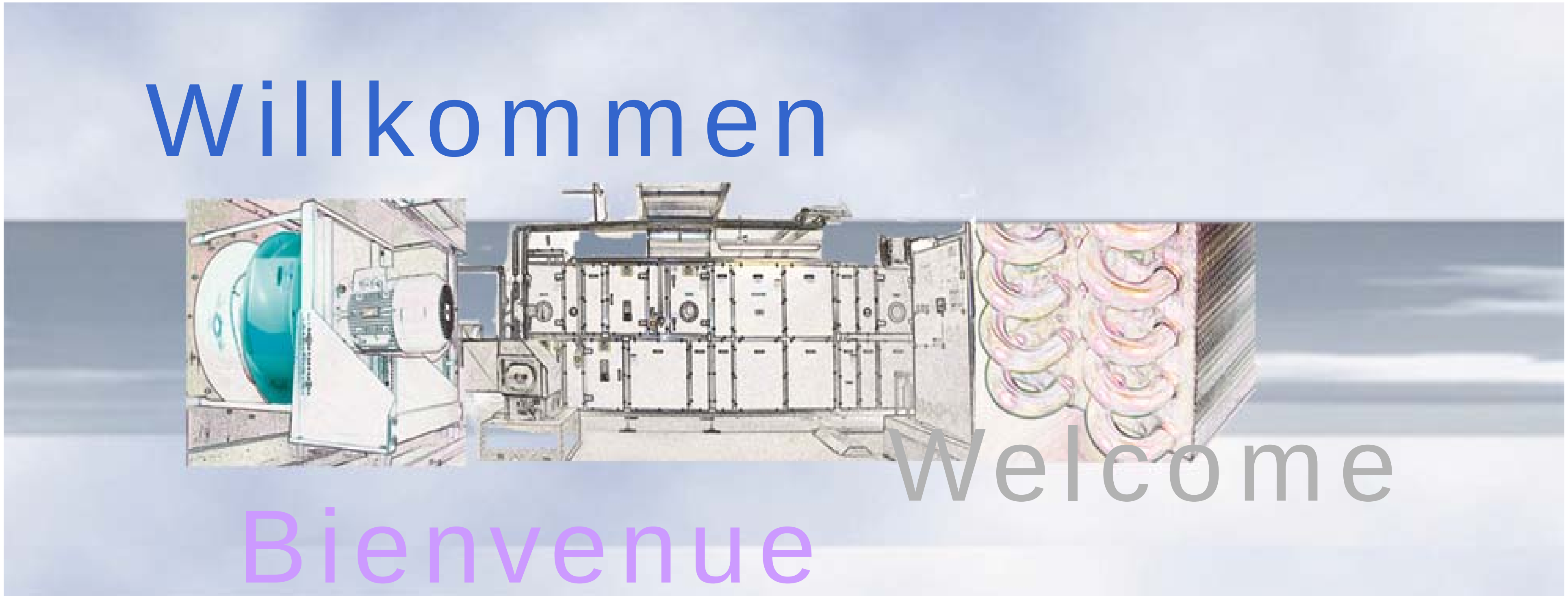

Ventilation
energy efficiency of fans and drives

Energy recovery and energy efficiency in ventilation technology

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Ventilation systems tasks:

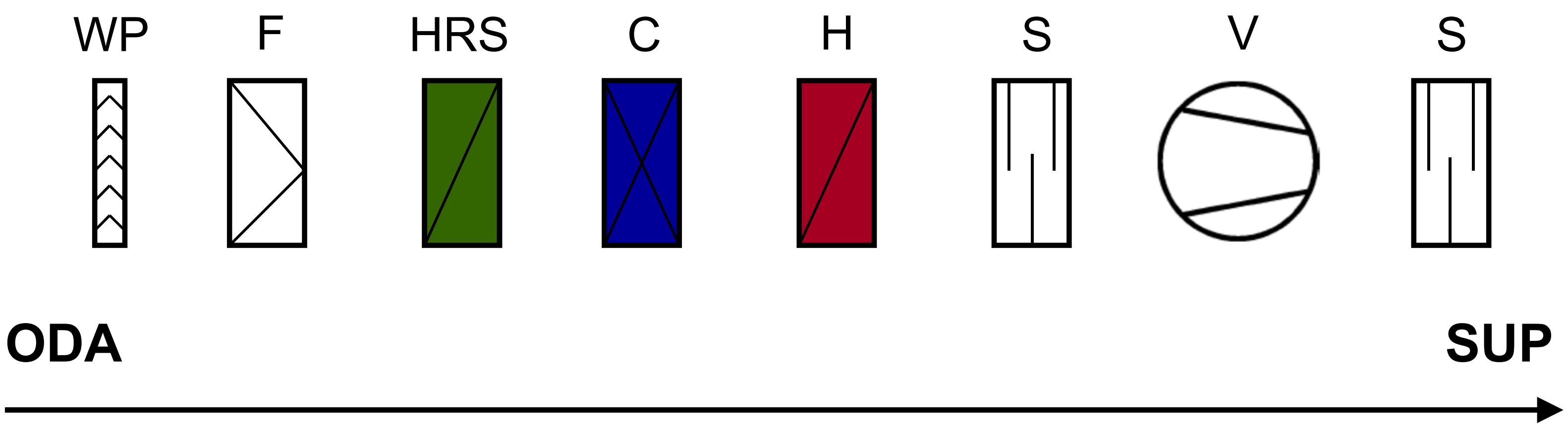
Thermodynamic air treatment

- Heating
- Cooling
- Humidification
- Dehumidification

Ventilation systems tasks:

Thermodynamic air treatment

Example of a ventilation system (supply air)



Ventilation systems tasks:

Transport of air

- fan
- motor
- drive
- control

Energy demand in ventilation systems

- Air treatment
  - heating/cooling/de-/humidification
- **Air transport**
  - **against Δp internal/external**

Power consumption

$$P_m = \dot{V} \cdot \Delta p \cdot 1 / \eta_s$$

P_m	absorbed power consumption [KW]
$\dot{V}$	air flow [m³/s]
Δp	pressure losses of the system [Pa]
η_s	system efficiency [./.]

$$\eta_S = \eta_F \cdot \eta_M \cdot \eta_D \cdot \eta_C$$

fan • motor • drive • control

AHU drives

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DIN EN 13779

Ventilation system non-residential

General requirements and measured values

specifische fan power (SFP)

$$P_{SFP} = \frac{P_{Input}}{q_V} = \frac{\Delta p_{fan}}{\eta_{total}}$$

P_{SFP}	specific fan power [W/(m³/s)]
P_{Input}	electric power consumption [W]
q_V	air flow rate [m³/s]
Δp_{fan}	total pressure [Pa]
η_{total}	system efficiency [-]

Specific Fan Power

EN 13779: 2007

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Europäisches Komitee für Normung

cate-goriy	P_{SFP} W/(m³/s)	Δp_{Fan} [Pa] η_{total} 0,55	Δp_{Fan} [Pa] η_{total} 0,65
SFP 1	≤ 500	275	325
SFP 2	≤ 750	410	485
SFP 3	≤ 1.250	685	810
SFP 4	**≤ 2.000**	1.100	1.300
SFP 5	≤ 3.000	1.650	1.950
SFP 6	≤ 4.500	2.475	2.925
SFP 7	> 4.500		

application	default value
EXH without HR	SFP 2
EXH with HR	SFP 3
SUP without HR	SFP 3
SUP full AC	SFP 4

for specific components (e. g. HEPA-Filter, HRS H1 or H2) is a use of additional SFP possible.

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Additional fan power

EN 13779: 2007

	component	add. P_{SFP} [W/(m³/s)]
1	add. filterstage	+ 300
2	HEPA filter	+ 1.000
3	gasfilter	+ 300
4	HRS class H2-H1	+ 300
5	high capacity cooler	+ 300

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Air velocity classes

EN 13053: 2012

class	velocity in m/s
V1	≤ 1,6 m/s
V2	≤ 1,8 m/s
V3	≤ 2,0 m/s
V4	≤ 2,2 m/s
V5	≤ 2,5 m/s
V6	≤ 2,8 m/s
V7	≤ 3,2 m/s
V8	≤ 3,6 m/s
V9	> 3,6 m/s

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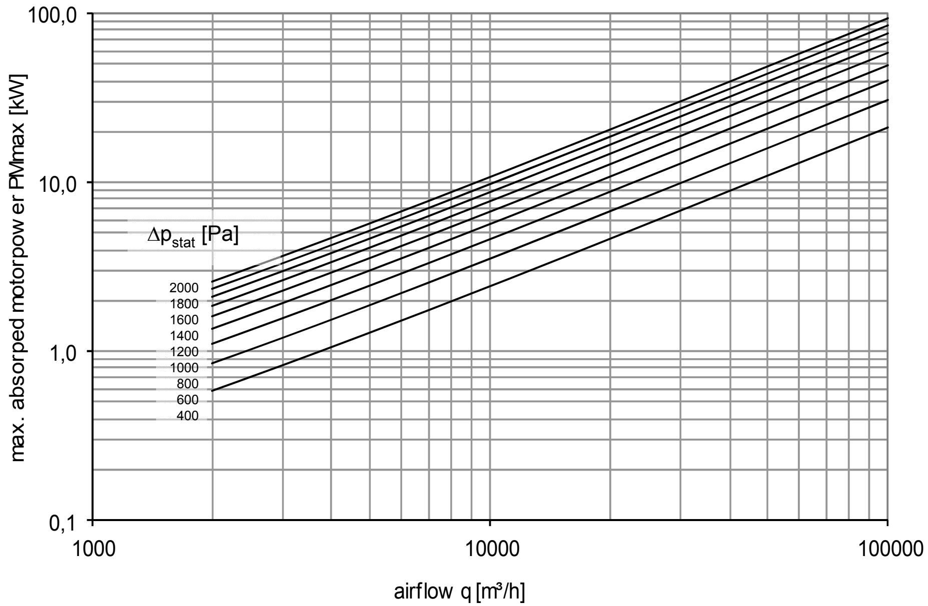
Electric power consumption fans



$P_{\text{input max}}$ (kW)

Δp_{stat} (Pa)

q_v (m^3/s)

class	equation
Base	$P_{\text{Input max}} = \left(\frac{\Delta p \text{ stat.}}{450}\right)^{0,925} \times \left(q_v + 0,08\right)^{0,95}$

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Power consumption classes

EN 13053: 2012

class	powerconsumption related to Pm_{ref}
P1	$\leq Pm_{ref} \cdot 0.85$
P2	$\leq Pm_{ref} \cdot 0.90$
P3	$\leq Pm_{ref} \cdot 0.95$
P4	$\leq Pm_{ref} \cdot 1.00$
P5	$\leq Pm_{ref} \cdot 1.06$
P6	$\leq Pm_{ref} \cdot 1.12$
P7	$> Pm_{ref} \cdot 1.12$

Energy efficiency

- reduction of components (e. g. drop eliminator)
- hybrid components (humidifier)
- bypasses in components

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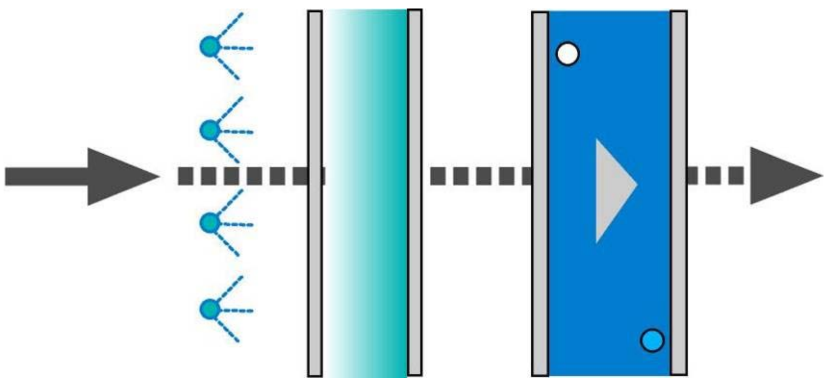
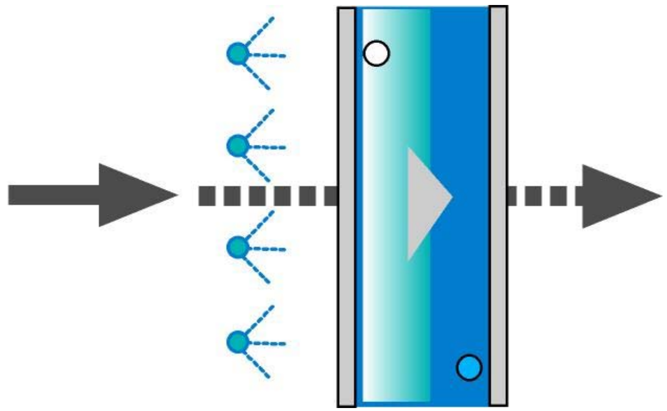
Energy efficiency

Internal pressure losses

components (example hybrid humidifier)



separate
humidifier



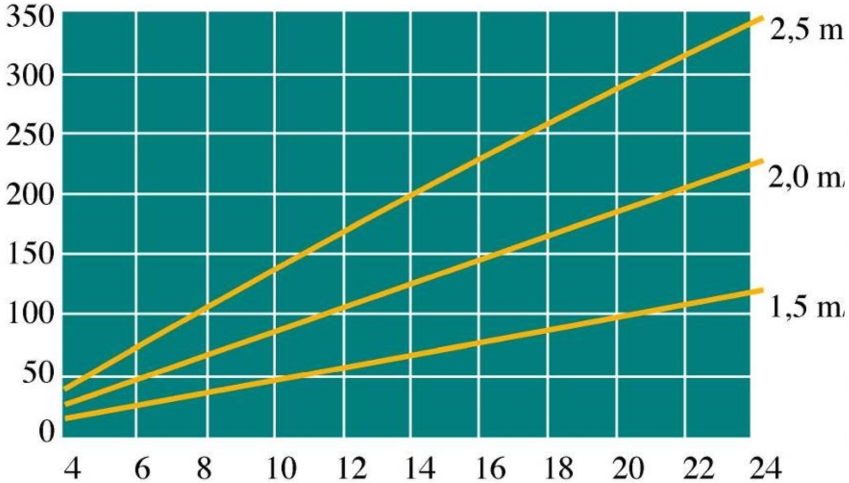
integrated
contact humidifier
(hybridsystem)

Energy efficiency

Internal pressure losses

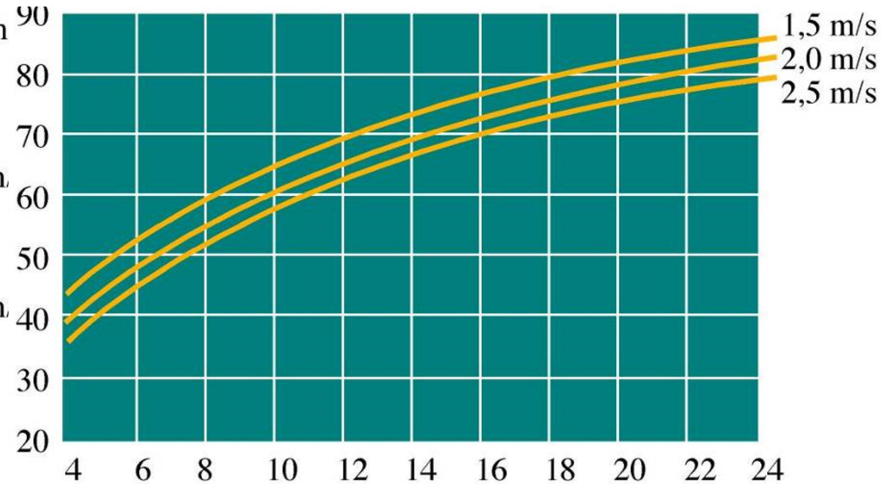
face velocity (example HRS – CC-System)

Pressure losses



number of rows

temperature efficiency

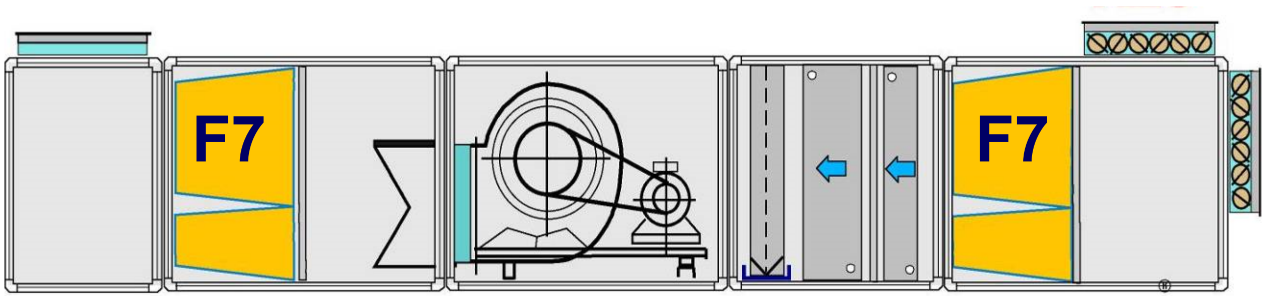


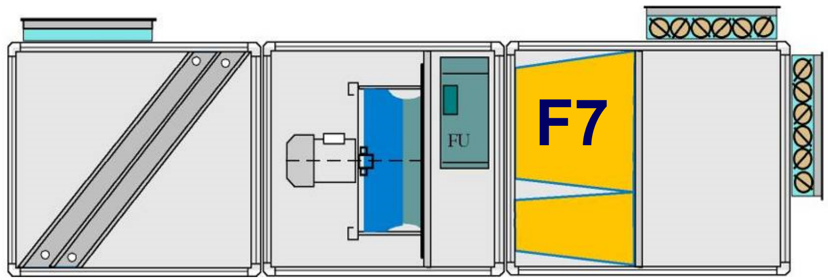
number of rows

Energy efficiency

Internal pressure losses

arrangment of components





Filter stages

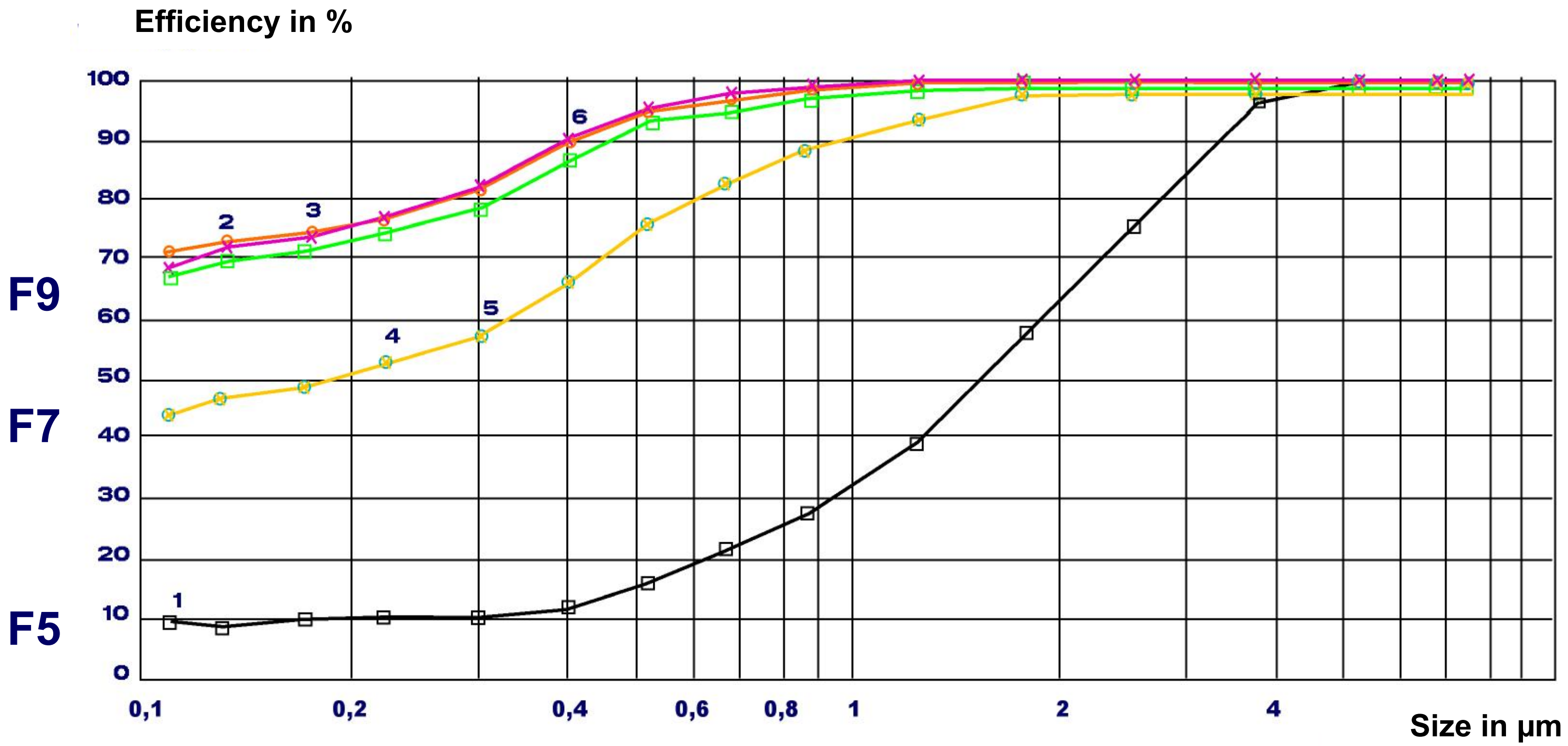
Single stage

- first stage F7 (80 %   at 1 µm)
- better protection of the AHU
- reduction of pressure losses
- reduction of AHU lenght

Two filter stages

- first stage F7 (80 %   at 1 µm)
- second stage F7 = efficiency (F5 / F9)
- reduction of pressure losses

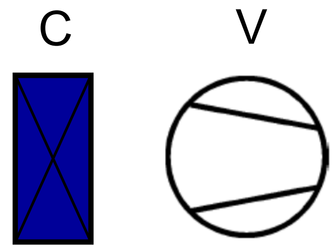
AHU components



F5 + F9	4,5 m²	F5	55 Pa	200 Pa	3.400 m³/h	450 Pa
	9,0 m²	F9	140 Pa	250 Pa	3.400 m³/h	
F7 + F7	9,0 m²	F7	95 Pa	150 Pa	3.400 m³/h	260 Pa
	9,0 m²	F7	95 Pa	110 Pa	3.400 m³/h	

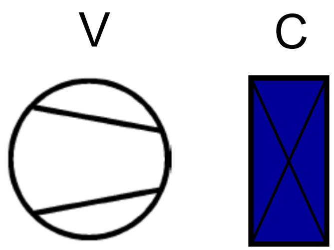
Cooler

Suction side



- use with dehumdification
- fan waste heat used to rewarm
- finspace e. g. 2,5 mm

Pressure side



- use with a „dry“ cooling
- fan waste heat before the coller
- bigger average log. temperature difference

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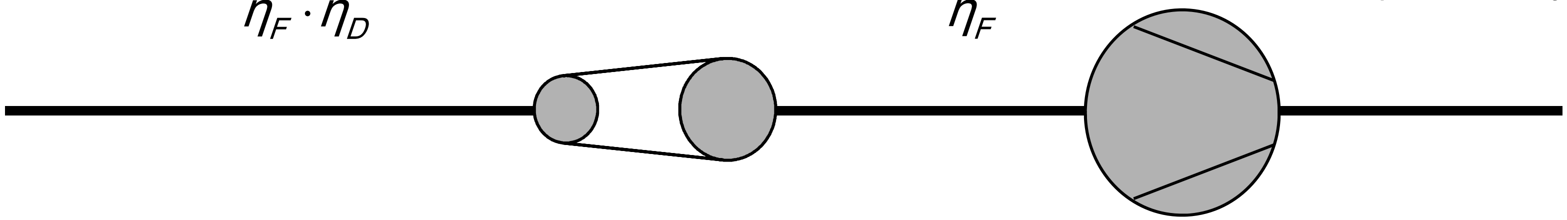
Air transport

Power

mechanical

$$P_N = \frac{\dot{V} \cdot p_t}{\eta_F \cdot \eta_D} \qquad P_K = \frac{\dot{V} \cdot p_t}{\eta_F} \qquad P_F = \dot{V} \cdot p_t$$



electrical

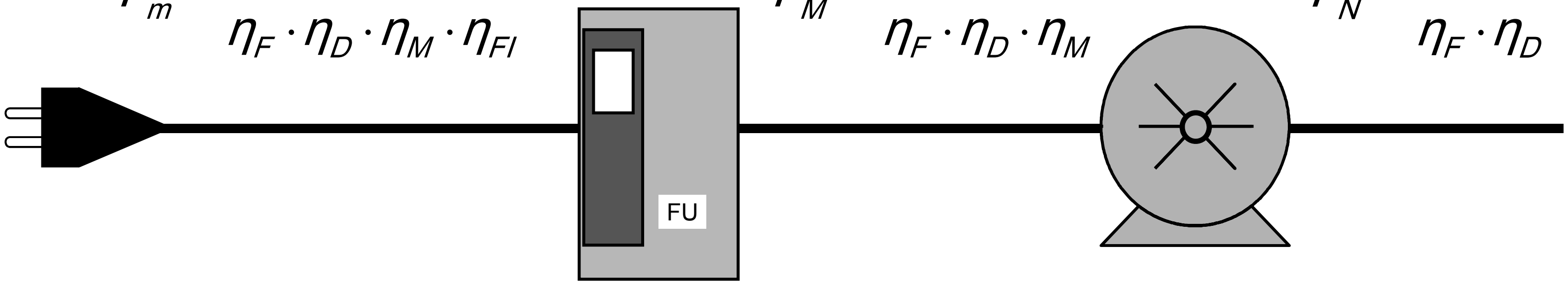
$$P_N = U \cdot I \cdot \sqrt{3} \cdot cos \quad \cdot \eta_{FI} \cdot \eta_M \qquad P_K = U \cdot I \cdot \sqrt{3} \cdot cos \quad \cdot \eta_{FI} \cdot \eta_M \cdot \eta_D \qquad P_V = U \cdot I \cdot \sqrt{3} \cdot cos \quad \cdot \eta_{FI} \cdot \eta_M \cdot \eta_D \cdot \eta_F$$

Air transport

Power

mechanical

$$P_m = \frac{\dot{V} \cdot p_t}{\eta_F \cdot \eta_D \cdot \eta_M \cdot \eta_{FI}} \qquad P_M = \frac{\dot{V} \cdot p_t}{\eta_F \cdot \eta_D \cdot \eta_M} \qquad P_N = \frac{\dot{V} \cdot p_t}{\eta_F \cdot \eta_D}$$



electrical

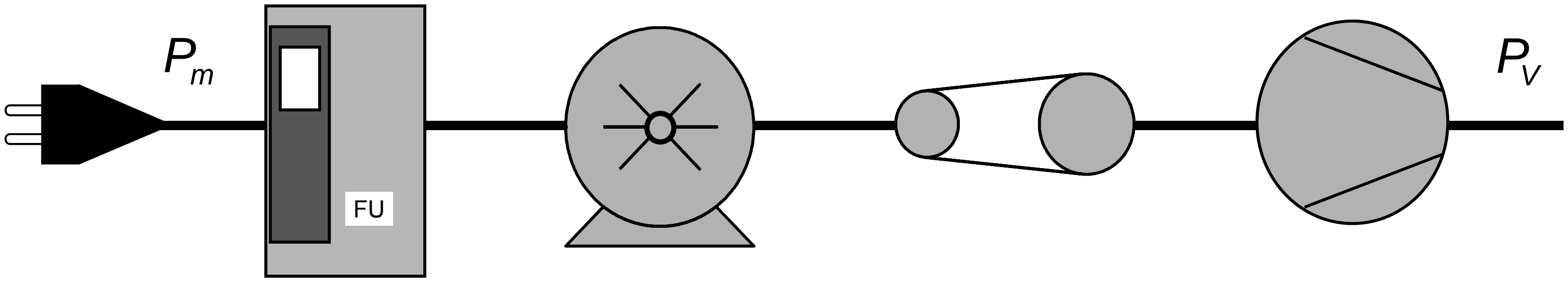
Motor:

$$P_m = U \cdot I \cdot \sqrt{3} \cdot \cos \qquad P_M = U \cdot I \cdot \sqrt{3} \cdot cos \quad \cdot \eta_{FI} \qquad P_N = U \cdot I \cdot \sqrt{3} \cdot cos \quad \cdot \eta_{FI} \cdot \eta_M$$

Air transport

Power

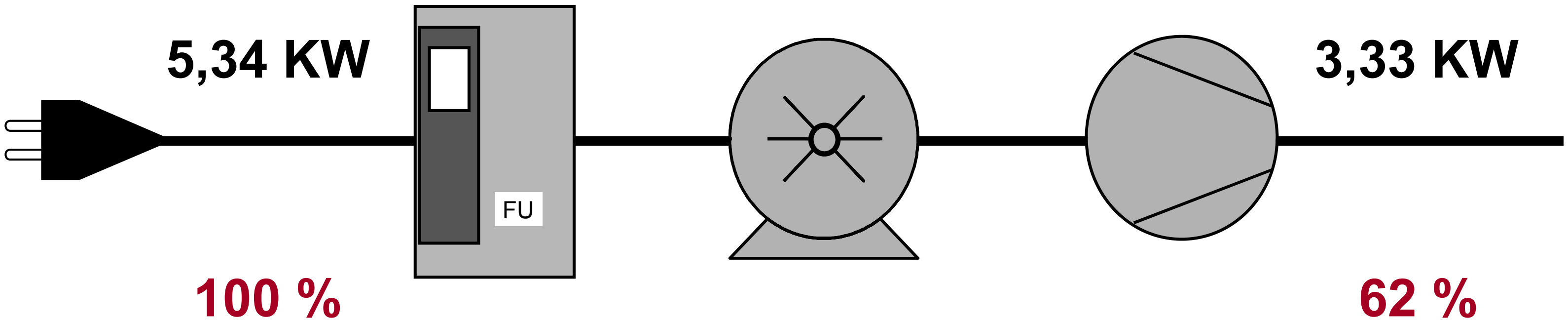
Systemefficiency η_{Syst}



$$\eta_{FI} \cdot \eta_M \cdot \eta_F \cdot \eta_D = \frac{P_V}{P_m} = \eta_{Syst}$$

Air transport

Example:



Air transport

Fan

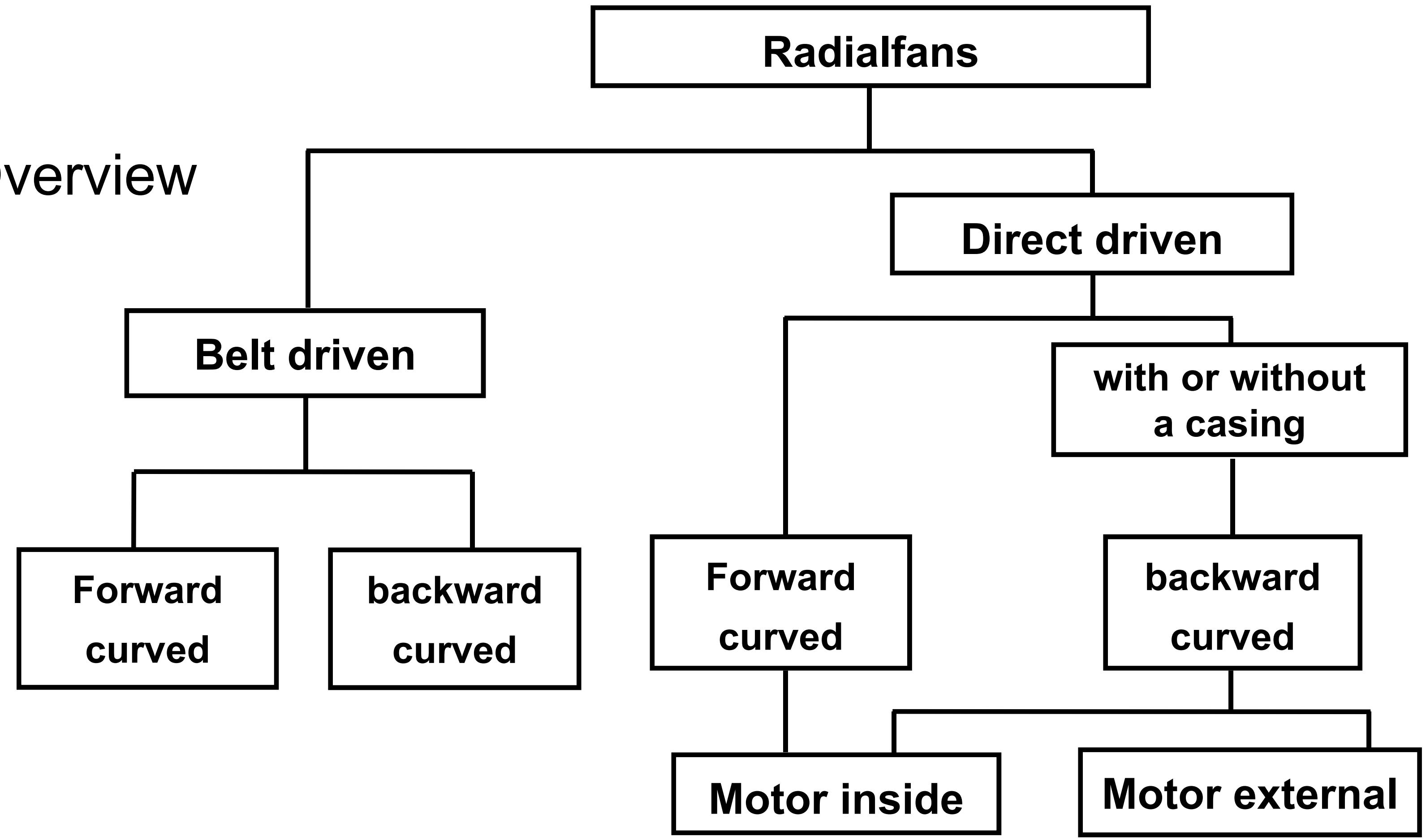
Types

Axial with or without a casing	Radial with a casing	Radial without a casing
		

Air transport

Fan

Overview

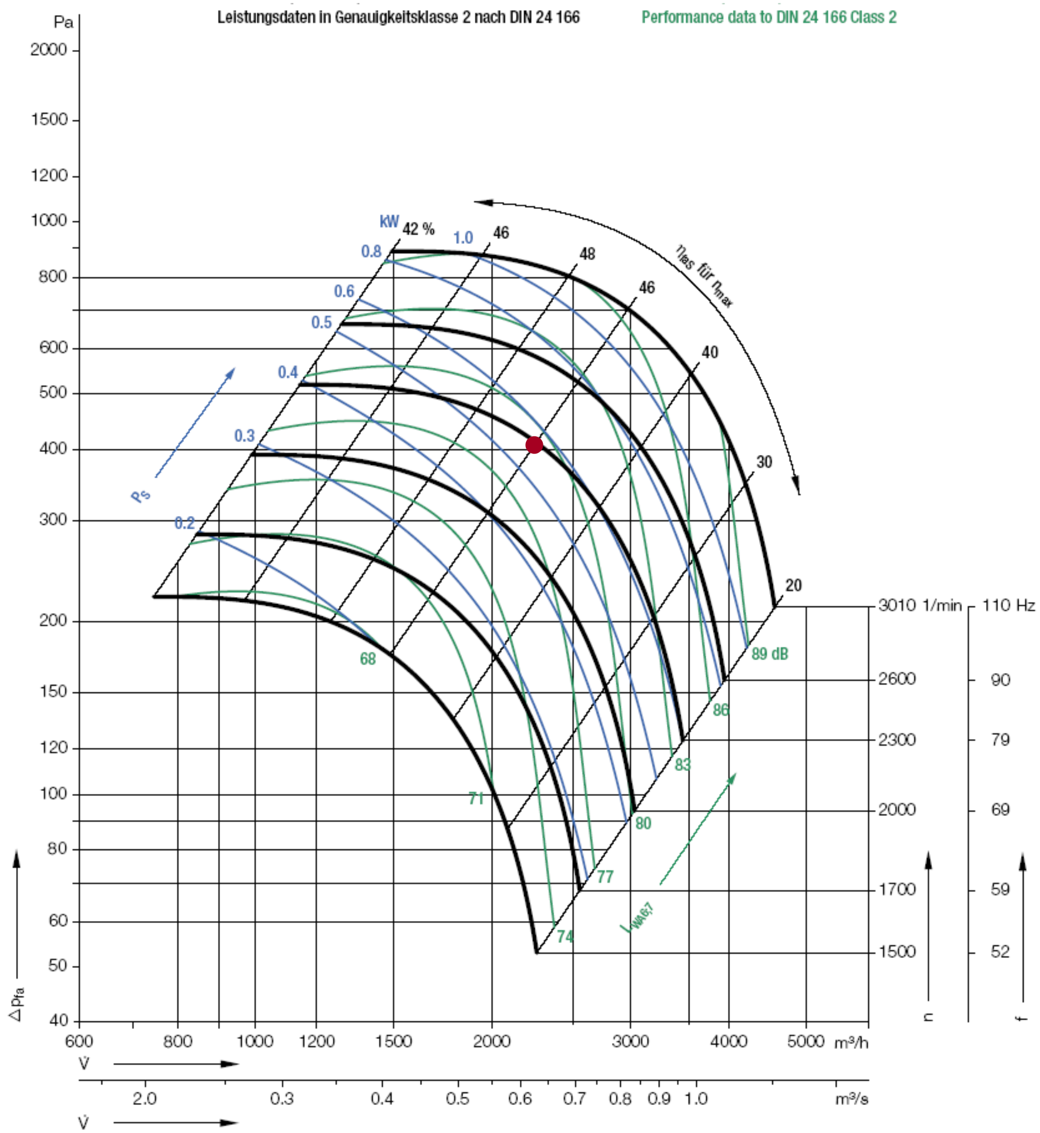


Air transport

Fan

Selection

characteristics



Fan concepts

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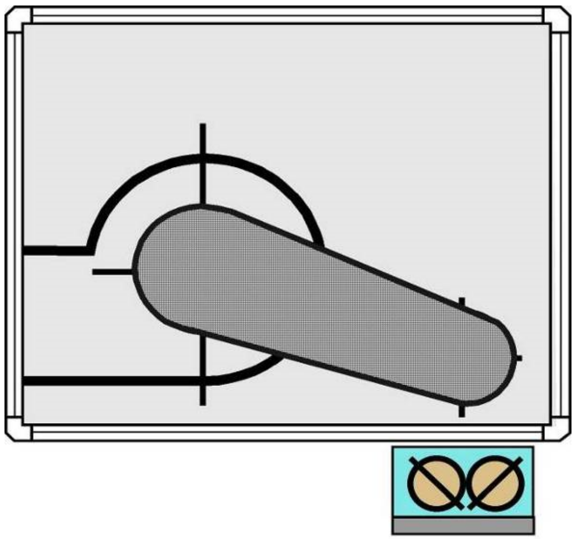
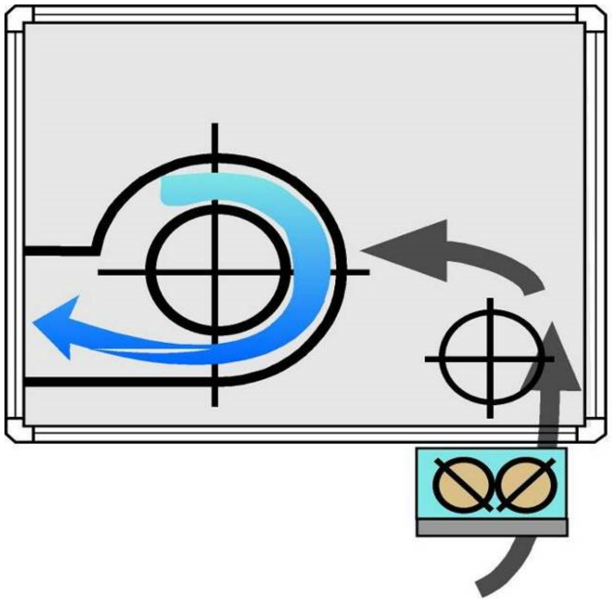
Energy efficiency

Internal pressure losses

inlet losses (example fan with a spiral housing)

$$\sum \Delta p_{EV} = 1{,}5 - 4{,}5 \cdot p_{dyn}$$



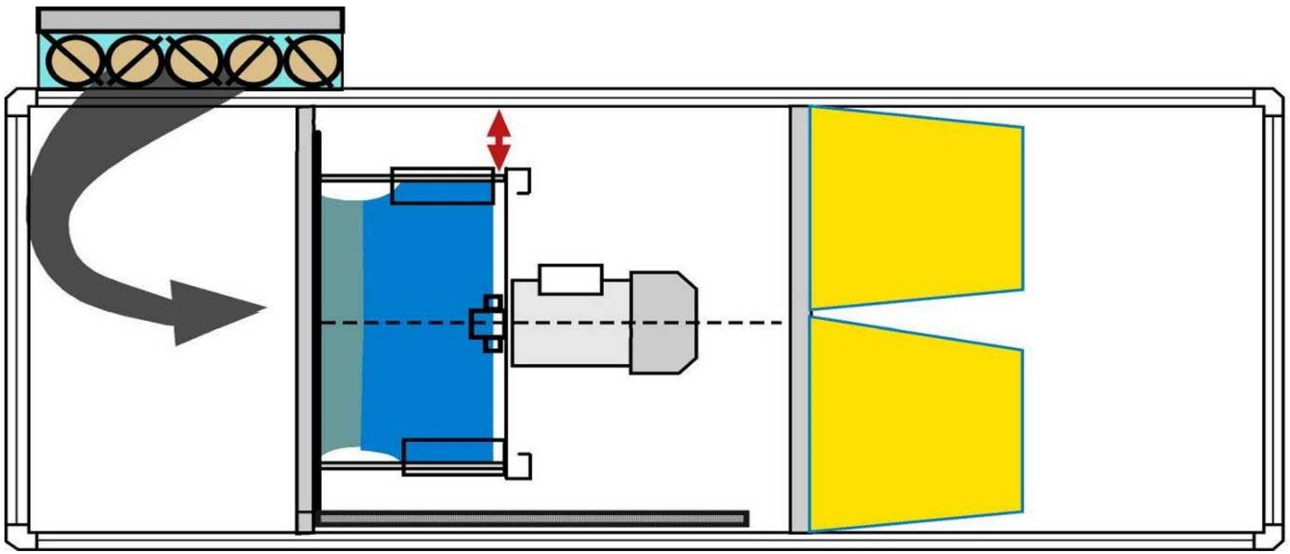


Energy efficiency

Internal pressure losses

inlet losses (example plugged fan without a housing)

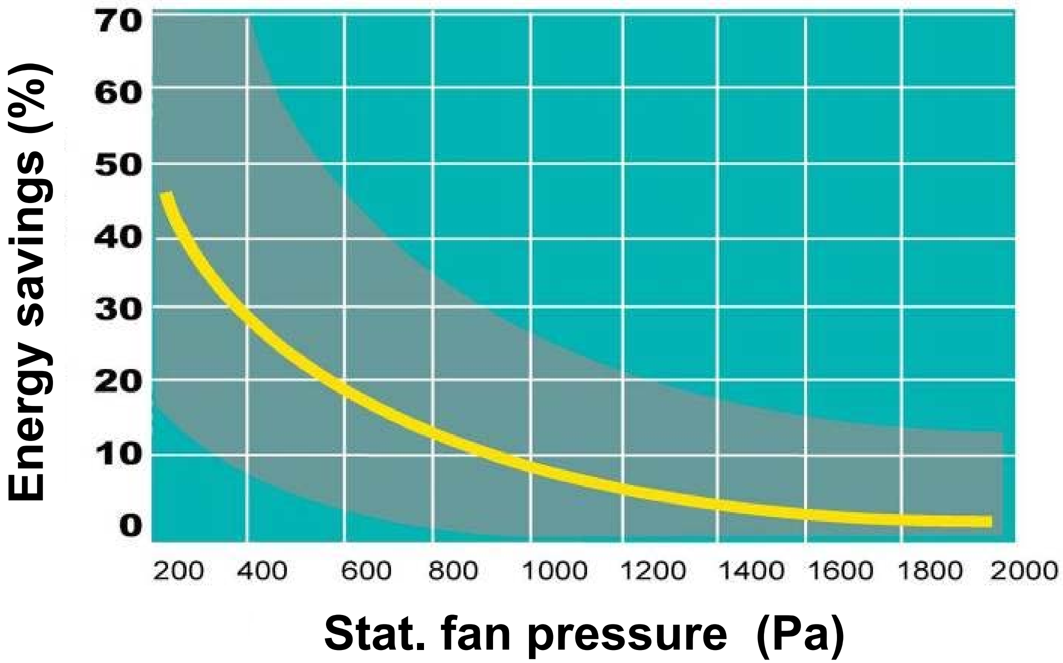
$$\sum \Delta p_{EV} = 0,5 - 1,5 \cdot p_{dyn}$$



Energy efficiency

Internal pressure losses

potential of plugged fans compared to spiral fans



Energy efficiency

Internal pressure losses

guide vane at a axial inlet situation

efficiency ▲ turbulence ▼

DE 101 21 940

Air transport

Internal pressure losses

practice:

10.000 m³/h transported in a AHU against
a stat. pressure of p_{stat} =1.171 Pa

given: η_{Vt} = 80,5 %; belt drive
impeller diameter D = 400 mm
outlet area 501• 501 mm

η_M = 88,3 %

η_B = 94,0 %

$\sum \Delta p_{EV}$ = 3,0 • p_{dyn}

asked: motor power P_N

Air transport

Internal pressure losses

solution:

$A_R = 0{,}501 \cdot 0{,}501 = 0{,}251\ m^2$

$w_{fan\ outlet} = 10.000 / 3.600 / A_R = 11{,}07\ m/s$

$p_{dyn} = \rho / 2 \cdot w^2 = 0{,}6 \cdot 11{,}07^2 = 74\ Pa$

$\Delta p_{EV} = 3 \cdot 74 = 222\ Pa$

$p_t = p_{stat} + \Delta p_{EV} = 1.171 + 222 = 1.393\ Pa$

$P_N = \dot{V} \cdot p_t / (\eta_{Vt} \cdot \eta_K) = 10.000 / 3.600 \cdot 1.393 / (0{,}805 \cdot 0{,}94)$

$= 5{,}113\ KW$

Air transport

Power

given:

10.000 m³/h in a AHU against a pressure drop of
p_t =1.200 Pa.

η_{Ffa} = 71,0 %; direct driven
Impeller diameter D = 630 mm
Impeller width b = 201 mm

η_M = 88,3 %

η_{Fl} = 97,0 %

calculate:

Motorpower	P_N
Systemeff.	$\eta_{Syst.}$
absorpt motor power	P_m

Air transport

Power

solution:

$A_R = D \cdot \pi \cdot b$ = 0,3978 m²

$w_{Impeller}$ = 10.000 / 3.600 / A_R = 6,98 m/s

$p_{dyn} = \rho / 2 \cdot w^2$ = 0,6 • 6,98² = 29 Pa

p_{stat} = 1.200 - 29 = 1.171 Pa

$P_N = \dot{V} \cdot p_{stat} / \eta_{fa}$ = 4,581 KW ; choosen motor 5,5 KW

$\eta_t = \dot{V} \cdot p_t / P_N$ = 72,8 %

$\eta_{Syst.} = \eta_M \cdot \eta_t \cdot \eta_{FI}$ = 0,883 • 0,728 • 0,97 = 62,4 %

$P_m = p \cdot \dot{V} / \eta_{Syst.}$ = 1.200 • 10.000 / 3.600 / 0,624 = 5,342 KW

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Air transport

Internal pressure losses

solution:

$A_R = D \cdot \pi \cdot b$ = 0,3978 m²

$W_{fan\ outlet}$ = 10.000 / 3.600 / A_R = 6,98 m/s

$p_{dyn} = \rho / 2 \cdot w^2$ = 0,6 • 6,98² = 29 Pa

p_{stat} = 1.200 - 29 = 1.171 Pa

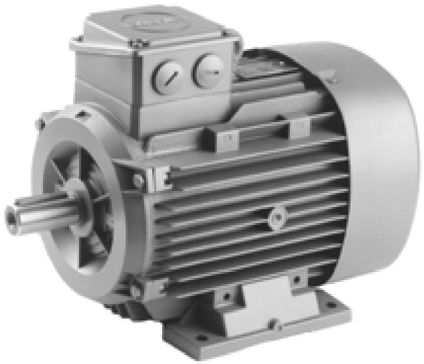
$P_N = \dot{V} \cdot p_{stat} / \eta_{fa}$ = 4,581 KW

choosen motor 5,5 KW

Air transport

Motor

Types

AC	EC	PM
Rotary current with 3 phases alternating current	electric commutaded continuous current	permanent magnet Motor
		

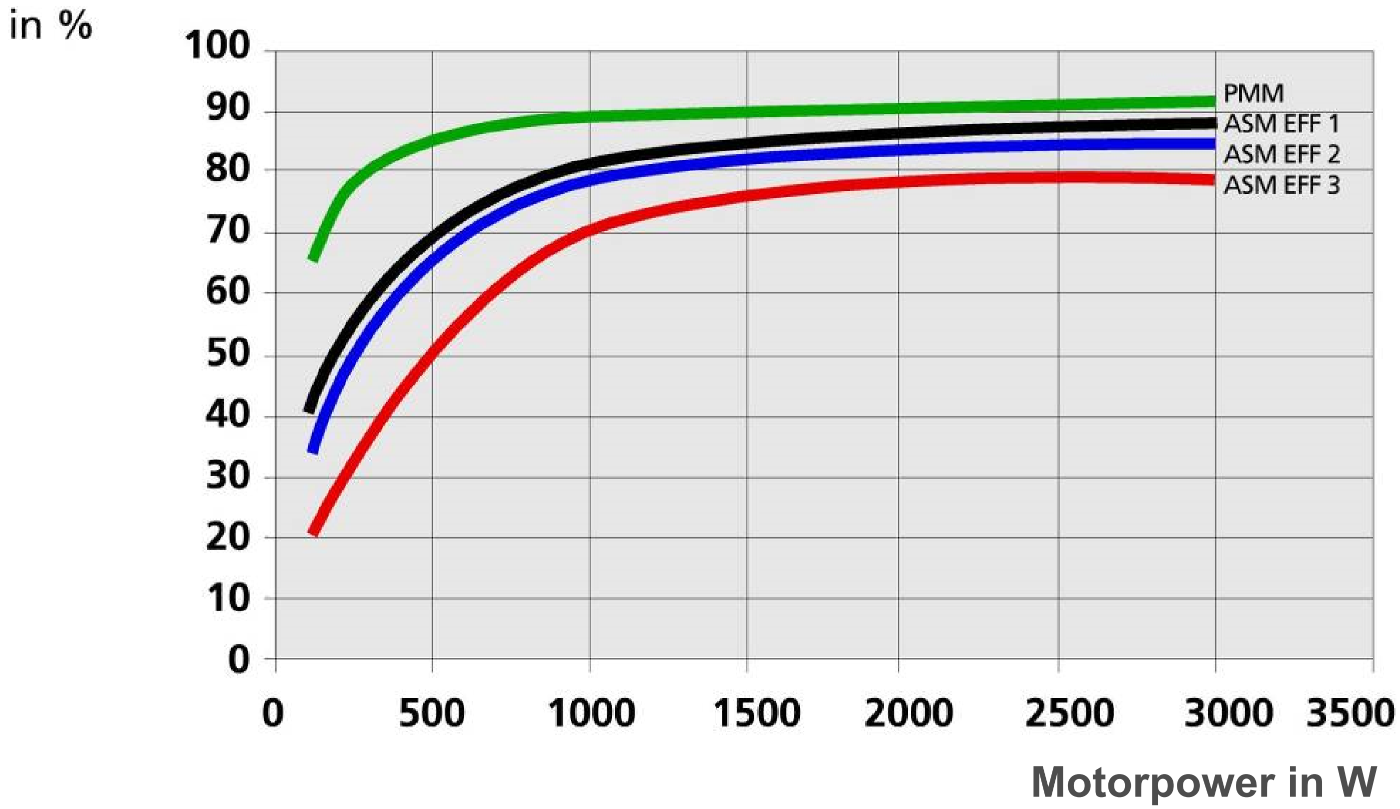
Air transport

Motor

Efficiencies (example n = 1.500 1/min)

Power	IE2	IE3
1,1 KW	77,0 %	84,0 %
2,2 KW	82,0 %	86,5 %
4,0 KW	85,0 %	88,5 %
7,5 KW	87,0 %	90,3 %
55,0 KW	93,5 %	95,1 %

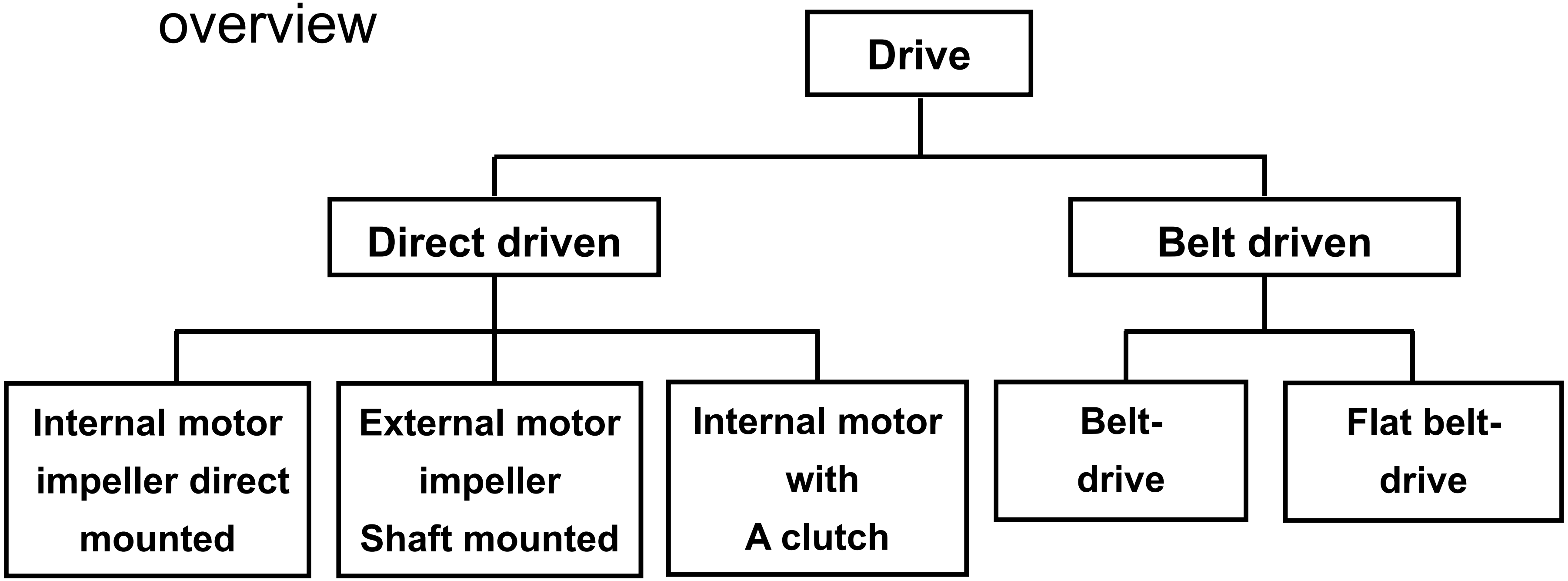
Motors


in %
100
90
80
70
60
50
40
30
20
10
0
0
500
1000
1500
2000
2500
3000
3500
PMM
ASM EFF 1
ASM EFF 2
ASM EFF 3
Motorpower in W

Air transport

Drive

Coupling fan / motor
overview



Air transport

Drive

Coupling fan / motor

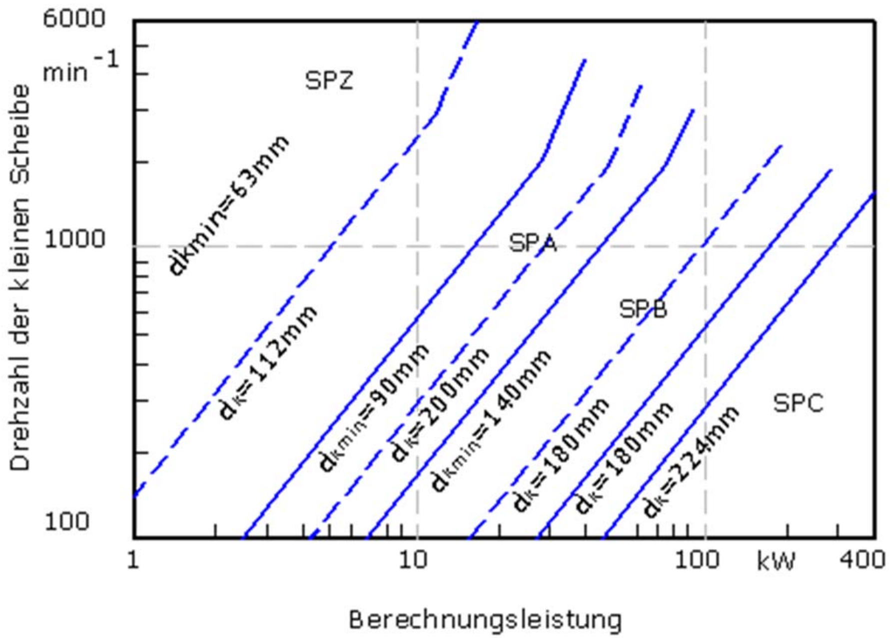
indirect
via belt
(standard or flat belt)

direct

Air transport

Drive

Coupling fan / motor



Waste power:

standard belt
3 – 12 %

flat belt
2 – 4 %

Air transport

Control

Air flow

speed control
e. g. via
frequency inverter

power losses:

3 – 5 %

pressure control
e. g. via
dampers

Energy efficiency

Proportional law

Air flow
$$\frac{\dot{V}_2}{\dot{V}_1} = \frac{n_2}{n_1}$$

Pressure
$$\left(\frac{\dot{V}_2}{\dot{V}_1}\right)^2 = \frac{\Delta p_2}{\Delta p_1}$$

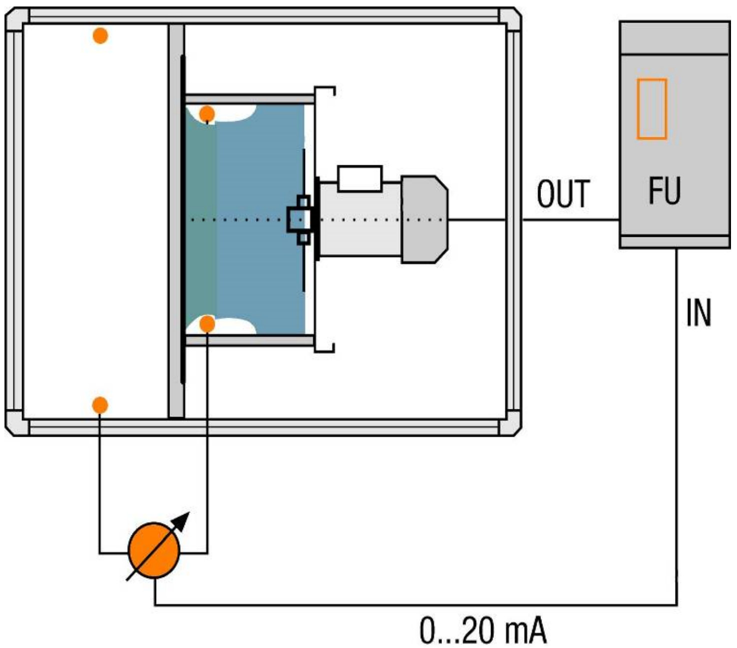
Power consumption
$$\left(\frac{\dot{V}_1}{\dot{V}_2}\right)^3 = \frac{P_1}{P_2}$$

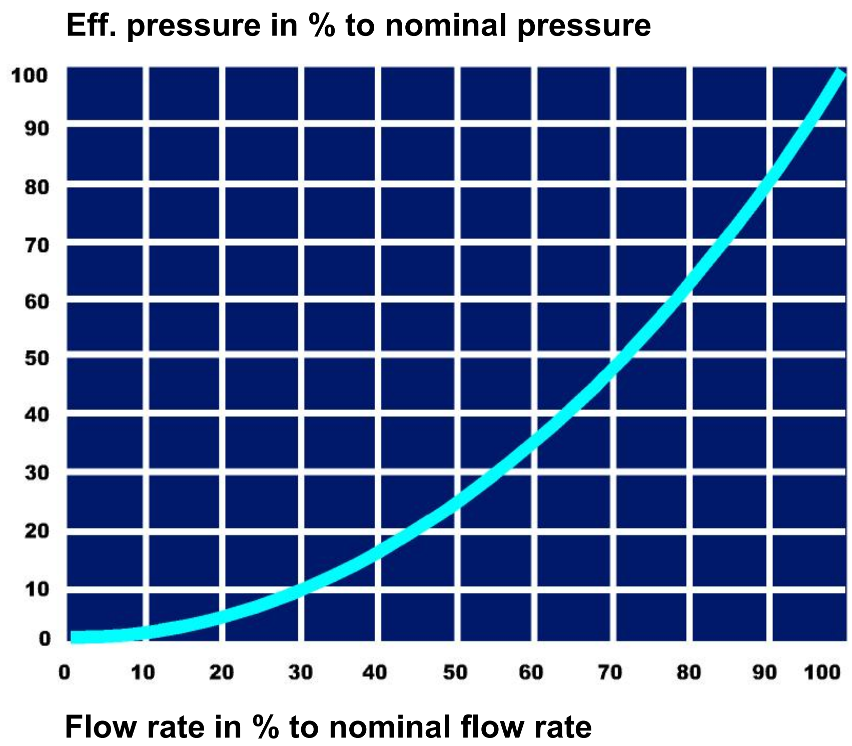
Energy efficiency

Air flow rate-measuring device

effective pressure to air flow

$$\dot{V} = \alpha \cdot \varepsilon \cdot \frac{d^2 \cdot \pi}{4} \cdot \sqrt{\frac{2 \cdot \Delta p}{\rho}}$$





Energy efficiency

Proportional law

given:

$\dot{V}_1$ = 10.000 m³/h transported with a air handling unit against
p_{t1} = 1.200 Pa with a speed of n_1 = 1.783 min^{-1}.
The absorbed motor power is Pm_1 = 5,7 KW.

calculate: Parameter p_{t2}, n_2, Pm_2
at a reduced air flow of 80%

($\dot{V}_2$ = 8.000 m³ / h).

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Energy efficieny

Proportional law

solution:

$$n_2 = (\dot{V}_2 / \dot{V}_1) \cdot n_1 = (8.000 / 10.000) \cdot 1.783 = \underline{1.426\ min^{-1}}$$

(-20,0%)

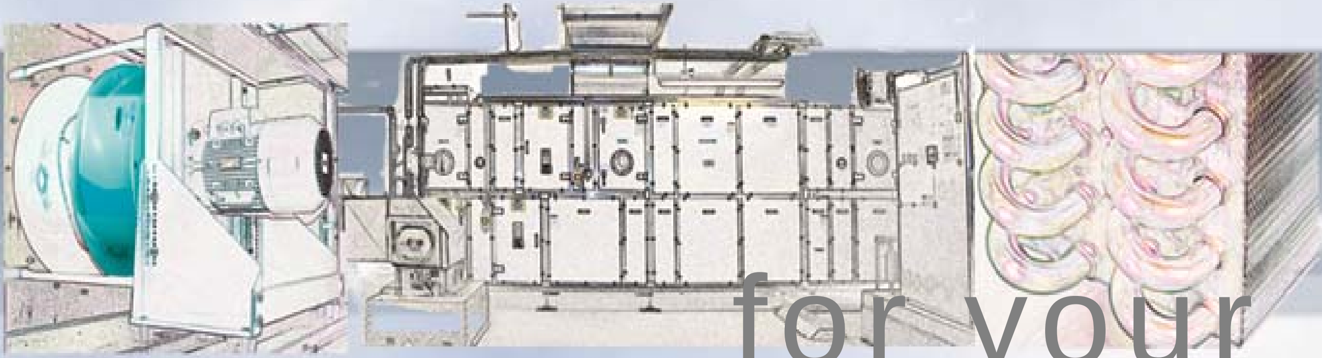
$$p_{t2} = (\dot{V}_2 / \dot{V}_1)^2 \cdot p_{t1} = (8.000 / 10.000)^2 \cdot 1.200 = \underline{768\ \ Pa}$$

(-36,0%)

$$P_2 = (\dot{V}_2 / \dot{V}_1)^3 \cdot P_1 = (8.000 / 10.000)^3 \cdot 5,7 = \underline{2,92\ \ KW}$$

(-48,8%)

Thank you



for your

Attention

Ventilation
energy efficiency of fans and drives

Energy recovery and energy efficiency in ventilation technology

Prof. Dr.-Ing. **Christoph Kaup**
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