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Calculation method for the energy use related to air filters in general ventilation systems

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Foreword

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1. Introduction

In the context of increasing energy prices and the imperative of reducing CO_2 emissions, the energy consumption related to air filters has become the focus of attention. Currently, air filters are classified only by their average particle collection efficiency according to the European standard EN 779. The aim of this guideline is to define a method of air filter evaluation with regard to energy-efficient operation, to give the user of air filters guidance for the filter selection. It has to be noted that to reduce the energy consumption by using more energy efficient filters, requires that the speed of the fan can be adjusted to supply a constant air volume flow rate. If the fan is operated at a fixed speed, lowering the (average) pressure drop of the air filters will result in an increased air volume flow rate. In the worst case this may even result in a situation where the fan is operated in a region with lower efficiency resulting in an increased overall energy consumption. It also has to be noted that the method provided in this document is based on laboratory test data with standardized test conditions which may differ significantly from the individual application in a building ventilation unit. Hence, the yearly energy consumption calculated in this document can only be used as an indicator and relates only to the contribution of the air filters involved. The yearly energy consumption in an individual, actual application may differ from this significantly.

The energy consumption of air filters can be determined as a function of the volume flow rate, the fan efficiency, the operation time, and the average pressure drop. Due to the dust loading during operation the pressure drop of an air filter is increasing. The related energy consumption during a certain period of time can be calculated from the integral average of the pressure drop over this period of time. As a laboratory test method, the average pressure drop is determined from an ASHRAE dust loading of the filter as defined in EN 779.

2. Energy consumption related to air filters

The energy consumption of a fan in an air handling unit can be evaluated as a function of the volume flow rate supplied by the fan, the fan efficiency, the operation time, and the difference of the total pressure (static plus dynamic pressure) after the fan and the static pressure of the ambient air (assuming that the fan sucks in air from a static reservoir). Typically, the volume flow rate supplied by the fan and the pressure difference the fan has to overcome are related to each other by the characteristic fan curve. The efficiency of the fan is a function of the fan speed. The actual fan efficiency also strongly depends on the design and the layout of the fan, and can be in the best case as high as 0.80 or even higher, and in the worst case as low as 0.25 or even lower.

To define an energy efficiency classification system for air filters, we consider only the portion of the total energy consumption which is related to the filters' pressure drop. This can be calculated using Eq. (1):

$$W = \frac{q_V \cdot \overline{\Delta p} \cdot t}{\eta \cdot 1000} \quad (1)$$

Where: q_V = 0.944 m³/s, t = 6000h and η = 0.50

Furthermore, we consider the volume flow rate to be fixed at 0.944 m/s (3400 m³/h). This corresponds in a real air handling unit to a fan with variable speed drive controlled to run at fixed volume flow. Additionally, the fan efficiency is defined to be fixed at 0.50, which can be considered as a typical average efficiency of a fan in an air handling unit.

3. Energy efficiency evaluation

The rating shall be carried out for a full size filter element (face dimension 592 mm x 592 mm to EN 15805) as described below.

1.) Carry out a full test to EN 779 at a flow rate q_V = 0.944 m³/s. As part of this test, the air filter is loaded with ASHRAE dust to the final pressure drop (250 Pa in case of a coarse dust filter and of 450 Pa in case of a medium and fine dust filter). During the course of dust loading, the pressure drop curve shall be recorded with at least five data points.

2.) Use the polynomial of 4th order $\Delta p = a \cdot m^4 + b \cdot m^3 + c \cdot m^2 + d \cdot m + \Delta p_i$ and curve fit the parameter a, b, c and d to the measured pressure drop data as a function of the dust loading, where Δp_i is the initial pressure drop of the filter at the flow rate q_V = 0.944 m³/s with no dust loading.

   The accuracy of the curve fit shall be checked by the coefficient of determination (R^2). A value of $R^2 \geq 0.99$ indicates a good correlation between the data point and the curve fit. Additionally, a graphical plot shall be used to check the shape of the curve. Typically, the curve must have a positive gradient at every point. If negative gradients occur at any point of the curve fit (e.g. strongly swings between the data points) or the curve fit does not correlate well with the data points ($R^2 < 0.99$), the order of polynomial may be changed to third or fifth order or an alternative mathematical method to integrate the pressure drop curve may be used. In this case Eq. (2) needs to be adapted to the actual method used.

3.) Calculate the average pressure drop using the formula

$$\overline{\Delta p} = \frac{1}{M_x} \int_0^{M_x} \Delta p(m) \cdot \mathrm{d}m = \tfrac{1}{5} a \cdot M_x^4 + \tfrac{1}{4} b \cdot M_x^3 + \tfrac{1}{3} c \cdot M_x^2 + \tfrac{1}{2} d \cdot M_x + \Delta p_i \quad (2)$$

   Where M_x represents a fixed amount of dust to simulate the dust loading of a filter after one year of operation. It depends on the group x = M, G or F where the filter under concern belongs to. For filters of group G (coarse dust filters) M_G equals to 350 g, for filter of group M M_M equals to 250 g and for filters of group F (fine dust filters) M_F equals to 100 g of ASHRAE dust.

   If the dust holding capacity of the filter – the amount of dust loaded to the filter to reach the final pressure drop to EN 779 – is lower than M_x, the filter cannot be evaluated to its energy efficiency and the procedure can be stopped.

4.) Calculate the yearly energy consumption W related to the filter at nominal flow rate by using Eq. (1).

4. Symbols

a, b, c, d	Parameters of a polynomial of 4th order to be fitted to the pressure drop curve.
η	Efficiency of a fan for the transmission of electrical energy into energy content of the air flow field. As a representative average value for the different installations and operating conditions η is assumed to equal 0.50.
M_x	Amount of ASHRAE dust in g used to calculate the average pressure drop. M_x represents one of the three values M_G = 350 g for group G filters, M_M = 250 g for group M filters, or M_F = 100 g for group F filters.
Δp_i	Initial pressure drop of an air filter, Pa
$\overline{\Delta p}$	Average pressure drop of an air filter, Pa
q_V	Air volume flow rate at filter, m³/s
R^2	coefficient of determination
t	Time of operation in h. For an air filter during a period of one year, a total operating time of 6000 h is assumed.
W	Yearly energy consumption, kWh

5. Example

As an example, the calculation method is shown based on the EN 779 test results for a F8 rigid filter tested at 0.944 m³/s.

EN 779 - Air Filter test results (Abstract)				
General				
Test no.: Report no.:	XYZ	Date of test:		Testing organisation: XYZ laboratories
Device tested				
Model: Construction:	ABC rigid filter 8x V-banks	Manufacturer: Net effective filter area:	Sample Filter Ltd. 18 m²	Weight 5063,2g Dim.: 592x592x292 mm
Test data				
Test air flow rate: 0.944 m³/s	Test air temperature: 21 °C	Test air relative humidity: 34 %	Test aerosol: DEHS	Loading dust: ASHRAE
Results				
Initial pressure drop: 77 Pa	Initial arrestance: 100 %	Initial efficiency: 58 %	Dust holding capacity: 535 g	Efficiency (0,4 µm) of media
Final pressure drop: 450 Pa	Average arrestance: 99 %	Average efficiency: 92 %	Filter class: **F8**	Untreated: 61 %
Remarks				IPA treated: 57 %

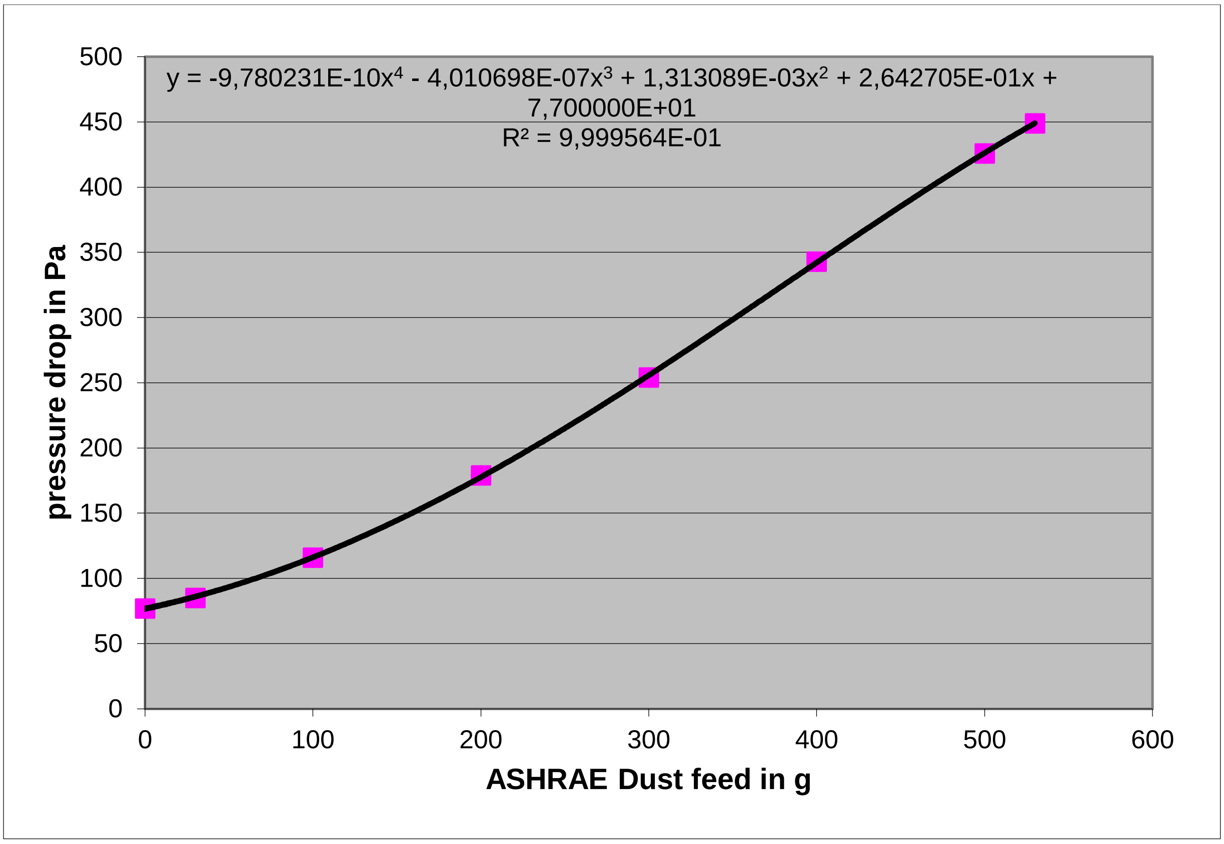

Figure 1: Pressure drop as a function of the dust loading as result of the EN 779 test at 0.944 m³/s. The function plotted on the top of the diagram shows the parameters a, b, c and d of Eq. (2) resulting from a curve fit of a polynomial of 4th order to the test data and the related coefficient of determination R^2.

Table 2: Test data for the pressure drop as a function of the ASHRAE dust feed.

Dust feed in g	Δp in Pa @ 0.944 m³/s
0	77
30	85
100	116
200	179
300	254
400	343
500	426
530	449

The initial pressure drop of the filter at 0.944 m³/s is $\Delta p_{\mathrm{i}} = 77$ Pa. Based on the curve fit to the data shown in the table on the left, the parameters for Eq. (2) calculate to

$$a = -9.780231 \cdot 10^{-10}\ \mathrm{Pa/g^4},\ b = -4.010698 \cdot 10^{-7}\ \mathrm{Pa/g^3},$$
$$c = 1.313089 \cdot 10^{-3}\ \mathrm{Pa/g^2}, \quad d = 0.2642705\ \mathrm{Pa/g}$$

For this curve fit, the coefficient of determination calculates to $R^2 = 0.9999564$.

With $M_x = M_{\mathrm{F}} = 100\ \mathrm{g}$ using Eq. (2) the average pressure drop computes in this example to $\overline{\Delta p} = 94.5\ \mathrm{Pa}$[1]. Hence, using Eq. (1), the yearly energy consumption results to $W = 1070\ \mathrm{kWh}$.

[1] The value of the average pressure drop is shown here with one decimal place to be precise in the example and to avoid rounding errors. It does not reflect the accuracy of the measurement.

6. Literature

[1] Goodfellow, H.; Tähti, E.: Industrial Ventilation, Academic Press, 2001.

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