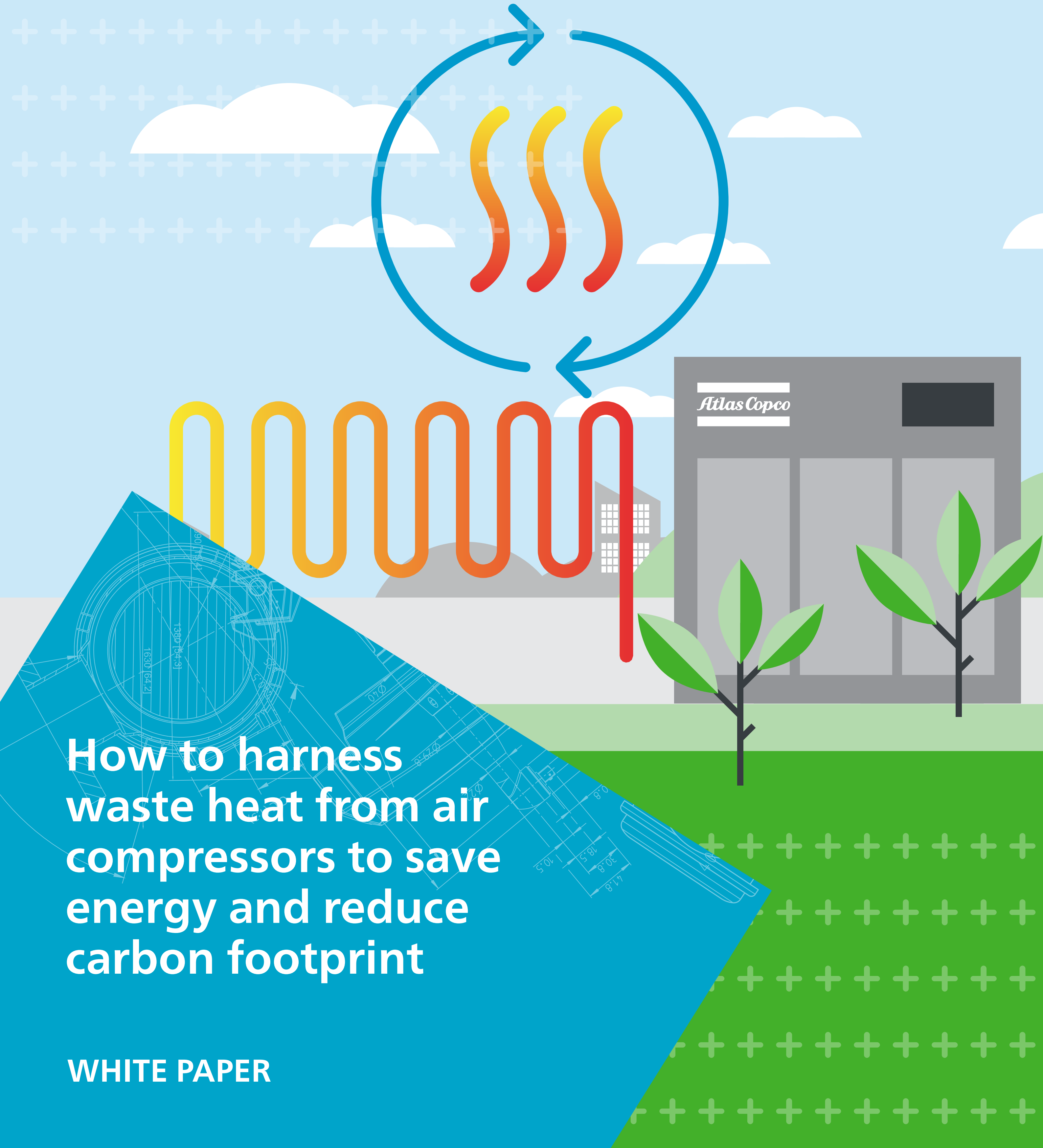
+ MORE THAN A COMPRESSOR

Atlas Copco



How to harness waste heat from air compressors to save energy and reduce carbon footprint

WHITE PAPER

This White Paper identifies compressed air waste heat utilisation opportunities, reviews the established recovery methods, and outlines the untapped carbon reductions and energy savings potential for compressor users.

To illustrate the financial benefits which investment in heat recovery technology can confer, examples of practical application case histories are also detailed.

1.

Compressor waste heat recovery – the untapped potential

The essential role of compressed air as the 4th utility for industry is well established, as are the statistics that show compressed air typically accounts for some 12% of the total energy costs encountered by manufacturing processes – and may be as much as 40% in some instances.

What is an equally significant fact, yet not widely recognised in the UK, is that up to 94% of a compressor's electrical supply energy is converted into heat that is led off from the compression process. Without any form of recovery, this is waste heat that is lost through radiation into the atmosphere or through compressor cooling systems.

But it does not need to be the case. In reality, this heat can be harnessed in its entirety to help reduce energy usage and costs substantially and, at the same time, to limit CO2 emissions thereby assisting companies in achieving their carbon savings targets. Furthermore, the technology is readily available – up to 90% of all industrial compressors in the UK could be equipped with waste heat recovery systems.

Capacity (cfm)	Nominal Motor Rating (kw)	Annual Heat Available (running 2000hrs/yr) (kwh)
90	15	24,000
125	22	35,200
350	55	88,000
700	110	176,000
1000	160	256,000
1250	200	320,000
1550	250	400,000

Fig 1. Table of compressor heat available expressed as kWh related to compressor capacity and motor rating

2.

How heat can be recovered from compressors

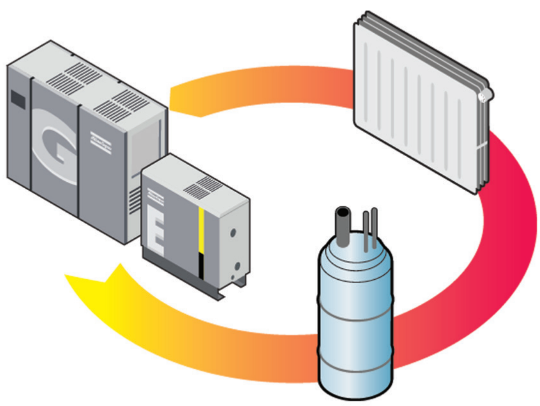
Compressing air generates heat. This is a natural consequence of forcing more air molecules into the same space. The problem is that the air must be cooled before it can be used. In many systems, the air is cooled between compression stages and then again at the end. Intercoolers remove heat between the first and second stage and after-coolers remove heat after the second stage.

Total energy transmitted by a compressor unit:

Heat from the element **9%**
Heat from the oil cooler **72%**
Heat dissipated in the ambient air **2%**
Heat from the after-cooler **13%**
Heat remaining in the compressed air **4%**

Total recoverable energy

94%



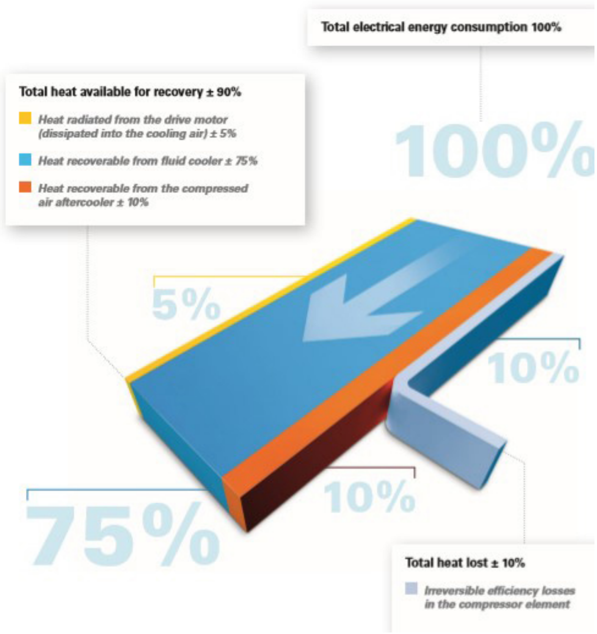
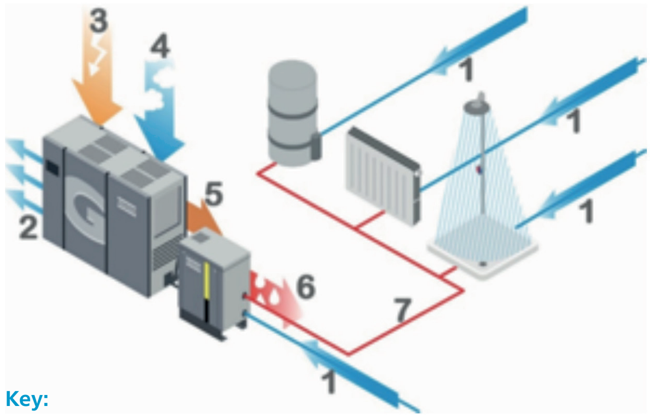


Fig 2. Total energy transmitted by a compressor unit

Stand-alone energy recovery units



Key:

1) Cold water
2) Compressed air
3) Electric power
4) Air
5) Oil circuit
6) Energy recovery
7) Warm water

Fig 3. Oil-injected screw compressor heat recovery system with a stand-alone energy recovery unit

Coolers remove heat from compressed air using air, water, or oil. They work on a system of heat exchange. The air transfers heat to the cooling medium in a cooler designed for the compressor flow rate and energy transfer requirements.

There are different types of cooling systems used in air compressors. The merits of each method are dependent upon the type of compressor and the recovered heat application. For instance, in the case of water-cooled compressors, the energy recovery can be applied as a low-temperature rise/ high water flow system or as the opposite, a high temperature/low rise water flow system.

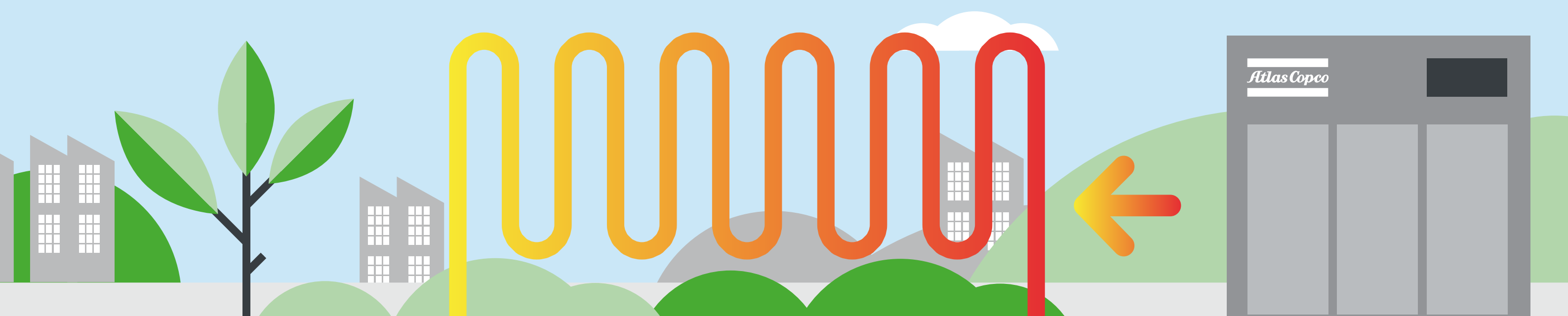
Energy recovery from compressed air installations may not always result in heat when it is required or in sufficient quantities. The quantity of recovered energy will vary over time if the compressor has a variable load. For recovery to be viable, a corresponding relatively stable heat energy demand is needed. In general, recovered waste heat energy is best utilised to supplement energy supplied to the system — that way the available energy is always utilised when the compressor is operating.

The Energy Recovery control unit is installed between the compressor and cooling- and heating circuits. Hot water up to 90 degrees C can be recovered from the compressed air system. This heat transferred via heat exchanger to a cold-water circuit can be used for sanitary purposes and heating but is particularly suitable for process-heating applications.

Levels of heat recovery

Air-cooled systems are conventional in small and medium compressor systems. They cool compressed air using a lower pressure air stream. This warmed air can then be used to heat buildings. The energy-saving comes from a reduction in heating purchased from external sources. The caveat to this benefit is that savings can only be fully realised in the colder months of the year.

Oil-cooled systems use a flow of oil to remove heat from the compressed air. In a closed system, the oil can be routed back into the manufacturing process. Heat is transferred into the manufacturing process via a heat exchanger, thus reducing the need for electric or gas heating.



Water-cooled systems can be open or closed and circulating or non-circulating. The most beneficial is a closed-loop system with circulating water. Water circulates between the air compressor cooler and a process heat exchanger. The net result is a transfer of excess compressor heat into the manufacturing process, thus reducing the need for heating. In a closed-loop system, water quality is strictly controlled using additives, which prevents the build-up of mineral deposits. As such, the system is efficient and clean and can remain operational for an extended period without intervention.

In every case, recovering heat from compressed air reduces the need for purchasing energy. It is this reduction that results in lower CO_2 emissions and operating costs. Due to the high cost of energy, these savings can be significant in terms of assisting companies in meeting their carbon reduction targets and improving manufacturing plant profitability.

Recovering energy in an air-cooled system

Air-cooled, packaged, rotary screw compressors are very amenable to heat recovery for space heating or other hot air use, such as industrial drying, preheating aspirated air for oil burners, or any other application requiring warm air. Ambient atmospheric air is heated by passing it across the system's after-cooler and lubricant cooler, where it extracts heat from both the compressed air and the lubricant that is used to lubricate and cool the compressor. As a rule, approximately 15kW/h of energy is available for each 100 cfm of capacity (at full load).

Because many packaged compressors are typically enclosed in cabinets and already include heat exchangers, and fans, the only system modifications needed are the addition of ducting and possibly another fan to handle the duct loading and to eliminate any back pressure on the compressor cooling fan.

These heat recovery systems can be modulated with a simple, thermostatically controlled hinged vent. When heating is not required – such as in the summer months – the hot air can be ducted outside the building. The vent can also be thermostatically regulated to provide a constant temperature for a heated area.

A limiting factor is the distance between the compressors and the building that needs to be heated. However, dependent upon the proximity of the compressor unit to the building or area with the heating requirement, potential heat losses in transfer can be mitigated through insulation lagging of the ductwork or, where practicable, through re-siting the compressor installation. Furthermore, the possibility of recovery may be limited to the colder periods of the year. Airborne energy recovery is more common for small- and medium-sized compressors.

Caution should be applied if the supply air for the compressor is not from outside, and the recovered heat is used in another space. This situation can cause a decrease in the static pressure within the cabinet and reduce the efficiency of the compressor. If outside air is used, some return air may be required to avoid damaging the compressor with below-freezing air.

Heating Water. Using a heat exchanger, it is also possible to extract waste heat from the lubricant coolers found in packaged water-cooled, reciprocating, or rotary screw compressors, and produce hot water. Depending on the design, heat exchangers can heat both non-potable and potable water. When hot water is not required, the lubricant is then routed to the standard lubricant cooler.

Recovering energy in a water-cooled system

The cooling water from a water-cooled compressor with a temperature up to 90 degrees C can supplement a hot water heating system. If the hot water is used instead for washing, cleaning, or showering, a typical base load hot water boiler is still required. The energy recovered from the compressed air system forms a supplementary heat source that reduces the load on the boiler, saves heating fuel and could potentially result in the use of a smaller boiler.

Heat recovery for space heating is not as common with water-cooled compressors because an extra stage of heat exchange is required, and the temperature of the available heat is lower. However, because many water-cooled compressors are of large capacity, heat recovery for space heating can present an attractive opportunity. Recovery efficiencies of 50 to 60 per cent are typical.

Standard oil-free, water-cooled compressors are easily modified for energy recovery. As previously stated, up to 90% of all industrial compressors in the UK could be equipped with waste heat recovery systems. They are the ideal solution for integration in a hot water heating system since they provide the water temperature (90 degrees C) required for efficient energy recovery.

The high initial water temperature means that waste energy can be used to increase the temperature of the return water from a hot water boiler. Therefore, the usual heating source can be periodically switched off and be replaced by the compressor's waste heat recovery system.

Waste heat from compressors in the process industry can also be used to increase the temperature of the process. Waterborne heat can be distributed to remote buildings using relatively small pipe diameters (40-80 mm) without significant heat losses.

This property contrasts with oil-lubricated compressors because the oil, which takes part in the compression process, is a factor that limits the possibilities for high cooling water temperatures. Likewise, in centrifugal compressors, the temperature levels are generally lower because of the lower pressure ratio per compression stage, thereby limiting the degree of recovery.

Waterborne waste energy recovery is best suited to compressors with electric motor power over 10 kW. and requires a more complex installation than that of air-cooled waste energy recovery. Conventionally, the essential equipment consists of fluid pumps, heat exchangers and regulation valves but the advent of the stand-alone, fully assembled energy-recovery retrofit unit, designed with compact vertical configuration to minimise floor-space footprint, have increased the opportunities for application industries to reduce the costs of traditional energy sources and to minimise the impact of their CO_2 emissions.

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3.

How much energy can be saved

When calculating energy savings and payback periods for heat recovery units, it is vital to compare heat recovery with the current source of energy for generating thermal energy, which may be a low-price fossil fuel, such as natural gas. The equations in the text box in Fig 4 illustrate the annual energy and costs savings available by recovering heat for space heating from an air-cooled, rotary screw compressor. Applications, where the existing heater is less than 85 per cent efficient, will see proportionally higher savings.

Calculating the recovery potential

The laws of physics dictate that nearly all energy supplied to a compressor installation is converted into heat. The more energy that can be recovered and utilised in other processes, the higher the system's overall efficiency.

Recovered energy in kWh/year:

W= [(K1 x Q1 + (K2 x Q2)] x TR
Savings per year: W x ep / η

T_R = Time of recovered energy demand (hrs/year)

K_1 = Part of TR with loaded compressor (hrs/year)

K_2 = Part of TR with off-loaded compressor (hrs/year)

Q_1 = Available coolant power with loaded compressor (kW)

Q_2 = Available coolant power with off-loaded compressor (kW)

e_p = Energy price level (£/kWh)

η = Normal heat source efficiency (%)

Fig 4. Equation for recovered energy calculation

In many cases, the degree of heat recovery could exceed 90% if the energy gained by cooling the compressor installation can be utilised efficiently. The function of the cooling system, the distance to the point of consumption, and the degree and continuity of the heat requirement are all decisive factors.

With large thermal flows, even selling the recovered heat energy is a possibility that should not be ignored. The electrical energy supplier could be a potential customer, and investment, sub-order and delivery might readily be negotiated. An opportunity for savings also exists by coordinating energy recovery from several processes.

4.

Recovered heat applications

Recovered hot water from compressor operation is employed in many industrial applications:

Food and beverage
Dairy processes: pasteurisation, scalding, cleaning and sterilising cooking vessels, drying products

Chemicals
Thermal steam crackers, re-boilers and stripping, heat tracing, humidity control

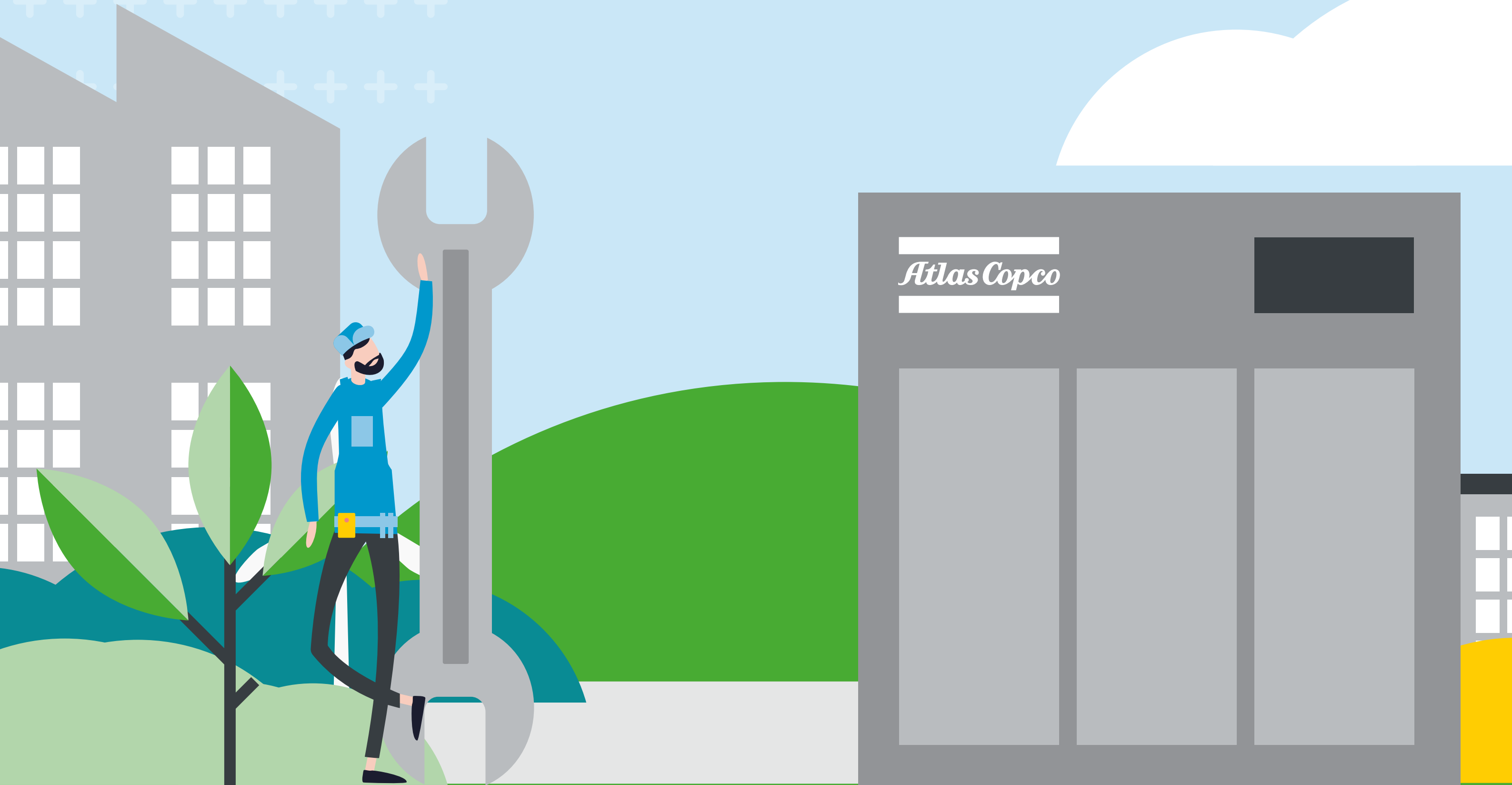
Pharmaceuticals
Fermentation temperature control, drying and sterilisation processes, The CIP (Clean in Place) cleaning method, SIP (Sterilisation in Place), direct contact sterilisation in bioreactors and fermenters, steam barriers against Bacteria

Textiles
Colouring of fabrics, yarn, and fibre treatment

Pulp & paper
Bleaching, digesters, pulp machines and black liquor evaporators.

Electronics
Humidity control in electronics assembly & chip manufacturing

Motive applications
Steam turbines



Case studies of compressed air heat recovery

Midlands automotive textile manufacturer

By using an oil coolant in their ER-S5 energy recovery unit, a Midlands-based automotive textiles manufacturer was able to recover heat from its air compressor outlet. Hot oil from the air cooler transferred energy into the process via a steel plate heat exchanger. This gave them a continuous supply of hot process water without any extra energy purchase. As a result, the company was able to reduce CO2 emissions by 260,000 tonnes per year by using this recovery method.

Northern Ireland packaging plant

A packaging plant in Northern Ireland found a different use for recovered energy. Greiner Packaging uses its excess heat to contribute to the central heating system of a local secondary school. Dungannon Integrated College has 600 pupils and uses £40,000 of heating on an annual basis. In this case, Atlas Copco installed Z-range oil-free screw compressors with water coolers for energy recovery. Up to 80% of the electrical input energy is recovered as hot water. The school also reduced its CO2 footprint by 200 metric tons through reduced energy purchase.

These case studies demonstrate both the environmental and financial opportunities for investing in compressed air heat recovery. Most industrial companies in the UK are still yet to embrace and realise the benefits of the technology. Indeed, it is estimated that 90% of all industrial air compressors used in the UK could be equipped with heat recovery systems. And, as stated above, 70-94 % of the supply energy to an air compressor can be recovered.

To illustrate the vast untapped potential of compressed air heat recovery, it is calculated that the technology could save 1.99% of the total industrial electricity consumption in the UK. If that statistic is not compelling enough, it is the equivalent of removing the emissions from 913,000 diesel/petrol cars per year or recovering the energy required to power 1.544 million households' electricity consumption per year.

5.

Return on investment

A central compressor plant that consumes 500 kW over 8,000 operating hours per year represents a yearly energy consumption of 4 million kWh. The possibilities for recovering substantial amounts of waste heat via hot air or hot water are very real. As much as 94% of the energy supplied to the compressor can be recovered as hot water from oil-free screw compressors. This fact illustrates that saving measures quickly provide a substantial return.

The return on investment for energy recovery systems can be as short as 1–3 years. Besides, energy recovered using a closed cooling system enhances compressor operating conditions, reliability and service life due to an equalised temperature level and high cooling water quality, to name but a few advantages.

Already, Nordic countries are somewhat of a forerunner in this arena and energy recovery has been standard practice for quite some time now for compressor installations. Most medium-to-large compressors from the major suppliers are now adapted for fitting with standard equipment for waste heat recovery or the addition of a stand-alone, plug-and-play energy recovery unit.

6.

Reducing carbon footprint

Major compressor equipment manufacturers continually seek to reduce their users' CO_2 footprint at every stage of a compressor's lifetime: from the design phase right through to the equipment's manufacture, distribution, consumer use, disposal, and recycling. That endeavour is justified for the fact that the typical carbon footprint of an air compressor, the energy consumed in its use, accounts for 99% of CO_2 emissions.

Compressor users throughout industry are encouraged to seek compliance with ISO50001 in order to establish consistent energy management and realise untapped energy efficiency. The main objective of this standard is to improve and to identify energy-related performance continuously and to identify energy reduction opportunities through a systematic approach and established procedures.

As energy consumption typically represents over 80% of a compressor's lifecycle cost, energy savings achieved through the application of energy recovery systems in compressed air installations will have a significant impact towards preserving not only the environment and the planet but, significantly, industry users' bottom line.

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