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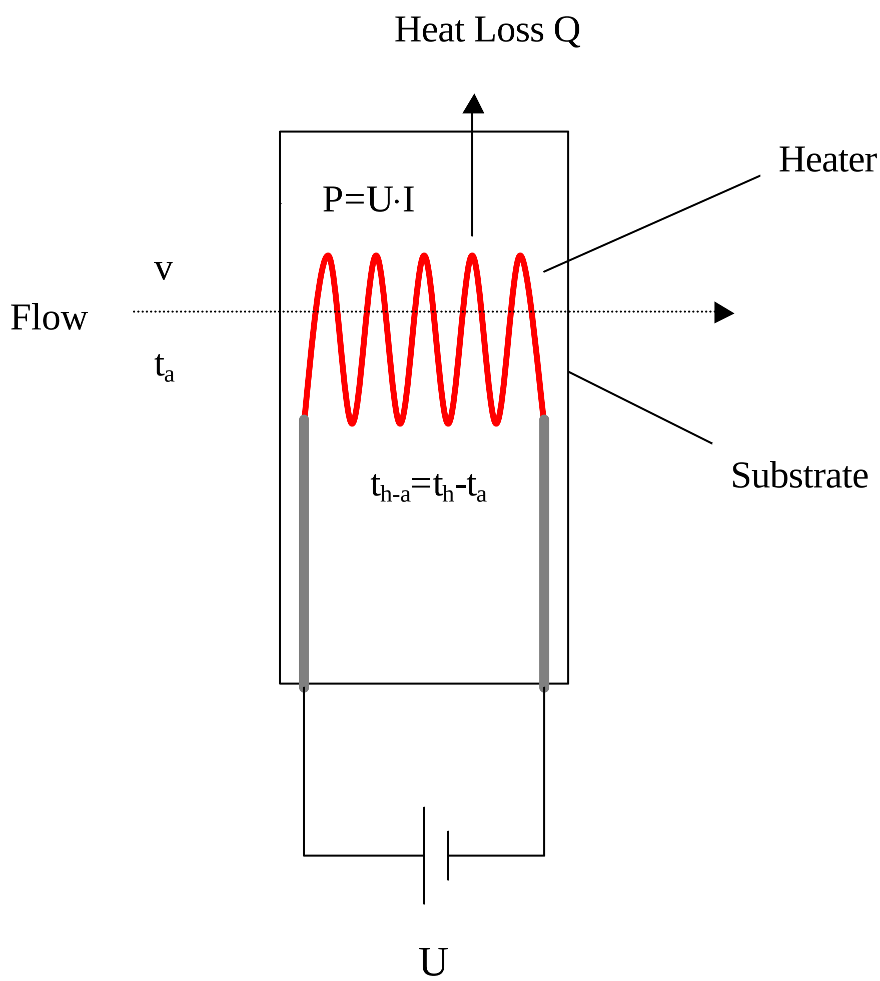
Flow Velocity Measurement
Principles of Hot Film Anemometry

The hot film anemometer (HFA) is made of a thin, structured, metallic resistive film ("heater") which is deposited onto a substrate. In the operating state of the HFA the electrical power P heats the heater up to a temperature t_h. A (air-) flow with velocity v and ambient temperature t_a cools the heater down until an equilibrium between the electrical Joule heat and the thermal heat loss Q is reached. The higher the velocity v and the difference $t_{h-a}=t_h-t_a$ ("overheating temperature" t_{h-a}) between the heater temperature t_h and the fluid temperature t_a, the higher is the heat loss from the heater. The overheating temperature t_{h-a} depends further on the ambient temperature t_a, which can change. Therefore t_{h-a} is measured with an additional temperature sensor which is often part of a bridge circuit in order to compensate changes in the ambient temperature automatically.

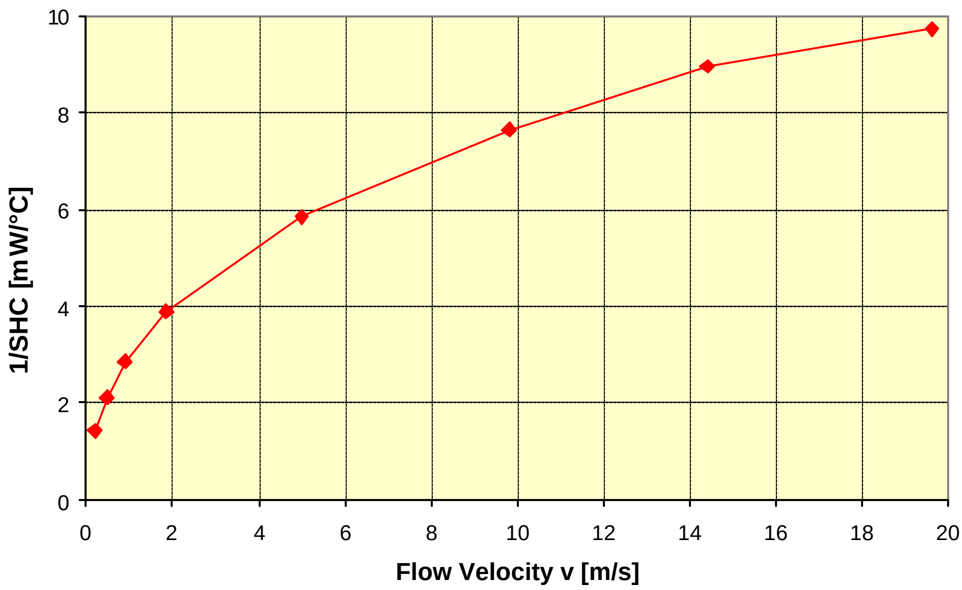


Flow Velocity Measurement – Constant-Temperature-Anemometer

The Constant-Temperature-Anemometer (CTA) determines the flow velocity v by measuring the power P for keeping the overheating temperature $t_{h\text{-}a}$ constant. This method achieves higher sensitivities than measuring directly the change of the overheating temperature with flow velocity.
The characteristic of the heater is described by the self heating coefficient SHC ($t_{h\text{-}a}$=constant)

$$SHC(v) = \frac{t_{h-a}}{P} = \frac{t_h - t_a}{P(v)}$$

which depends on the flow velocity. So after a proper calibration of your system you can determine the flow velocity from the value of the self heating coefficient.



Typical 1/SHC(v)-characteristic for t_a=25°C, $t_{h\text{-}a}$=40°C

Keeping the overheating temperature $t_{h\text{-}a}$ constant requires a system control which is usually done using the well known **Wheatstone bridge** circuit: when flow velocity increases the heater resistance and the overheating temperature $t_{h\text{-}a}$ decreases. So the bridge gets out of balance and the amplifier converts the resulting voltage input signal into an output signal for increasing the current in a feedback loop so that the overheating temperature $t_{h\text{-}a}$ is reached again.

FAQ-What is the influence of atmospheric pressure on the air velocity measurement?

Measurement of the air velocity with a hot film-anemometer (which is the principle of the E+E transmitters) is dependant on the actual air pressure p.

E+E transmitters are calibrated at p_0=1013.25 mbar. Measuring air velocity at a height h you have to correct the measuring value according to the barometric formula (p_0=1013 mbar, H=8005 m) :

$$p_h = p_0 \cdot e^{-\frac{h}{H}}$$

Practically you have simply to multiply the measured velocity value v_T with a correction factor (from the table below) which depends on your actual height h.

Example: If you measure v_T=10m/s at a height h=800m, then the real flow velocity is v=10·1,105 m/s=11,05m/s.

h [m]	p[Torr=mm Hg]	p[hPa=mbar]	p[atm]	p[at=kp/cm²]	correction factor
0	760,0	1013,25	1	1,03323	**1,000**
50	755,3	1006,94	0,994	1,027	**1,006**
100	750,6	1000,67	0,988	1,020	**1,013**
150	745,9	994,44	0,981	1,014	**1,019**
200	741,2	988,25	0,975	1,008	**1,025**
300	732,0	975,98	0,963	0,995	**1,038**
315	730,7	974,15	0,961	0,993	**1,040**
500	714,0	951,90	0,939	0,971	**1,064**
800	687,7	916,88	0,905	0,935	**1,105**
1000	670,8	894,26	0,883	0,912	**1,133**
1500	630,1	840,11	0,829	0,857	**1,206**
2000	592,0	789,24	0,779	0,805	**1,284**
2500	556,1	741,45	0,732	0,756	**1,367**
3000	522,5	696,56	0,687	0,710	**1,455**
4000	461,1	614,76	0,607	0,627	**1,648**
5000	407,0	542,57	0,535	0,553	**1,868**
6000	359,2	478,85	0,473	0,488	**2,116**
7000	317,0	422,62	0,417	0,431	**2,398**
8000	279,8	372,99	0,368	0,380	**2,717**
9000	246,9	329,19	0,325	0,336	**3,078**
10000	217,9	290,53	0,287	0,296	**3,488**

FAQ-How do you convert air velocity into mass flow ?

You start from the

general gas equation

$$\frac{p \cdot V}{T} = \text{konstant}$$

the definition of the **massflow Q** [kg/s]

$$Q = r \cdot v \cdot F$$

the definition of the **specific massflow q** [kg/(s·m²)]

$$q = r \cdot v$$

p	[mbar]	pressure
V	[m^3]	volumne
T=t+273.15	[K]	absolute temperature
t	[°C]	temperature
ρ	[kg/m^3]	density
v	[m/s]	flow velocity
F	[m^2]	flow cross section

With the air density ρ, absolute temperature T and atmospheric pressure p you get with the general gas equation

$$r = r_0 \cdot \frac{p}{p_0} \cdot \frac{T_0}{T} \quad [kg/m^3]$$

with

T_0=273.15 K absolute normal temperature

ρ_0=1.2922 kg/m^3 the density of air at normal conditions

p_0=1013.25 mbar the air pressure at normal conditions

The **specific mass flow q** comes out from a temperature- and pressure independent measurement of the air velocity v (which can be done e.g. with a Laser Doppler Anemometer (LDA)) :

$q = 0.3483 \cdot \frac{p}{(273.15 + t)} \cdot v$	[kg/(s·m²)]

Application to EE-Transmitters

The EE transmitters are temperature compensated, but not pressure compensated. Thus you get a systematic error on your air velocity measurement due to the barometric pressure.

The transmitters are calibrated at a normal pressure of p_0= 1013.25 mbar so the measured air velocity is

$v_T = v \cdot \frac{p}{p_0}$	[m/s]

However the real and actual air velocity v is

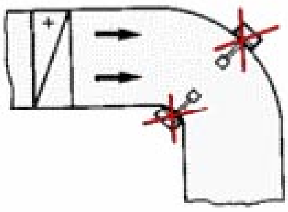
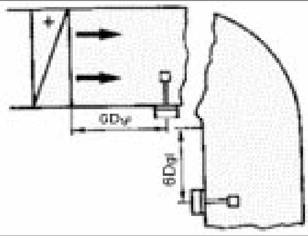
$v = v_T \cdot \frac{p_0}{p}$	[m/s]

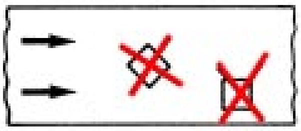
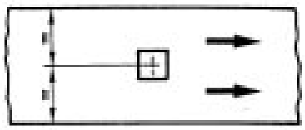
If you insert this into the expression of the specific mass flow you get

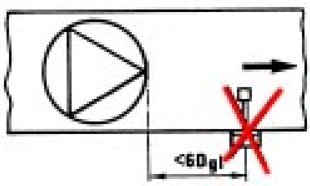
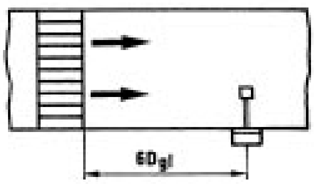
$q = \frac{353}{273.15 + t} \cdot v_T$	[kg/(s·m²)]

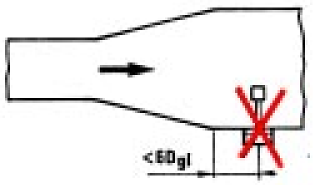
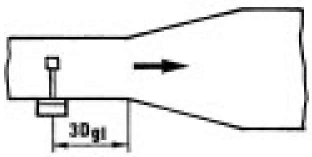
FAQ-How do you install E+E air velocity transmitters?

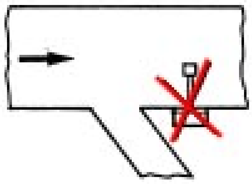
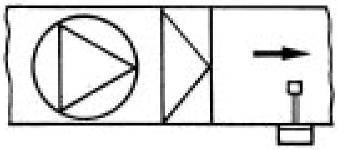
Important guidelines for rectangular ducts (cross section a x b) :

$D_{gl} = 2 \cdot a \cdot b / (a + b)$		

		Probe in the middle of the channel

		Preferred mounting after filters, rectifiers, coolers (no twist there)

		Place the probe in front of diffusers or confusers

		Filters and coolers calm down the air flow

Generally you should have long straight ducts after bends in pipes, turn offs, behind flaps, fans or changes in cross-sections in order to maintain a laminar flow.

FAQ-What about the angular dependence of E+E air velocity transmitters?

The right shape of the transmitter measuring probe is significant for the accuracy of the velocity measurement. It is essential for an accurately measured value when the transmitter is turned around its longitudinal axis out of the right position.

E+E transmitters are excellent in this field and show only a small angular dependance. We optimize our transmitters by use of a Laser Doppler Anemometer (LDA) in development and calibration for achieving best results.