

ENGINEERING
TOMORROW

Drives Solutions for **Energy Efficient Buildings**

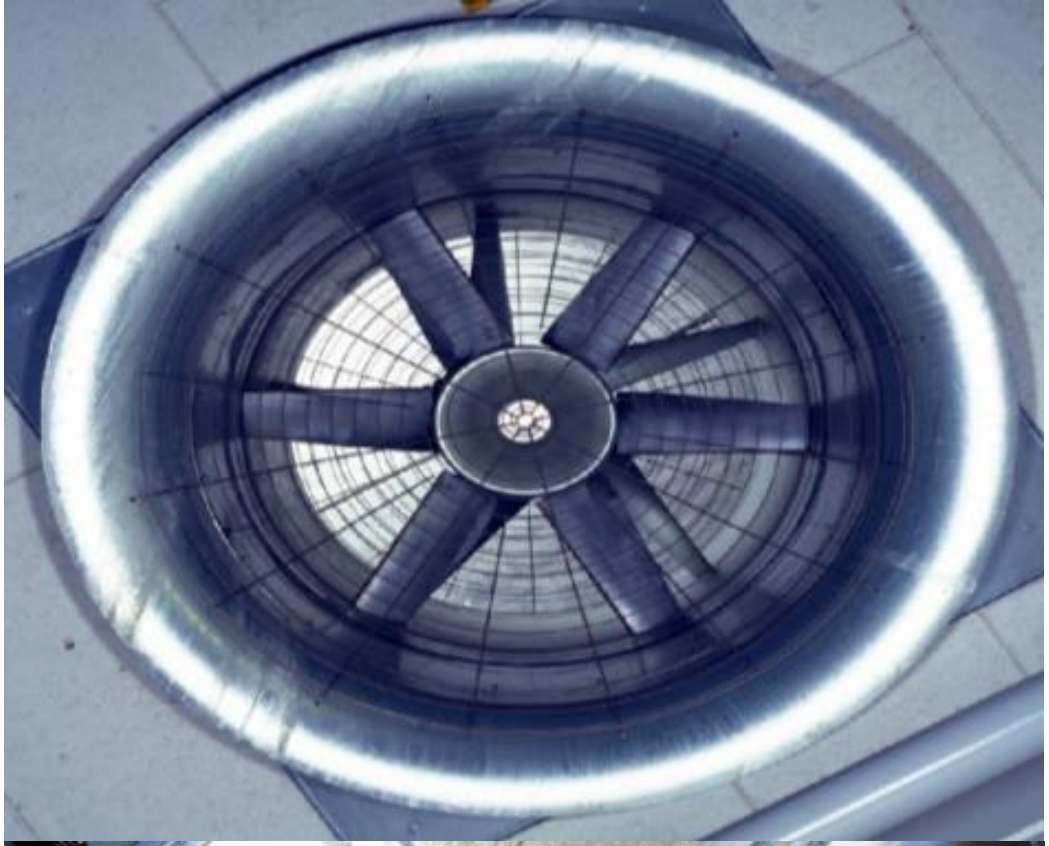
Jesper Therbo, Global Director HVAC, Danfoss Drives

www.danfoss.com



Content

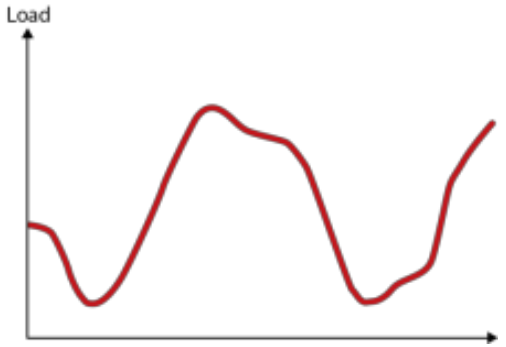
- Why VSDs in HVAC systems
- New Motor Technologies
- Motor Efficiency Classes
- European Ecodesign Standards
- Ventilation System Efficiency
- VSDs on Screw Chillers
- Heat Management on VSDs
- Consultant Specification





Why to use VSD's in HVAC

The considerable daily load variation in HVAC facilities makes it economical and attractive to install VSD's on more or less all rotating equipment such as pumps and fans.



The benefits obtain are typically:

- Better Air quality and indoor comfort
- Substantial Energy Savings
- Better asset protection
- Less maintenance cost
- Higher plant reliability/performance



VSD's energy saving possibilities within HVAC

Control your pump & fans

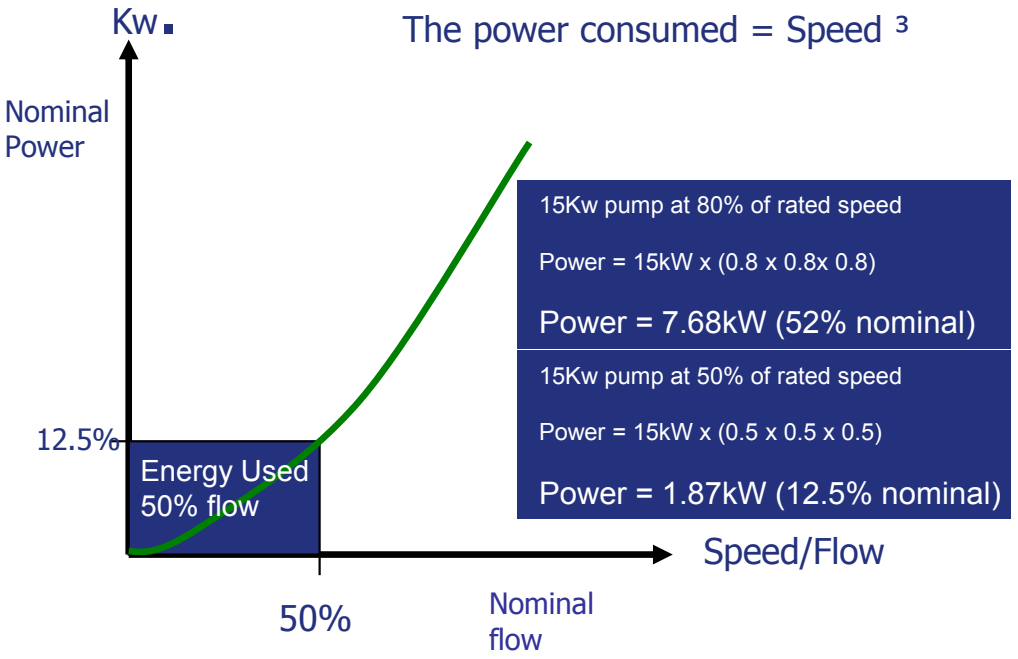
- Obtain 20-60% energy saving
- Just 20% reduction in pump / fan speed can offer ~ 45% energy savings

The Affinity Laws:

$$\frac{Q_1}{Q_2} = \frac{n_1}{n_2} \qquad \frac{H_1}{H_2} = \left(\frac{n_1}{n_2}\right)^2 \qquad \frac{P_1}{P_2} = \left(\frac{n_1}{n_2}\right)^3$$

The Cube Law

The power consumed = Speed ^{3}



New Motor Technologies

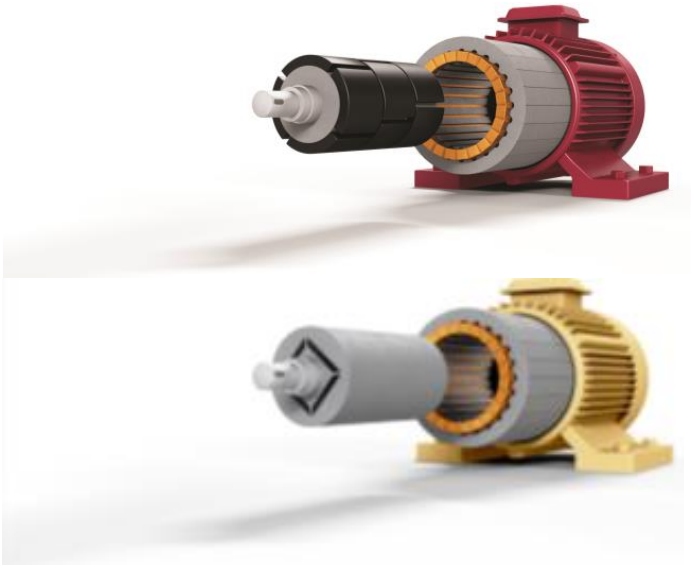


Motivation for new motor technology

- Ecodesign Directive for Energy related Products (ErP): reduce CO_2 emission by 20% from 2005 to 2020. EN 50598
- NEMA Premium labeling: prevent~ 80 million metric tons of CO_2 emission over next 10 years
- International Minimum Efficiency Performance Standards (MEPS). IEC 60034-30-1 and NEMA MG1
- Classic ASM is reaching its limit within cost-effective energy efficiency – other technologies are emerging/ maturing
- Pull from the market

Permanent Magnet motor (PM)

- basics



- Rotor has rare earth magnets that create constant magnetic field. The design is either SPM (non-salient) or IPM (salient) types
- Stator has windings and produce rotating magnetic field, similar to ASM
- At synchronous speed the rotor poles lock to the rotating magnetic field, no slip (requires a frequency converter)
- No rotor loss, low stator resistance
- SPM has a higher power factor than IPM and is easier to control but each type its own benefits

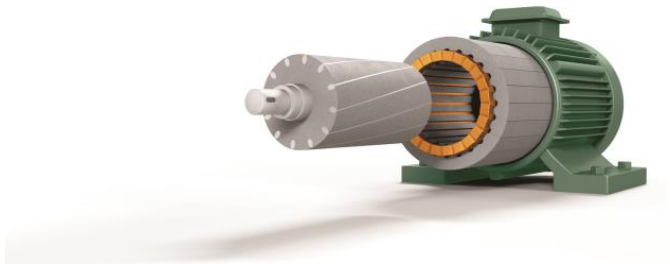
- New parameters
  - Multi-poles
  - Back-EMF
  - Saliency (Ld/Lq Inductance)

Permanent Magnet motor (PM)
- highlights





Reference motor: ASM



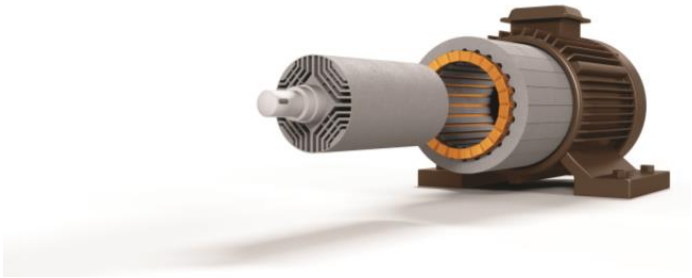
- **Highly energy efficient, also in part-load**
- High dynamics (close to servo)
- High torque capability
- Multipoles available (ideal for gearless)
- Compact/ lower weight/ high power density
- Easy retrofit (IEC enclosure available)
- Easily available, many manufacturers, competitive price, IE4 full range very popular in Europe

Be aware of

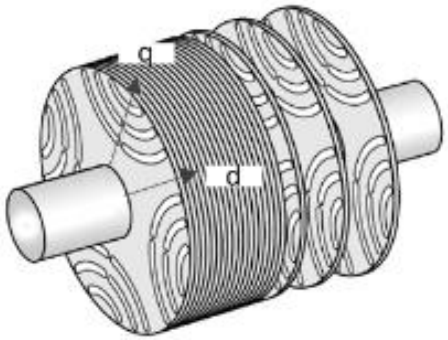
- Back-EMF!
- Efficiency drops in field weakening. IPM is better than SPM in high-speed applications
- Risk of de-magnetization (temperature) (SPM)
- Repair of bearings requires special tools
- History of price sensitivity
- Dimensioning of the frequency converter

Synchronous Reluctance motor (SynRM)

- basics

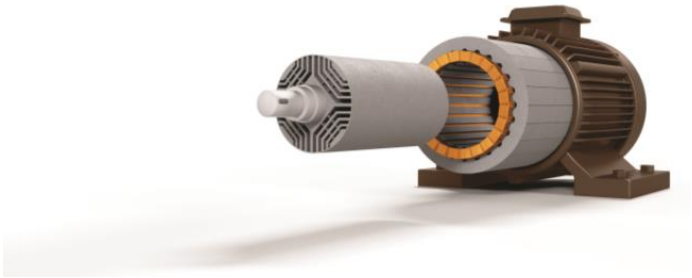


- Principle of magnetic reluctance
- Rotor is built-up from laminated disks with an optimal design for saliency
- Stator has windings and produce rotating magnetic field, similar to ASM and PM
- Torque is produced as the rotor attempts to align itself in a position with the lowest reluctance. The strength of the produced torque is directly related to the saliency ratio
- No slip (requires a frequency converter)
- No rotor loss but poor cos(ϕ)



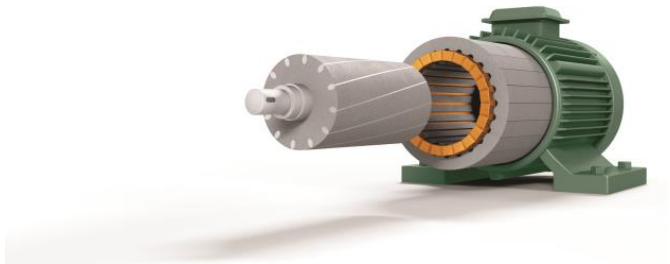
- New parameters
  - Saliency (Ld/Lq Inductance)
  - 'Saturated' inductance (Ld & Lq)
  - Ld saturation point

Synchronous Reluctance motor (SynRM)
- highlights



- **New trend**
- Highly energy efficient, also in part-load, close to PM performance
- Can produce 20-40% higher torque than same motor size ASM
- Overload capacity up to 5 times nominal load
- Good field-weakening performance ~ ASM
- Lower weight (heavier than PM)
- Easy retrofit (IEC enclosure)
- Easily available in some markets only, competitive price, IE4 full range popular in Europe
- Very robust motor design, high reliability
- Cold motor shaft

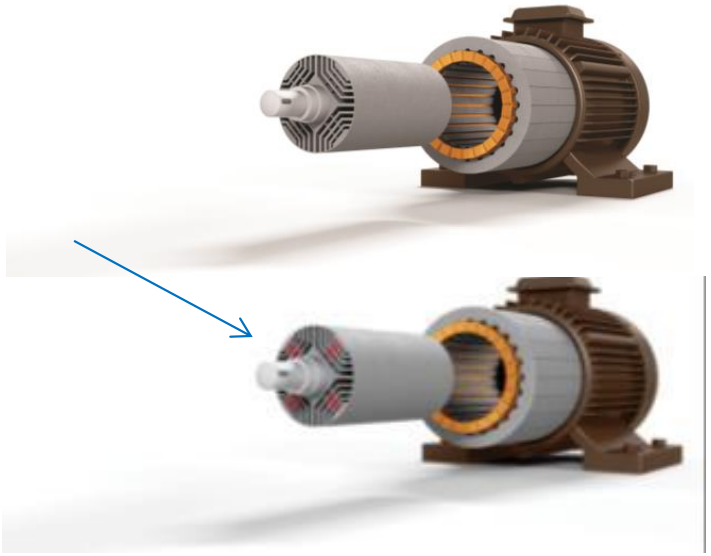
Reference motor: ASM



Be aware of
- Cos(ϕ) for SynRM is not good – often needs over-sizing of frequency converter
- Max 6 poles

PM assisted SynRM (PMaSynRM)

- basics and highlights



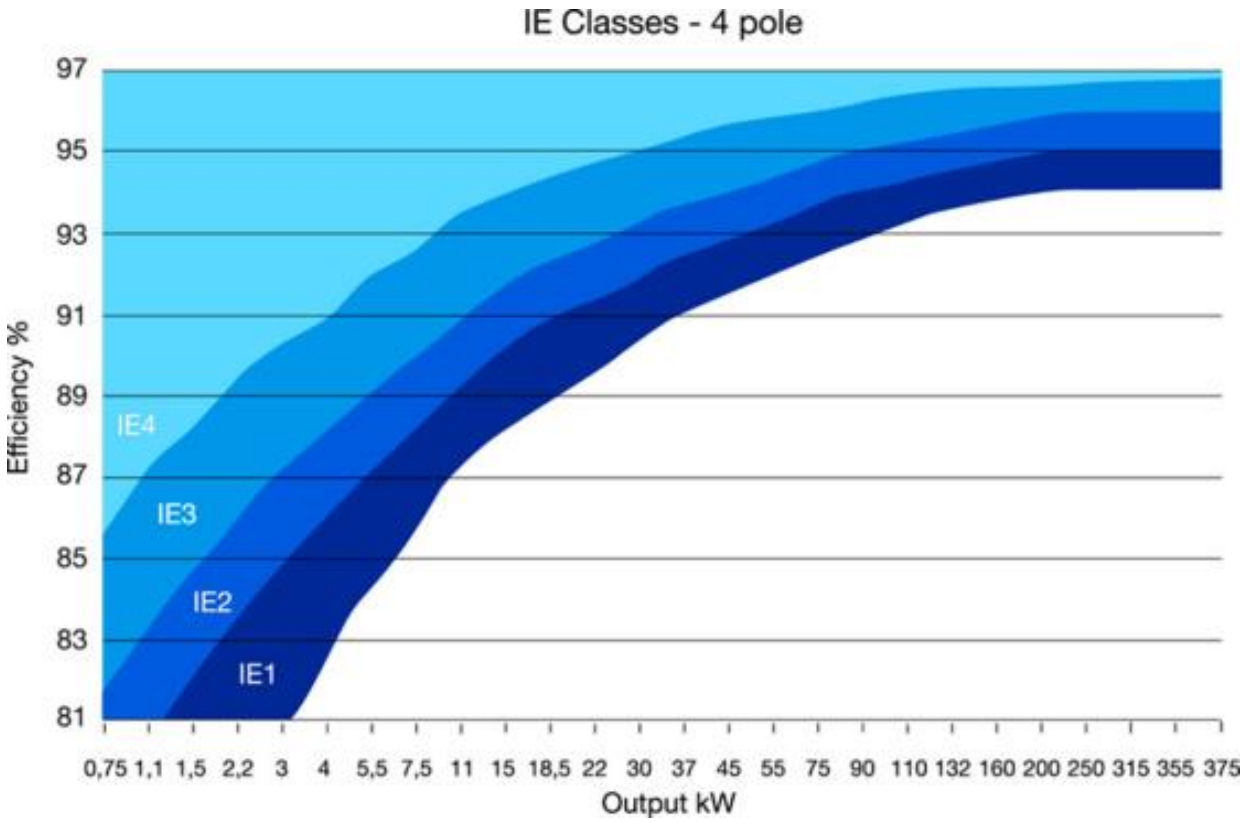
- **Next step**
- Combines the best of PM and SynRM
  - Principle of magnetic reluctance
  - Magnets introduced to improve cos(ϕ) and avoid over-sizing of drive
  - No rare earth magnets (ferrite instead)

- **IE5 Energy efficiency classes expected**

Motor Energy Efficiency Classes

IE class defined in the IEC60034-30 and IEC 60034-31

- IE efficiency classes for 50 Hz 4-pole motors

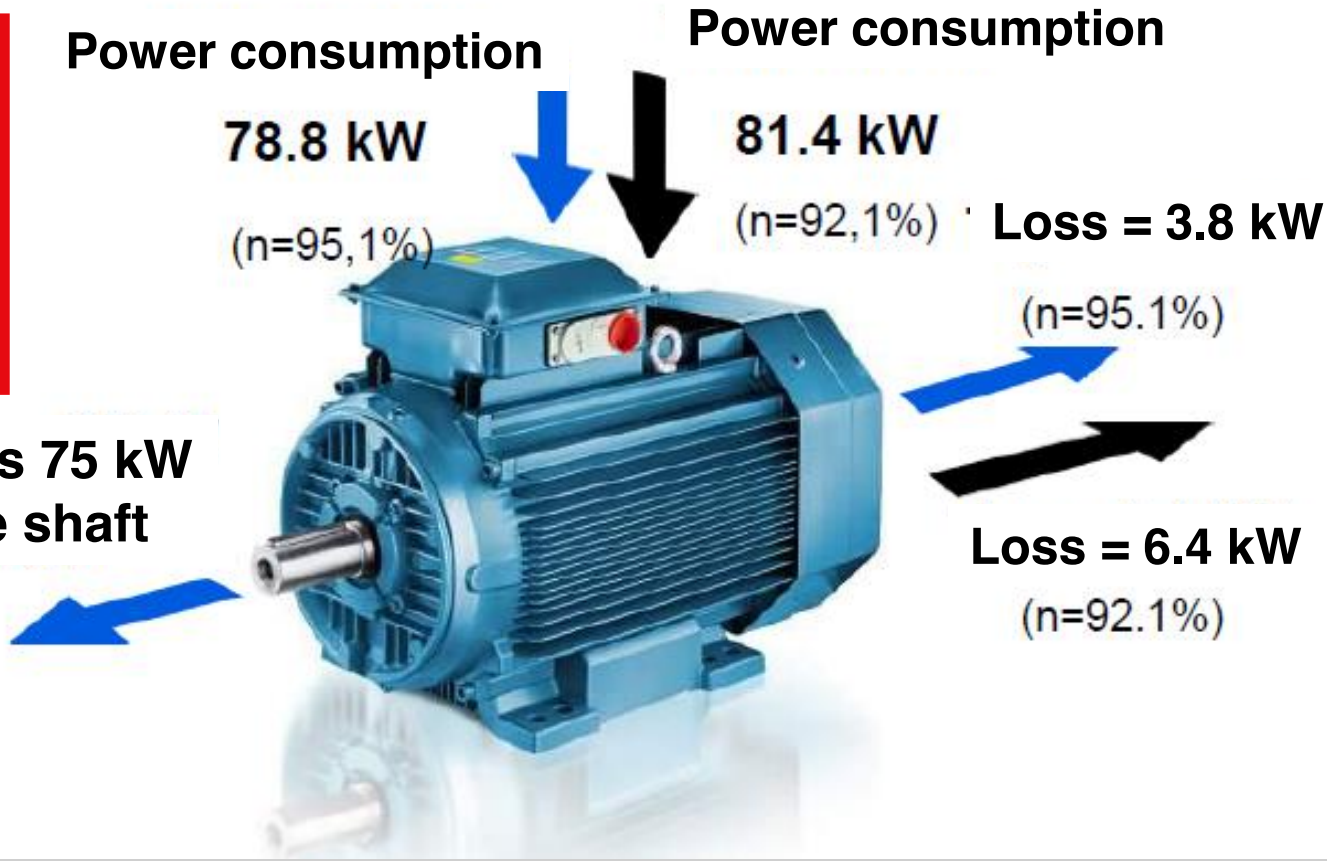


Note!
IE4 level for asynchronous and synchronous motors defined by IEC 60034-31: 2010 Technical specification

Why choose high efficiency?

40%

3% p.t. improved efficiency reduces losses by 40%



3% p.t. improved efficiency reduces losses by 40%

Approx. 22 MWh = 2000,- € / year = 11 tons CO_2 (0.5 kg / kWh)

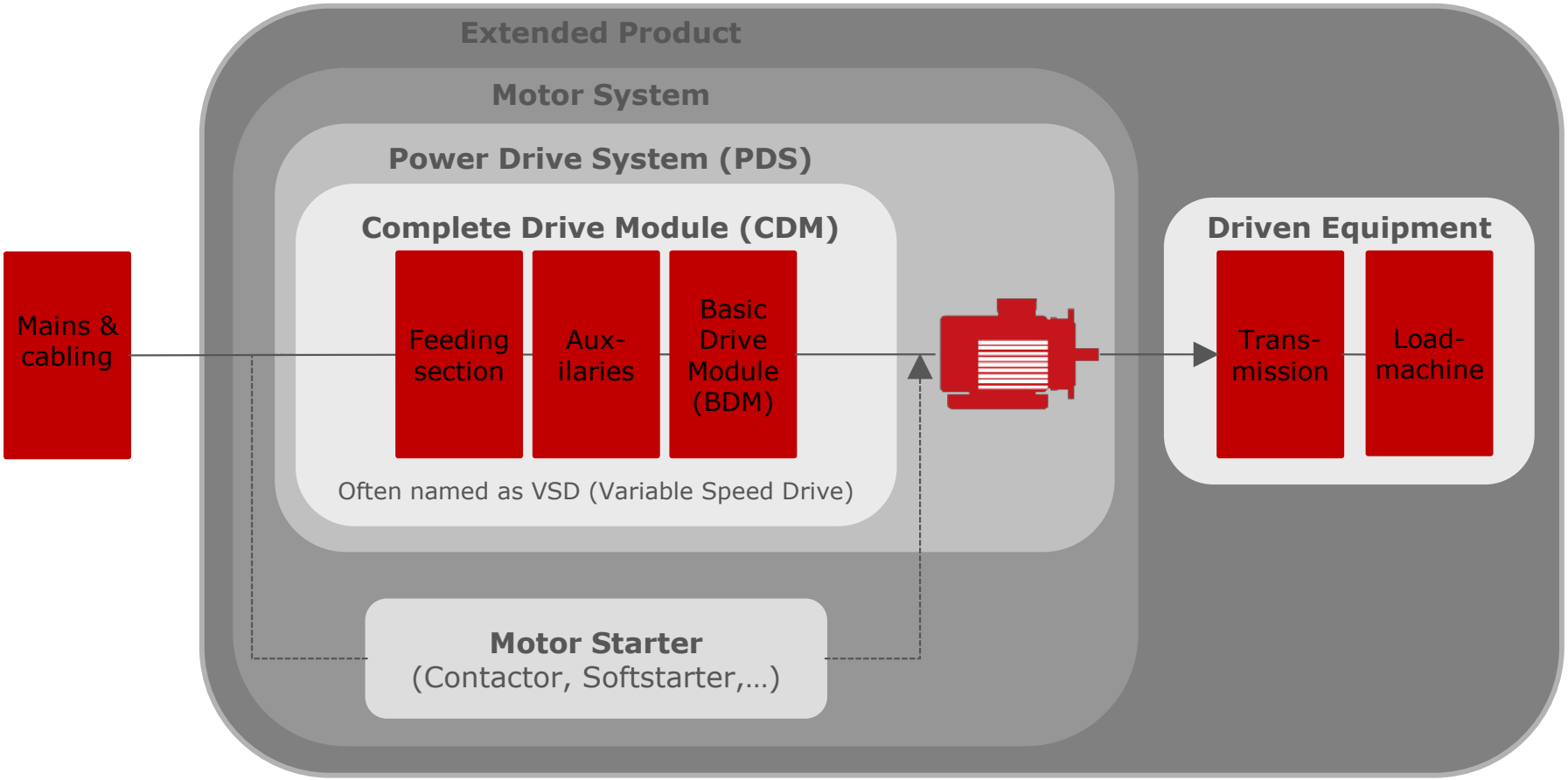
European Eco-design Standards

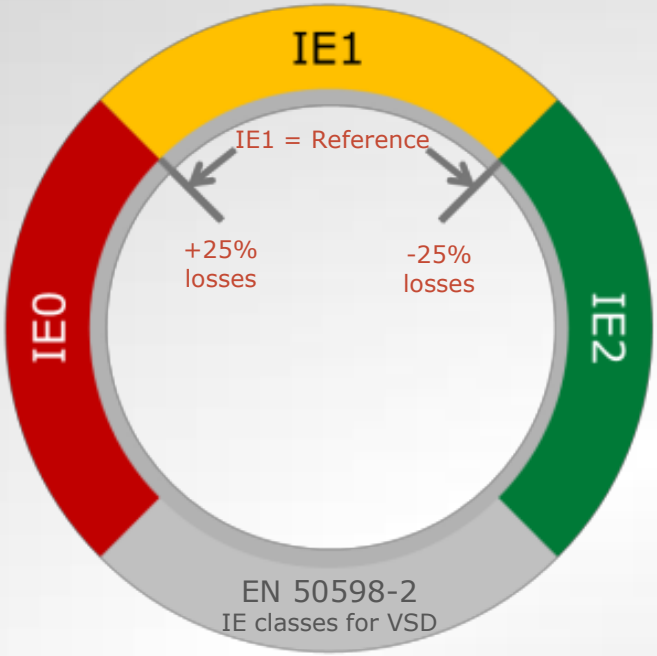


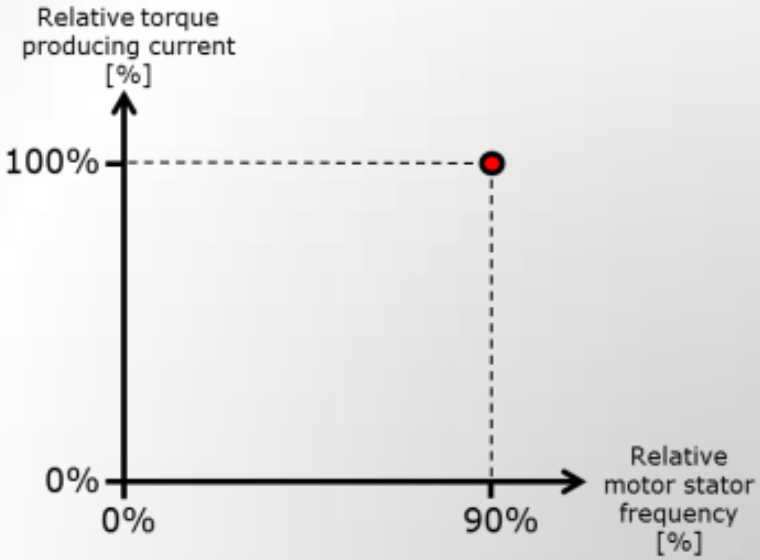
Timing & Market Relevance

- The European standard EN 50598 "Ecodesign for power drive systems…" was published end of 2014 and applies in the European Union
- EN 50598 deals with the energy efficiency of drives, drive – motor systems and extended products
- Work is in progress to develop the IEC61800-9 international IEC standard, heavily based on EN 50598. The IEC standard will apply worldwide
- IEC 61800-9 is expected to be published by the end of 2016. After the publication of the IEC standard, the EN standard will be withdrawn

Definitions according to EN 50598

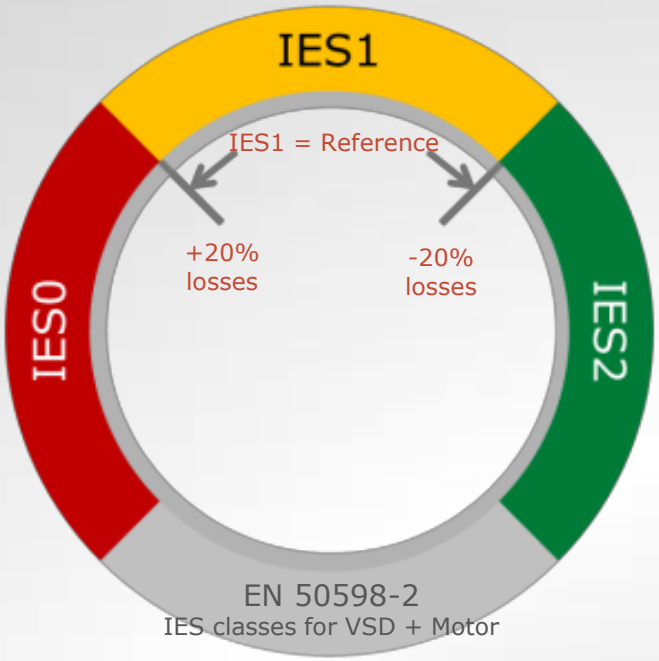


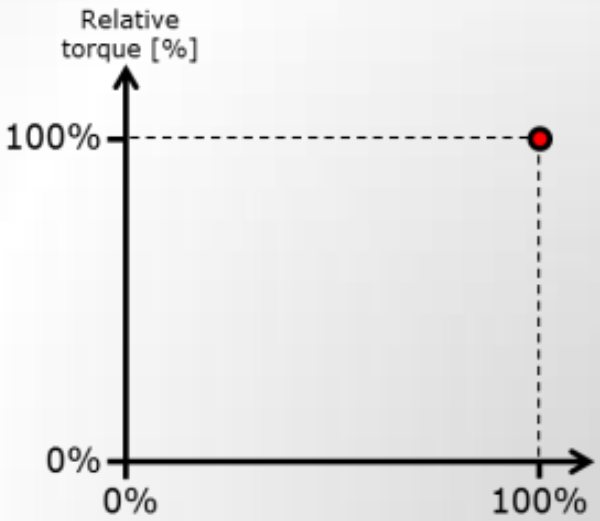




Definition
IE classes VSD

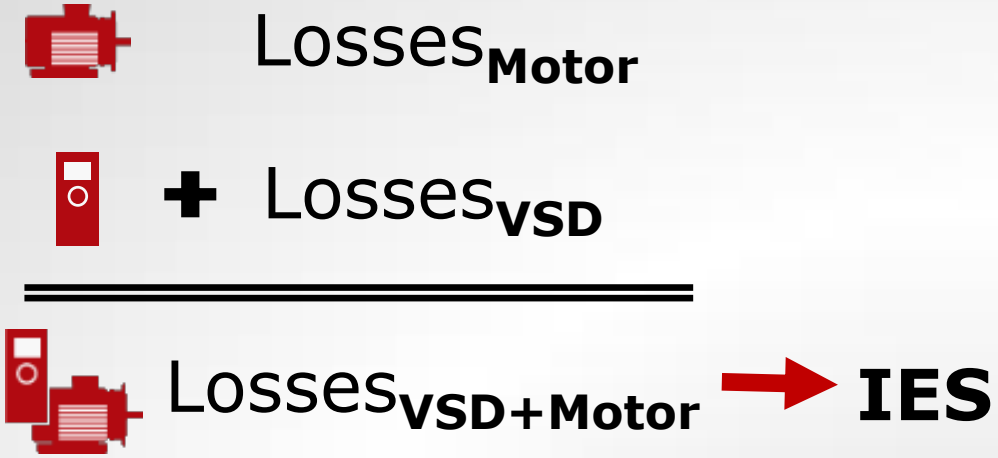
- IE classes according to EN 50598-2
  - IE0 – Below technical standard
  - IE1 – Technical standard
  - IE2 – Above technical standard
- IE class is defined at 90% frequency and 100% torque-producing current
- VSD is measured “as delivered”
  - No special “test mode” allowed
  - All built-in options are included (RFI, PLC,…)





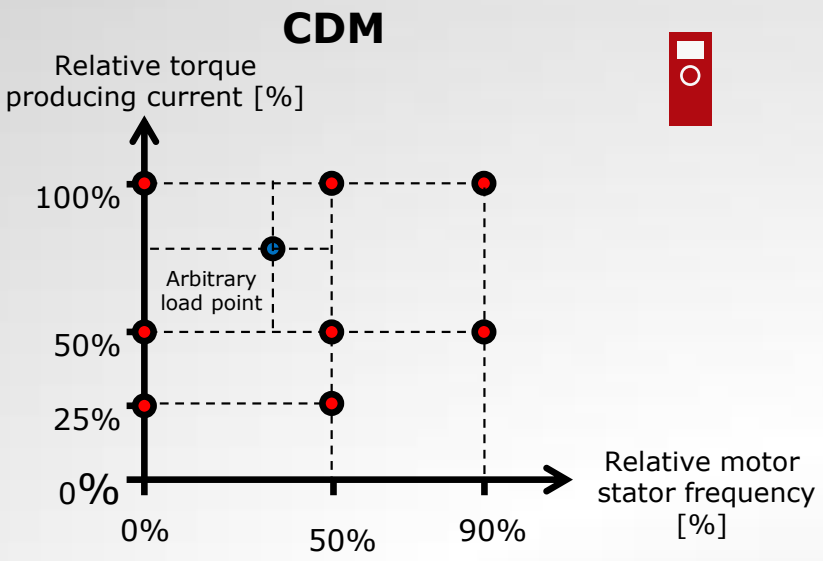
Definition IES classes VSD + Motor

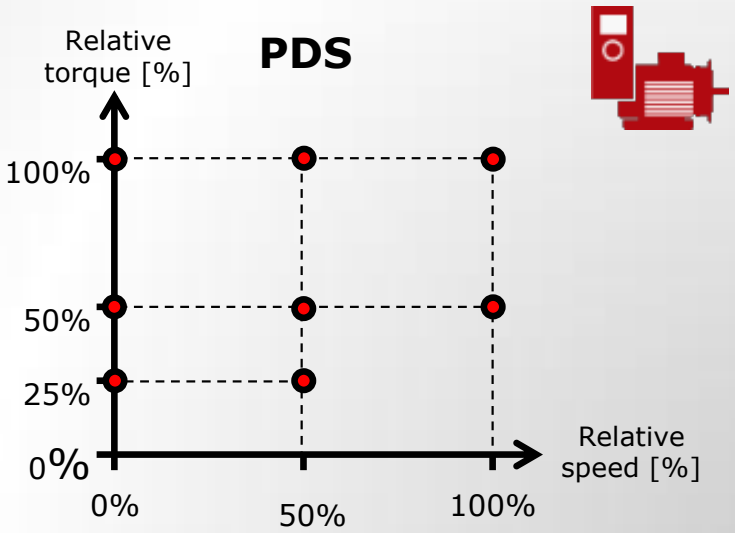
- IES classes according to EN 50598-2
  - IES0 – Below technical standard
  - IES1 – Technical standard
  - IES2 – Above technical standard
- IES class limit is defined at 100% speed and 100% torque
- Conditions for testing are defined
- Deviations are allowed but must be documented:
  - longer/shorter cable
  - screened / unscreened cable
  - optimized settings
  - adjusted switching frequency



Determining IES classes VSD + Motor

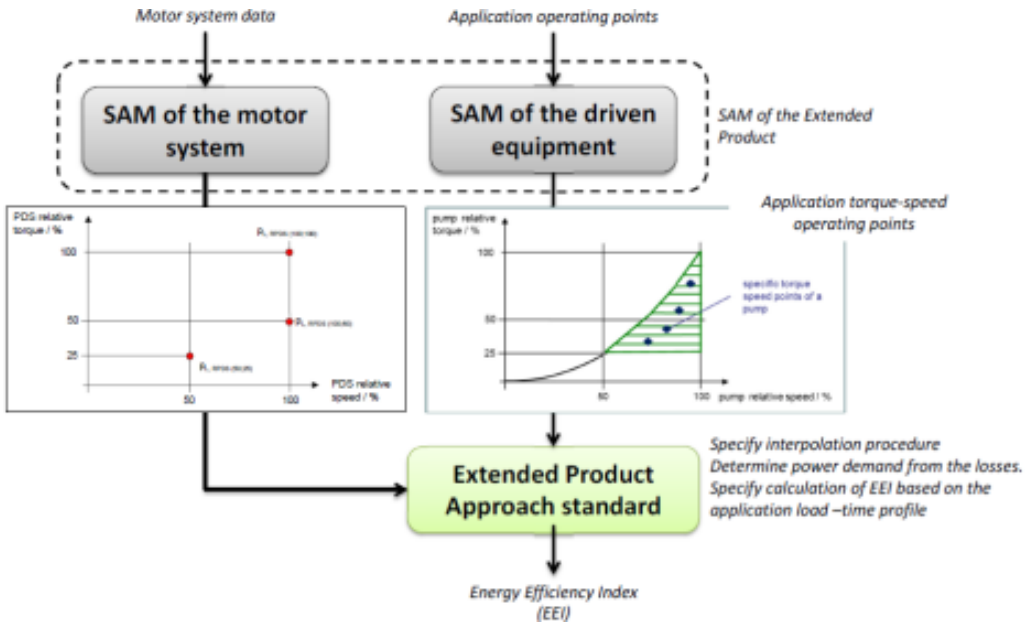
- It is not possible to calculate the IES class out of the IE classes for VSD and motor: $IE2_{motor} + IE2_{VSD} \neq IES2$
- The IES class can be calculated using motor and VSD losses and comparing the sum with the IES reference value
- Motor and VSD manufacturers must declare losses in classification point
- For determining the IES class of a system consisting of a drive and any induction motor, it is possible to use an on-line / app calculation tool

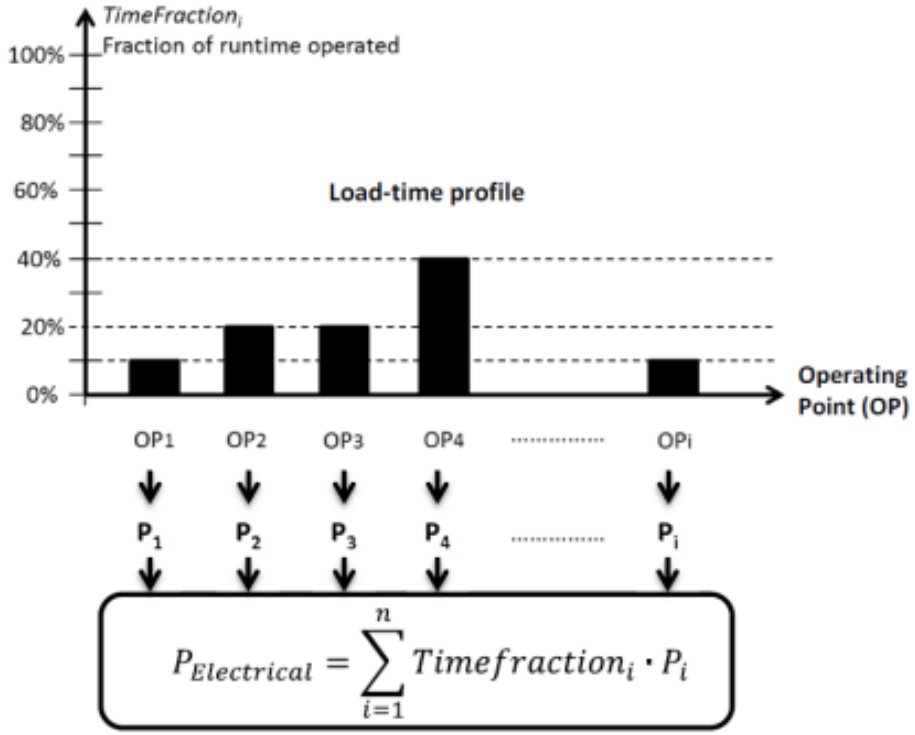




Part load losses

- Part load losses are defined in the nominal point and in 7 additional part load points for
  - CDM (drive)
  - PDS (drive + motor)
- Note that the nominal point for drives is 90% of nominal load and 100% for systems
- Some VSD producers have decided to publish both the 90% and 100% points for drives, in total 10 load points
- Part load losses can be determined in any point by interpolating between the 8 standardized points

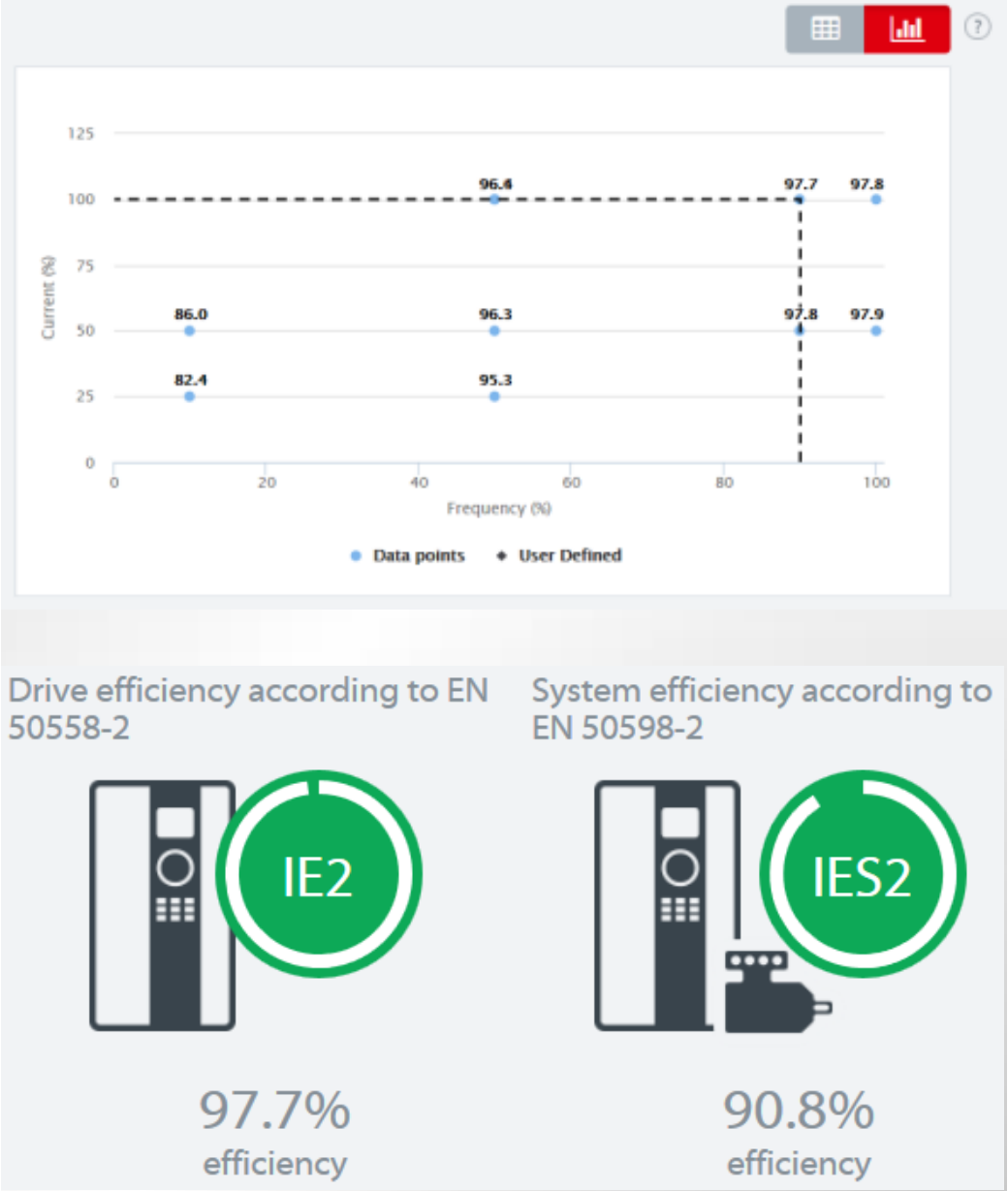




Extended product approach

- The extended product approach combines the losses or efficiency of the motor system with the losses/efficiency of the driven system (pump, fan, conveyor, etc.)
- Based on the losses or efficiency of the extended product, the **energy efficiency index (EEI)** can be calculated for a given load-time duty profile
- Knowing the part load losses for the motor-drive system is essential for calculating the EEI, which is the ultimate purpose of the ecodesign standard

Calculation Tool



Example of energy efficiency calculation tool

Features

- Energy efficiency calculation according to the EN50598 standard
- Display efficiency data of drives in standardized and user defined partial load points
- Calculates drive efficiency class (IE) and motor + drive system efficiency class (IES) based on user input motor parameters (only nameplate data)
- Issues an "Energy efficiency certificate"

Benefits

- User friendly determination of part load efficiency helps system designers to determine system efficiency
- Calculation of system efficiency class (IES) supports the combination of a VSD with any motor

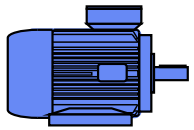
Ventilation System Efficiencies

High Efficiency Ventilation (EC+) Package



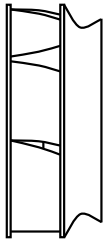
Variable Speed Drive





PM motor

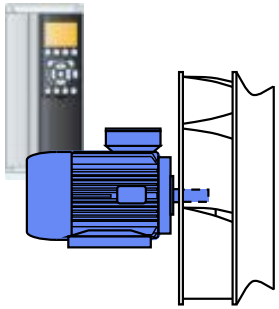




High Efficiency Drive







High Efficiency System

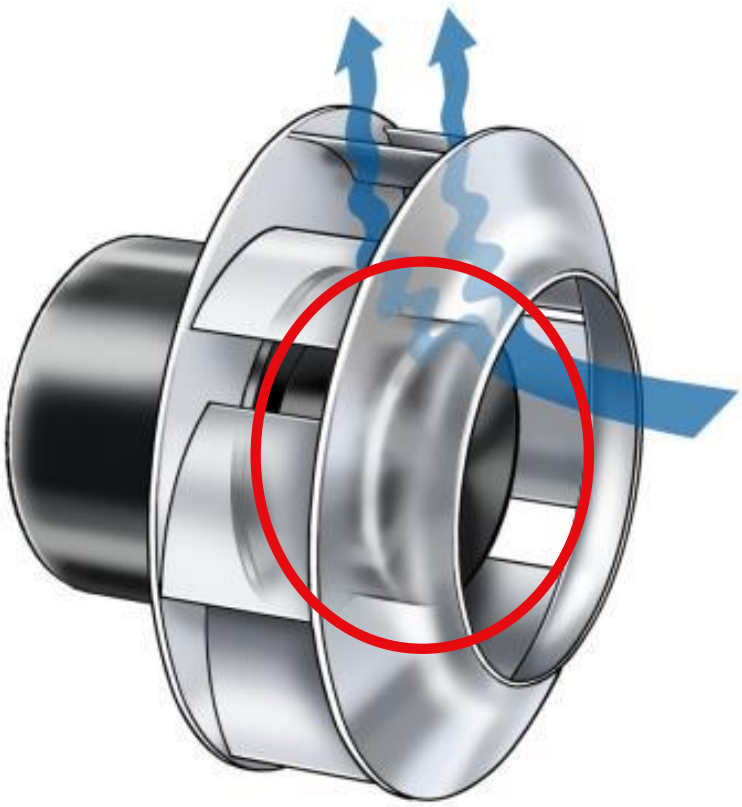


- Ideal undisturbed airflow through Fan

EC Motor / Fan System

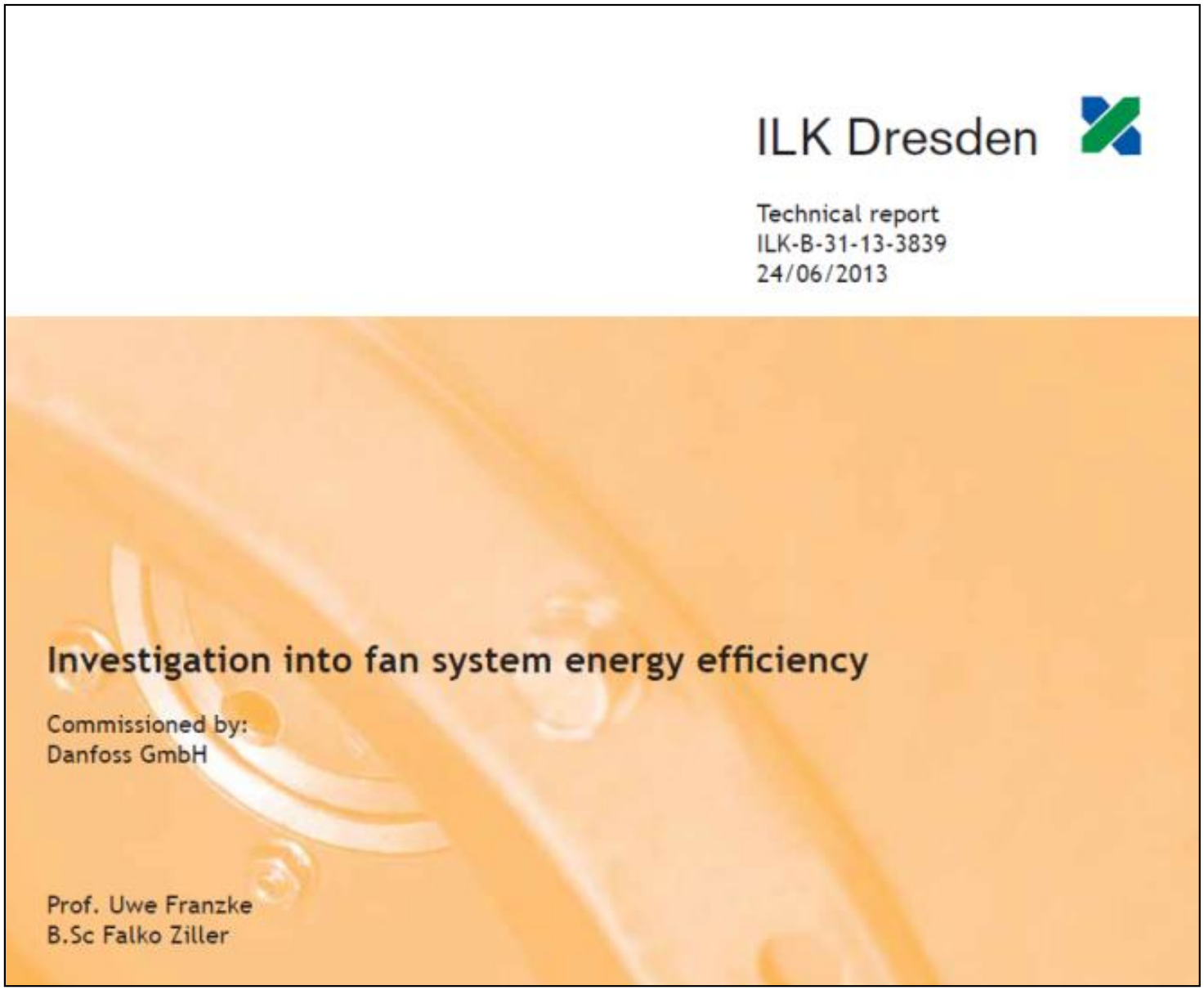


EC Motor / Fan Solution
Very Compact..
But compactness comes at a price



Airflow through fan disturbed by Motor

ILK Dresden Test Results



ILK Dresden Tests Scope

The following fan drive systems were tested:

- A Permanent Magnet IE4 motor with a frequency converter
- An asynchronous IE2 motor with a frequency converter
- An asynchronous IE3 motor with a frequency converter
- An EC fan with an integrated motor

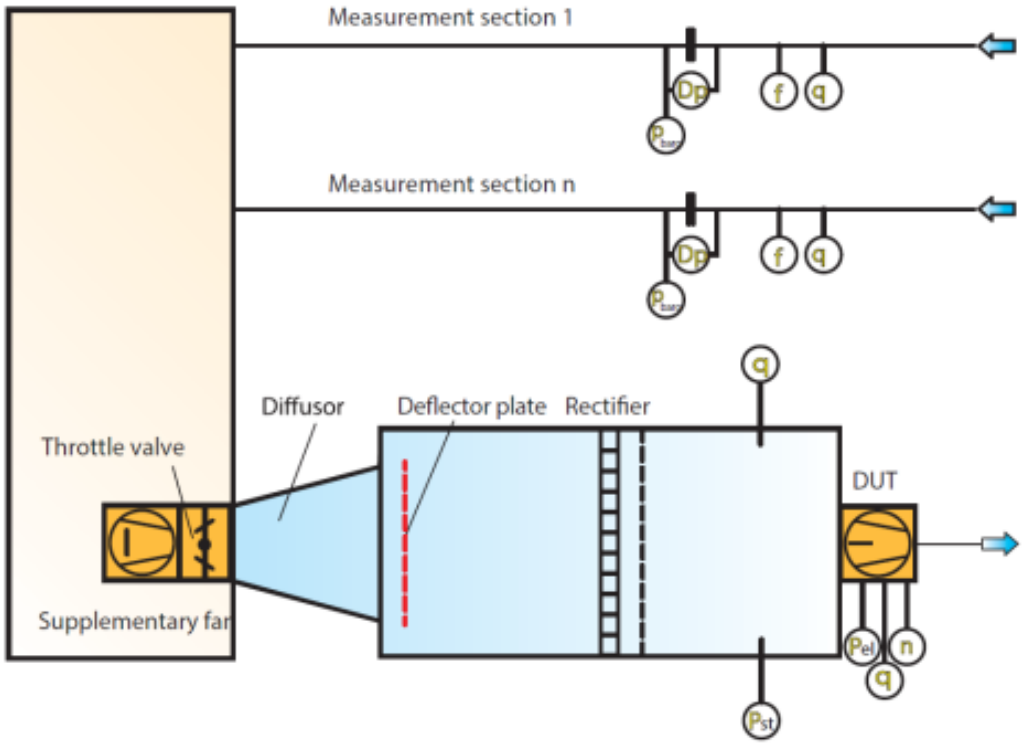
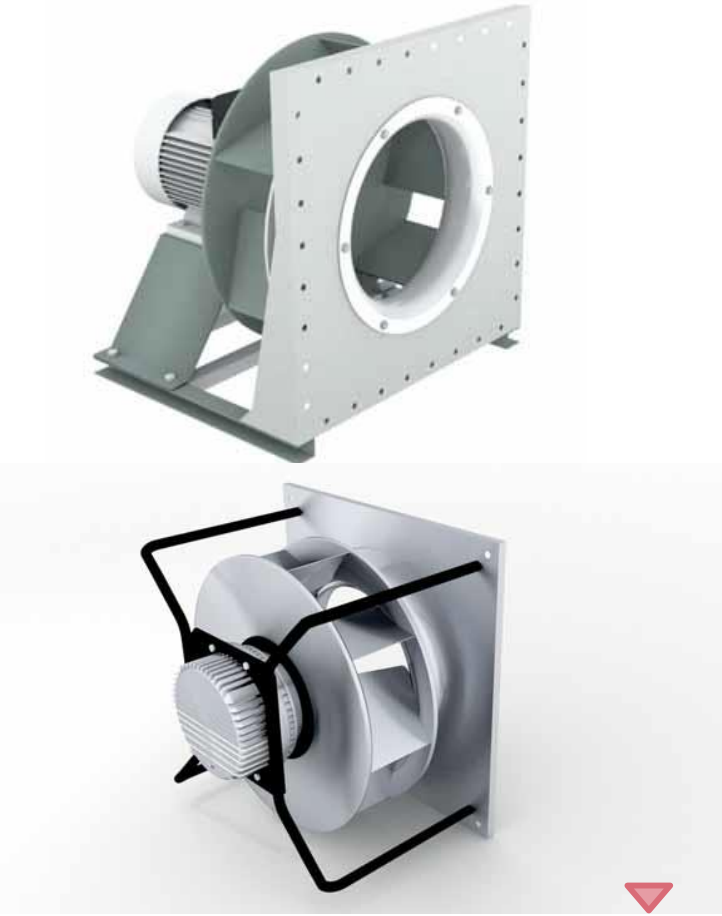


Figure 1
Schematic layout of the testing facility



ILK Dresden Test Results

10%

10.8% lower system losses in High Efficiency Ventilation Systems EC+

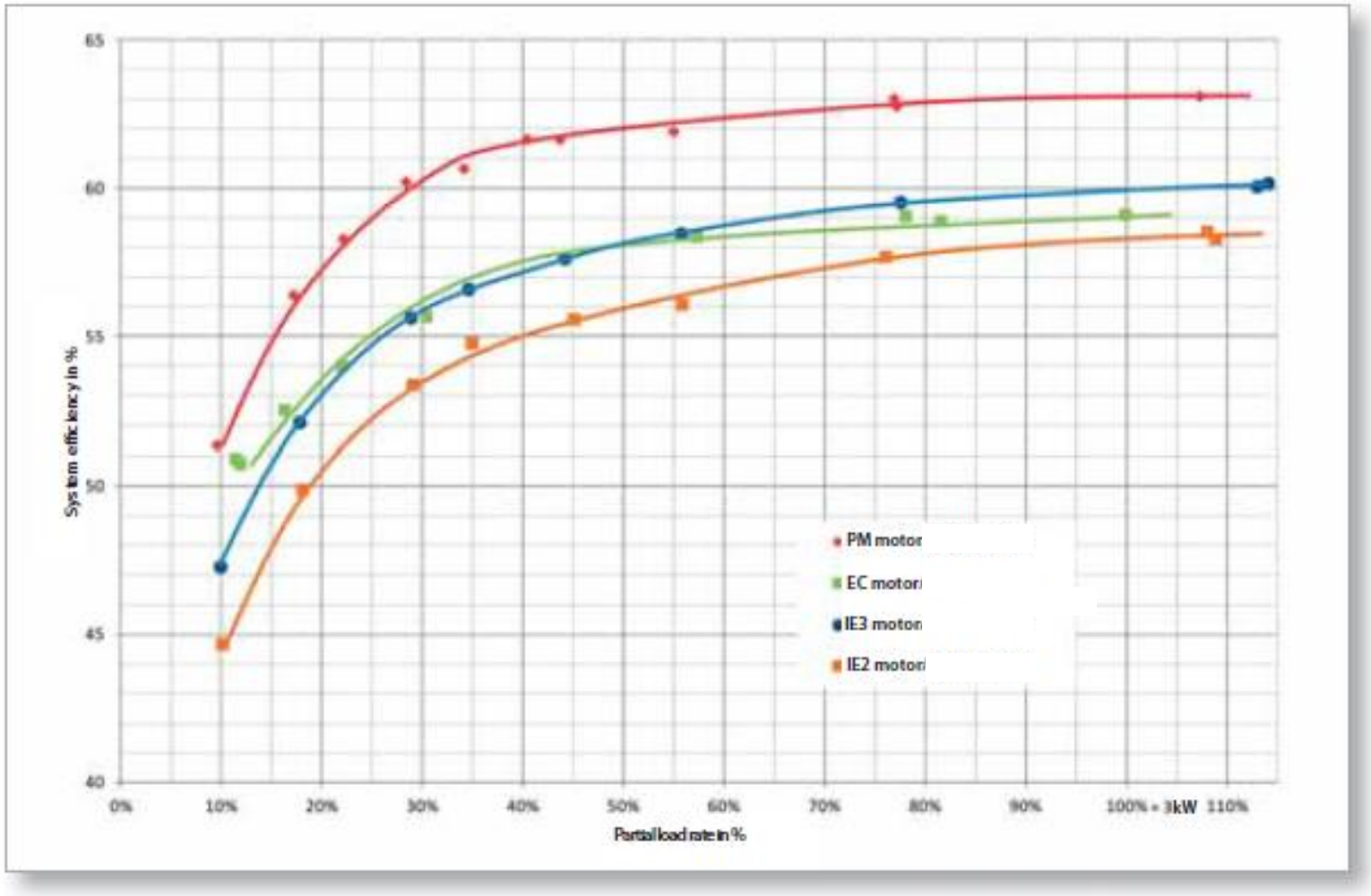
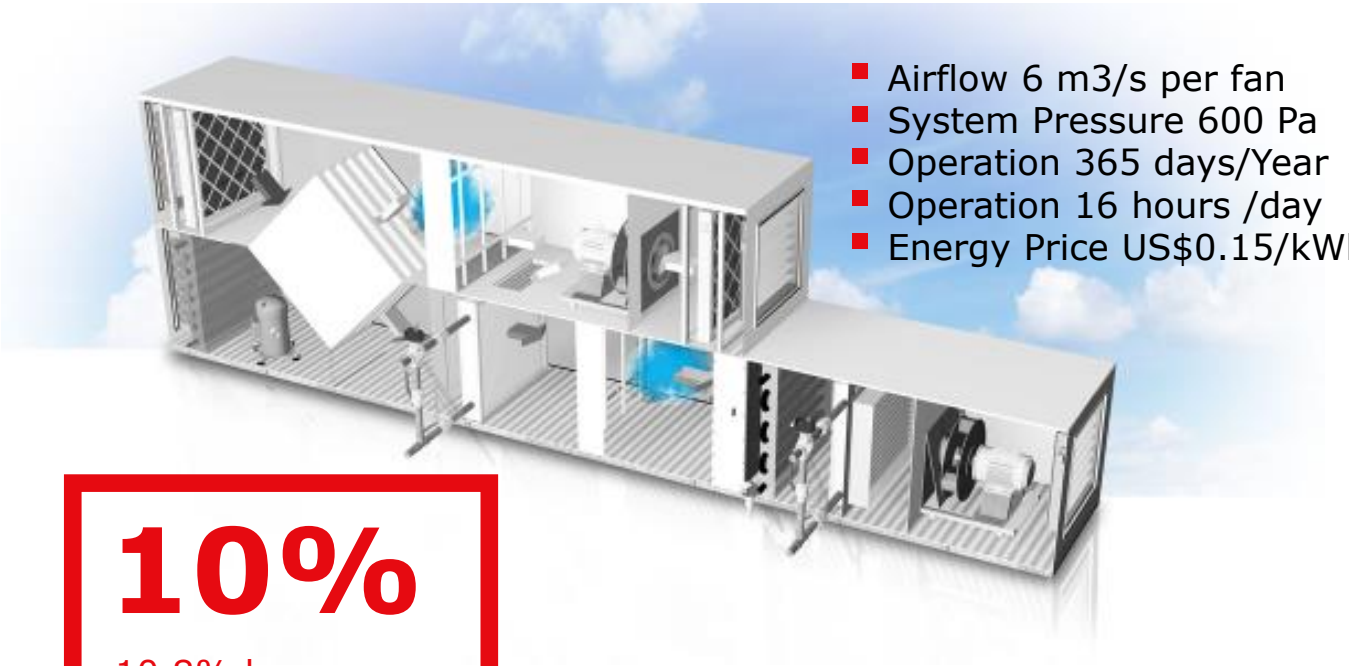


Figure 16
Optimum system efficiency for individual characteristic curves dependent upon power demand and fan motor system

Energy Saving - Example



- Airflow 6 m3/s per fan
- System Pressure 600 Pa
- Operation 365 days/Year
- Operation 16 hours /day
- Energy Price US$0.15/kWh

10%

10,8% lower system losses in High Efficiency Fan Systems

EC+ Brings 6.7% higher System Efficiency
EC+ Brings 10.8% lower losses

EC+ Brings saving of US$700 / Year on Electricity Bill (Above Example)

EC+



- System Efficiency 63%
- Power Comsumption 11.4kW
- Annual Electricity Bill US$9.986

EC /Fan Motor



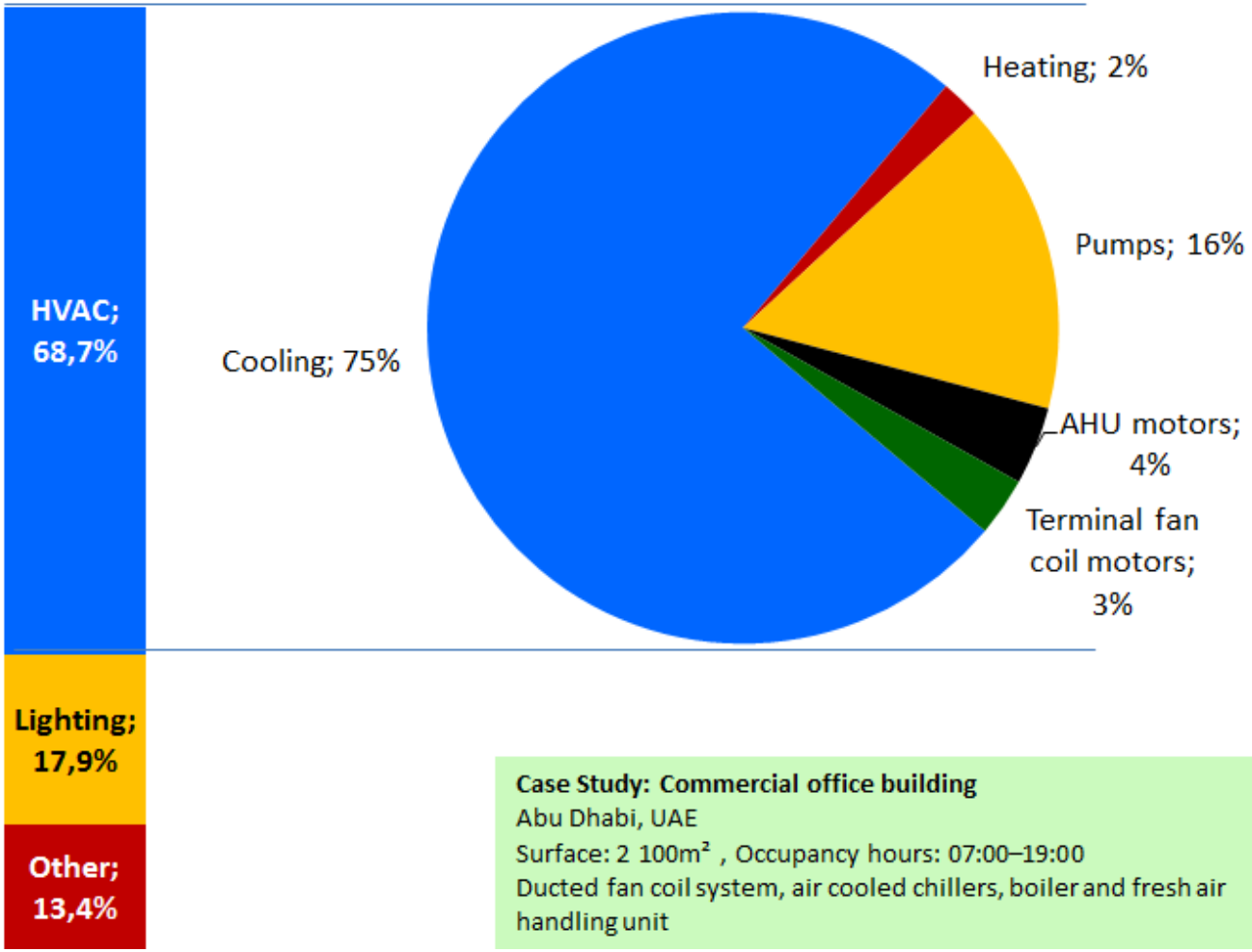
- System Efficiency 59%
- Power Comsumption 12.2kW
- Annual Electricity Bill US$10.687

VSDs on Screw Chillers

HVAC largest electricity consumer *

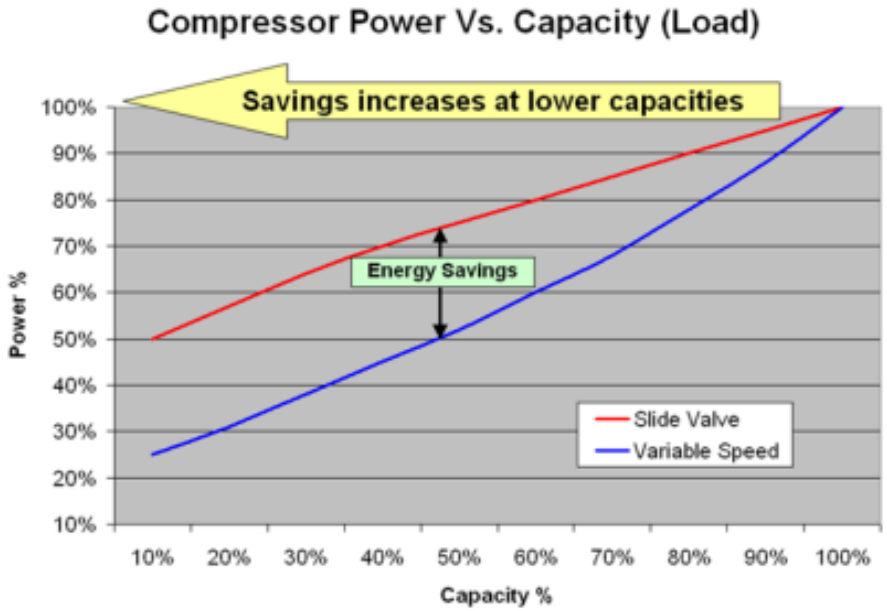
Typically, a 35,000 sq. ft. commercial building would pay an electricity bill of AED 5.0 -5.5M, or a 20,000 sq. ft. hotel would pay AED 3.0-3.5 M annually; of this, ~70% is for HVAC systems.

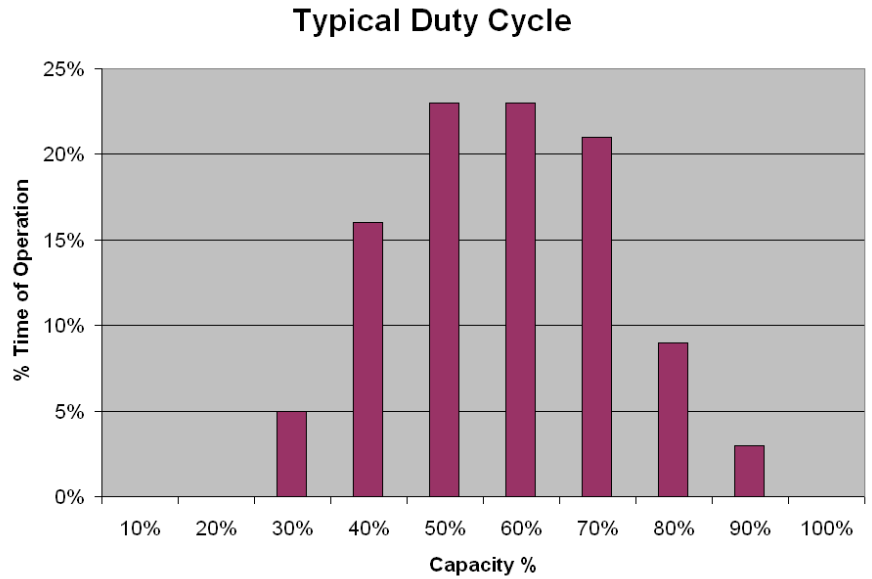
Electricity consumption in a building



Case Study: Commercial office building
Abu Dhabi, UAE
Surface: 2 100m² , Occupancy hours: 07:00–19:00
Ducted fan coil system, air cooled chillers, boiler and fresh air handling unit

Potential Savings fitting VSD to Screw Chiller





Compressor Duty Cycle

- Energy savings with a VS compressor increases as capacity/load is reduced
- Chillers typically operate the majority of the time at part-load conditions, therefore VFD compressors provide significant energy savings

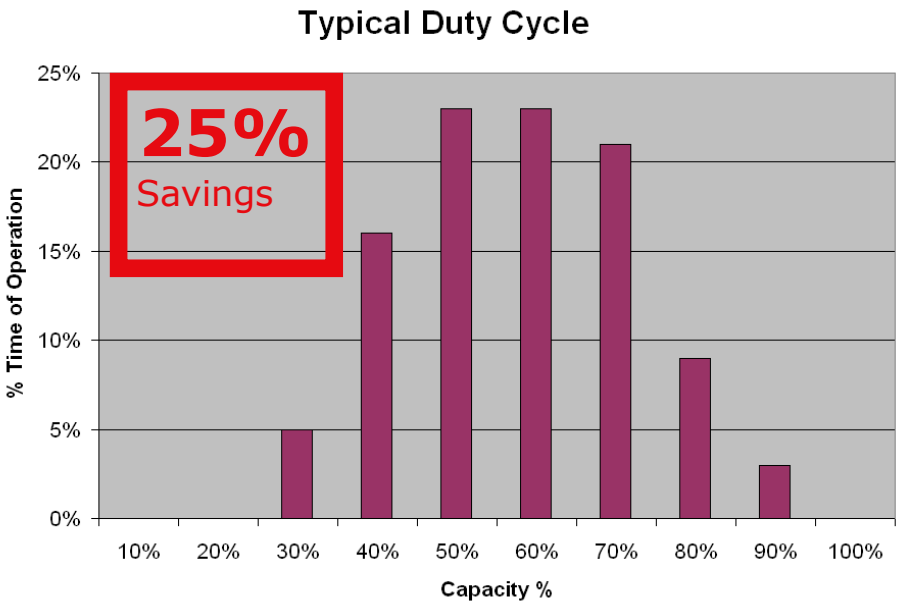
Electricity Cost

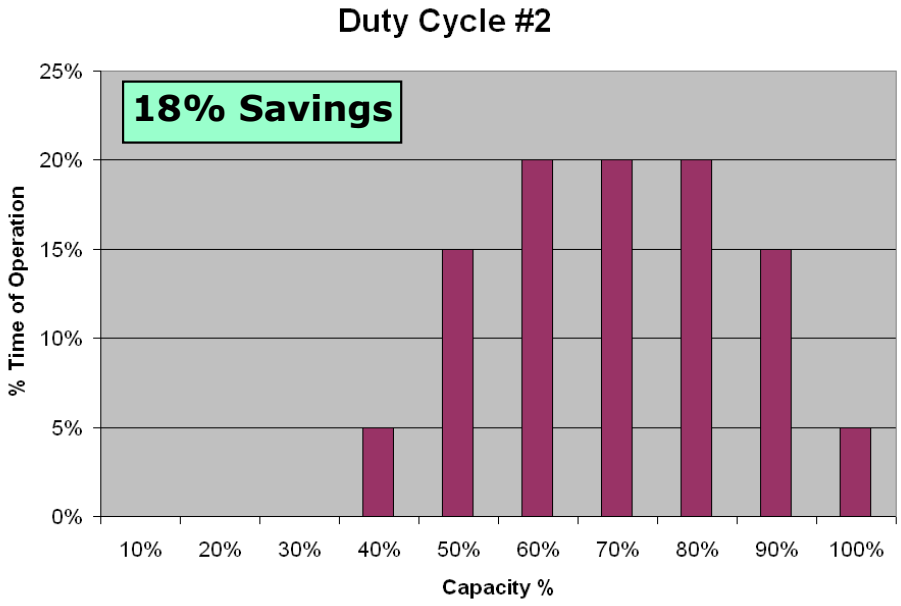
- The price of electricity dictates the amount of money saved in a VFD retrofit
- Higher electricity cost = higher savings and quicker pay-back

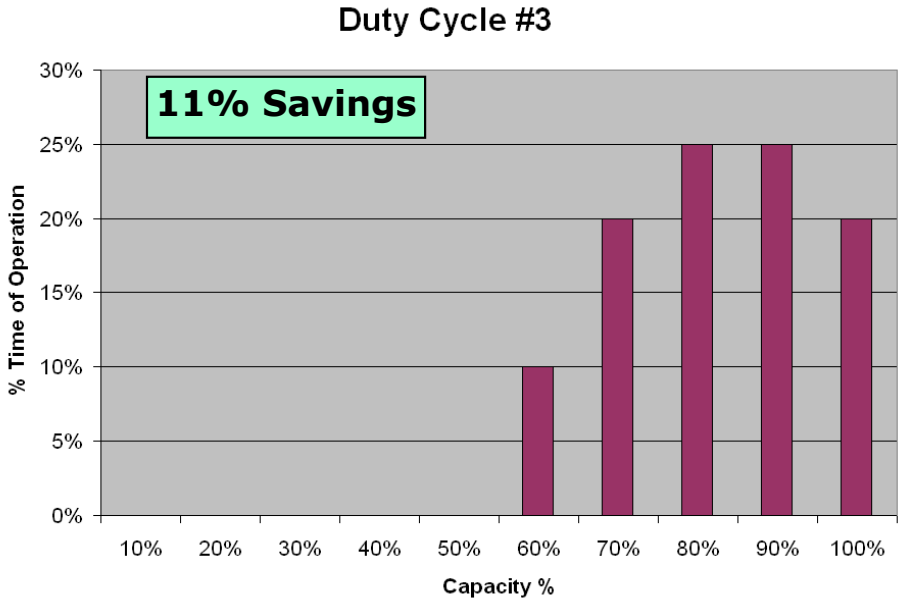
- **Annual Operation**
  - Applications with higher annual operation result in higher savings

- Significant Saving Potentials when retrofitting Chillers with VSDs

Savings Sensitivity – Duty Cycle







Variable speed energy savings are lower for applications that have more operation time closer to full load

Example Savings Calculations

Assumptions

Drive Size (kW)	315	
Drive Cost	$10,000	
Annual Operation (hrs)	4,380	(12 hrs/day, 365 days)
Energy Cost (US$/kWh)	$0.10	
System Modification Cost	$5,000	

Estimated Savings

Single-Speed Annual Cost	$108,789
Variable-Speed Annual Cost	$81,126
Annual Savings:	**$27,663**
Payback (months):	**7**

Single-Speed Compressor

Capacity %	% Time of Operation	% Power	Required Power (kW)	Weighted Power
100%	0%	100%	315	0.0
90%	3%	95%	299	9.0
80%	9%	90%	284	25.5
70%	21%	85%	268	56.2
60%	23%	80%	252	58.0
50%	23%	75%	236	54.3
40%	16%	70%	221	35.3
30%	5%	64%	202	10.1
20%	0%	57%	180	0.0
10%	0%	50%	158	0.0
		Average Annual Power:		**248**

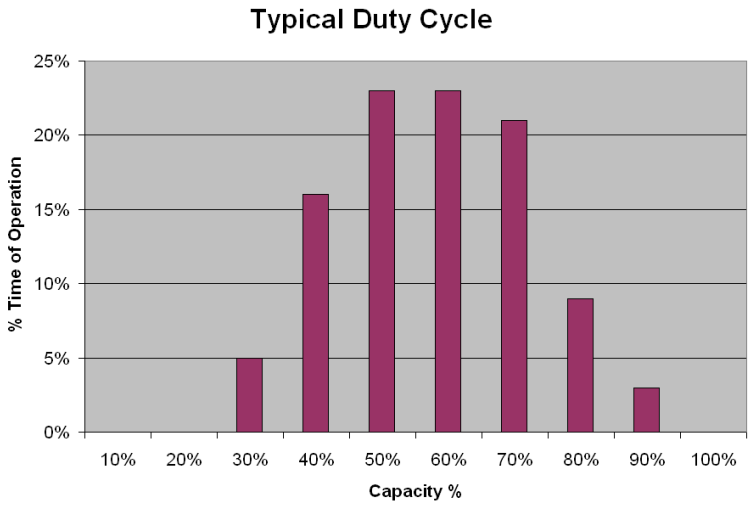
Variable-Speed Compressor

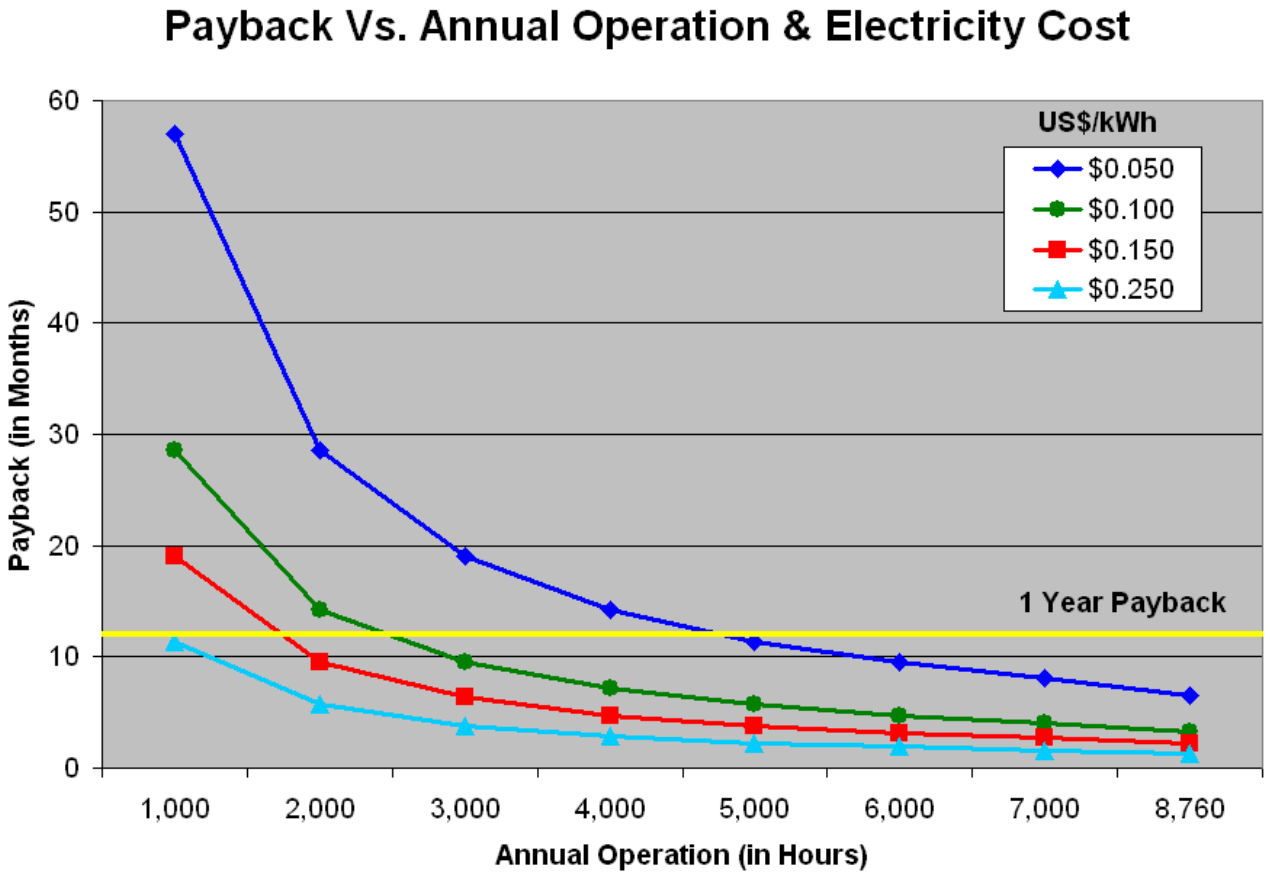
Capacity %	% Time of Operation	% Power	Required Power (kW)	Weighted Power
100%	0%	100%	315	0.0
90%	3%	88%	277	8.3
80%	9%	78%	246	22.1
70%	21%	68%	214	45.0
60%	23%	60%	189	43.5
50%	23%	52%	164	37.7
40%	16%	45%	142	22.7
30%	5%	38%	120	6.0
20%	0%	31%	98	0.0
10%	0%	25%	79	0.0
		Average Annual Power:		**185**
		Energy Savings:		**25%**

- Example high level savings estimate – savings vary

Savings Sensitivity - Cost/kWh & Annual Operation

US$/ kWh	Annual Operation (hours)							
	1000	2000	3000	4000	5000	6000	7000	8760
$0.050	57.0	28.5	19.0	14.3	11.4	9.5	8.1	6.5
$0.075	38.0	19.0	12.7	9.5	7.6	6.3	5.4	4.3
$0.100	28.5	14.3	9.5	7.1	5.7	4.8	4.1	3.3
$0.125	22.8	11.4	7.6	5.7	4.6	3.8	3.3	2.6
$0.150	19.0	9.5	6.3	4.8	3.8	3.2	2.7	2.2
$0.200	14.3	7.1	4.8	3.6	2.9	2.4	2.0	1.6
$0.250	11.4	5.7	3.8	2.9	2.3	1.9	1.6	1.3





Payback decreases as electricity cost increases

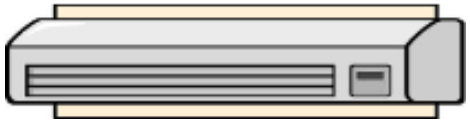
Longer annual operation provides paybacks less than 1 year even in low cost electricity locations

Calculations based on typical duty cycle (above)

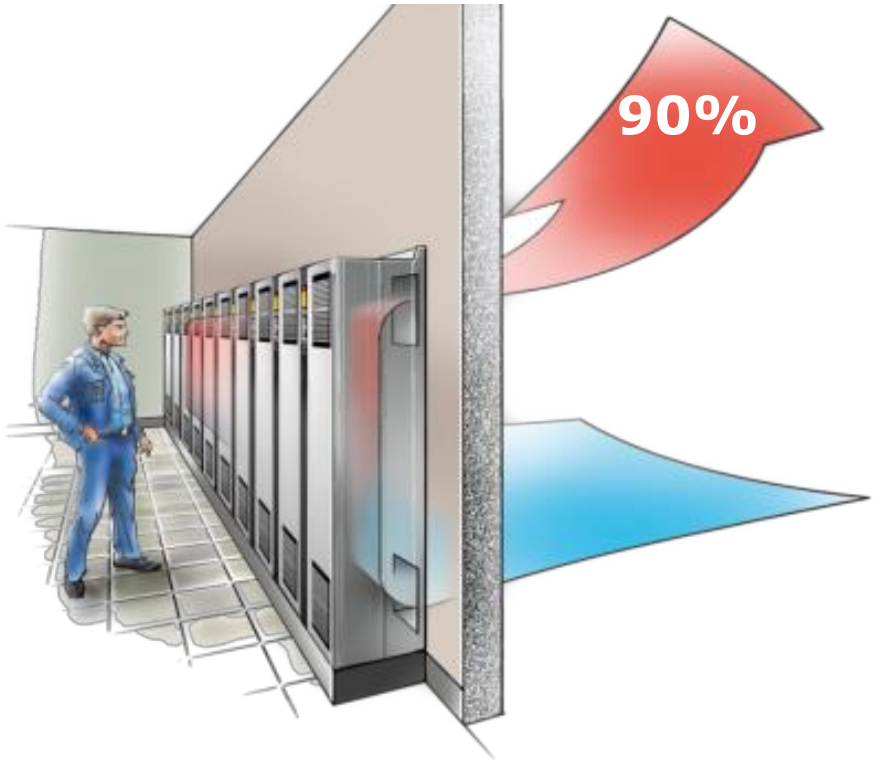
Heat Management on VSDs

Intelligent heat management

part of installed efficiency



A back channel cooling concept transfers up to 90% of heat away from the room.





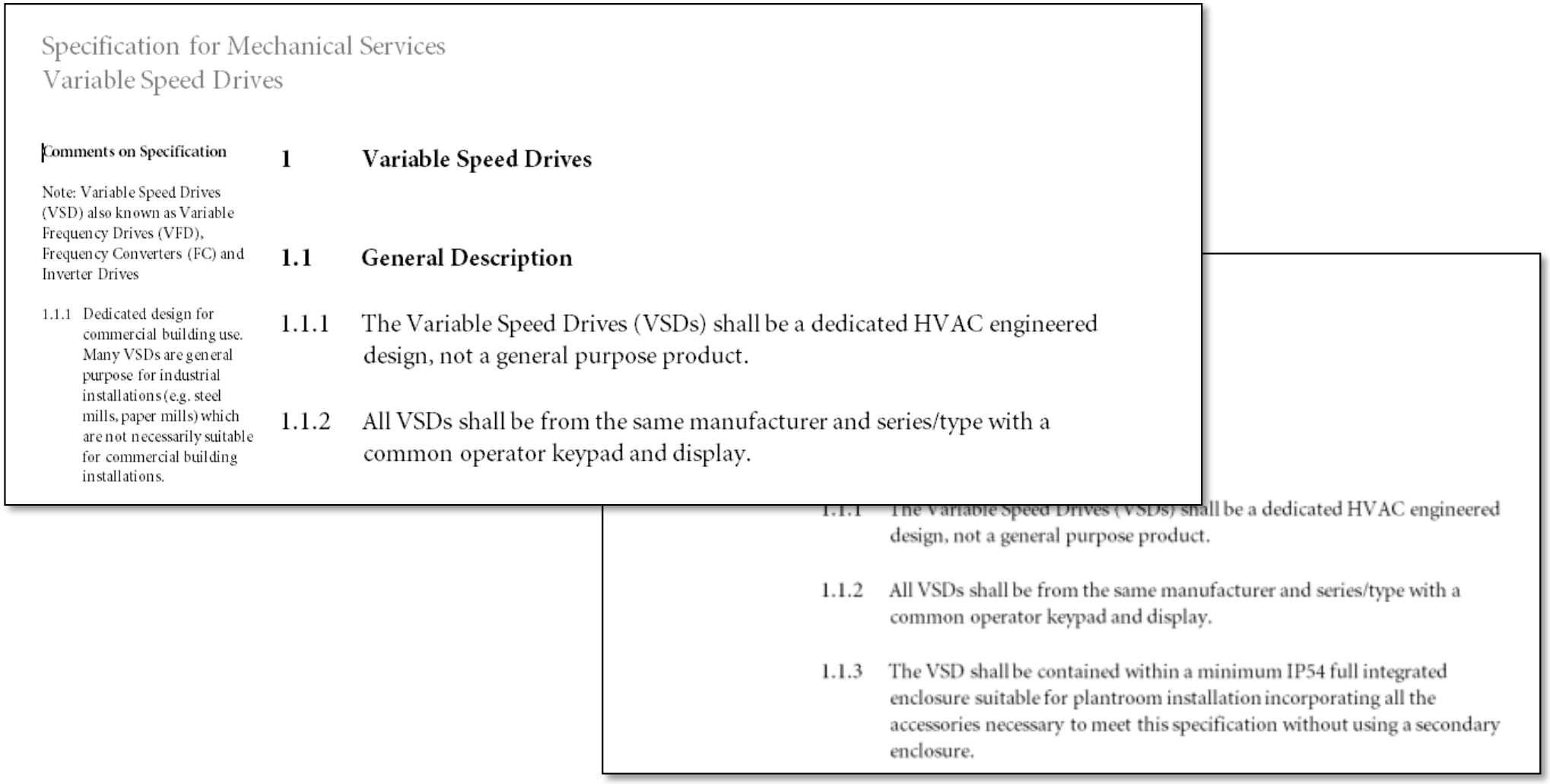


The energy saving for a 160 kW drive will be about 15 % of investment made in the Variable Speed Drive

160 kW AC drive standard: Heatloss 3770 W. ~ 15 % of AC drive purchase price

Consultant Specifications

Consultant Specifications



Specification for Mechanical Services
Variable Speed Drives

Comments on Specification

Note: Variable Speed Drives (VSD) also known as Variable Frequency Drives (VFD), Frequency Converters (FC) and Inverter Drives

1.1.1 Dedicated design for commercial building use. Many VSDs are general purpose for industrial installations (e.g. steel mills, paper mills) which are not necessarily suitable for commercial building installations.

1 Variable Speed Drives

1.1 General Description

1.1.1 The Variable Speed Drives (VSDs) shall be a dedicated HVAC engineered design, not a general purpose product.

1.1.2 All VSDs shall be from the same manufacturer and series/type with a common operator keypad and display.

1.1.3 The VSD shall be contained within a minimum IP54 full integrated enclosure suitable for plantroom installation incorporating all the accessories necessary to meet this specification without using a secondary enclosure.

Thank You