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Fundamentals of Measurement and Visualization of KPIs

Pascal van Putten
VPInstruments

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About Pascal van Putten

- CEO and Founder of VPInstruments
- 20 years of experience in flow measurement, compressed air monitoring and industrial energy management
- VPInstruments offers industrial clients energy management solutions for compressed air, technical gases and other utilities since 1999

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What is measurement? What is calibration?

- Assigning a number to a characteristic of an object, so you can compare it with another object or event
- Types, units, magnitudes, uncertainties
- Fundamental units: Time, Length, Mass
- Standardization (SI vs Imperial)
- Traceability to standards (NIST/ National Standards)

Calibration is the comparison of measurement values delivered by a device under test with those of a calibration standard of known accuracy.

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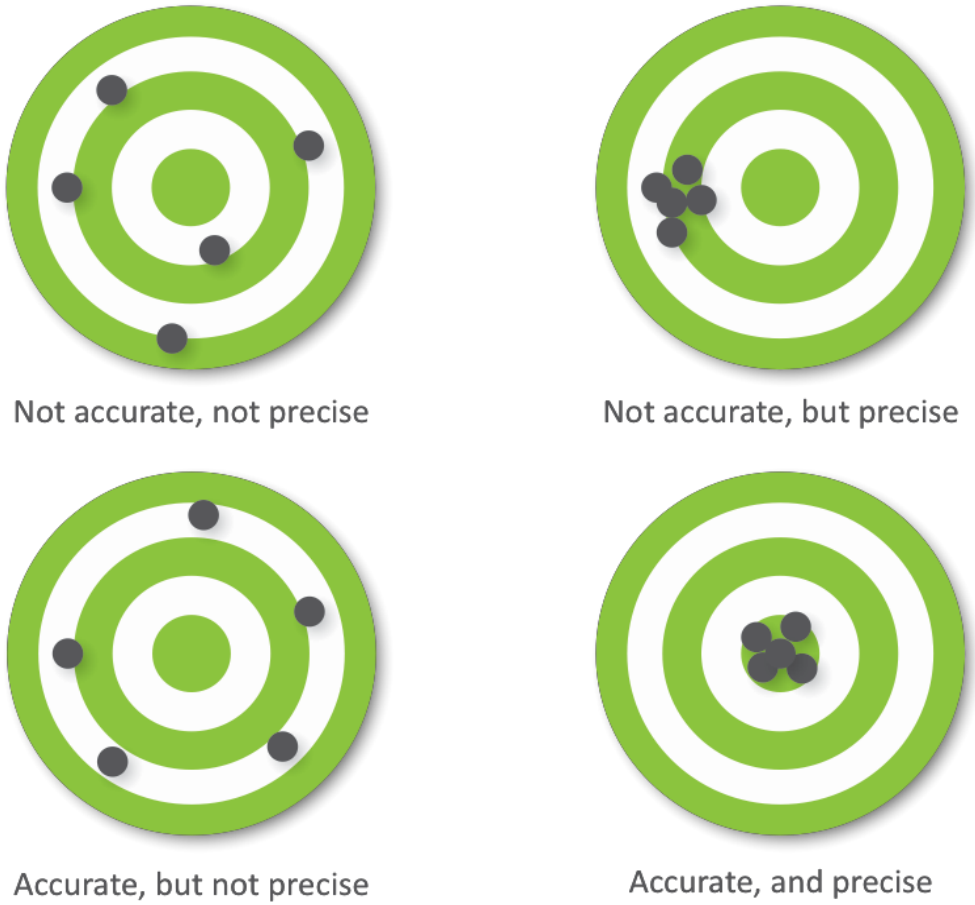
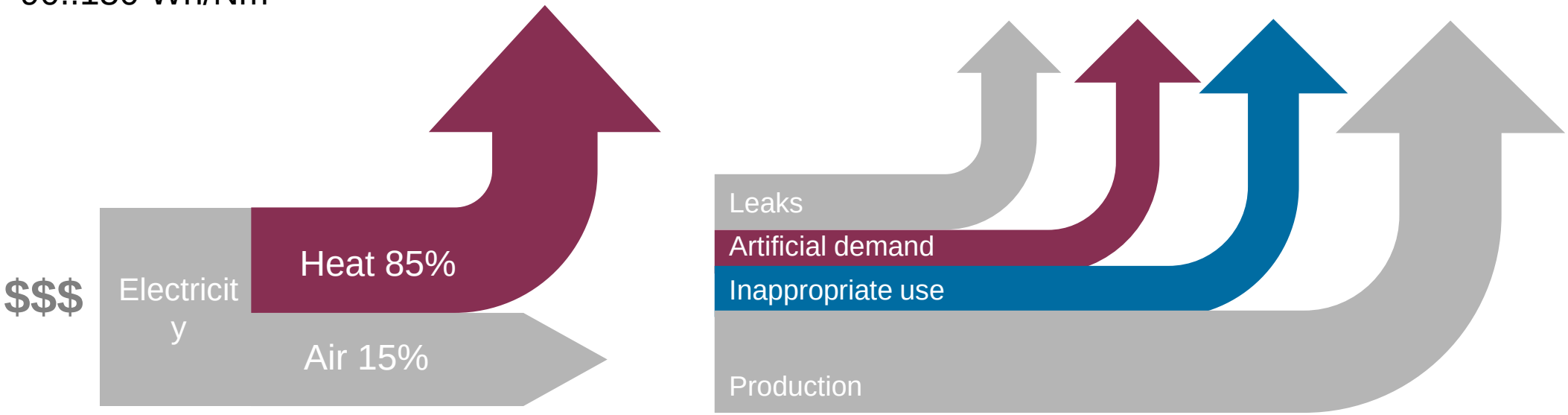
Interpretation of measurement data

Accuracy and repeatability (precision)



Costs of compressed air

- 8 to 10 x more than electricity!
- 0,018..0,07 USD per m^3 produce
- 90..150 Wh/Nm^3



Why KPI's are important

Know where you are and where you're going…

- Company purpose
- Savings goal
- Production goal
- Maintenance goal
- Compliance goal

30% Leakage	400K $/ Year
23.2 kW/100 scfm	3 psi Pressure loss

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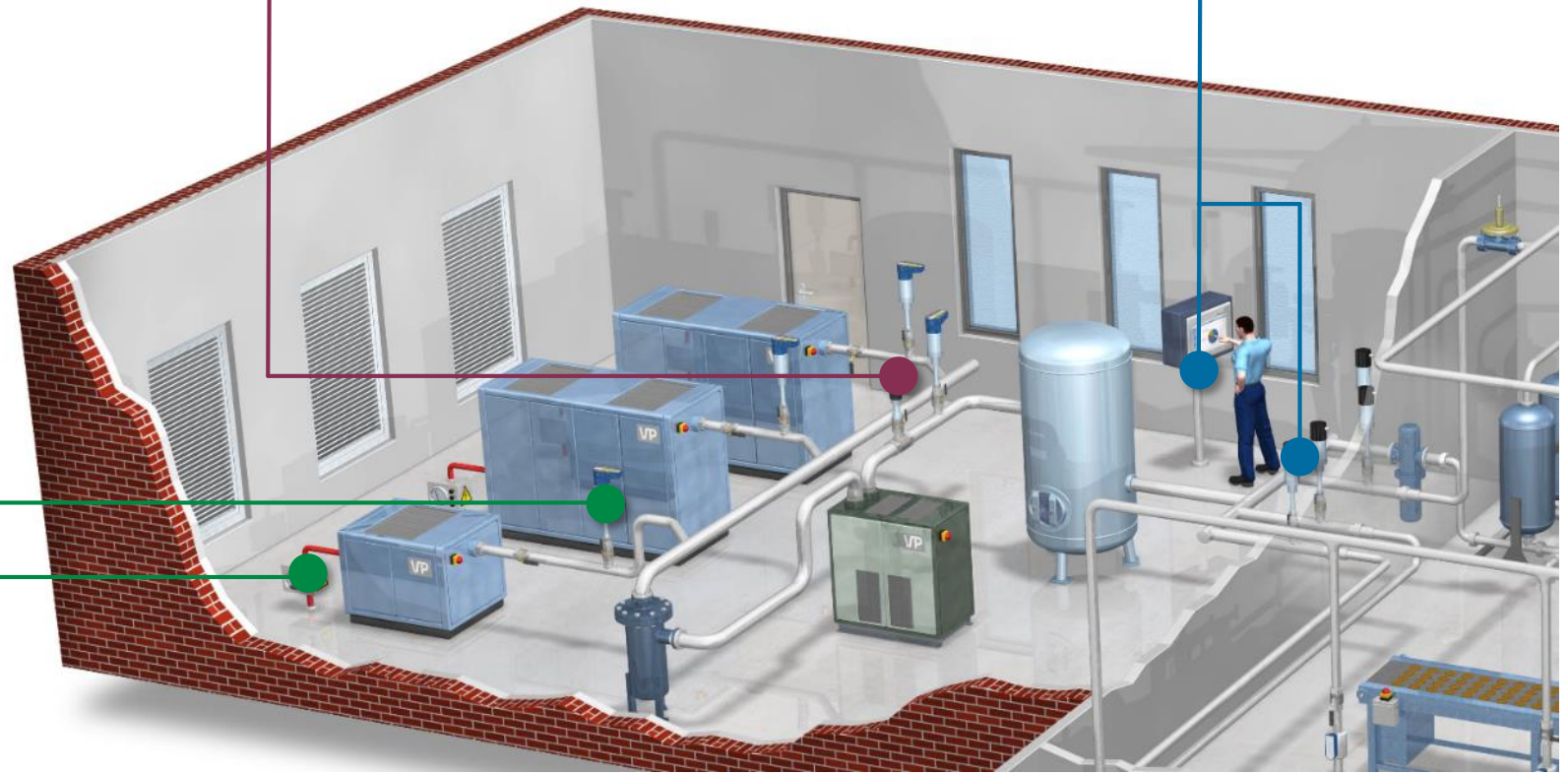
Where to start? What is your goal?

Efficiency monitoring

Air audits/ Leakage management

Cost allocation



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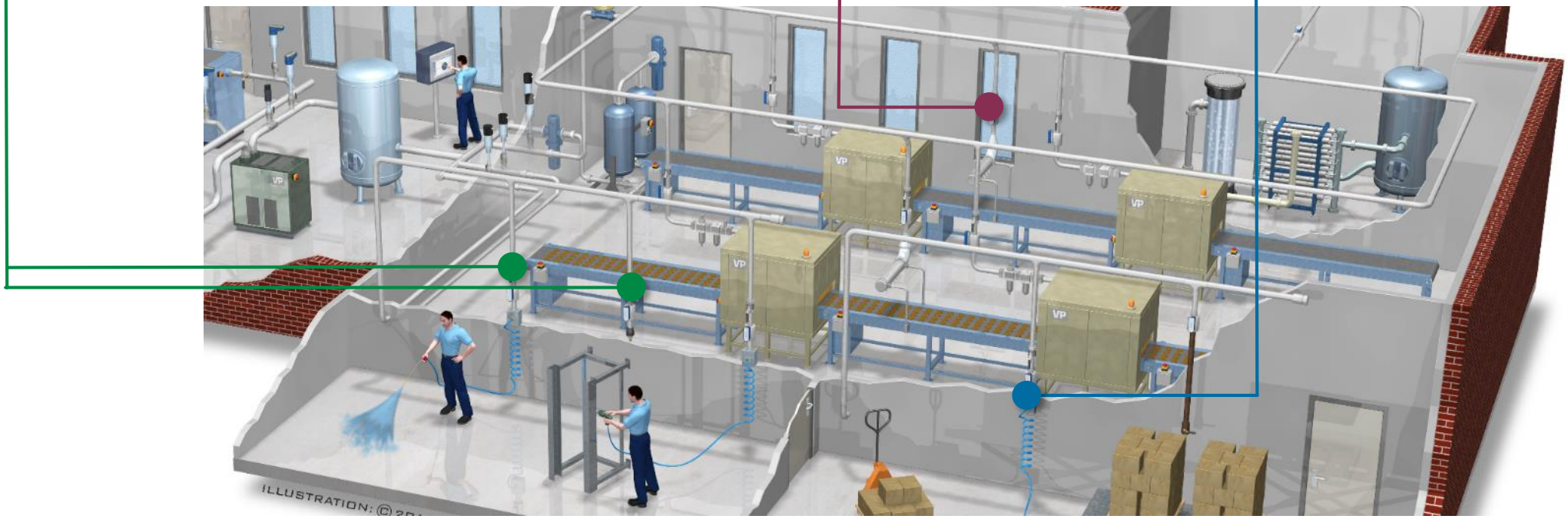
Where to start? What is your goal?

Point of use measurement

Benchmarking

Pressure loss



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5 Typical compressed air KPI's

- Specific power / Efficiency per 100*SCF or kW/m3n/min
- Dew point
- Leakage % or leakage costs per annum
- Pressure loss
- Costs per widget produced

5 Typical compressed air KPI's

- Specific power / Efficiency per 100*SCF or kW/m3n/min
- Dew point
- Leakage % and $$$ per annum
- Pressure loss
- Costs per widget produced

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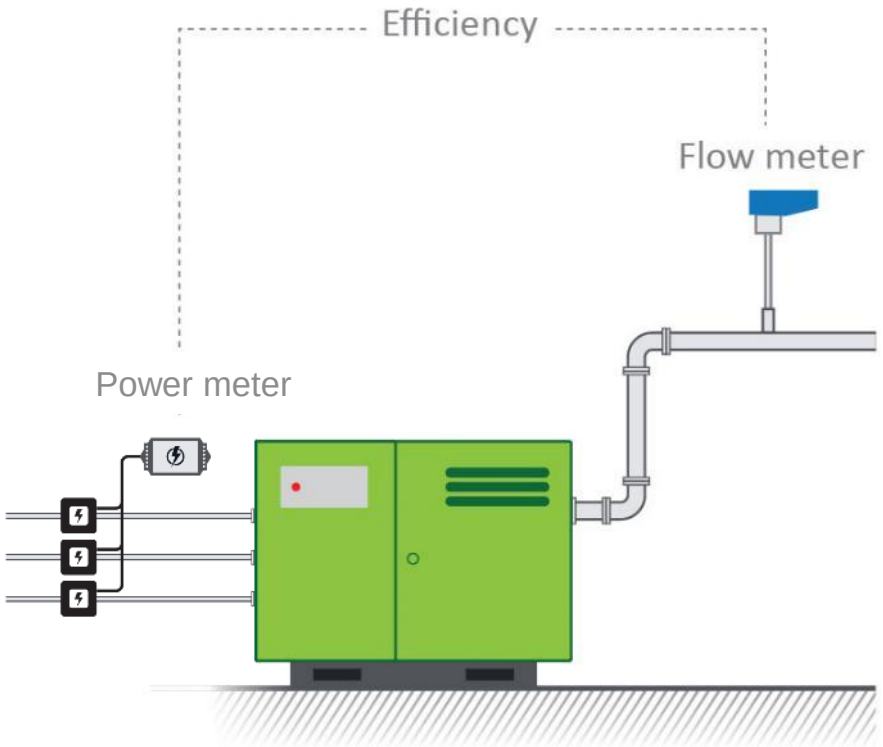
KPI: Specific power / compressor efficiency

- kW / 100 scfm
- ISO 1217 (acceptance tests)
- Mandatory in some states
  - Title 24 (California)
  - Tax incentives
  - EED (Europe)



22

kW/100 scfm

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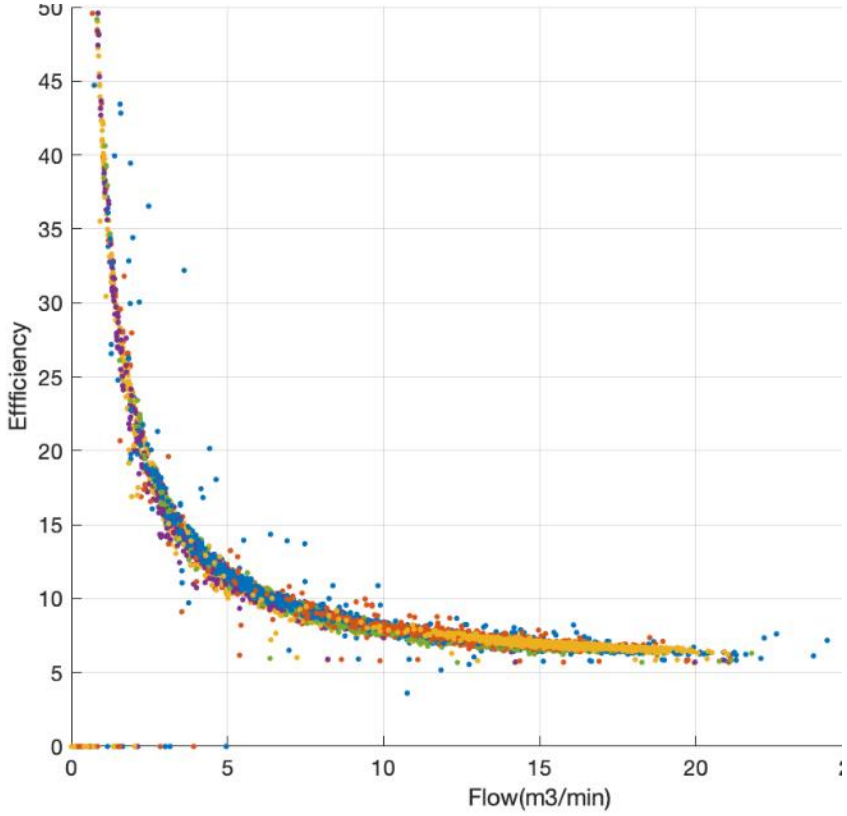
Specific power / compressor efficiency

Why specific power is important:

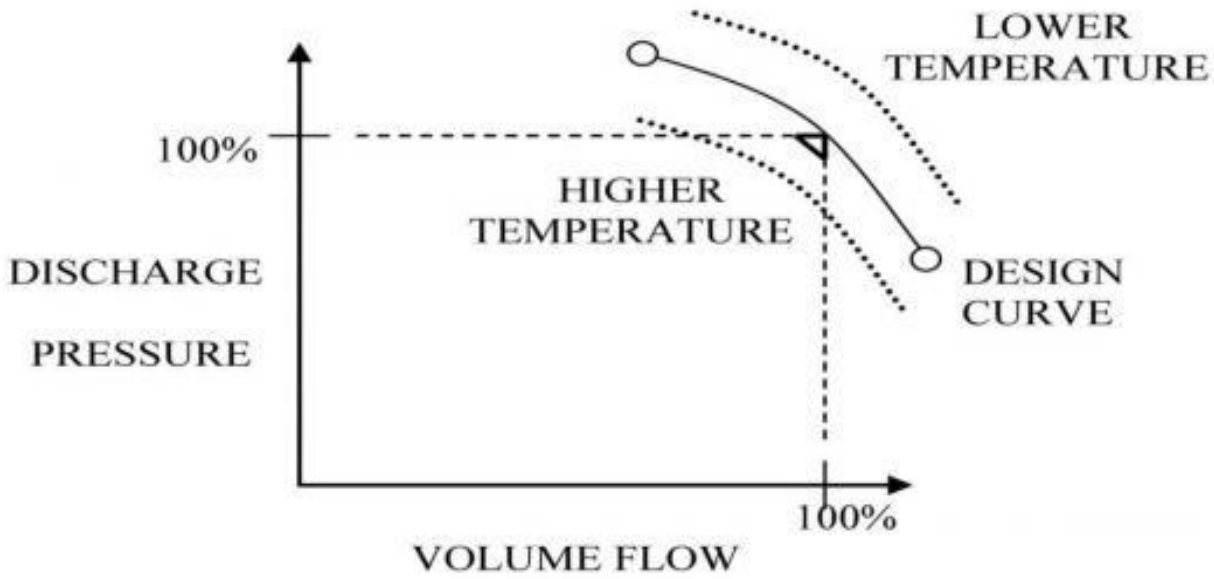
- Maintenance management
- Flow based (smart) control
- Master controller selection / optimization



Specific power: Environmental factors

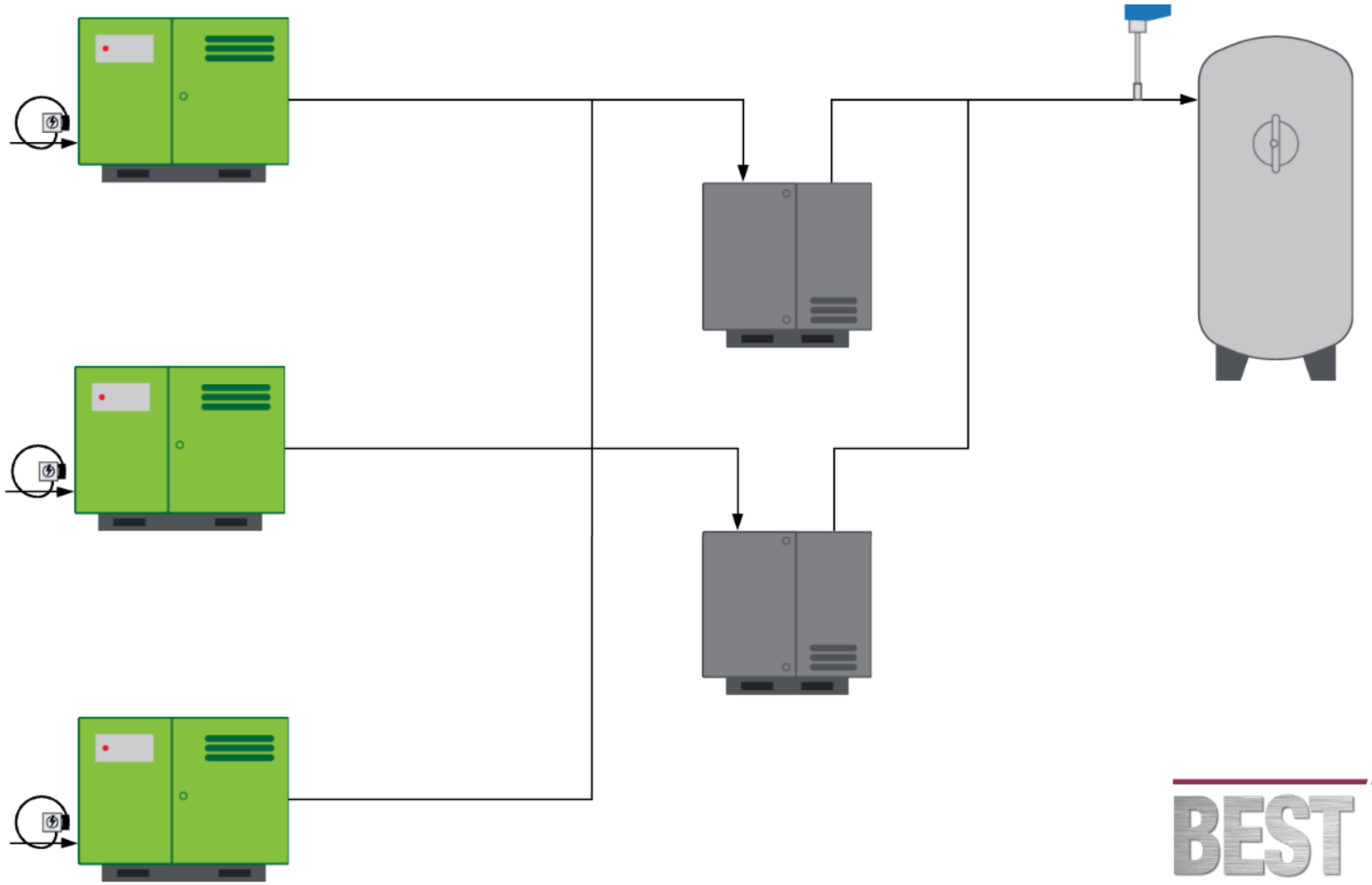
- Ambient pressure
- Ambient temperature
- Cooling water temperature

→ Monitor them all

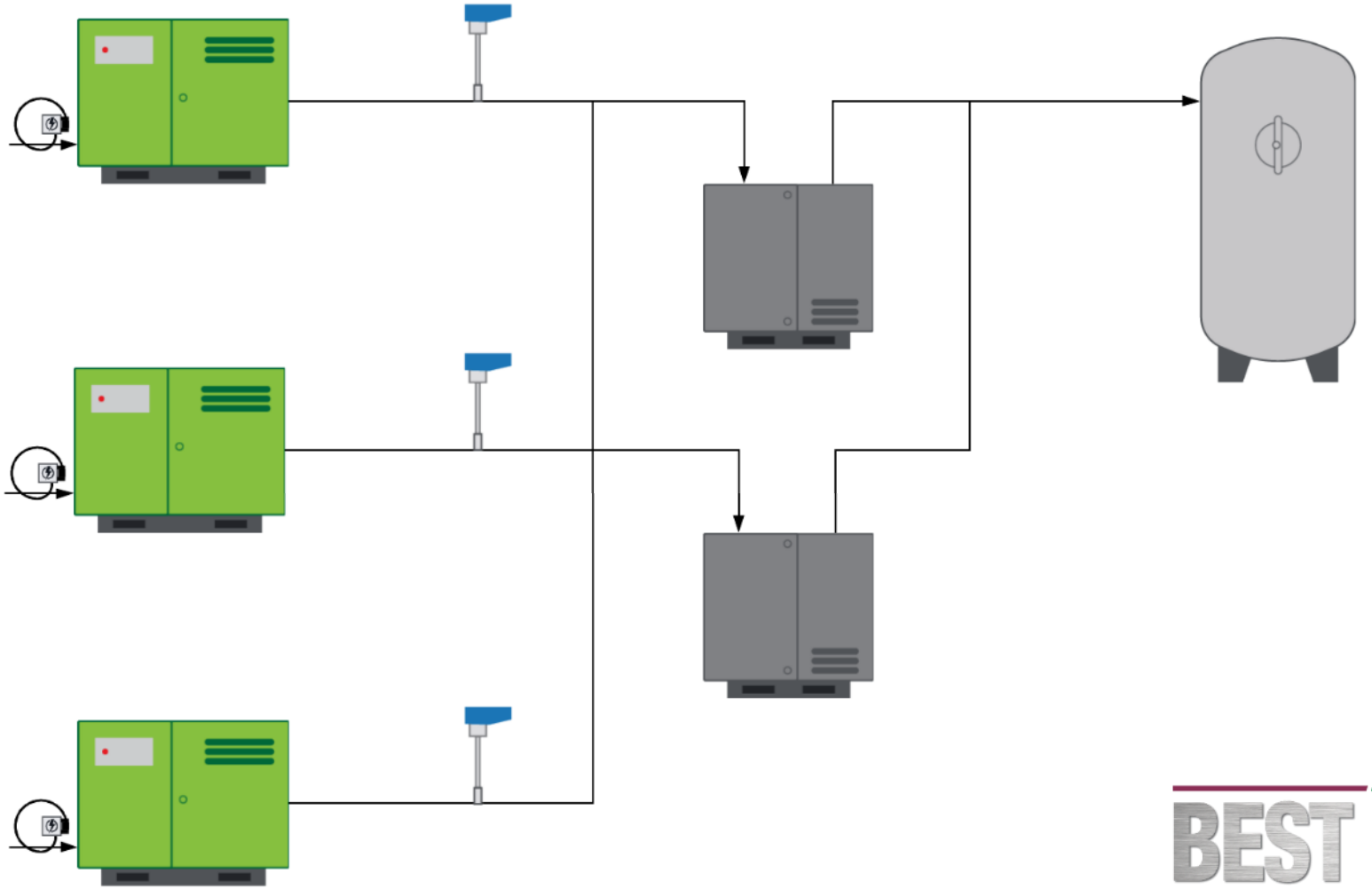


Impact of inlet conditions
Airbestpractices.com

Scenario 1: Efficiency of all compressors combined



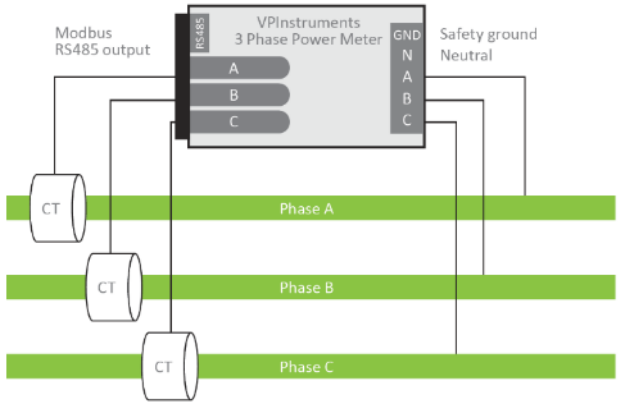
Scenario 2: Efficiency of each compressor



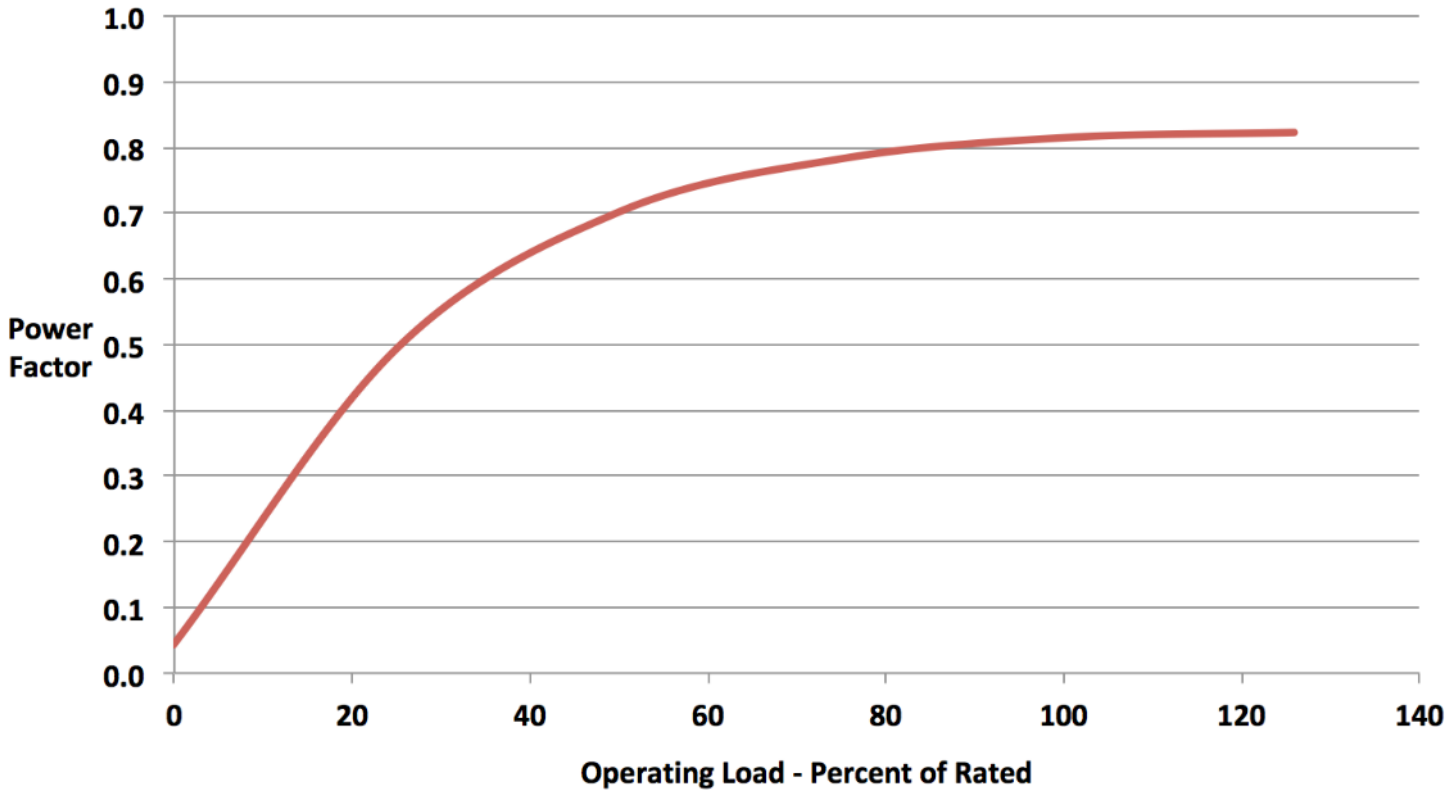
Power measurement

- Power meter classes (0.5 / 1 / 2)
- Take a CT that can measure current and voltage
- Amp meter: $P^*_{(kW)} = \sqrt{3} \times PF \times I_{(A)} \times V_{(V)} / 1000$
- Accuracy can vary:
  - 1 or 3 phase measurement
  - Measured voltage: tolerance & accuracy of potential transformers
  - Tolerance measured current
  - Balance between voltages
  - **Power factor (PF) assumption (cos phi)**

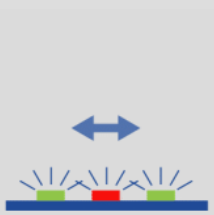
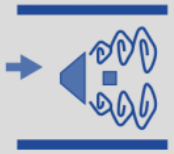
***** Line to line Voltage based



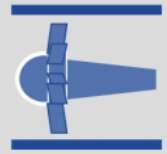
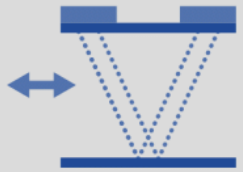
Power factor as function of load



Flow measurement technologies

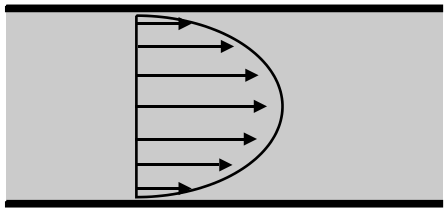


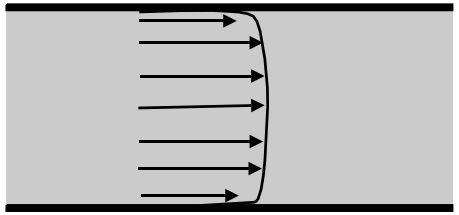
	Thermal	Vortex	DP – Orifice plate	DP – Cone meter	Coriolis	Turbine/ rotary displacement	Clamp on ultrasonic
Mass flow	Yes	Optional	Optional	Optional	Yes	Optional	Optional
Meter run	20D	15D	15D	5D	0D	10D	20D
Pressure loss	Low	Medium/high	high	high	Low	Low	Low
Dirty air	Fouling	OK	Clogging	Clogging	Internal fouling	Faillure	OK
Wet Air	Spikes	OK, spikes	OK	OK, orientation	Yes, but affects reading	Faillure	Spikes
Range	1:250	1:10	1:10	1:10	1:100	1:100	1:100
Accuracy	2%	2%	2%	2%	0.5 .. 1%	0.5…1 %	1%
Purchase price	$	$	$	$	$$$$	$$	$$$
Maintenance	Medium	Low	Medium	Medium	Low	High	Low

Insertion/ single point flow meters: Profile

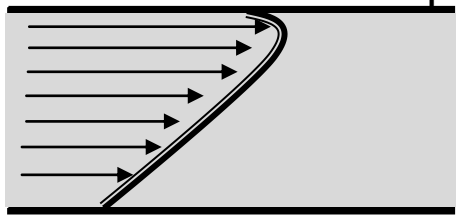
Laminar flow profile

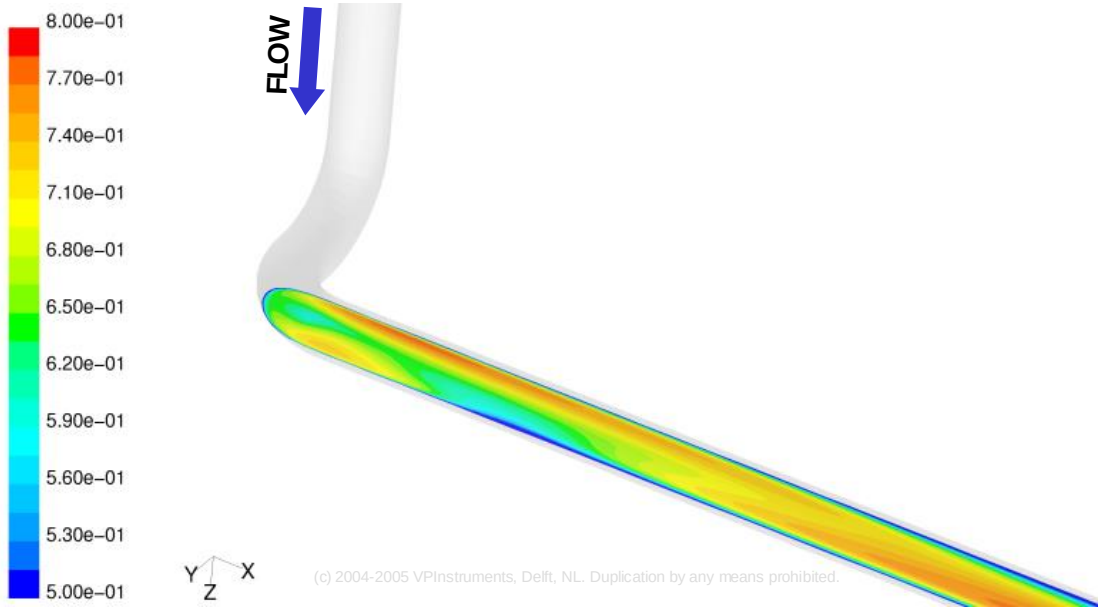


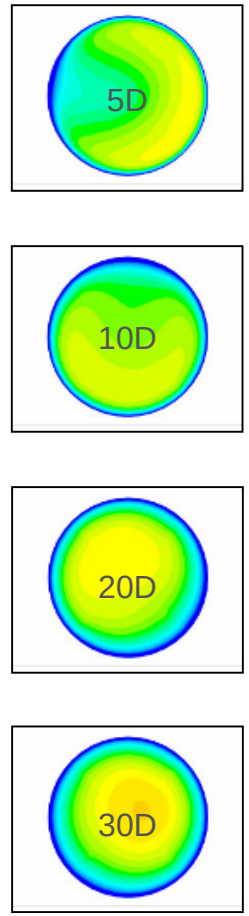
Turbulent flat profile after 20..40 D



Distorted Turbulent profile 10D







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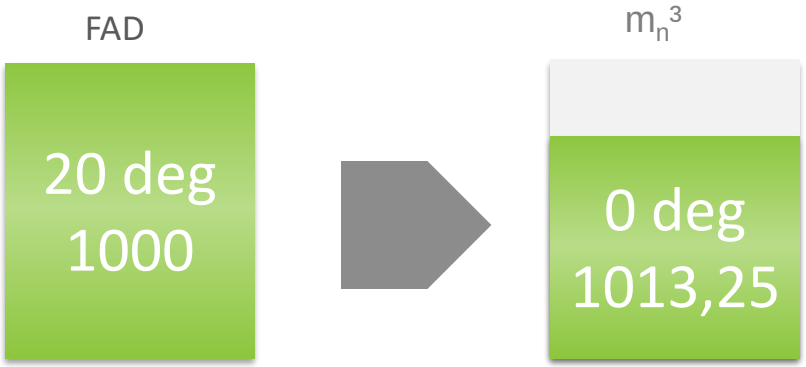
Reference conditions: Comparing apples with apples

- Volume flow vs. mass flow. (CFM/time vs pound/time)
- Mixing compressor types: Centrifugal vs Screw: mixing reference conditions
- A few reference conditions:
  - 32˚F reference (Normalized): DIN 1343
  - 68˚F reference (FAD): See ISO 1217
  - 59˚F reference: See DIN 1533 or ISO 2533



- From FAD to normal: 8,7% difference!

  100 SCFM FAD ∗ 273,16/(273,16+20) * 1000/1013,25 = **91,95 SCFM** (Normalized)

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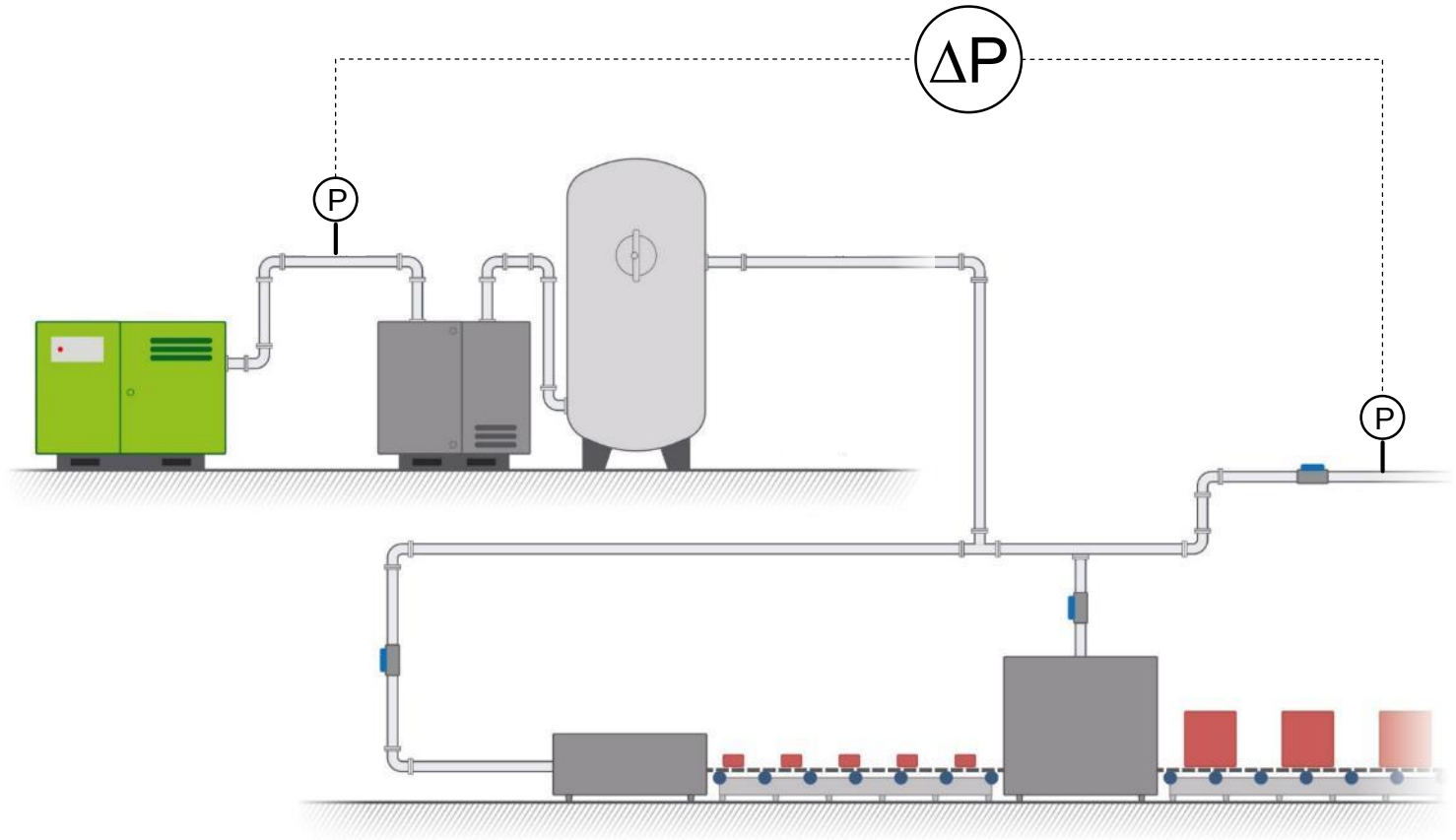
Compressor discharge flow

- Condensate
- Temperature swings
- Reverse flow
- Short pipe run
- Vibrations

Compressor efficiency – take aways

- Accuracy vs. goal of the measurement: Just trending or legal compliance?
- Be aware of uncertainties (cos phi and flow)
- Take latency into account in real-time measurements
- Choose reference conditions and stick to them

KPI: Pressure loss



5.3

ΔP - psi

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KPI: Pressure loss

- Power is in the combination: Pressure + Flow measurement
- Trend monitoring rather than absolute measurements
- Pre-event early warning
- Disclaimer: Filters do age: **follow supplier instructions**

Example: filter replacement → Accuracy

- 500 psi sensor, 0.5% full scale -> +/- 2.5 psi
- Two new P sensors: 5 psi difference at zero flow --> filter replacement?
- Check pressure difference in reading at “0 flow” state,
  or: use DP cell to avoid this
- Be aware of initial state, and trend

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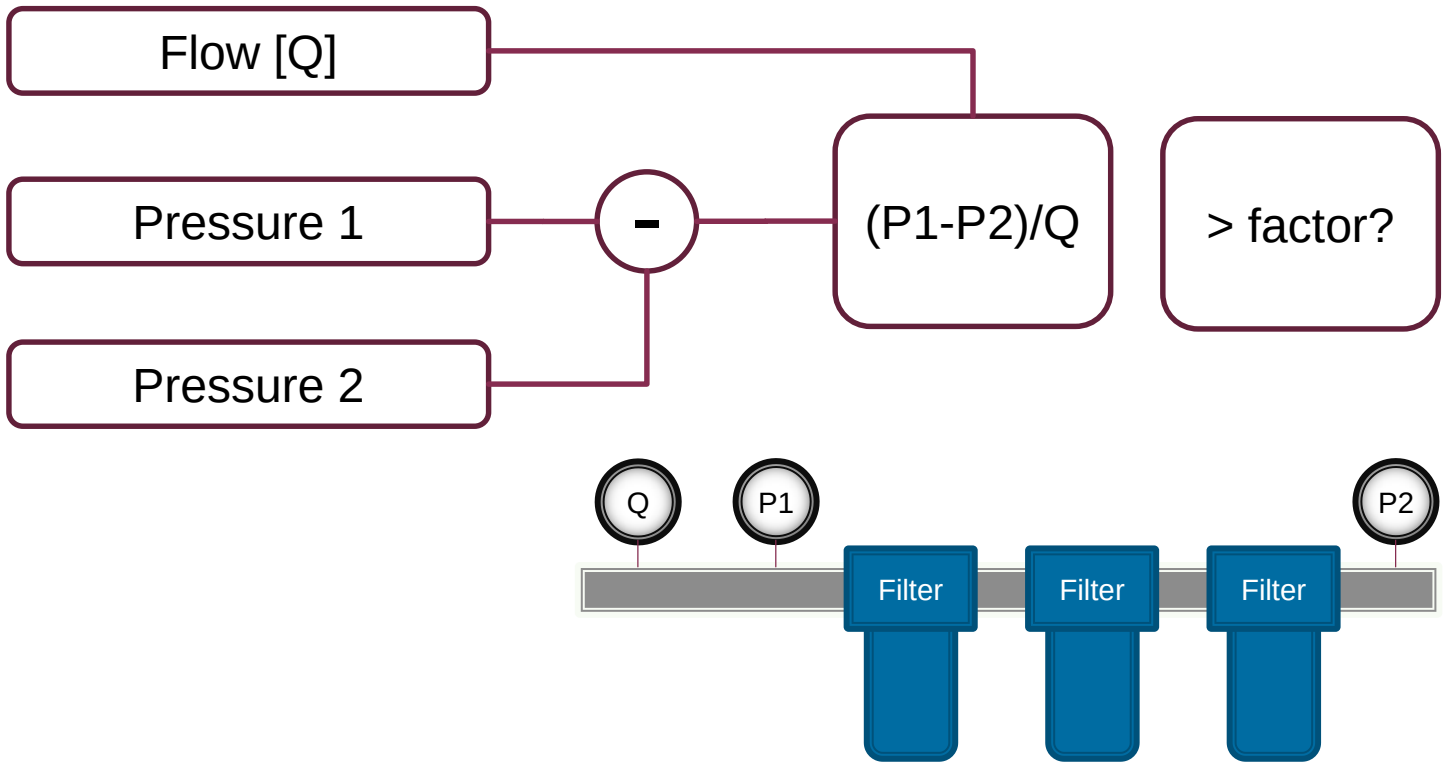
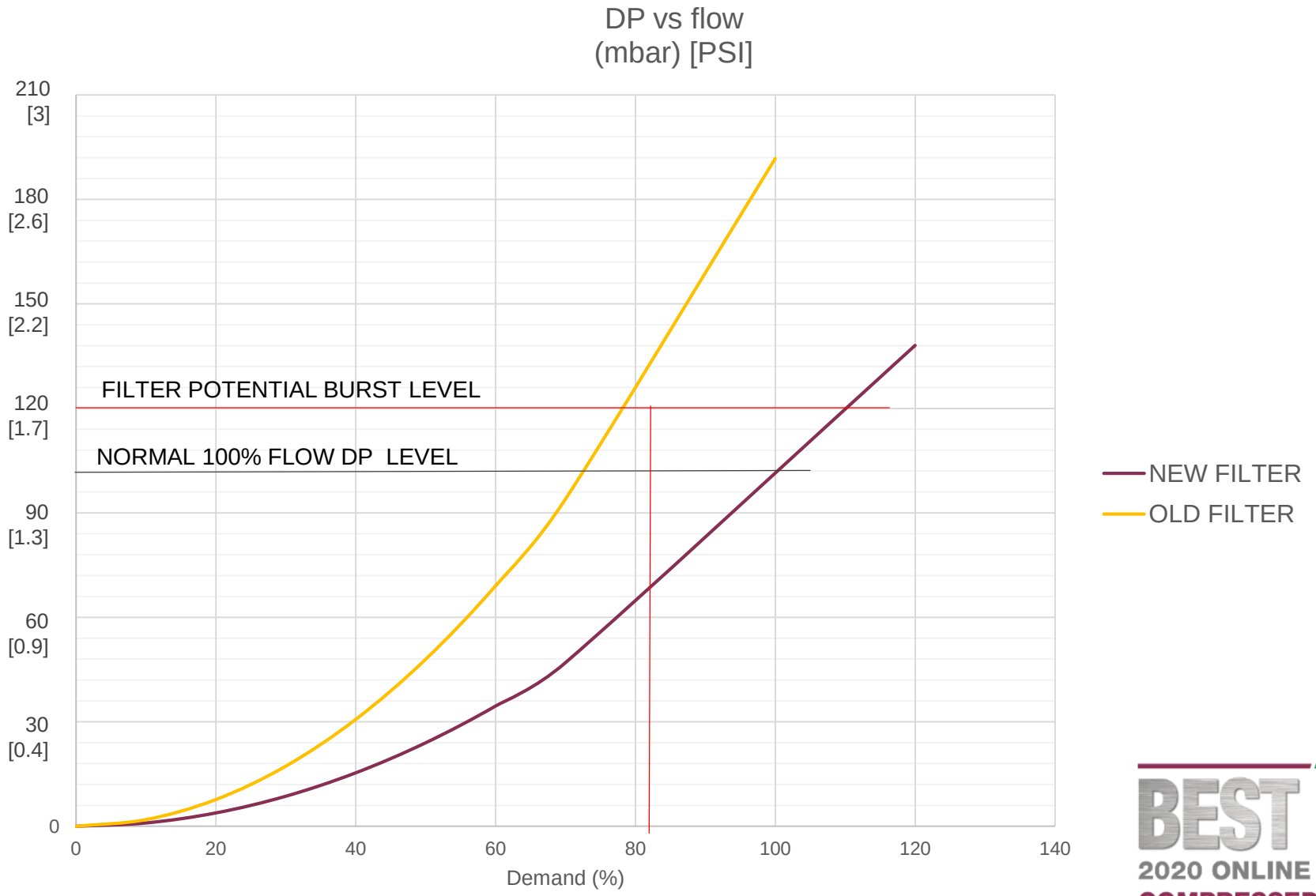
Example: filter replacement



Example: filter replacement



Compressor capacity or pressure loss?

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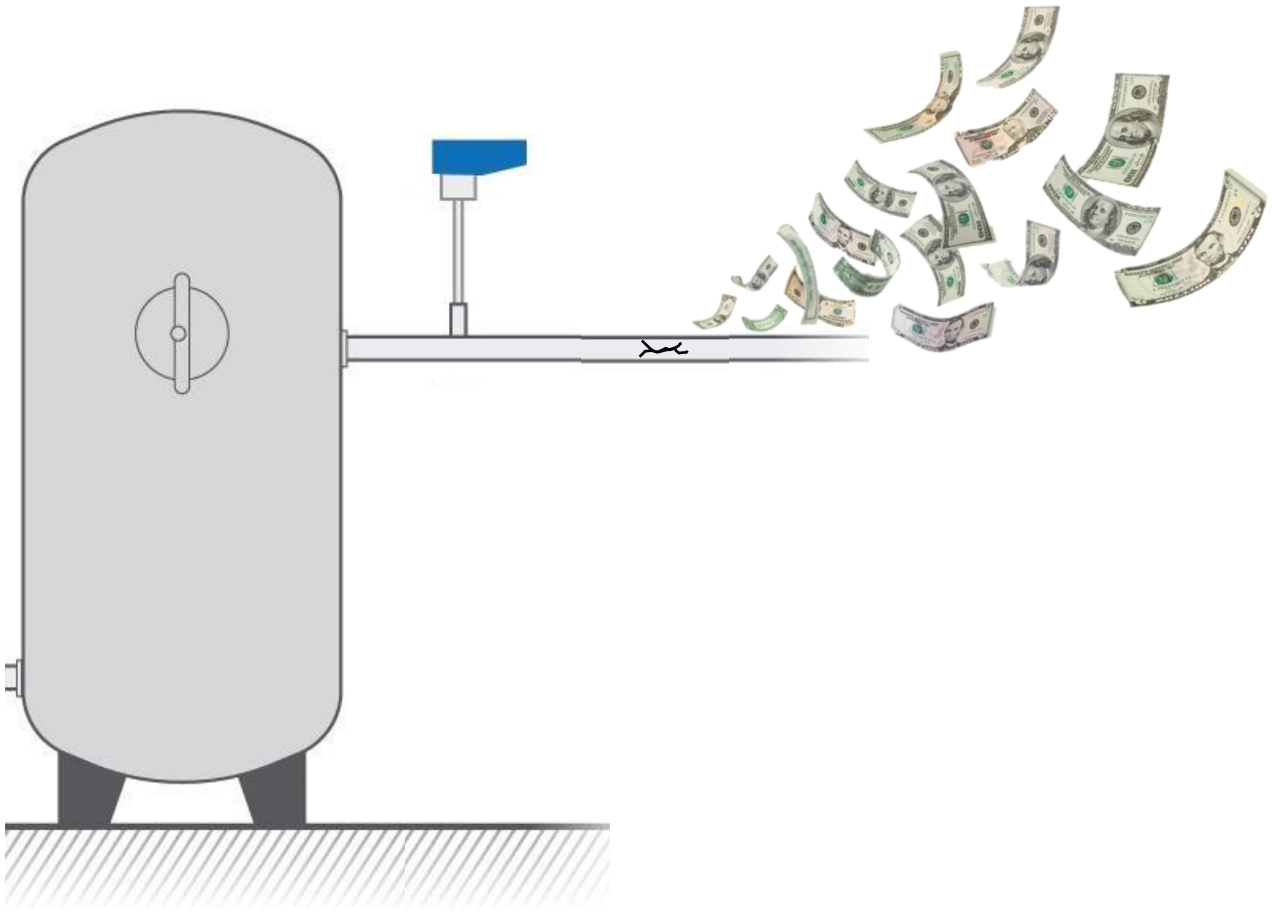
KPI: Leakage level



30%

Leakage

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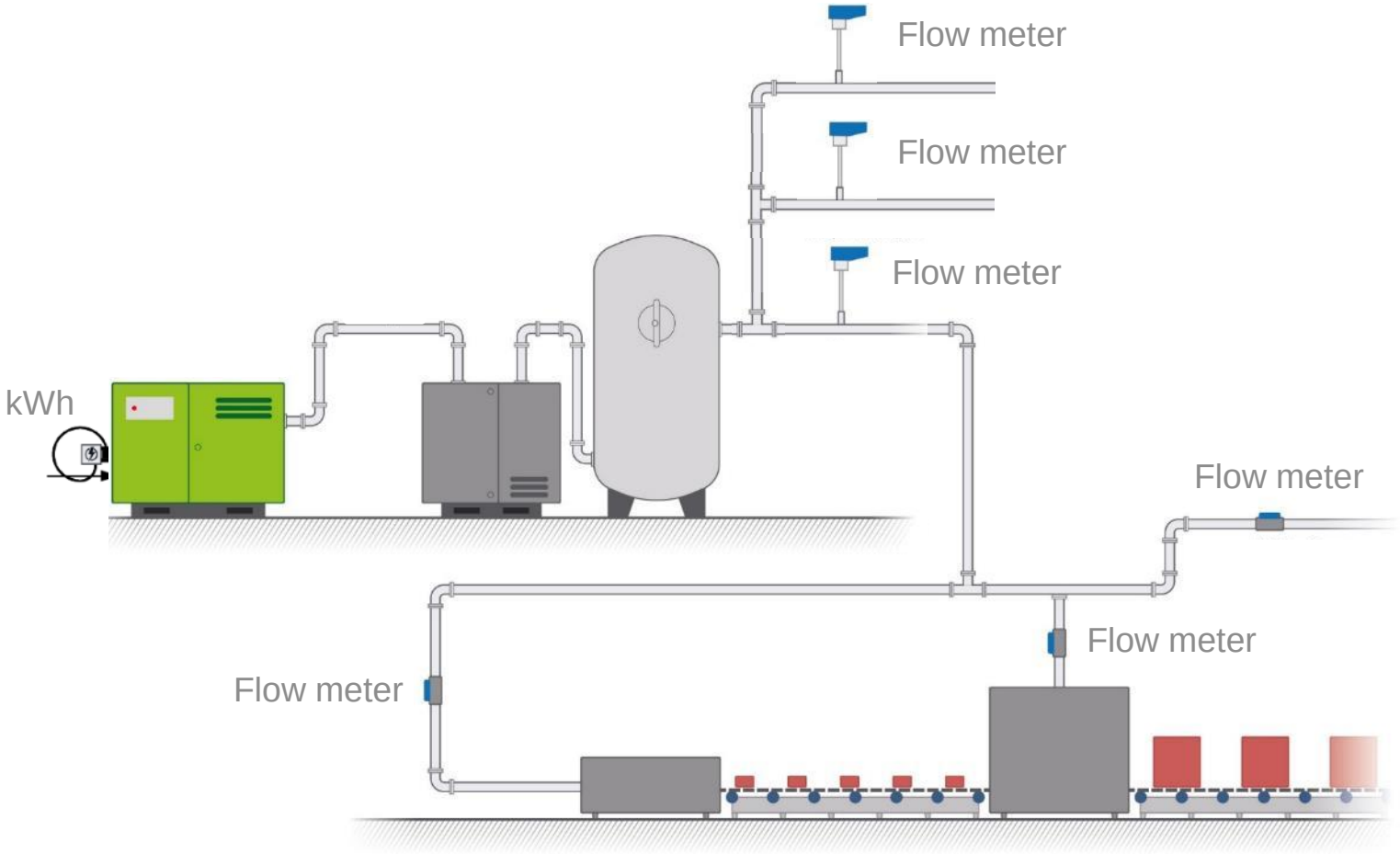
KPI: Leakage level

- Leakage costs: Measure power consumption in downtime
- What to do in a 24/7 factory?
- Ultrasonic leak detection is subjective and time consuming
- How to find the leaks in an efficient way?

Leak allocation



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Leak allocation accuracy

- Flow meters show instant readings where pressure decay measurement can take a lot of time
- Use kWh meters as “master” meters and flow meters to calculate % consumption per area
- Detect unusual consumption patterns: Leakage
- Leakage % is a relative number, so systematic errors can be reduced or even cancelled out

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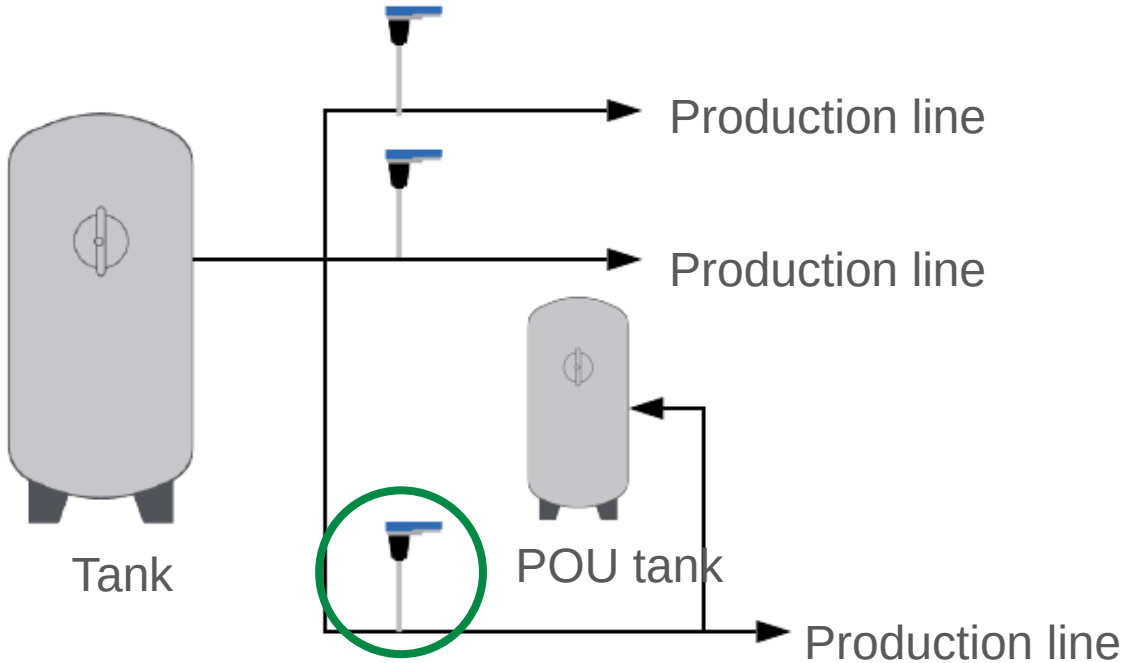
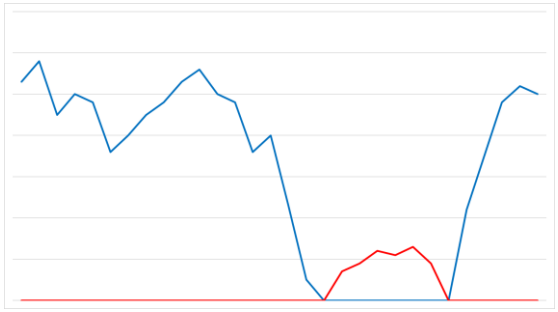
Leak allocation: Bi-directional flow example

Demand side (reverse flow)

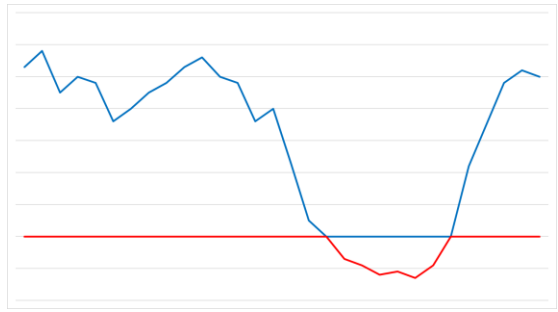


Flow



Flow

+3500 ft^3



+3300 ft^3
- 200 ft^3

+3100 ft^3

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24/7 Factories: how to derive leakage% KPI

- Measure air consumption during down time if possible
- Check air consumption before/after repair
- Isolate machines if possible
- Use a permanent monitoring system

Permanent monitoring

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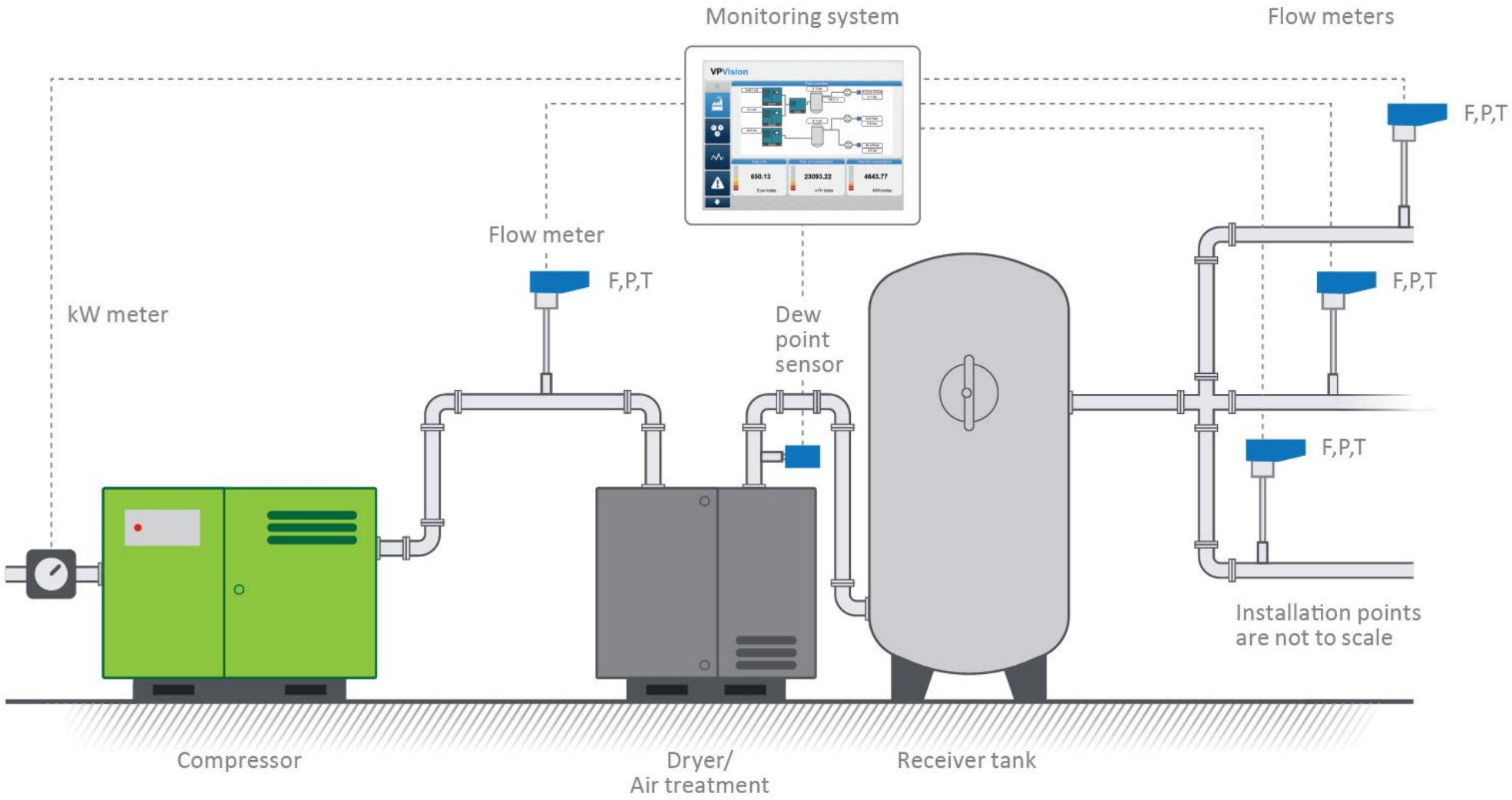
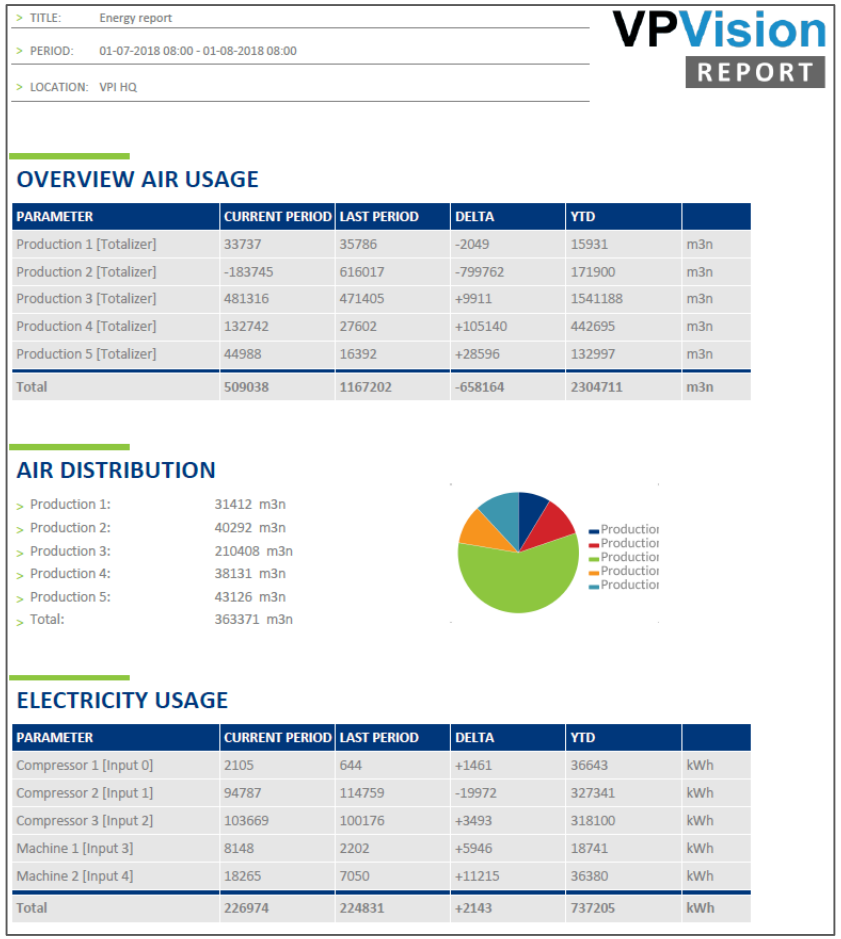
Permanent monitoring



KPI Automated reports and alarms example Report

- Weekly updates with KPI's and other important data
- Summarizes alarms on important KPI's / measurement data
- Provide key data to (remote) auditors



> TITLE: Energy report

> PERIOD: 01-07-2018 08:00 - 01-08-2018 08:00

> LOCATION: VPI HQ

VPVision REPORT

OVERVIEW AIR USAGE

PARAMETER	CURRENT PERIOD	LAST PERIOD	DELTA	YTD	
Production 1 [Totalizer]	33737	35786	-2049	15931	m3n
Production 2 [Totalizer]	-183745	616017	-799762	171900	m3n
Production 3 [Totalizer]	481316	471405	+9911	1541188	m3n
Production 4 [Totalizer]	132742	27602	+105140	442695	m3n
Production 5 [Totalizer]	44988	16392	+28596	132997	m3n
Total	509038	1167202	-658164	2304711	m3n

AIR DISTRIBUTION

> Production 1: 31412 m3n
> Production 2: 40292 m3n
> Production 3: 210408 m3n
> Production 4: 38131 m3n
> Production 5: 43126 m3n
> Total: 363371 m3n

ELECTRICITY USAGE

PARAMETER	CURRENT PERIOD	LAST PERIOD	DELTA	YTD	
Compressor 1 [Input 0]	2105	644	+1461	36643	kWh
Compressor 2 [Input 1]	94787	114759	-19972	327341	kWh
Compressor 3 [Input 2]	103669	100176	+3493	318100	kWh
Machine 1 [Input 3]	8148	2202	+5946	18741	kWh
Machine 2 [Input 4]	18265	7050	+11215	36380	kWh
Total	226974	224831	+2143	737205	kWh

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Conclusions

- Have a clear goal in mind and derive your KPI’s from it
- Accuracy of measurement should serve your goal
- Combine measurement data to get better insights
- Best results can be achieved with just a few KPI’s
- Permanent monitoring systems make your life easier

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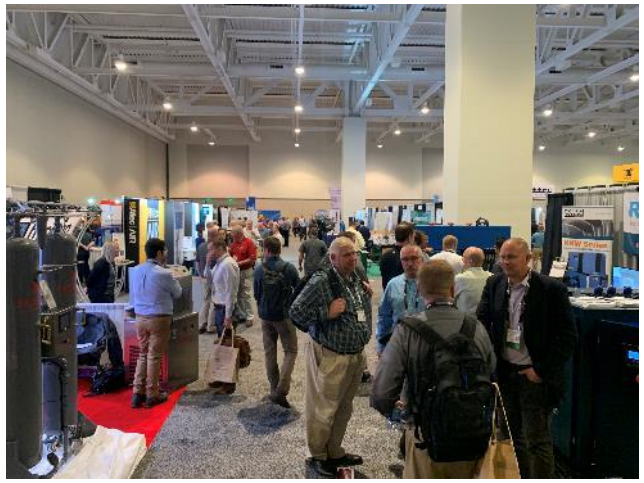

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Renaissance Schaumburg Convention Center Hotel
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Questions

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