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Efficient compressed air production

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Abstract

Compressed air is often referred to as the fourth utility. We all know the generation of compressed air consumes energy but at the same time the compressor and downstream components are often neglected, which means there are significant savings to be made. It is suggested that savings of around 33 % on average in a compressed air system are possible. It follows that cost effective compressed air production is energy efficient compressed air production, as energy is by far the biggest lifetime cost factor.

Many of the different levers for cost reduction may be known, but just not applied, due to lack of knowledge about the financial savings possible. This paper shows and explains the different ways to efficient compressed air production (leakages, compressor selection, pressure losses, …) and gives simple calculation examples that are easy to follow and to be reproduced in your compressed air stations.

Efficient compressed air production

Compressed air is one of the most important utilities used in industrial applications world wide; if not the most important. There is hardly any industrial facility working without compressed air. Two reasons are its unique flexibility and easy handling. Many processes depend on compressed air, therefore compressed air will definitely remain an important driver for production in the future.

Compressed air has been in use for many years. The first known application is almost as old as our Christian time scale. Over the years industry became used to the presence of compressed air. It is just there, a utility, very much comparable to electricity in a private household. But just like electricity compressed air does have its costs. Due to ever increasing energy prices the cost for generating compressed air has moved more and more into the focus of the managers responsible for generating it. In former years the situation was different. Compressed air stations or compressed air production was more or less a neglected part of any facility. Energy efficiency was not in focus and any possible saving potential was never contemplated. This resulted in a rather bad reputation of compressed air today. Many compressor stations actually do not work efficiently. However this is not a general problem of compressed air itself but only a problem of ignoring the high energy saving potential that is undoubtedly available. Compressed air is definitely a viable and safe utility. The skill is knowing and practising the methodology to reduce the generation and distribution costs to a minimum.

Costs of compressed air

When buying a new compressed air station, especially with the smaller motors, say 22 kW and below, the usual situation is that supplier and purchaser only talk about investment costs or maintenance costs. Energy costs are rarely discussed. Therefore a vital part of the equation is missed. Three cost factors are most important: Energy costs, investment costs and maintenance costs. Depending on the annual working hours of the compressor the proportion of these three factors is slightly different.

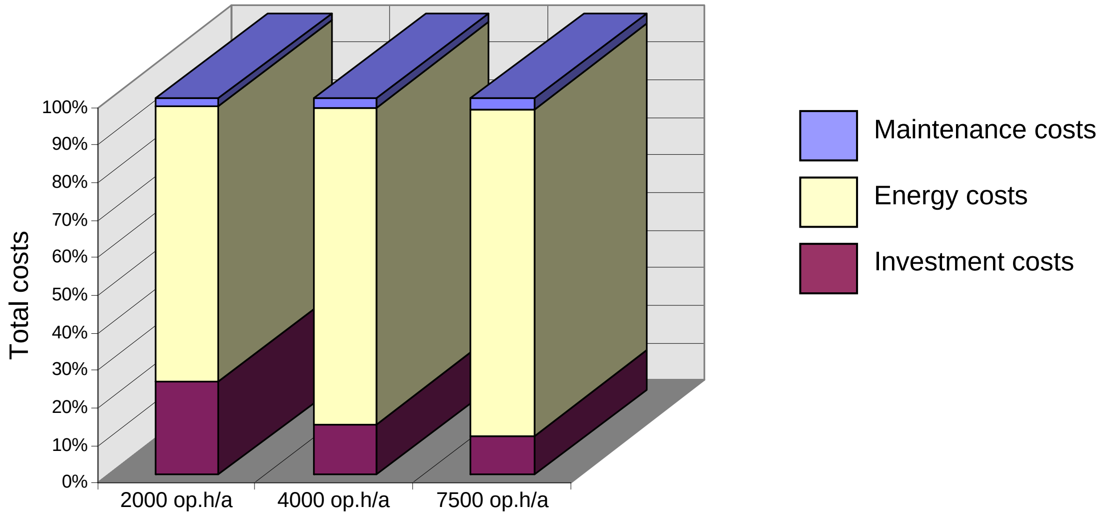
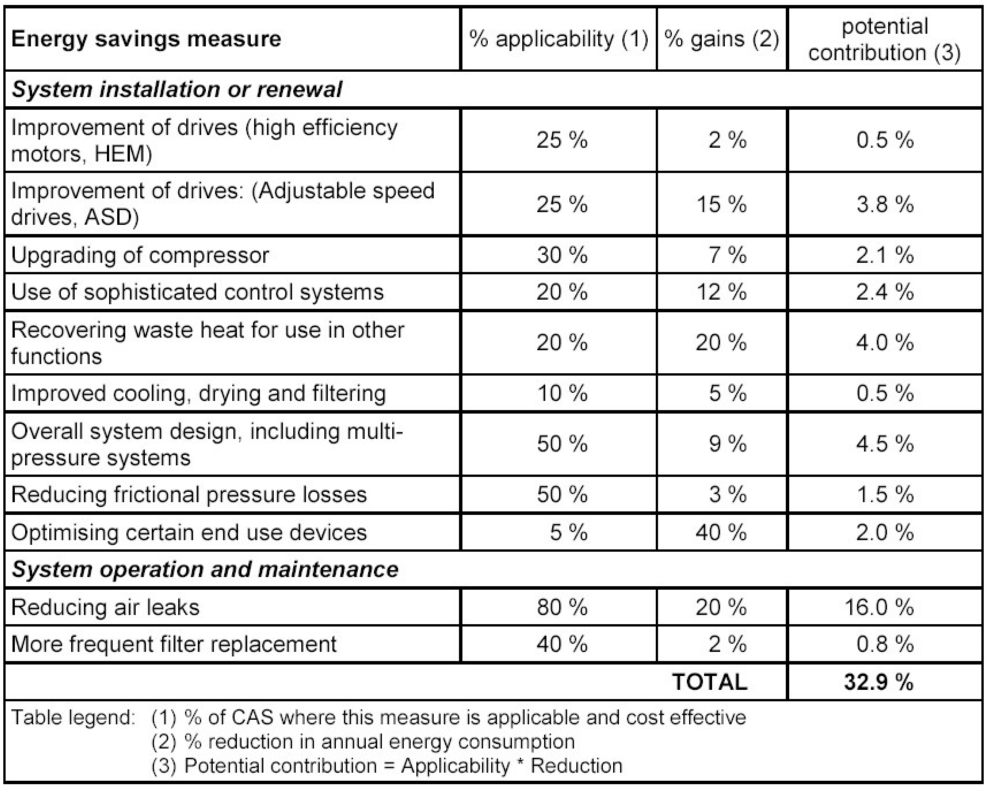


Fig. 1: Cost factors for compressed air production [1]

Fig. 1 clearly shows that energy is the biggest factor in the cost of compressed air, no matter how many hours per year the compressor is in use. The significance of energy costs rise even more with increased operating hours. The investment costs only form a small percentage of the total costs and clearly do not represent the amount of time spent in all those negotiations during the buying process. Also the maintenance costs are less important, compared to the total costs. As the energy costs have the biggest share it should be very clear that this is the area that should be tackled when talking about reducing costs. Reducing costs basically means reducing energy consumption.

In 2001 a study was published by Peter Radgen and Edgar Blaustein called “Compressed Air Systems in the European Union”. This study analysed the situation of compressed air stations in the European Union and found out that, in that time in the European Union, about 321,000 industrial compressed air systems (CAS) were in use, consuming about 80 billion kWh of energy per year. The study also analysed the possible energy saving potential for these compressor stations. (Fig. 2)



Energy savings measure	% applicability (1)	% gains (2)	potential contribution (3)
System installation or renewal			
Improvement of drives (high efficiency motors, HEM)	25 %	2 %	0.5 %
Improvement of drives: (Adjustable speed drives, ASD)	25 %	15 %	3.8 %
Upgrading of compressor	30 %	7 %	2.1 %
Use of sophisticated control systems	20 %	12 %	2.4 %
Recovering waste heat for use in other functions	20 %	20 %	4.0 %
Improved cooling, drying and filtering	10 %	5 %	0.5 %
Overall system design, including multi-pressure systems	50 %	9 %	4.5 %
Reducing frictional pressure losses	50 %	3 %	1.5 %
Optimising certain end use devices	5 %	40 %	2.0 %
System operation and maintenance			
Reducing air leaks	80 %	20 %	16.0 %
More frequent filter replacement	40 %	2 %	0.8 %
		TOTAL	**32.9 %**
Table legend: (1) % of CAS where this measure is applicable and cost effective (2) % reduction in annual energy consumption (3) Potential contribution = Applicability * Reduction			

Fig. 2: Potential contribution to energy saving measures [2]

The table suggested an energy saving potential of 32.9 %. Taking the total 80 billion kWh used per year this would result in 26.3 billion kWh per year of saved energy. With an average energy price of 0.06 €/kWh the saving potential results in 1.58 billion Euro saved per year.

The table also shows the most important contributors to this saving potential. Obviously leakage reduction is the most important one, followed by overall system design, heat recovery, intelligent drives and intelligent controls. These are some of the measures that will be discussed in this paper.

The mentioned 32.9 % is a value which is, on average, applicable to all stations in the European Union. No matter what size the station is. But why is this big saving potential not used, especially in times like this, where energy costs are rising faster than ever before?
One possible explanation is that in many industrial facilities compressed air costs are not evaluated in a transparent way. It is often very hard to find out the costs specifically used for the compressed air production, because the necessary data is not collected. If one does not know the total costs it is hard to figure the saving potential. Because the importance of the energy costs is not clear to all compressed air users this small calculation will highlight the significance:

Calculation of cost factors

The compressed air station in this example consists of a single, fixed speed 45 kW oil injected screw compressor operating 6,000 hours per year, with an idling time ratio of 33 %. Thus the compressor runs 4,000 h/a in load run and 2,000 h/a in idle run. This ratio is not very efficient, but it is quite common to installations of this kind.
In this example we will calculate the three cost factors: a) energy, b) investment and c) maintenance costs.

a) Calculation of energy costs
The rated motor power of this compressor is 45 kW. This is the power available at the motor shaft. The power intake of the compressor, the value which has to be paid for, also includes the motor efficiency (estimated with 93 %) and the rated power including efficiency of the cooling fan motor (estimated with 0.7 kW and 70 %), which is also installed in compressors of this size. The power intake therefore results to: 45 kW / 93 % + 0.7 kW / 70 % = 49.4 kW. This is what the compressor uses during load run. During idle run the compressor usually uses about one third of this energy. This is the basis for our following energy calculation. The energy costs are estimated with 0.06 €/kWh.
Costs for load run: 4,000 h/a x 49.4 kW x 0.06 €/kWh = 11,856 €/a
Costs for idle run: 2,000 h/a x 49.4 kW / 3 x 0.06 €/kWh = 1,976 €/a
Total energy costs: 13,832 €/a.

b) Calculation of investment costs
The purchase price of this example compressor is estimated at 14,000 €. With a linear depreciation over 7 years and 8 % interest rate the yearly costs for investment are roughly calculated with 14,000 € / 7 a x 1.08 = 2,160 €/a.

c) Calculation of maintenance costs
The compressor runs 6,000 hours per year. The total maintenance costs for an installation like this are roughly estimated with 1,200 €/a.

Total costs

Adding all three cost factors gives total annual costs for this compressor of 17,192 €. The 13,832 €/a energy cost equates to 80 % of the total. Investment costs are only 13 % and maintenance costs only 7 % of the overall figure.

The costs per m^3 can now also easily be calculated. With a volume flow of 7 m^3/min at 8 bar the compressor delivers 7 m^3/min x 60 min/h x 4000 h/a = 1,680,000 m^3/a. This results in cost per m³ of 1 Cent/m³. This of course only includes the costs for the compressor, leaving out the costs for all other components of the compressor station.

This calculation example clearly shows that the real money saving potential does not lie in buying a cheap compressor but in buying an energy efficient compressor. In this example the result of even only 2 % improved energy efficiency exceeds the saving potential of a 10 % reduction in purchasing price. Unfortunately the total Life Cycle Costs (LCC) are not always used as the relevant basis for purchasing decisions.
Choosing energy efficient compressors is something that should be done every time a new compressed air station is designed or when a compressor is exchanged. But there are also other measures for existing compressor stations that can reduce energy costs.

Effect of leakages

The study by Radgen/Blaustein shows an average saving potential of 16 % for leakage reduction. The operator of any compressor station should therefore keep a careful eye on leakages in his compressed air system. The following figure illustrates the cost of leakages.

Leakage size ⌀		Leakage volume at 8 bar$_{ü}$	Losses	
			Energy	Money
[mm]	Size	[l/min]	[kW]	[€/J]
1	·	75	0,6	315,-
1,5	∘	150	1,3	683,-
2	°	260	2,0	1051,-
3	○	600	4,4	2312,-
4	○	1100	8,8	4625,-
5	◯	1700	13,2	6938,-

Money values for:
Electricity costs 0.06 €/kWh
Leakage time 8,760 h/a

Fig. 3: Costs of leakages [1]

Every compressed air system has leakages. Some installations have an excellent leakage rate of only 5 %, others have leakage rates of 50 % or even higher. The leakages seldom occur in the main piping, but in flanges, connections, couplings, maintenance units or in the compressed air tool itself.

In our example the overall average leakage saving potential of 16 % results in an energy saving potential of 13,832 €/a x 16 % = 2,213 €/a.
Additionally, reducing leakage volume also results in reduced operating hours of the compressor: 6,000 h/a x 16 % = 960 h/a. This will reduce the maintenance costs. (6,000 h/a is used because reducing the load run time will also affect the total idle run time.)

Finding air leakages is not a problem, if the right tools are used, for example an ultra sonic sensor that detects emissions from a leakage (see Fig.4). This sensor should be used at least twice a year to audit a system and leakages should then immediately be repaired. To purchase an ultra sonic leak detector is a small investment, thereafter the only additional overhead is your labour cost. The annual saving potential definitely outweighs the

Fig. 4: Leakage detector [3]

investment and manpower cost. As this device only detects ultra sonic sound emissions it can be used during normal operation of
the plant.

There also is one way to find out the absolute leakage volume flow. During complete standstill of all compressed air users there still is air consumption because of the leakages. When the receiver is brought to a certain pressure value the compressors are switched of and the time for the pressure reduction in the receiver is measured. A pressure reduction from 8 bar to 6 bar in a 1,000 l receiver over 2 minutes equals to a leakage volume flow of 1,000 l x (8-6) / 2 min = 1,000 l/min. The costs for this leakage rate would be approx. 4,500 €/a. (see Fig. 3)
Another method to measure the leakage rate is of course a complete measurement of the compressed air volume flow. The measured flow during times of standstill of all air consumers, for example during night or weekend, must then be leakages.

One of the easiest ways to prevent leakage costs, at least during non shift times, is to shut down the compressors during this time, or, to prevent changing pressures in the receiver, to close a valve after the receiver.

Operating pressure

Another very important factor affecting the energy consumption of a compressed air system is the working pressure required. The pressure generated should always be at the minimum possible level to save energy. One important fact is: every 1 bar of additional pressure requires approx. 6-10 % more energy. This means, reducing the pressure by 1 bar immediately reduces the energy costs by 6-10 %. Therefore it is very important to reduce all pressure losses in the compressed air system from the receiver to the air consumer.

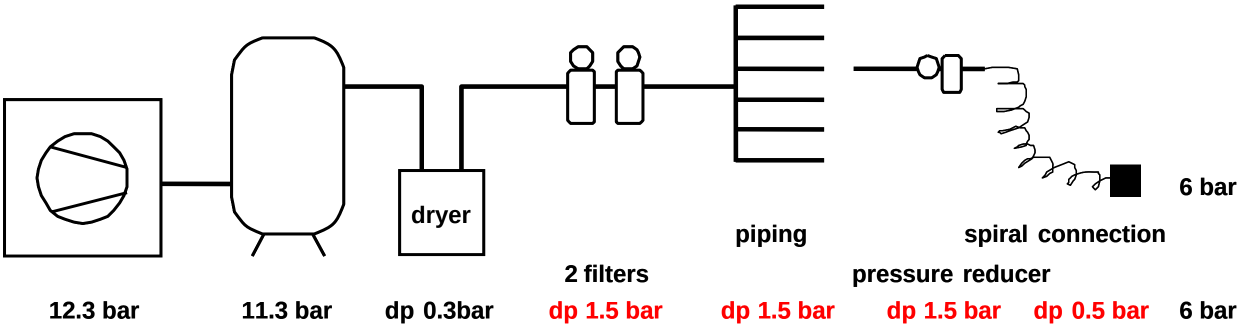


Fig. 5: Example of a compressor station with unnecessary pressure losses

Fig. 5 shows a compressor installation with many unnecessary pressure losses that cost money. Although only 6 bar is needed at the point of use the receiver pressure has to be 11.3 bar and the compressor has to run with a maximum pressure of 12.3 bar, due to the necessary pressure hysteresis in the compressor cut-in and cut-out pressure settings. Connections with spiral hoses create a high pressure loss, pressure reducers should be avoided wherever possible, the piping diameter should be big enough to reduce pressure losses and filter elements should be replaced as early as possible. The pressure drop in this installation could certainly easily be reduced by 2 bar, reducing the energy consumption by approx. 15 %. Taking the 13,832 €/a energy costs of our example compressor this equals to 2,075 €/a. In most cases this saving potential can be used with almost no additional investment. Small things like early filter element change already save money. Reducing the pressure loss in these to filters to the half will alone save more than 800 €/a. This is much more than the cost of two new filter elements.

The diameter of the piping is also very important for the energy costs. In many installations the piping diameter is much too small. Calculating the energy costs caused by the piping pressure loss and comparing them to the costs of an additional piping will in most cases show a return on investment of less than one year.

Of course the pressure can only be lowered to such a level that all consumers still work efficiently. But if only a small percentage of compressed air is needed at an exceptional high pressure level it makes sense to use a booster compressor which can be fed from a standard low pressure net, produced at lower energy costs.

Intelligent plant layout

Generating different pressures from the main system is already one factor in an intelligent plant layout. But there are many more. The most important basis for a decision of what compressor plant layout to choose is the knowledge of the compressed air requirements. This does not only include an average volume flow but also information about maximum and minimum flow, the fluctuation in flow, required pressure, necessary compressed air quality and much more.
Only when this information is known can a system layout be optimised to keep the energy costs at a minimum level. This especially includes the idling times of the installed compressors.
For screw compressors with an intelligent compressor controller it is quite easy to analyse the idling time. The controller will give information about load run hours and idle run hours or total hours. The idling ratio can be calculated by dividing the idle hours by the total hours. This ratio should be as small as possible. Simple and cheap compressor controllers that only show the total hours on an analogue mechanical hour counter do not offer this information. These compressors usually also do not include intelligent systems to minimise idling time.
Unfortunately in most cases the information about the required volume flow is not available. A layout therefore will always include uncertainties and also some unwanted idling times.

In cases where an existing plant is to be modified or extended a measurement of the compressor station is highly advisable. These measurements should be done over one complete week to receive information about every working day, night time and also the weekends.

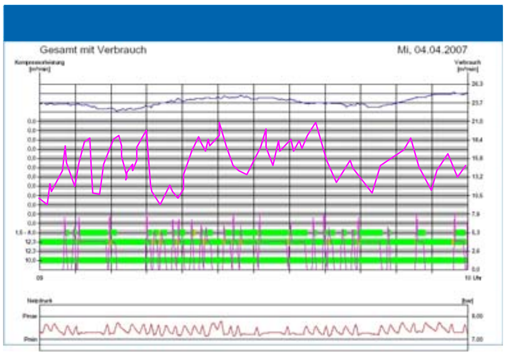


Fig. 6: Measurement result [4]

The diagram in Fig. 6 shows the working characteristic of a compressor station on a certain day, including the working mode of all compressors, pressure, volume flow and, in this case, also speed of a frequency controlled compressor. All this can be measured with a device that is easily installed into any compressor station. An analysis like this gives valuable information about the compressor station performance and efficiency.

A measurement like this is the ideal basis for evaluating a system design requirement. It can determine whether to choose a single compressor, several compressors at different sizes or maybe a frequency controlled compressor.
Looking at our example plant from the beginning maybe a prior measurement would have shown that a combination of two differently sized compressors (probably 30 kW and 15 kW) would be more efficient. This combination would use the bigger compressor as the base load compressor and the smaller one for peak loads. This would help reduce the idling costs of almost 2,000 €/a by half.

For compressor stations with several compressors it is very important to have an intelligent higher level control that decides what compressor combination should run at a certain required air flow, minimising the total idling time and costs. There are small base load switch over controls for small installations and powerful energy saving controls for stations with 16 connected compressors or more. In stations with more than 2 compressors a higher level control should be used. Using this, instead of the formerly used cascaded settings for multiple compressor installations definitely saves energy and money. Only the most efficient compressor combination will run, thus minimising idling time whilst at the same time optimising the pressure.
In all discussions about the efficiency of a compressed air station and plant layouts it is always important to see the compressed air production as a complete system. An efficient compressor does not automatically make an efficient compressed air system. One mistake in the plant layout can destroy the complete plant efficiency. It is therefore very important to include all components from the very beginning in order to create an optimised system.

Heat recovery

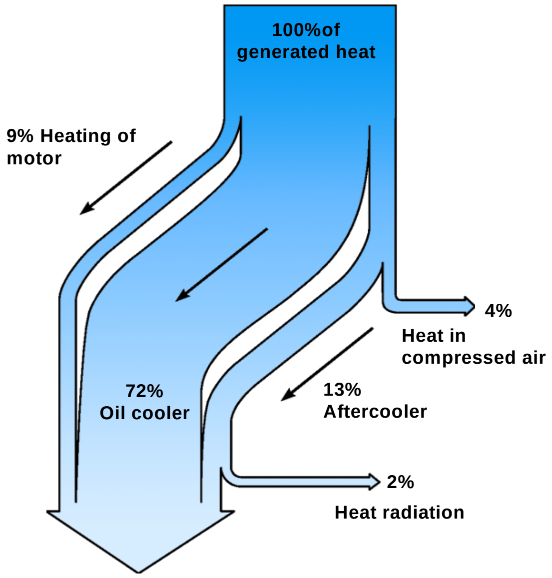


Fig. 7: Compression heat in a screw compressor [1]

During the compression process a high percentage of the consumed energy is transferred into heat. In an efficient compressor installation this heat is not lost, but used to save energy in other applications where heat is needed. About 70 % to 80 % of the energy used to run a compressor can be recovered and therefore saved in other places.
There are two main ways for heat recovery on screw compressors:

- use the warm cooling air flow coming from the compressor
- use the heat from the compressor oil circuit

Fig. 7 shows the different streams of heat out of an air cooled oil injected screw compressor. The heat from the drive motor, the oil cooler and the air aftercooler leaves the compressor in one stream of warm air, taking out 94 % of the generated heat. This cooling air flow can be used to heat rooms or production facilities. All that is needed is an air duct connected to the compressor cooling air outlet. Fig. 8 shows an example installation. This is the simplest method of heat recovery, immediately saving energy which otherwise would have to be used to heat the building.

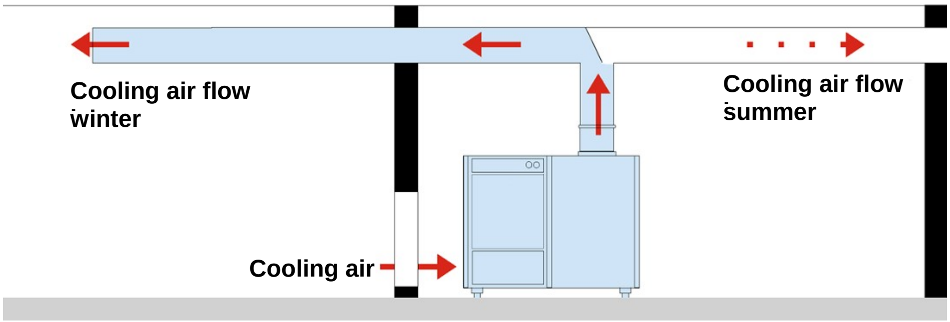


Fig. 8: Example installation of heat recovery from cooling air [1]

Another possible way for heat recovery is to take the heat from the oil circuit in the compressor with a heat exchanger. The advantage is that heat is then taken from the place where it is generated and from the hottest medium. Hot water with a temperature of up to 70°C can be generated which can be used in other places. This way of heat recovery is independent from the type of compressor cooling. One possible application would again be to supplement a central heating system whereby a significant amount of oil or gas for the heater can be saved.

Drive rate [kW]	Discharged power [kW/h]	Usable heat amount [MJ/h]	Saving potential at 1,000 op.h [€]
22	17,7	63,7	1,118
30	24,4	87,8	1,540
37	30,3	109,0	1,912
45	37,7	135,7	2,381
55	45,5	163,8	2,874
65	54,9	197,6	3,467
75	63,1	227,1	3,984
90	74,0	266,4	4,674
110	90,0	324,0	5,684
132	110,5	397,0	6,965
160	133,5	480,6	8,432
200	168,3	605,8	10,628
250	208,9	752,0	13,193

Fig. 9 shows a table with possible saving potential when heat recovery is used. The saving potential is calculated for a single shift operation (2,000 op. h) and heat recovery only done during half of the year (1,000 op. h). In an application where the recovered heat is used in a three shift operation throughout the year, the saving potential is even six times bigger. In most cases the return on investment for heat recovery installations is very short. When building a new compressor station heat recovery should always be considered. That would also include choosing the compressor location as near as possible to a heat consumer.

Fig. 9: Saving potential for heat recovery (calculated at a price of only 0.50 €/l for heating oil)

Conclusion

Compressed air can be produced in an energy efficient and cost efficient manner. Unfortunately savings potential is seldom recognised by air consumers. In total an average saving potential around 33 % is possible. If this total saving potential was realised in the illustrated compressor installation a total saving of 13,832 €/a x 32.9 % = 4,550 €/a can be achieved. Many of the key measures have been discussed in this paper. When planning a new compressor station or renewing an existing one all the above mentioned points should be taken into consideration. Compressed air can then be used in any facility at highest flexibility and best price/performance-ratio.

Bibliographic details

[1] BOGE Compressed Air Compendium, BOGE Kompressoren
[2] Radgen/Blaustein, Compressed Air Systems in the European Union, 2001
[3] Picture: BOGE
[4] Extract from BOGE AIReport analysis