter and the other one express as pressure. Equation 1 helps to determine how much power is required to transport one cubic meter of air and it is main equation that is used for SFP calculations. /2, p.3./

$$SFP = \frac{\sum P}{q_v} \quad (1)$$

where $\sum P$ is a sum of fan powers, kW, q_v is gross amount of air circulated, m³/s, SFP is specific fan power, kW/(m³/s) or kPa. /2, p.3./

Gross amount of air is air circulated through the fan or fans by effect of all present driving forces that can be mechanical or natural. Generally gross amount of air is the largest supply or exhaust air flow that is moved by whole system. /2, p.3./

Equation 2 helps to determine SFP by means of pressure rise that is created by the fan and total efficiency of fan system. /2, p.3./

$$SFP = \frac{\Delta p_{tot}}{\eta_{tot}} \quad (2)$$

Where SFP is specific fan power, kPa, η_{tot} is total efficiency of fan system, Δp_{tot} is pressure rise of fan, kPa. /2, p.3./

The efficiency of fan systems is the share of useful electrical energy that results in useful driving pressure to transport air in the ventilation system. Pressure rise of the fan should be equal to resistance of the system in order to make system functioning. If efficiency of fan system and allowed SFP value are known, maximum possible resistance of the system can be calculated with help of equation 2 that is described above. /2, p.3./

To show connection between different units of equation 1 and equation 2 the following equation 3 is used. /2, p.3./

$$[SFP] = \frac{kW}{m^3 / s} = \frac{W}{l / s} = \frac{kJ}{m^3} = kPa \quad (3)$$

2.2 Calculation of SFP in different cases

2.2.1 Calculation of SFP for individual fans

SFP_i is specific fan power of individual fan. It shows how much power is utilized by single fan. It must be used to check correspondence with requirements or manufacturer's data after installation or during maintenance and to enable the designers to determine whether a given fan will meet the overall demands on power efficiency. If requirements are not meet, reasons of inefficient work should to be found and solved in order to avoid waste of electricity. Calculations for individual fan can be made by equation 1. SFP_i can be checked in buildings where there is only exhaust ventilation and it is to be compared with regulations. /2, p.6./

2.2.2 Calculation of SFP for individual AHUs

SFP_{AHU} is specific fan power of individual conventional AHUs. These calculations of SFP are used to determine correspondence with provided technical data of manufacturers and to find out how efficient AHU works. For conventional balanced AHU with 2

fans, SFP_{AHU} should be calculated by equation 1 but also can be estimated as the sum of SFPs of the individual fans by equation 4. /2, p.6./

$$SFP_{AHU} = SFP_{i,sup} + SFP_{i,exh} \quad (4)$$

where SFP_{AHU} is specific fan power of AHU, kW/(m³/s), $SFP_{i,sup}$ is specific fan power of individual supply fan, kW/(m³/s), $SFP_{i,exh}$ is specific fan power of individual exhaust fan, kW/(m³/s). /2, p.6./

This equation 4 is correct only when supply and exhaust airflows are equal. If airflows are not equal, equation 1 should be used with the gross amount of air. /2, p.6./

Manufacturers should generally measure and document $SFP_{V,AHU}$ with new air filters, dry and clean heat exchangers and cooling coils. Index V means verification. This verification can be done by field test after acquisition. Electricity consumption of external variable frequency drive must be taken into account when total consumption of fan system is calculated. /2, p.6./

Manufacturers should also document $SFP_{E,AHU}$ for energy performance calculations. Index E means energy. $SFP_{E,AHU}$ reflects the average operating conditions where average pressure drop of filters and dry heat exchanger are taken into account due to occasional condensation of water on surface. /2, p.6./

2.2.3 Calculation of SFP for entire building

SFP_{BLDG} is specific fan power of the entire building. It must be checked after installation and balancing of the system to verify meeting the requirements. SFP_{BLDG} is the amount of electric power consumed by all the fans divided by the total airflow rate through the building under design load. Supply and exhaust fans, exhaust fans from toilets, kitchen extract fans and fans that are connected to the main ductwork system should be included in all calculations. Ceiling fans and fan coil units without connection to main ductwork are not taken into account in calculation. SFP_{BLDG} can not be constant because there are different operating modes for system and fans have different operation points that create different pressure drops in system. If system has kitchen hoods or another fans that do

not work constantly, possibility of their operation should be taken into account. It can be done with Microsoft Excel function that is presented in equation 5. /2, p.7./

$$n = \text{BINOMDIST}(N, p, \alpha) \quad (5)$$

Where n is a number of intermittently used fans that are operating, N is the number of intermittently used fan operates at any given time, p is the probability that any given intermittently used fan operates at any given time, α is confidence limit. /2, p.7./

2.2.4 Calculation of SFP for variable flow rates

Variable air volume systems are installed to reach better efficiency by reducing power demand of fans. Power demand is reduced by lower air flow rate that is regulated according to needs of occupants or in accordance with other parameters. If ventilation system is VAV system, SFP should be calculated with equation 6. /2, p.4./

$$SFP = \frac{\sum_{i=1}^N (\Sigma P_i \Delta t_i)}{\sum_{i=1}^N (q_{v,i} \Delta t_i)} = \frac{\sum_{i=1}^N (SFP_{e,i} q_{v,i} \Delta t_i)}{\sum_{i=1}^N (q_{v,i} \Delta t_i)} \quad (6)$$

where N is different operating modes, each with a duration Δt_i hours /2, p.4./

There is another way of calculations for VAV system. SFP at design operating point differ from SFP at part-load operating in each point and can be estimated as a function of the air flow rate reduction factor r. The following generic equation 7 is valid only for $0.2 \leq r \leq 1.0$ /2, p.4./

$$\frac{SFP_{part..load}}{SFP_{max..load}} = a + br + cr^2 + dr^3 \quad (7)$$

where a, b, c are coefficient that are presented in Table 1 below. /2, p.4./

TABLE 1. Coefficient of a, b, c for use in equation 7 /2, p.4./

	a	b	c	d
Poor	1.0	0.0	0.0	0.0
Normal	1.0547	-2.5576	3.6314	-1.1285
Good	0.5765	-1.5030	2.6557	-0.7292

Ideal	0.2869	-0.8836	1.9975	-0.4008
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The illustration of equation 7 is presented on Figure 1 below.

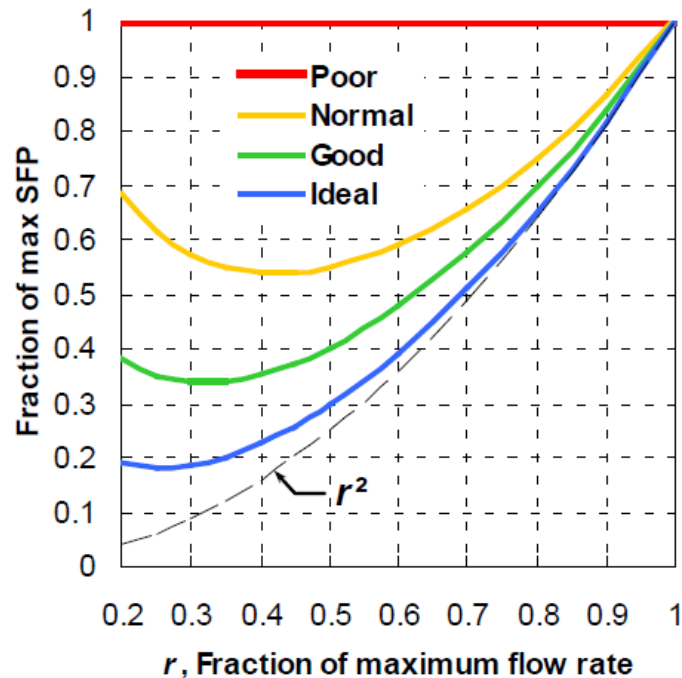


FIGURE 1. Illustration of equation 7 /2, p.4./

"Poor" represents system with poor efficiency at part load operating points. It includes old traditional systems that use outmoded equipment. "Normal" represents system for which the fan pressure drops slightly as flow rate is reduced. It includes VAV systems with constant pressure control that are maintained by the fan with the fan speed controller. "Good" presents systems for which the fan pressure decreases with flow rate. It includes best-practice VAV systems that are equipped with fans with VFD and pressure control system that tries to reduce pressure to optimal minimum operating pressure. "Ideal" presents real system with efficient variable speed drive and where the fan pressure falls ideally at low flow rates. It can be ideal also in CAV systems when it operates during night with part load. /2, p.4./

2.3 Measuring of power of fan system

Fan motors are usually fed 3-phase power via variable frequency drives. To measure active power that is supplied to the fan system it is needed to use indirect measurements with Power Quality and Energy Analyzer or advanced wattmeter that can measure true-

RMS 3 phase power for unbalanced loads with up to 50 harmonics. Power supplied to the fan should be measured at the inlet to VFD in order to take into account losses through it. This equipment measures voltage and current on the grid on each phase at the same time and calculates momentary active power. It is important to measure currents on each of 3 phases at the same time because they change all the time. There is a Power Quality and Energy Analyzer FLUKE 435 series II on Figure 2. /2, p.9./



FIGURE 2. Power Quality and Energy Analyzer FLUKE 435 series II /3/

The Power Quality and Energy Analyzer is quite expensive and can cost more than 7000€. This equipment can measure even consumption of electricity of whole building. The following equation 8 can be used to double-check the Power Quality and Energy Analyzer. /2, p.9 /

$$P = \sqrt{3} \cdot \overline{V_L} \cdot \overline{I_L} \cdot \cos \varphi \quad (8)$$

where P is total active power use for all 3 phase, kW, V is true RMS line phase voltage, V, I_L is true RMS line phase current, A, $\cos \varphi$ is power factor /2, p.9 /

Direct measurements with ampere and voltage meters are not appropriated in measuring of active power. This type of equipment does not measure voltage and current and voltage at the same time on each 3 phases of electrical grid and therefore correct Active Power can not be calculated. There is Fluke 325 True RMS Clamp Meter on Figure 3 below. This type can not be used in order to get correct value of active power.



FIGURE 3. Fluke 325 True RMS Clamp Meter /4/

These measurements with electricity require permission. Electrical engineer must be involved in process in order to avoid lethal accidents or damage of equipment. Moreover, it is quite difficult to find needed connection of wires and therefore competent electrical must carry out this work in order to get correct results.

2.4 Requirements

SFP requirements are used for limitation of SFP in designing stage. Moreover, they are used for calculation of energy consumption, performance of the building and for controlling the system during operation. SFP can be lowered in many ways what gives engineers opportunity to find proper solution in each project. New ventilation system must meet requirements on designing stage and then controlled to avoid inefficient work. Requirements in different countries can set SFP for whole building, single fan

and AHU. There are SFP_{BLDG} regulation values for only mechanical exhaust ventilation system and for mechanical supply and exhaust ventilation systems of some Norway and Sweden countries in Table 2.

TABLE 2. SFP regulation values of Finland, Sweden and Norway /2, p.10-11./

Country	SFP_{BLDG} only exhaust, kW/(m ³ /s)		SFP_{BLDG} , kW/(m ³ /s)	
	without heat recovery	with heat recovery	without heat recovery	with heat recovery
Sweden	0.6	1.0	1.5	2.0
Norway	-	-	-	2.0

In Finland SFP_{BLDG} for mechanical supply and exhaust air system generally may not exceed 2 kW/(m³/s). The SFP_{BLDG} for mechanical exhaust air system generally may not exceed 1 kW/(m³/s). The SFP_{BLDG} may be higher than 2 kW/(m³/s) if building requires not-standard air-conditioning. /5, p.14/

SFP also can be classified with help of EN 13779-2007. These regulations are easy to use because they classify SFP for each fan of the system. With this values engineers can find out how efficient separate fan works. In addition, these values can be used for system controlling. Values are presented in Table 3 below.

TABLE 3. SFP values according to EN 13779-2007 for individual fan /6, p.23./

Category	P_{SFP} , kW/(m ³ /s)
SFP 1	< 0,5
SFP 2	0,5 – 0,75
SFP 3	0,75 – 1,25
SFP 4	1,25 – 2,0
SFP 5	2,0 – 3,0
SFP 6	3,0 – 4,5
SFP 7	> 4,5

2.5 FANS

2.5.1 General information

SFP can be lowered with more efficient fans that require less electric power for air transporting. Consumption of electricity of the fans is the largest part of the total energy consumption of the ventilation system. To estimate efficiency of electricity usage a number of new terms, like Life Cycle Costing and SFP, are introduced in HVAC vocabulary. The fan power depends on the resistance in the system, efficiency of the fan and the air flow velocity through the units and ductwork. Two of the most important parameters for fan control are the operating time and use of VAV system that are introduced to reduce consumption of electricity. Correct fan operating time helps to limit fan work when it is not needed. VAV helps to supply required air volume that reduces pressure drops and electricity consumption of fan.

2.5.2 Power consumption of fan system

The purposes of fan system are to overcome resistance across system and provide required airflow. Electric power demand of the fan system depends on the total pressure rise, the airflow rate and the total efficiency of the fan system. This electric power can be calculated by equation 9 that is presented below. /5, p31./

$$P_{input} = \frac{P_{tot} \cdot q_V}{\eta_{tot}} \quad (9)$$

where P_{input} is electric power supplied to fan motor, W, p_{tot} is total pressure rise across the fan, Pa, η_{tot} is total fan efficiency, %./7, p31./

2.5.3 Efficiency of fan system

Efficiency of fan system shows the fraction of supplied electric power that is transformed as a useful air pressure rise across the fan. It is based on the efficiencies of the single components as fan, motor, belt drive, variable speed drive and etc. Equation 10 expresses total fan system efficiency as presented below. /2, p12./

$$\eta_{tot} = \frac{P_{out}}{P_{in}} = \eta_{vsd} \cdot \eta_{motor} \cdot \eta_{transfer} \cdot \eta_{fan} \quad (10)$$

where P_{out} is useful power output from the fan, kW, P_{in} is power input to the fan, kW, η_{fan} is fan aerodynamic efficiency, η_{motor} is motor efficiency, η_{vsd} is variable speed drive efficiency, $\eta_{transfer}$ is power transfer efficiency /2, p12./

There is illustration of losses of belt-driven fan on Figure 4 below. It shows each step of losses.

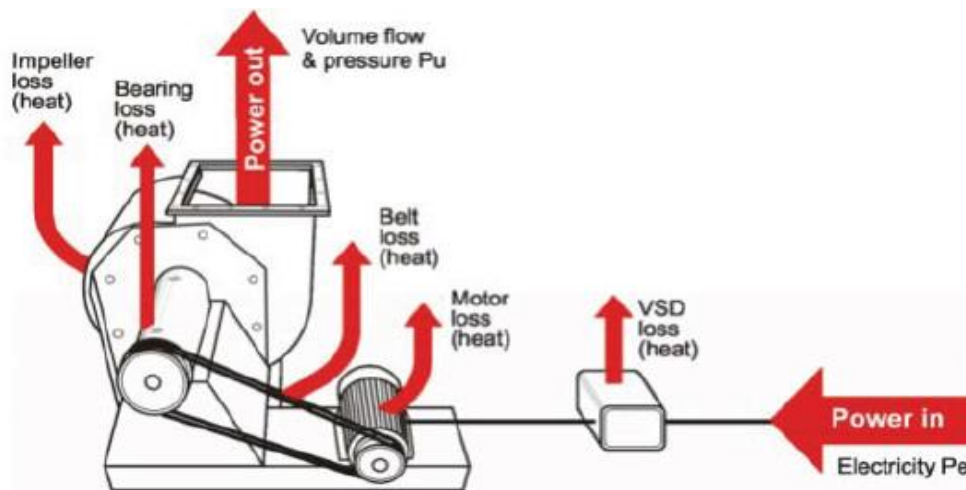


FIGURE 4. Breakdown of efficiency losses in belt-driven centrifugal fan /2, p12./

Direct-driven fan has bigger efficiency because there are less steps of energy conversion. There is illustration of losses of direct-driven fan on Figure 5 below.

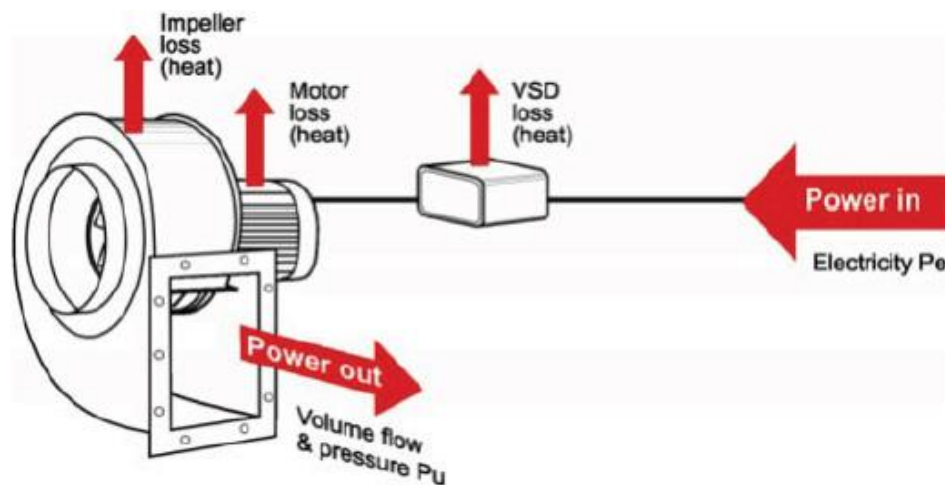


FIGURE 5. Breakdown of efficiency losses in direct-driven centrifugal fan /7, p12./

2.5.4 Efficiency of motors

Motor's efficiency is main element in efficiency of the fan system because it transforms electric power to mechanical work. The best motors are brushless DC motors also known as EC because they are electronically commutated. Their efficiency is normally between 70% and 90% at small power demand. They are currently available in the low power ranges but they are slowly penetrating into the market of higher motor power. The advantage of EC motors is in part-load operation that is more efficient than operation of AC motors that are asynchronous induction motors. EC motors are about 10-20% more efficient than AC motors but in high power demand conditions AC motors are the only available in the market. /7, p.91-93./

EC motors are the most efficient but in high power requirements they are not available and we have to use AC motors with variable speed drive that meet IE3 requirements. Efficiency classes of motors are classified according to IEC 60034-30 standard /8, p.14./

IE1 = Standard efficiency (comparable to EFF2) (not allowed anymore)

IE2 = High efficiency motors (comparable to EFF1)

IE3 = Premium efficiency

IE4= This level is defined according to IEC 60034-31:2010

This standards are represent on Figure 6 that is presented below:

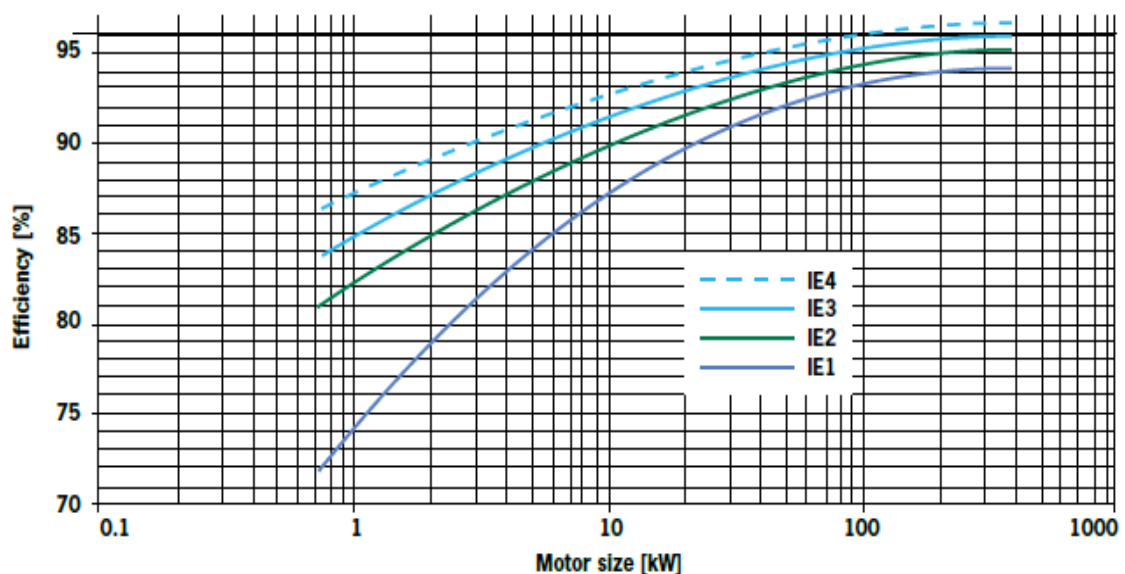


FIGURE 6. IEC standard for motor efficiency /8, p.14./

It is very important to select electric motor correctly in order to allow the motor to operate in its most efficient range. An undersized or oversized motor gives reduced efficiency.

2.5.5 Efficiency of variable frequency driver

A variable frequency driver is a type of motor controller that drives an electrical motor by varying the frequency and voltage supplied to the electric motor. It transforms current from the grid to the appropriate current and voltage of the motor in order to reach better efficiency. VFD can increase and decrease input power in order to control the fan according to the demand. /7, p.93/.

Variable speed drives adjust speed of motor that is needed to meet designed load conditions. The VFD losses are typically 2 – 5 % at the nominal load and 10-30% at 25% load of nominal load. /7, p.24/.

2.5.6 Efficiency of transmission

Belt-driven connection of motor to the fan cause considerable losses of energy. Example of these losses were shown on Figure 2. Normal efficiency is about 90% but it can be decreased if the gears are adjusted incorrectly and in this case efficiency will be 60-70%. AHU manufacturers and HVAC engineers try to avoid belt-driven connections and apply direct-driven connections which transmission efficiency is 100% in order to increase efficiency of fan system and meet requirements./7, p.24/.

Moreover, belt-drive connections require extra service and investments during maintenance because belts have certain life time period. During operation belt gradually comes into disrepair and loses efficiency that is why belt should be change after certain period.

2.5.7 Aerodynamic efficiency

Aerodynamic efficiency shows what is the dynamic pressure losses of the inlet and outlet of the fan chamber. Dynamic pressure is created by the air flow. There are always

dynamic pressure losses in the fan chamber. Pressure losses depend on the aerodynamic properties of AHU chamber but even well-designed ones always give dynamic pressure losses. /5, p.24/

Equation 11 can help to find out aerodynamic efficiency:

$$\eta_{fan,tot} = \frac{\Delta p_{tot} \cdot q_v}{P_{shaft}} \quad (11)$$

where P_{shaft} is bare shaft power, W /2, p.13./

2.5.8 Efficiency of fan wheel and types of fans

Different types of fans have different efficiency and they are usually selected for most suitable conditions where fan has its maximum possible efficiency. There are several types of fan wheels with different efficiency that vary, depending on the design of the blades. Propeller fan does not create much air pressure and has limited effect on ductwork therefore it is not used in AHUs. It is usually used at air openings in windows and walls. Propeller fan is shown on Figure 7 below.

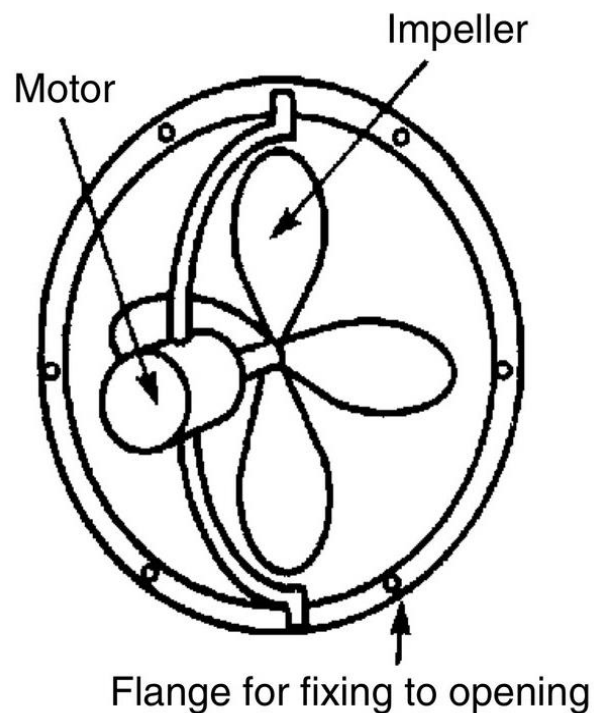


FIGURE 7. Propeller fan /9, p.245/

Axial flow fan can create much higher pressures than the first one and is used for moving air through long sections of ductwork. This type of fans can be integrated without a base in the ductwork. Axial flow fan is shown on Figure 8 below. /9, p.245/.

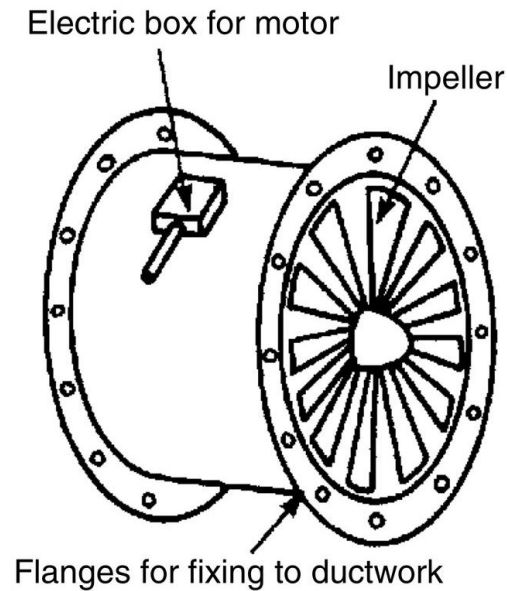


FIGURE 8. Axial flow fan /9, p.245/

Bifurcated axial flow fan is suitable for moving hot gases, flue gases and greasy air from commercial cooker hoods. This type of fans is mostly used in industry and commercial kitchens where there is a risk of fire. Bifurcated axial flow fan is shown on Figure 9 below. /9, p.245/.

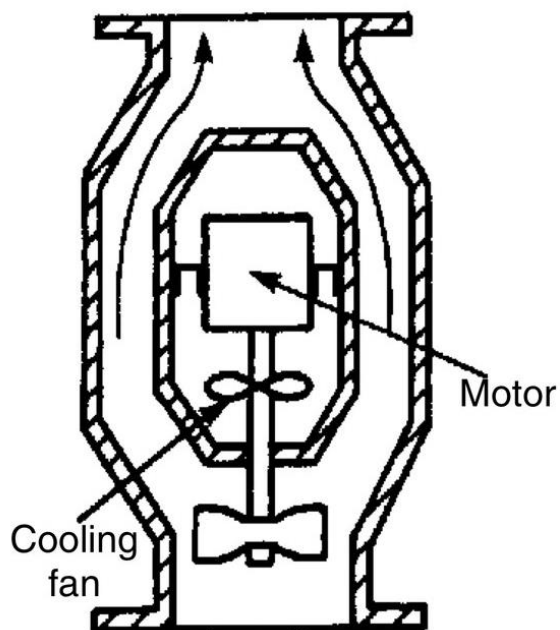
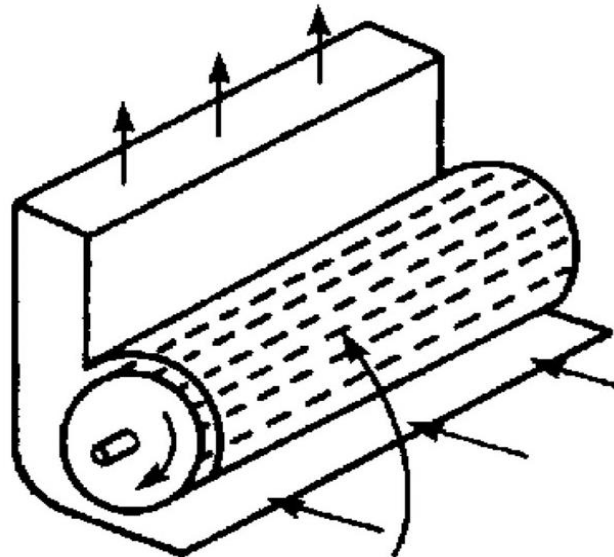


FIGURE 9. Bifurcated axial fan /9, p.245/

Cross flow fan is used in fan convectors units. It is extensively used in HVAC industry for different purposes. This type of fan has low noise level and high pressure capacity. Cross flow fan is shown on Figure 10 below. /9, p.245/.



Forward curve blades scoop the air inward

FIGURE 10. Cross flow fan /9, p.245/

Centrifugal fan can produce high pressure and has big capacity for transporting of big amount of air. It is most suitable for large installations. It is shown on Figure 11 below.

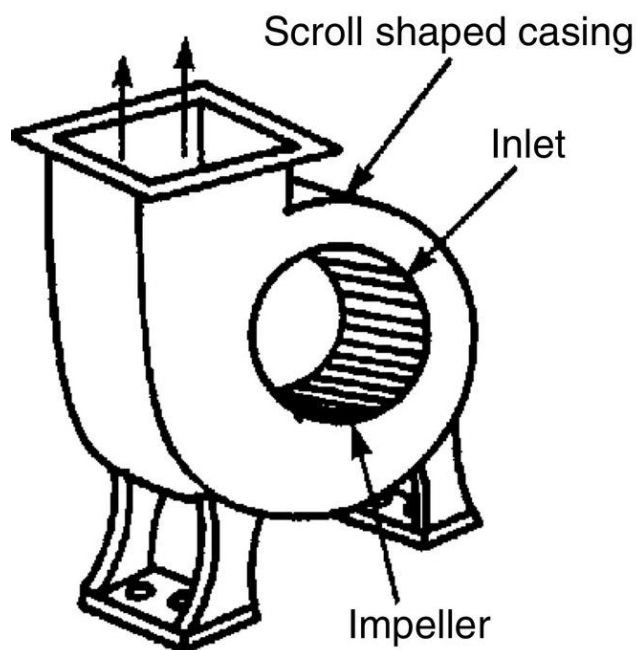


FIGURE 11. Centrifugal fan /9, p.245/

Various forms of impellers can be selected according to the air conditions. These various forms are shown on Figure 12 below. The highest efficiency, up to 85%, has type B wheel with backward-curved blades.

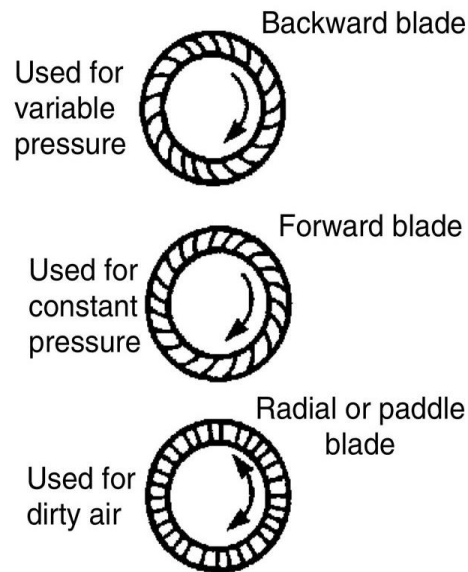


FIGURE 12. Types of impellers /9, p.245/

2.5.9 Overview of fan energy efficiency

Despite all the textbooks and handbooks, which describe the procedure of fans' selection, practice has shown that fans in existing HVAC systems have very low efficiency. In Sweden, ECIS AB (Energy Concept in Sweden) performed efficiency measurements of 779 fans in existing HVAC systems between the years 2005 and 2009. Average fans' efficiency was only 33%. Only some fans have efficiencies that are more than 50% and suits in the range of EU fan efficiency requirements. It shows problem with fans efficiency. We can save up to 50% electricity if we increase energy efficiency of fans. These results are the typical practice for all EU countries. Results are shown below on Figure 13. /7, p.23/

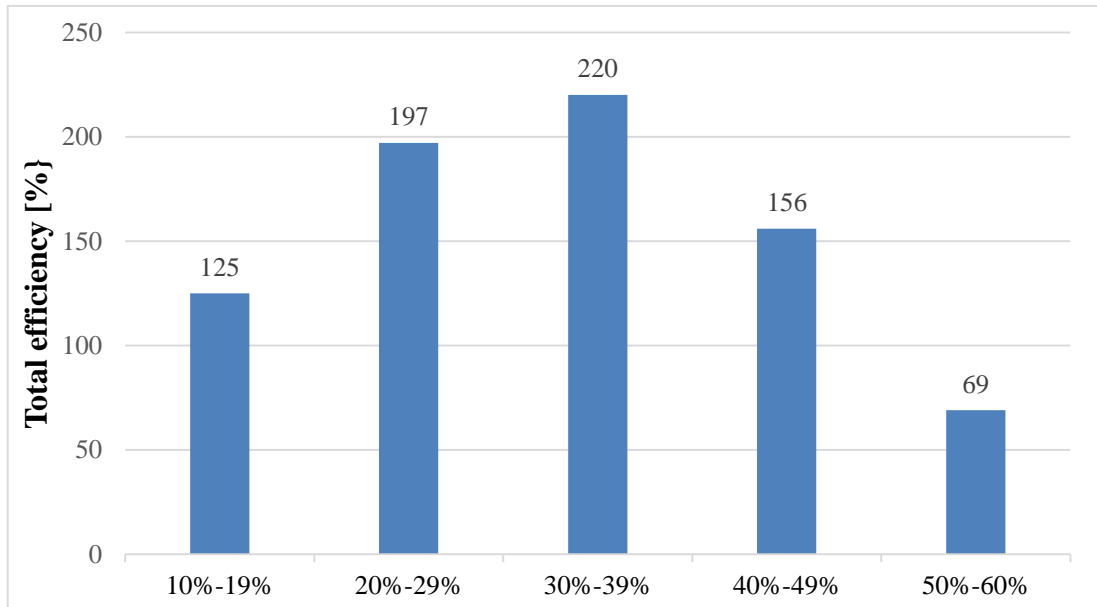


FIGURE 13. Results of energy efficiency measurement of 779 fans /7, p.23/

2.5.10 Role of fan in life cycle cost

Life Cycle Costing (LCC) is a technique to estimate environmental and economical impacts on all the stages of product’s life from designed stage to predicted end of use. The cost of the electricity used by the fan is a half of the total life cycle cost of AHU. On Figure 14 you can see shares of energy consumption. /7, p.16/

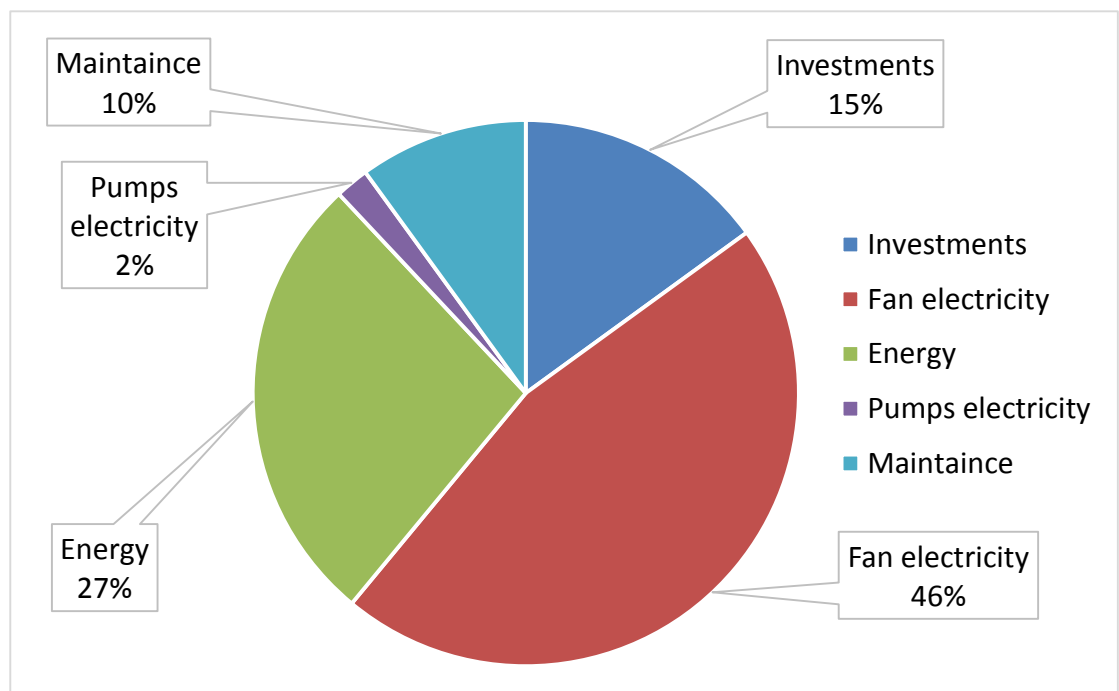


FIGURE 14. Typical split of life-cycle costs for AHU /7 p.16/

2.6 PRESSURE DROPS

2.6.1 Pressure drops

One more important way of reducing fan power is decreasing of system resistance. It can be done by means of selecting proper equipment, better designing of ductwork and using fan with variable speed driver. As shown in equation 2 SFP can be expressed in units of pressure, since pressure is a measure of energy per m^3 air. /2, p3./

2.6.2 Pressure drops in different parts

Air handling units are the main energy users in ventilation systems. Purposes of AHU are air treatment, which include cooling, heating, humidification and dehumidification, filtering and air delivery, etc. In order to reduce energy consumption, we have to think about losses that every step causes and properly select equipment to reduce these losses. The main criteria for energy efficient air handling unit is face velocity that is average parallel to the normal of the observing plane or face i.e section of air handling unit (AHU). Higher face velocity cause bigger pressure drops in all system, lower energy efficiency of fans and bigger specific fan power. Pressure drops cause greater energy consumption. Traditionally, air handling units are selected with face velocities of 2 m/s or bigger, and with pressure drops in the range of 1000 Pa, but today engineers should try to select AHUs with face velocity of 1,5 m/s or lower, and total pressure of 250 Pa or lower. From Table 4 one can see typical values for designing. /7, p16-17./

TABLE 4. Pressure drops for all-air HVAC systems in large buildings /7, p 17/

		Poor design	Typically design	Good design	Units
AHU	Face velocity	2.5	2.0	1.5	m/s
	Filter F3 bag	80	70	50	Pa
	Filter M5 bag	140	115	75	Pa
	Filter F9 bag	190-250	160	110	Pa
	Rotary heat exchanger	200-250	150	90-100	Pa
	Heating coil	120	80	40	Pa
	Cooling coil	140	100	60	Pa

	Sound attenuator	80-235	50	30	Pa
	Total AHU internal ΔP	670	420	250	Pa
Air distribution	Ductwork (supply or exhaust)	300-490	200-230	100-115	Pa
	Duct silencers	15	10	0	Pa
	VAV box	112	112	25	Pa
	Air terminal device (supply or exhaust)	70	50	20	Pa
	Exhaust stack/jet	175	175	175	Pa
	Fan system efficiency	40%	50%	63%	%
	SFP (in SI units)	6	3	1.3	kW/(m ³ /s)
	SFP (in m ³ /h)	1.67	0.83	0.36	W/(m ³ /h)

3 INVESTIGATION IN MAMK

3.1 Overview of A-building of MAMK

Ventilation system of A-building was designed in 1994 by REJLERS OY and after upgraded by Schneider Electric with new automation and controlling equipment. There are 4 AHUs that have different types of heat exchangers and different airflow rates. Each AHU perform air-conditioning in each zone. VFD of AHU 1 keeps constant pressure in ductwork and VAV-dampers change their positions according to controllers. VFD of AHU 2 has constant frequency and there is no control of pressure or air flow rate.

3.2 Methods

3.2.1 General overview

Measuring of SFP is a difficult task to perform. This task needs cooperation between HVAC engineers and electrical engineers. To estimate SFP_{AHU} of AHU1 and AHU2 of MAMK the following procedure was made. The first step is to measure power consumption and airflow rates through each system then pressure rises of fans can be measured in order to calculate efficiency of fan systems.

3.2.2 Measurements

Measuring of power consumption needs assistance of electrical engineer that has permission to open electrical boxes and measure voltage and current. Supplied power must be measured in the inlet of VSD in order to take into account losses of VSD. It will be measured by electrical engineer with Power Quality and Energy Analyzer FLUKE 435 series II that was shown on Figure 2. It is correct method of measuring of Active Power that uses indirect measurements. In addition, direct measurements will be used to find out mistake of this incorrect method. Current will be measured by electrical engineer with KYORITSU kew snap model 2031 that is shown below on Figure 15. After Active Power will be calculated with equation 8.



FIGURE 15. KYORITSU kew snap model 2031

The second step is to estimate air flow rates through each fan. Measuring of AHU air-flow rate will be done with Kytola DPA-AM06 equipment that is installed on casing. It is shown on Figure 16 below.



FIGURE 16. WOLF Kytola DPA-AM06

The third step is to estimate resistance of the ventilation system that fan has to overcome. Pressure rises of the fans will be taken from manometers that are installed on AHU casing. In case when there is no manometer, pressure rise will be taken from technical information of AHU.

3.2.3 Calculation of SFP

Calculation of SFP will be done for each individual fan and for each AHU. Equation 1 will be used to calculate SFP_{AHU} . After these values will be compared with each other and with European standard for single fans.

4 RESULTS AND ANALYSIS

4.1 Measurements

Fans that are used in AHU 1 and AHU 2 have 3-phase connection via VFD to electrical grid. Fluke was connected to the electrical grid. It is shown on Figure 17 below. There are three red wires that measure current on each of three phase and there are black probes that measure voltage on each of these three phase.

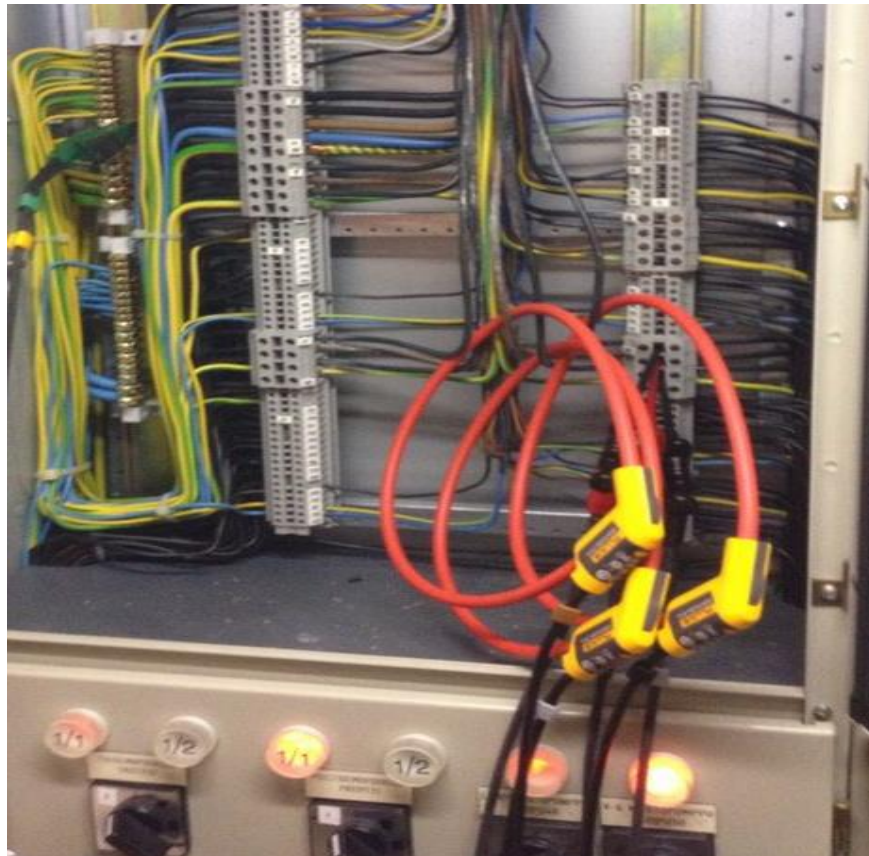


FIGURE 17. Fluke connection to the electrical grid

When measurements of AHU 1 were started it was found that active power is oscillating with airflow rate. Minimum airflow rate was $1.5 \text{ m}^3/\text{s}$ and maximum was $2.7 \text{ m}^3/\text{s}$. Maximum active power was 2.5 kW and minimum was 1.6 kW. Changes of Active Powers and airflow rates were during about 30 second from minimum value to maximum value. This oscillating can be because of VAV dampers. It was decided to wait 15 minutes to give opportunity to the system to find proper operating point but there was no changes after this time. It was decided to start recording the measurement during 5 minutes in order to find out minimum and maximum active power supplied to the fan. Results are shown on Figure 18.

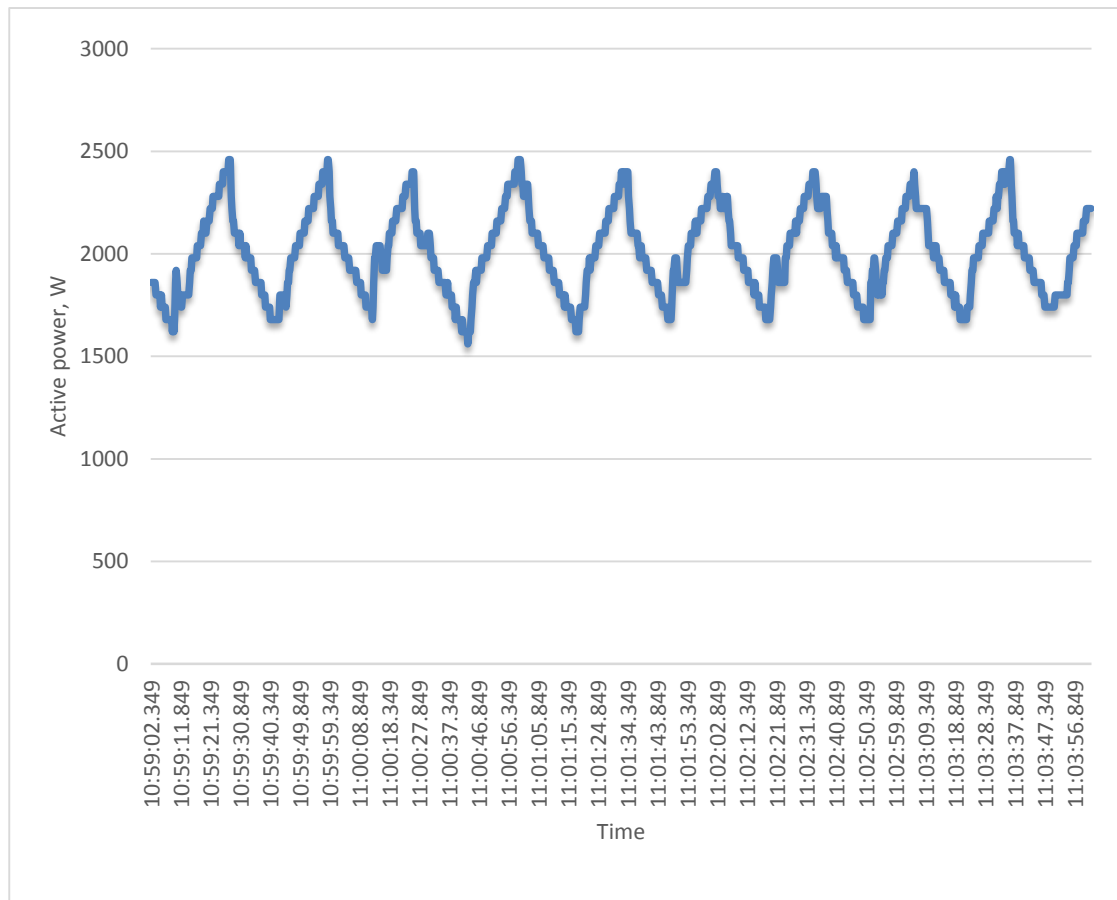


FIGURE 18. Active power supplies to TK01

Also it was found that VFD of TK01 and PK02 were changing all the time. Their frequencies were changing from 32 Hz to 52 Hz. It was observed from digital displays of Danfoss VFDs that control these fans. It can be because of pressure in duct that VFDs try to keep constant. Airflow rate of TK01 was taken from Kytola DPA-AM06 that is shown on Figure 19 below. At first it was balanced to the zero with HVAC specialist and only after measurements were started. Oscillating was during 30 seconds from minimum value to maximum.



FIGURE 19. Airflow rate of TK01

With exhaust fan PK01 situation was the same. Minimum airflow rate 3.5 m³/s and maximum was 4.2 m³/s. Maximum active power was 3.8 kW and minimum was 2.5 kW. Results are shown on Figure 20 below.

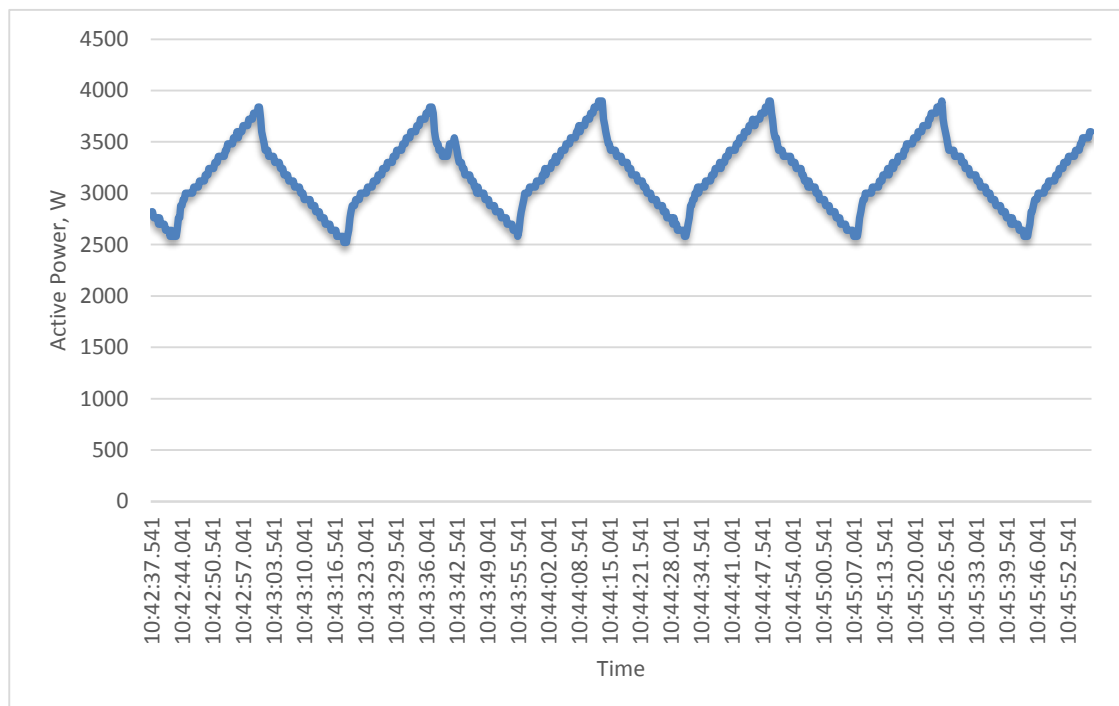


FIGURE 20. Active power supplies to PK01

Then measurements on AHU 2 were started. Active powers were constant on supply and exhaust fans therefore it was decided to make only screenshots of equipment measurements. There is Active Power of TK02 on Figure 21 below.

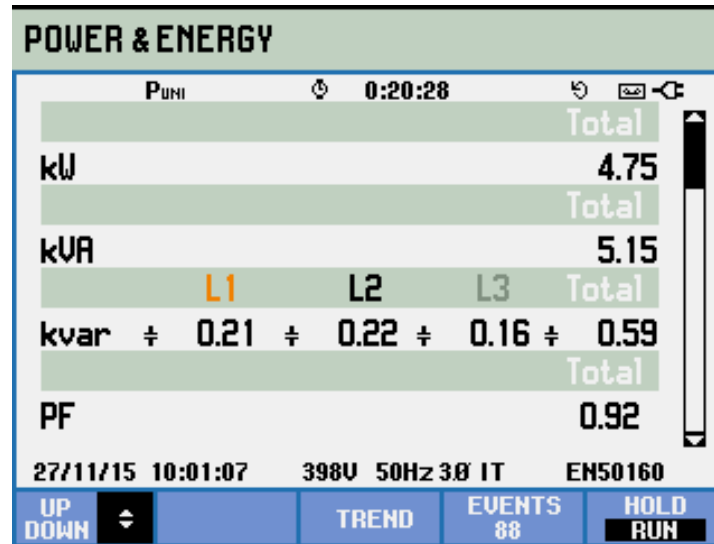


FIGURE 21. Active power of TK 01

There is active power of PK02 on Figure 22 below. It can be seen that consumption is quite big. This value is constant too. Fan of PK02 was stopped and opened in order to find out problems of too big consumption. It was found out that there is smell of burnt rubber. It was because belt was in bad condition.

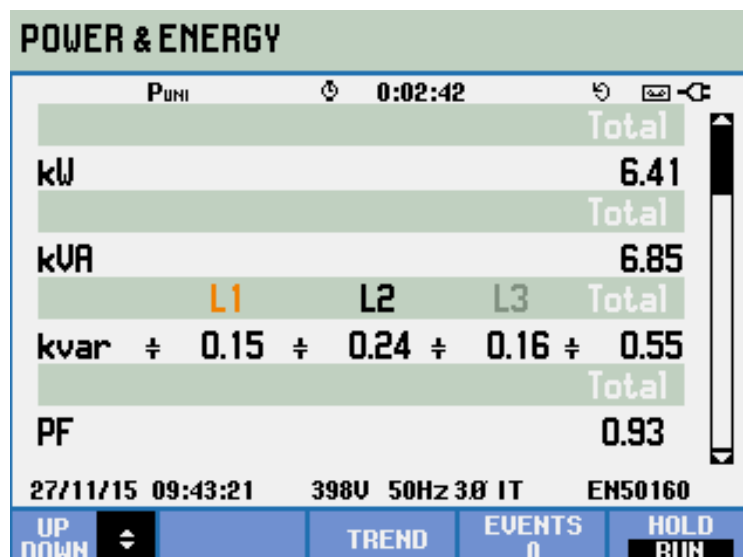


FIGURE 22. Active Power of PK02

Next day direct measurement was done with KYORITSU kew snap model 203. Power factor that is $\cos\phi$ was assumed to be 0.85 according to AVIC SFP recommendation.

Voltage of the grid was 400V. AHU 2 had the same airflow rates. AHU 1 had another values that were constant. It is supposed that system had found our proper operation point. The way how current was measured is shown on Figure 23 below.

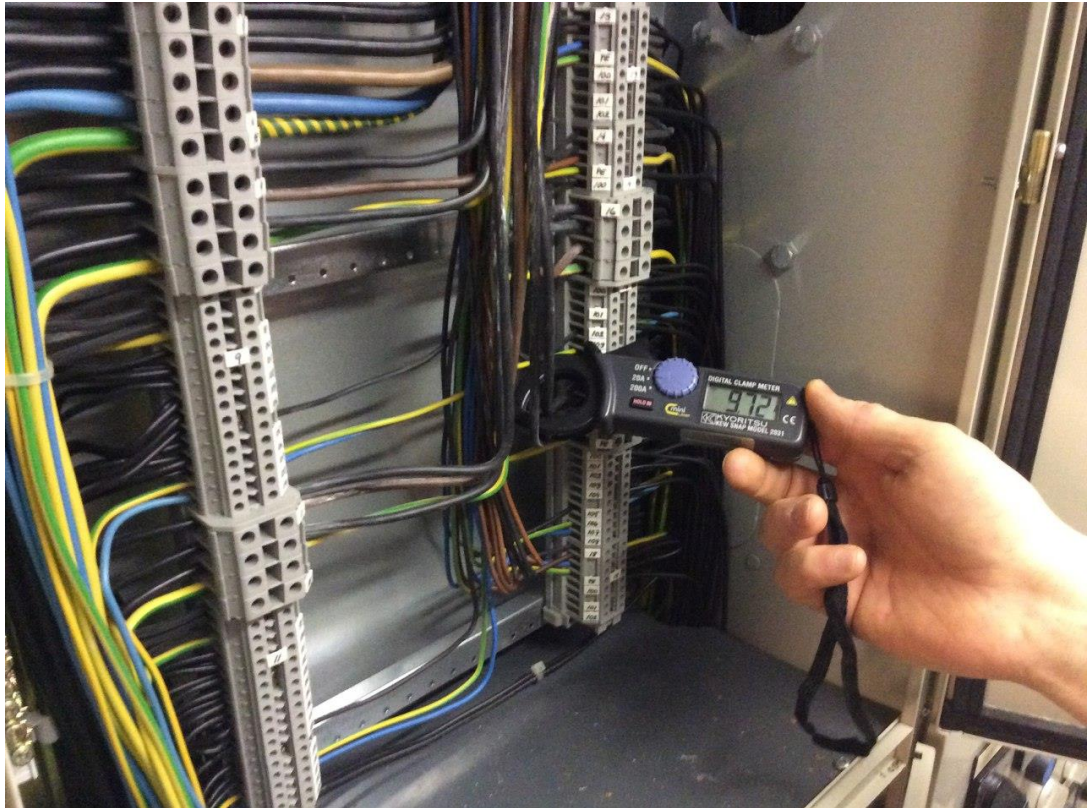


FIGURE 23. Measuring of current on PK02

Result of measurement are shown in Table 5 below. There are currents that were measured and voltages that were constant in the whole system.

TABLE 5. Results of measurements

System	Fan	Airflow rate, m ³ /s	Current, A	Voltage, V
AHU1	TK01	3	3,2	400,0
	PK01	-4,5	6,5	400,0
AHU2	TK02	5,31	7,2	400,0
	PK02	4.8	9,6	400,0

During measurements it was observed that there is no possibility to measure pressure of the fan because there is no manometer for it. Designing values are too old and we can not rely on them because air flows are different. Some parts of the system were

changed and have another properties for instance, filters have smaller pressure drop then outmoded ones.

4.2 Calculations

SFP for each fan and AHUs are calculated according to equation 1. For indirect method result are shown in Table 6 that is followed below.

TABLE 6. SFP results

System	Fan	Air flow rate	Fan power	SFP _f	SFP _{AHU}
		m ³ /s	kW	kW/(m ³ /s)	kW/(m ³ /s)
AHU1	TK01	2.5	2.7	1.08	1.55
	PK01	4.2	3.8	0.9	
AHU2	TK02	5.31	4.7	0.88	2.11
	PK02	4.8	6.5	1.35	

SFP for each fan and AHU are calculated according to equation 1. For direct method result are shown in Table 7 that is presented below.

TABLE 7. SFP results

System	Fan	Air flow rate	Current	Voltage	Power factor	Fan power	SFP _f	SFP _{AHU}
		m ³ /s	A	V	cosφ	kW	kW/(m ³ /s) _f	kW/(m ³ /s)
AHU 1	TK01	3	3,2	400	0,85	1,88	0.62	1.27
	PK01	4,5	6,5	400	0,85	3,83	0.85	
AHU 2	TK02	5,31	7,2	400	0,85	4.24	0.79	1.85
	PK02	4.8	9,6	400	0,85	5.6	1.16	

4.3 Analysis

AHU 1 has lower SFP_{AHU} then AHU 2 on 36%. It means that fans work more efficient or resistance of the system is lower. There are no manometers for measuring of fan pressure rise that is why it is difficult to evaluate efficiency of the fan system. According

to EN 13779-2007 each fan is classified and results are shown in Table 8 that is presented below.

TABLE 8. Classification of fans according to EN 13779-2007

Fan	Classification
TK01	SFP 3
PK01	SFP 3
TK02	SFP 3
PK02	SFP 4

There is a problem with fan of PK02. It can be because of belt-driven connection that is in bad conditions. Efficiency of transmission is going to be worse and worse that leads to lower efficiency and bigger power consumption. It should be changed as soon as possible.

Direct and indirect measurement have big deviation. With direct measurement it is difficult to choose correct power factor that has big influence on results. Also from Figure 21 and 22 different currents on each 3-phase can be seen. Moreover, with direct measurements it was not possible to find oscillation of the system. It can lead to incorrect results.

5 DISCUSSION

In conclusion it should be said that belt driven connection should not be used in order to avoid uncontrolled drop of efficiency. Direct driven connection can improve efficiency of the fan system that will cause to lower SFP. It was shown on example of the fan system of PK02 that damaged belt causes to bigger power consumption. Overall others fan systems of AHU1 and AHU 2 are good designed according to classification of REHVA.

It was shown that indirect measurements give more precise and reliable results. Indirect measurement should be only used to get correct result. Direct measurements have shown that they give less information about power factor of supplied electricity. Power factor is important value in calculation of active power. Also with direct measurement it was impossible to measure current on each phase in order to get average value form all phases.

Problems with controlling of AHU1 was found. Such big oscillations can cause to damage of belt driven connection and worse transmission efficiency. Moreover, it can lead to lower life period of motors of VAV-dampers because they always have to adapt system to needed conditions.

In this work was no possibility to estimate efficiency of fan systems. It would be possible with manometers that will measure pressure rises of fans. Every modern AHU has to have manometers in order to have possibility for HVAC engineers to estimate efficiency of the fan system and to control fan operation conditions.

Summing it up, I have to say that measuring of SFP is quite difficult task. SFP is practical value in order to estimate how much power is utilized by the fan system.

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