



Making business sense  
of climate change

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# Heat recovery

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A guide to key systems and applications



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# Introduction

This guide can provide you with an appreciation of heat recovery and how it can be applied to the various systems and processes carried out in your building.

This guide is intended for anyone who has responsibility for the efficient and cost-effective operation of buildings, or those who use an industrial process where heat might be unnecessarily wasted.

The application of heat recovery techniques can significantly reduce energy consumption, running costs and carbon emissions. These techniques can be applied in isolation, but would be better as part of an overall strategy to reduce energy, cost and carbon.

## How to use this guide

This guide will help you understand the basic principles of heat recovery as well as some of the common terminology.

The main part of this guide is divided into sections which reflect the key applications for heat recovery in buildings.

You'll find some useful tables on the next few pages to help you decide which types of heat recovery application might be of interest to you. It may also be useful for you to complete the heat recovery checklist alongside this guide so that you can focus on the areas that are most specific to you.

The application of heat recovery techniques can significantly reduce energy consumption, running costs and carbon emissions

## Heat recovery application chart by building type

Use this chart to determine which technologies and applications are most applicable to you, either by the type of building you have or the systems you have installed.

| Building type             | Waste heat source and applications for heat recovery |                         |                           |   |  |                     |                                     |                 |                      |            |                           |                            |
|---------------------------|--|-------------------------|---------------------------|---|--|---------------------|-------------------------------------|-----------------|----------------------|------------|---------------------------|----------------------------|
| Systems installed         | Boilers (steam or hot water)                         |                         |                           | Refrigeration (cooling plant)                   |  | Ventilation systems |                                     |                 | Industrial processes |            |                           |                            |
|                           | Flue economisers                                     | Pre-heat combustion air | Blowdown on steam boilers | High-grade heat recovery using a de-superheater | Low-grade heat recovery from the condenser | Thermal wheel       | Plate heat exchanger or recuperator | Run around coil | Heat pumps           | Heat pipes | Low-temperature processes | High-temperature processes |
| Page                      | 14   | 17                      | 19                        | 25  | 27   | 32                  | 34                                  | 38              | 35                   | 39         | 45                        | 50                         |
| Airport                   | ◆  | ◆                       | ◆                         | ◆   | ◆  | ◆                   | ◆                                   | ◆               | ◆                    | ◆          | ◆                         | ◆                          |
| Courts                    |  | ◆                       |                           |   | ◆  | ◆                   | ◆                                   | ◆               | ◆                    |            |                           |                            |
| Food and drink            | ◆  | ◆                       | ◆                         | ◆   | ◆  | ◆                   | ◆                                   | ◆               | ◆                    | ◆          | ◆                         | ◆                          |
| Distribution – warehouses |  |                         |                           |   |  | ◆                   | ◆                                   | ◆               |                      |            |                           |                            |
| Dwellings                 |  |                         |                           |   |  |                     | ◆                                   |                 |                      |            |                           |                            |
| Education                 |  |                         |                           |   | ◆  | ◆                   | ◆                                   | ◆               | ◆                    |            |                           |                            |
| Emergency services        |  |                         |                           |   | ◆  | ◆                   | ◆                                   | ◆               |                      |            |                           |                            |
| Hospital/healthcare       | ◆  | ◆                       | ◆                         | ◆   | ◆  |                     | ◆                                   | ◆               | ◆                    | ◆          |                           | ◆                          |
| Hospitality – hotel       |  | ◆                       |                           | ◆   | ◆  | ◆                   | ◆                                   | ◆               | ◆                    | ◆          |                           | ◆                          |



## Heat recovery application chart by process type

Use this chart to inform discussions about which technologies and applications might be appropriate to you, either by the type of processes you undertake or the systems you have installed.

| Processes on the site                   | Potential heat recovery approaches |   |                              |                          |   |                                  |                         |                               |
|---|------------------------------------|---|------------------------------|--------------------------|---|----------------------------------|-------------------------|-------------------------------|
| Potential heat recovery approaches      | Page                               | Gas (or vapour)<br>-to-liquid heat<br>exchanger | Direct ducting<br>of hot air | Use of steam<br>blowdown | Heat captured<br>during phase<br>change | Heat recovery<br>from condensers | Air-to-air<br>exchanger | Liquid-to-liquid<br>exchanger |
| Boilers used for space heating          | 15 & 17                            | ◆   | ◆                            |                          |   |                                  |                         |                               |
| Boilers used for domestic water heating | 15 & 17                            | ◆   | ◆                            |                          |   |                                  |                         |                               |
| Cold rooms                              | 25 & 27                            |   |                              |                          | ◆                                       | ◆                                |                         |                               |
| Chilled water systems                   | 25 & 27                            |   |                              |                          | ◆                                       | ◆                                |                         |                               |
| Space or process refrigeration          | 25 & 27                            |   |                              |                          | ◆                                       | ◆                                |                         |                               |
| Supply and extract ventilation systems  | 32 & 51                            |   |                              |                          |   |                                  | ◆                       |                               |
| Air compressors                         | 45                                 | ◆   | ◆                            |                          |   |                                  |                         |                               |
| Distillation processes                  | 45                                 |   |                              |                          |   | ◆                                |                         |                               |
| Drying processes                        | 45                                 |   | ◆                            |                          |   |                                  | ◆                       |                               |

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| Processes on the site                      | Potential heat recovery approaches |   |                              |                          |   |                                  |                         |                               |
|--|------------------------------------|---|------------------------------|--------------------------|---|----------------------------------|-------------------------|-------------------------------|
| Potential heat recovery approaches         | Page                               | Gas (or vapour)<br>-to-liquid heat<br>exchanger | Direct ducting<br>of hot air | Use of steam<br>blowdown | Heat captured<br>during phase<br>change | Heat recovery<br>from condensers | Air-to-air<br>exchanger | Liquid-to-liquid<br>exchanger |
| Dyeing and finishing processes             | 46                                 |   |                              |                          |   |                                  |                         | ◆                             |
| Evaporation to create concentrates         | 47                                 |   |                              | ◆                        |   |                                  |                         | ◆                             |
| Systems creating mechanical energy         | 47                                 | ◆   | ◆                            |                          |   |                                  | ◆                       | ◆                             |
| Industrial scale ovens for food processing | 48                                 | ◆   | ◆                            |                          |   |                                  |                         |                               |
| Dairy pasteurisation and sterilisation     | 49                                 |   |                              | ◆                        |   |                                  |                         |                               |
| Cooling of primary processes               | 49                                 | ◆   | ◆                            |                          |   | ◆                                | ◆                       |                               |
| Large-scale laundering or other washing    | 49                                 |   |                              | ◆                        |   |                                  |                         | ◆                             |
| Use of furnaces                            | 50                                 | ◆   | ◆                            |                          |   |                                  | ◆                       |                               |

# Heat recovery: the basics

Heat recovery is a method of reducing the overall energy consumption of your site and therefore reducing the running costs. Recovered heat can help you reduce energy consumption or provide useful heat for other purposes.

## Definition of heat recovery

Heat recovery in the context of buildings and their services can be defined as the collection and re-use of heat arising from a process that would otherwise be lost.

In most processes, some of the energy used will be lost as heat. Sometimes, the loss of this heat is intentional, such as in air conditioning, where the purpose of the system in cooling mode is to remove heat from a space. In other instances, the loss is either incidental, such as the heat lost by a compressed air system, or accidental, such as heat lost through the fabric of the building.

Most buildings using energy for heating, cooling, ventilation or any sort of industrial process have the potential to benefit from the application of heat recovery devices and systems.

## Glossary

**Air handling unit or AHU** A mechanical device typically used to supply or extract air from a space within a building.

**CHP** A combined heat and power machine where waste heat from the process of generating electricity is used for some other purpose (such as raising steam) within the same machine.

**Fluid** Any substance in either a liquid or gas state.

**Heat recovery** The collection and re-use of heat from a process that would otherwise be lost.

**Heat sink** A process where waste heat from a heat source can be usefully put to work.

**Heat source** The place or the environment from where heat is obtained.

**HVAC** Heating, ventilation and air conditioning systems as found in buildings.

**Latent heat** The heat released or absorbed by a substance during a change of state (or phase) that occurs without a change in temperature.

**Liquid** One of the three basic states of matter. The density of a liquid is relatively stable and is close to that of a solid and much higher than a gas. Due to its closeness in density to solids, both are known as condensed matter.

**LPG** A fossil fuel – liquid petroleum gas.

**LTHW** Low-temperature hot water.

**MTHW** Medium-temperature hot water.

**Phase or state change** Where a substance changes from a solid to a liquid or a liquid to a gas (or vice versa) usually through the application or withdrawal of heat and/or pressure.



**Recuperator** A device for waste heat recovery that works by counter-flowing hot gases and cold air through a heat exchanger.

**Regenerator** A cyclic heat storage device which continuously stores and releases energy.

**Sensible heat** The energy exchanged during a process that has as its sole effect a change of temperature.

**Vapour or gas** One of the three basic states of matter. Gases fill the entire volume of wherever they are contained and, like liquids, have the ability to flow. Both liquids and gases are therefore known as fluid matter.

**Waste heat** Heat which is a by-product of a process or operation which is not captured or recovered and is therefore not re-used in a secondary system.

## The basic concept of heat recovery

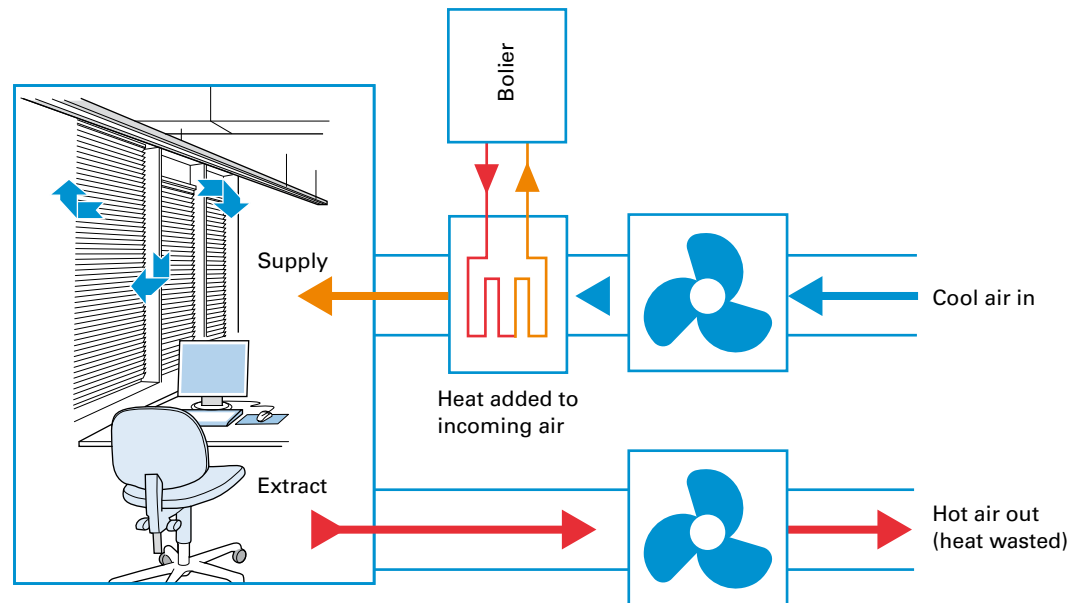
### Without heat recovery

In this example building without heat recovery, energy is used to heat incoming air which would otherwise be too cold to supply directly to an office. The heat is typically supplied by the boiler via a heating coil in the air handling unit.

Air in the office will continue to heat up due to the warming effects of the people in the space as well as the equipment being used (such as computers, photocopiers or printers). The levels of carbon dioxide will also increase as people breathe the air.

The hot, stale air is removed from the space by an extract ventilation system, which discharges it directly outside along with the heat it contains.

**Figure 1** Typical office ventilation system without heat recovery



With heat recovery

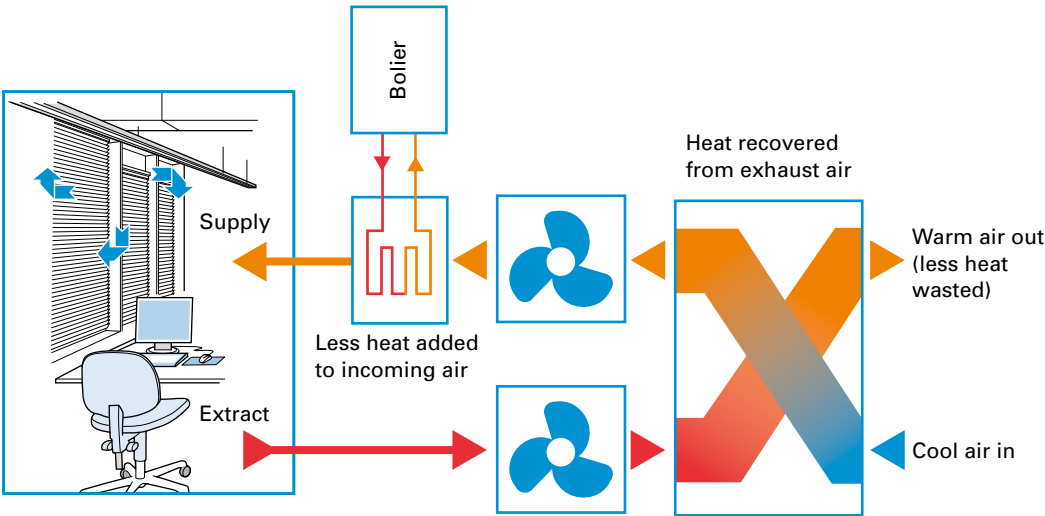
In our example building a cross flow heat exchanger has been added to the system. When the cool fresh air is drawn into the system it passes over a series of pipes which contain the hot outgoing exhaust air. Some of the heat from the exhaust air is transferred to the cool incoming air, which means that less

heat needs to be added by the boiler before the air is supplied to the space.

The recovery efficiency of this type of system is typically between 55% and 65%. Some heat recovery devices can be much more efficient depending on the temperature and nature of the waste heat.

The recovery efficiency of this type of system is typically between 55% and 65%

Figure 2 Typical office ventilation system with a plate heat exchanger added for heat recovery



## Sources of waste heat

You're likely to have sources of 'waste' heat in your building, for example, from the heating or ventilation systems in an office, or the industrial drying process or compressed air system in a factory.

The following common sources of waste heat often present opportunities for cost-effective heat recovery:

- ventilation system extracts
- boiler flue gases
- boiler blowdown
- air compressors
- refrigeration plant
- high-temperature exhaust gas streams from furnaces, kilns, ovens and dryers
- hot liquid effluents
- power generation plant
- process plant cooling systems.

## Uses for recovered heat

The most cost-effective use of waste heat is to improve the energy efficiency of the heat generating process itself. Common uses (or 'sinks') for recovered heat include:

- pre-heating of combustion air for boilers, ovens, furnaces, and so on
- preheating fresh air used to ventilate the building
- hot water generation, including pre-heating of boiler feed water
- space heating
- drying
- other industrial process heating/pre-heating
- power generation.



# Heat recovery applications: boilers

A boiler is a device that converts the chemical energy of a fuel into a useful heat output, such as steam or hot water.

## Principles of operation

In the UK, the most common fuel for boilers is natural gas. However, where there is no mains gas network, or the network infrastructure is poor, oil, LPG and, in some cases, coal-fired boilers are used. There is also a relatively small number of biofuel-fired (biomass, biogas, and so on) boilers in operation where there is good availability of fuel, and these continue to increase in popularity.

Inside a boiler, the fuel is combusted by flames from burners. The resulting hot combustion gases transfer heat to water, which is fed into the boiler from an external source.

There are many different types of boiler design and construction, but all boilers are derivatives of two main types:

**The shell type**, where the hot combustion gases pass down a tube and into subsequent bundles of tubes immersed below water level where heat is transferred. Most steam and hot water boilers in the UK are derivatives of the shell type, which are also referred to as 'fire tubes'.

**The water tube type**, where the water is contained in tubes and the hot combustion gases pass around them to transfer heat to the water.

In either case, the heat must transfer across the surface of the tubes containing the water or combustion gases. After use, the combustion gases exit the boiler via a chimney known as a flue.

The output steam or hot water will be fed out of the boiler into a distribution system. This is a network of insulated pipes that transfer the steam or hot water to where it is used.

## Where is heat wasted?

The operational efficiency of a boiler is measured by the percentage of the fuel input energy that is eventually delivered as useful heat output. Not all of the heat released when the fuel is combusted can be used; some potential heat is never released due to incomplete combustion and some is lost.

Major sources of heat loss from steam boilers are through the flue gas, blowdown and radiation to the boiler's surroundings. For a shell type steam boiler the losses are:

- Flue losses ~18%
- Heat transfer gas and water side losses ~2%
- Insulated chamber radiation losses ~2%
- Water outlet blowdown losses ~3%

This makes total losses of around 25%.  
The heat recovery options which follow  
can be used to reduce these total losses.

## Where heat recovery is appropriate

Boiler flue economisers are available for boiler outputs as low as 100 kilowatts (kW) and in some cases even less. However, for boilers with an output rating of less than 150-200kW (the typical maximum size of packaged wall-hung boilers) replacement with a fully condensing boiler should be considered before retro-fitting a boiler flue economiser.

## Further references

[Low temperature hot water boilers technology overview \(CTV008\)](#)

[Steam and high temperature hot water boilers technology overview \(CTV018\)](#)

[How to implement blowdown heat recovery \(CTL020\)](#)

## Condensing boilers

Condensing boilers are highly efficient because they already have a form of heat recovery built in. By capturing a large proportion of the heat from hot flue gases, they significantly reduce the amount of wasted heat.

This means that adding heat recovery directly to a condensing boiler may not be possible. However, it is likely that there are other opportunities for heat recovery elsewhere in the system.

## Tips for implementation

Installing boiler heat recovery systems is a good way to reduce energy costs and carbon emissions. However, there are a few things you should look at before you implement heat recovery. A qualified engineer will talk you through these issues, but they will include:

**Controls** Make sure the boiler controls are set correctly. Running the boiler when it isn't needed or heating to overly high temperatures are common problems leading to inefficiency.

**Insulate** Make sure the boiler, pipework and any storage vessels are properly insulated as this can be a major source of wasted heat.

**Maintain** Ensure you have a regular and thorough maintenance programme. If your equipment is running optimally this will always help increase efficiency.

Other energy saving techniques, such as the use of variable speed pumps, should also be investigated alongside heat recovery techniques.

Figure 3 Boiler classification by temperature

| Type                              | Temp °C      | Note   |
|-----------------------------------|--------------|--|
| Steam boiler                      | >100         | Water heated and allowed to vaporise into steam          |
| High-temperature hot water (HTHW) | >90 but <140 | Water heated, pressurised and maintained in liquid state |
| Low-temperature hot water (LTHW)  | <90          | Water heated and circulated at less than 90°C            |

### Boiler flue economisers

Boiler flue economisers are a tried and tested technology for recovering heat from flue gases. You can normally retro-fit an economiser to most steam and high-temperature hot water boilers, and there are also opportunities to fit economisers to conventional, non-condensing heating boilers.

After the hot flue gas has passed through the boiler it contains energy which can be used to improve efficiency. To achieve this, the flue gas is passed through an economiser to capture some of the heat. The captured heat can be used in different ways to increase the efficiency of the boiler. The main applications are:

### Heat recovery applications

- Boiler flue economiser **Page 14**
- Pre-heat combustion air using flue gas heat or boiler house heat **Page 17**
- Steam boiler blowdown **Page 19**

### Non-condensing boiler

Gas-to-water heat exchange to pre-heat boiler feed water to a steam boiler or to provide hot water for other heating purposes.

### Condensing boiler

Gas-to-water heat exchange to pre-heat the return water to a low temperature hot water heating boiler.

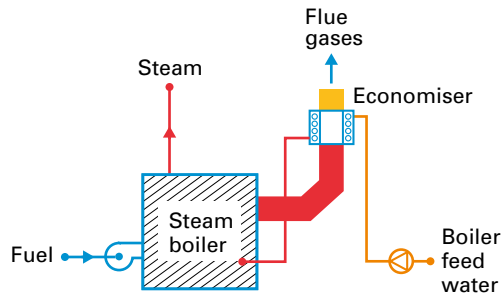
### Non-condensing boiler

Gas-to-air heat exchange to pre-heat the combustion air to a steam or hot water boiler.

Economisers are generally more financially viable when fitted to gas-fired boiler plant.

# Non-condensing gas-to-water economiser

*Figure 4 Non-condensing gas-to-water economiser fitted to boiler flue*



## Steam boilers

In steam boilers, the economiser is normally a water jacket fitted around the flue stack. The relatively cool boiler feed water is pumped through the heat exchanger tubes, where it absorbs heat from the hot flue gas before being pumped into the boiler (see *Figure 4*). Less energy is therefore required to raise the steam. As the economiser is on the high-pressure side of the feed pump, feed water temperatures in

excess of 100°C are possible – see [page 20](#) for some key tips on implementing heat recovery on steam boilers.

The boiler water level controls should be of the ‘modulating’ type (ie not ‘on/off’) to ensure a continuous flow of feed water through the heat exchanger.

## High-temperature hot water boilers

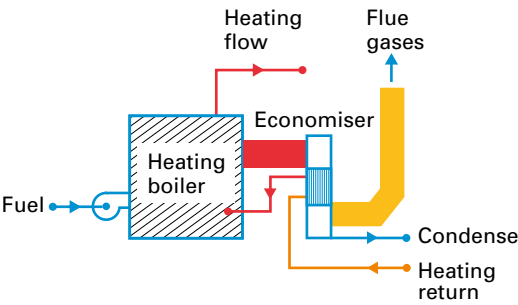
Where an economiser is fitted to the flue of a high-temperature hot water boiler, the water circulated through the economiser can be used for alternative heating purposes local to the boiler house such as space heating, domestic hot water heating or pre-heating heavy fuel oil.

## Benefits

Increase the net thermal efficiency of your boiler by up to 5% by using a non-condensing gas-to-water economiser or by up to 15% by using a condensing gas-to-water economiser.

# Condensing gas-to-water economiser

*Figure 5 Condensing gas-to-water economiser fitted to boiler flue*



In this type of economiser, the return water from the heating system is pumped through the heat exchanger tubes where it absorbs heat from the hot flue gases before being pumped into the boiler, as shown in *Figure 5*. Less energy is therefore required to heat the outgoing flow from the boiler.

### Tips for implementation

Consider these issues carefully when implementing boiler flue economisers:

- Ensure your economiser is the correct size. It is important to ensure that the flue gases are not condensed (changed from gas to liquid) and that the feed water does not boil in the exchanger.
- If you are installing an economiser which is designed to condense flue gases, you should ensure that the water returning from the heating circuit is cool enough to gain the maximum benefit. For correct operation in hot water boilers this should be less than 50°C; for steam boilers this will be closer to 90°C.
- The condensing type economiser is normally installed at floor level, near to the boiler flue outlet. Therefore, you should consider how much floor space you will require in the boiler housing.

### Investment and payback

In an office with an annual energy spend on gas of around £15,000, an investment of £6,000 to £8,000 to retro-fit a boiler flue economiser could see a payback in four to five years.

If you're replacing a boiler, consider buying a condensing model as this already contains economiser technology, and the extra capital cost will pay back far more quickly than retrofitting.

## Case study

### A drinks manufacturer

A global drinks manufacturer saved 4.1% on gas consumption due to installing a flue economiser when they upgraded to a new steam boiler. The economiser cost was 10.5% of the overall new budget and achieves payback in a little over two years.



## Pre-heating boiler combustion air

Boiler efficiencies can be improved by pre-heating the combustion air to the burner. You can do this by using a flue economiser or by making use of the warmer air from the top of the boiler house or around the boiler shell.

In most boiler installations, the air required as part of the combustion process is generally taken from within the boiler room. In the case of a forced draught burner this is assisted by a fan, but in a natural draught burner there is no assistance. This incoming combustion air is at boiler room temperature, which is cooler than boiler operating temperature.

Boiler efficiency can be improved by pre-heating the incoming combustion air up to boiler operating temperature. This reduces the amount of boiler energy that becomes transferred to the combustion air as it enters the system, and, as a result, provides a higher flame temperature from the burner.

The usual heat sources for heating combustion air are:

- heat remaining in the flue gases
- higher temperature air drawn from the top of the boiler house
- heat recovered by drawing air over or through the boiler casing to reduce shell losses.

## Energy saving potential of preheating combustion air

Boiler efficiency can be increased by 1% by raising the combustion air temperature by 20°C, although the savings achieved will depend on the type of system installed.

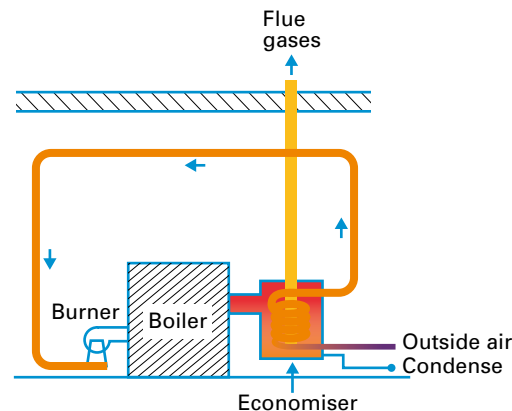
### Benefits

You can increase boiler efficiency by 1% by raising the combustion air temperature by 20°C. Ducting hot air down from the top of the boiler house into the boiler will typically provide savings of up to 1%, while drawing combustion air over or through the boiler casing can provide savings of up to 2%.

## Boiler flue economiser

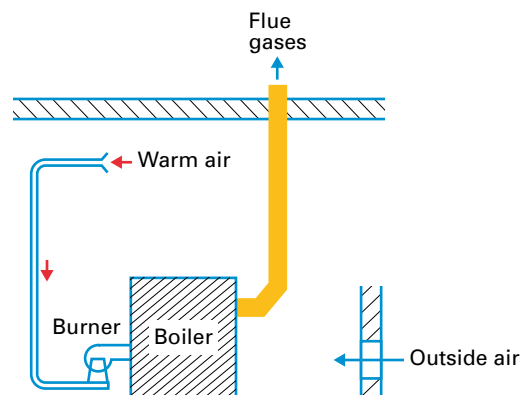
Ambient outside air is drawn through the boiler flue economiser and ducted to the burner air input. The burner-forced draught fan must be capable of overcoming the additional back pressure of the air ducting.

*Figure 6 Boiler flue economiser used to pre-heat boiler combustion air*



## Use warm air from boiler house

**Figure 7** Warm air ducted to boiler burner to pre-heat boiler combustion air



Warm air from the top of the boiler house is ducted down to the burner air input. The burner-forced draught fan must be capable of overcoming the additional back pressure of the air ducting.

Alternatively, air can be drawn through the boiler casing but this may involve modifications to the manufacturers' casing.

## Tips for implementation

There are some key things to remember when considering increasing combustion air temperatures.

Most gas and oil burners can only tolerate a maximum increase in combustion air temperature of around 50°C and increases of more than this without changing the burner in your boiler may cause damage. However, there are modern burners that can stand much higher temperatures and can normally be retro-fitted to existing boilers.

Each of the techniques described will require additional space in the plant room

so you should ensure that there is sufficient space to allow for safe access for ongoing maintenance to the plant.

Using the heat remaining in the flue gases can be expensive, so you might only consider using an economiser in this way if other uses are impractical. This technique also requires a stainless-steel heat exchanger to be fitted in the boiler-flue system. It is also necessary to fit bypass dampers when firing fuel oil instead of natural gas, which will add to the cost of implementation and increase payback times.

## Investment and payback

Adding simple ducting to bring hot air from the top of the boiler house onto the burner using the existing fan in a typical office of around 250 people could cost as little as £1,000 and give a payback of around five years.

## Steam boiler blowdown heat recovery

You can improve both energy and water treatment efficiency by recovering flash steam and residual heat from blowdown and achieve a payback of less than five years.

When water is converted to steam in a boiler it leaves behind suspended solids and dissolved salts, or Total Dissolved Solids (TDS). Over time, the remaining water contains an increasing concentration of TDS and, if left unchecked, will eventually lead to crystallisation of the salts on the surfaces it comes into contact with. In turn, this will lead to the fouling of heat transfer surfaces and a general build-up of solids in the base of the boiler.

Controlling the quantity of TDS is an integral part of maintaining an efficient steam boiler system and is achieved by removing steam with high concentrations of TDS (blowdown) and replacing it with make-up water with lower TDS levels. This process reduces the TDS content in the boiler water and the likelihood of scaling. The blowdown process can be controlled manually or automatically and the regime can be intermittent or continuous, or a combination of both.

*Figure 8 Schematic of a steam boiler blowdown heat recovery system*

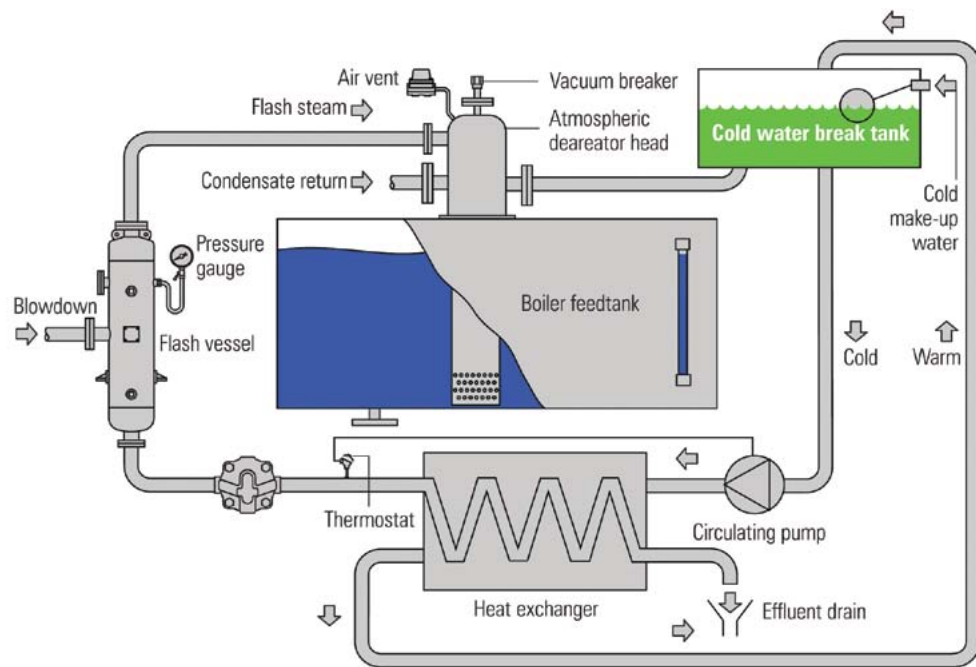


Image courtesy of Spirax Sarvo Ltd

Before discharging the blowdown water to drain, it must be cooled to below 43°C to comply with trade effluent consent conditions. This temperature reduction is achieved by diluting the blowdown water with cold water.

The main disadvantage of blowdown is that typically 1% to 5% of the energy input to the boiler is lost. However, up to 80% of the heat in the boiler blowdown water can be recovered.

Implementing heat recovery saves energy by increasing the temperature of the feed water to the boiler and reducing the amount of fuel consumed in the boiler.

### Recovery of flash steam

Passing blowdown water through a flash vessel generates low-pressure steam. The flash steam that separates as the pressure is reduced downstream of the boiler blowdown valve can then be collected and re-used for feed tank heating or other uses. This system of heat recovery is suitable for plants with continuous blowdown systems.

### Energy saving potential from blowdown heat recovery

Blowdown heat recovery systems can potentially be used with any steam boiler, but are unlikely to be cost-effective on boilers below 1,000kW. As a guide, they work best when blowdown is carried out on a continuous basis, rather than intermittently. Continuous blowdown means you can install a much smaller heat recovery system for the same benefit.

### Benefits

Heat recovery can reduce blowdown energy losses by up to 50%, to give an energy saving of 0.5% to 2.5% of heat input in a boiler plant. Heat recovery from the remaining blowdown water can further reduce blowdown energy losses by up to 25%, providing a total energy saving of 0.75% to 3.75% of heat input.

Heat recovery can reduce blowdown energy losses by up to 50%

## Tips for implementation

Before thinking about heat recovery ensure you have a robust TDS regime in place. If levels are too high, water carryover may result due to 'priming' and water may enter the steam system, degrading the quality of steam produced.

Because there may be high levels of TDS in the fluid passing through the heat recovery equipment it is prudent to select equipment that can handle large quantities of contaminants to avoid fouling and similar issues.

Heat can be recovered from both the steam and water stream, which is released from the system during continuous blowdown by using a two-stage process.

As a minimum, feed water should be raised to temperatures over 85°C to minimise the oxygen content, but care must be taken to avoid damage to pumps through cavitation. Cavitation is the formation and immediate implosion of bubbles when water is subjected to a rapid change in pressure in the pump. The continuous implosion of the bubbles on pump surface can cause excessive wear and in extreme cases failure of the pump.

The Combustion Engineering Association ([www.cea.org.uk](http://www.cea.org.uk)) may be able to help you find a steam boiler heat recovery specialist.

## Investment and payback

Costs of implementing steam boiler heat recovery can range from £6,000 to £10,000, but in most situations would be expected to pay back in around two years.

# Heat recovery applications: refrigeration

Refrigeration is a process where heat is moved from one location to another.

There are many applications for refrigeration, most commonly to provide cooling in refrigerators, freezers and cold stores. Refrigeration is also commonly used for cooling and heating in air conditioning systems. Large central systems are used to provide cooling to a number of appliances or pieces of equipment in commercial applications such as supermarkets and in industrial applications.

## Principles of operation

The most common type of refrigeration system uses the vapour-compression refrigeration cycle, which is sometimes referred to as a direct expansion (DX) system. This type of system comprises the following essential components:

- a compressor (with motor drive)
- a condenser (heat exchanger)
- an expansion device (usually an expansion valve)
- an evaporator (heat exchanger).

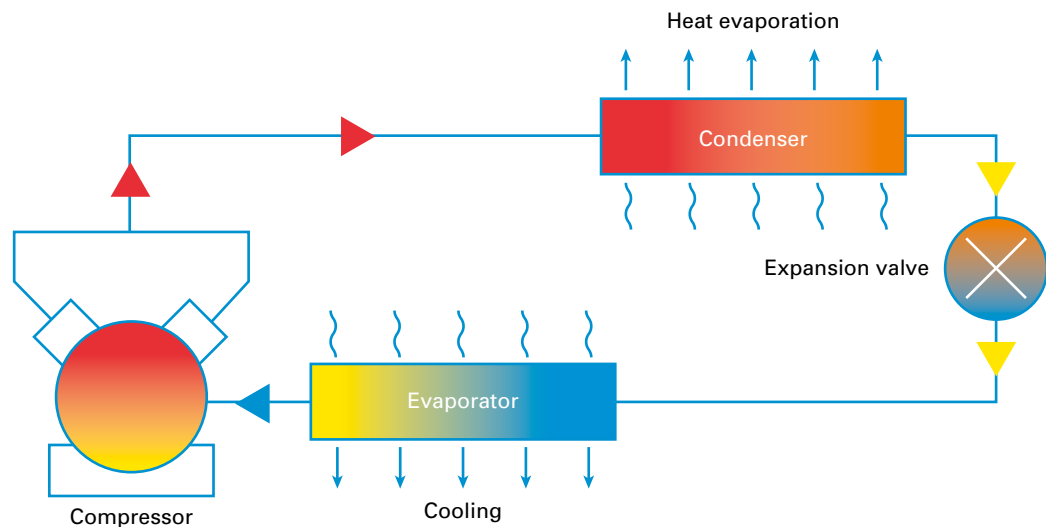
These components are connected together with pipework and arranged as indicated in *Figure 9* on the next page.

## Where heat is wasted

Refrigerant is circulated around the system and is subjected to differing pressures and temperatures. At different times, the refrigerant varies between vapour and liquid state, depending on where it is in the cycle.

The refrigerant enters the compressor as a vapour where it is then compressed, which increases the pressure and temperature. The vapour passes into the condenser, where heat is rejected and the refrigerant cools. As it cools, it changes from a vapour to a liquid. The pressure of the refrigerant is reduced by passing through an expansion device before it enters the evaporator. In the evaporator the refrigerant evaporates (boils) to a vapour state, absorbing heat from the surroundings and therefore providing cooling.

**Figure 9** Refrigeration circuit – vapour compression system



About 20% of the heat rejection is due to 'de-superheating' of the refrigerant prior to condensation and this heat has the potential to be recovered as 'high-grade' heat for other heating purposes. This is described on [page 25](#).

The remainder of the heat rejection from the condenser can also be recovered and used as 'low-grade' heat as described on [page 27](#).

### Further references

[Refrigeration systems technology guide \(CTG046\)](#)

### Heat recovery applications

High-grade heat recovery using a de-superheater **Page 25**

Low-grade heat recovery from condensers **Page 27**

## Tips for implementation

There are some general tips to consider when implementing heat recovery on refrigeration systems.

Before implementing heat recovery, you should ensure the system is operating as efficiently as possible. This will mean looking at the time when the system operates and the pressures and temperatures that are being provided as well as ensuring there are no refrigerant leaks. Your contractor or engineer should be able to help you with these issues.

If you require heat at a higher temperature than can be provided by the systems shown in this section, you could consider linking them with a heat pump to achieve the temperature you need.

Heat recovery can be applied to most sizes of plant, from small units used for a single

room (such as a server room or cold store) to units of more than 1,000kW used in large food storage facilities such as chilled warehouses.

The amount of heat that can be recovered from a refrigeration system will be heavily influenced by the temperature required for use. The higher the temperature (typically up to a maximum of around 65°C), the lower the amount of heat that can be recovered.

If you are considering using recovered heat for space heating, be sure to factor in the cost of any ducting in your calculations as this can affect viability.

Recovered low-grade heat is most suited to providing space heating, so it's important that there is a constant requirement for heating during the winter months to make the most of any investment.

## Investment and payback

By choosing to include de-superheater heat recovery (see [page 26](#)) on a refrigeration system in a typical new-build office for around 250 people and using the recovered energy for space heating, it should be possible to reduce overall gas consumption by 5% to 10%, saving around £1,000 from utility bills and giving paybacks in the region of two to three years.

Using a 'full' heat recovery system, nearly 100% of the heat can be recovered, but it will be at low grade (around 40°C-45°C) and therefore less versatile in its application.



## High-grade heat recovery using a de-superheater

Most refrigeration systems have the potential to incorporate heat recovery and one way you can do this is to install a de-superheater ahead of the condenser in the circuit (see *Figure 10*).

Typically the heat of the refrigeration fluid, at the discharge from the compressor (commonly known as the hot gas line), is between 60°C and 90°C but can be as high as 110°C.

A refrigerant-to-water heat exchanger can be installed in the hot gas pipeline to recover the superheat for alternative heating purposes near the refrigeration plant.

The heat exchanger provides recovered heat for use elsewhere and also de-superheats the refrigerant, which reduces the cooling duty of the condenser. High-grade heat recovered from a de-superheater has wide applications, including in:

- a process plant where demand for hot water is high, such as in steam boiler water pre-heating
- food processing plants where, for example, large amounts of hot water are needed for washing down
- buildings that need air conditioning and hot water, such as swimming pools and hospitals.

**Figure 10** High-grade heat recovery using a de-superheater

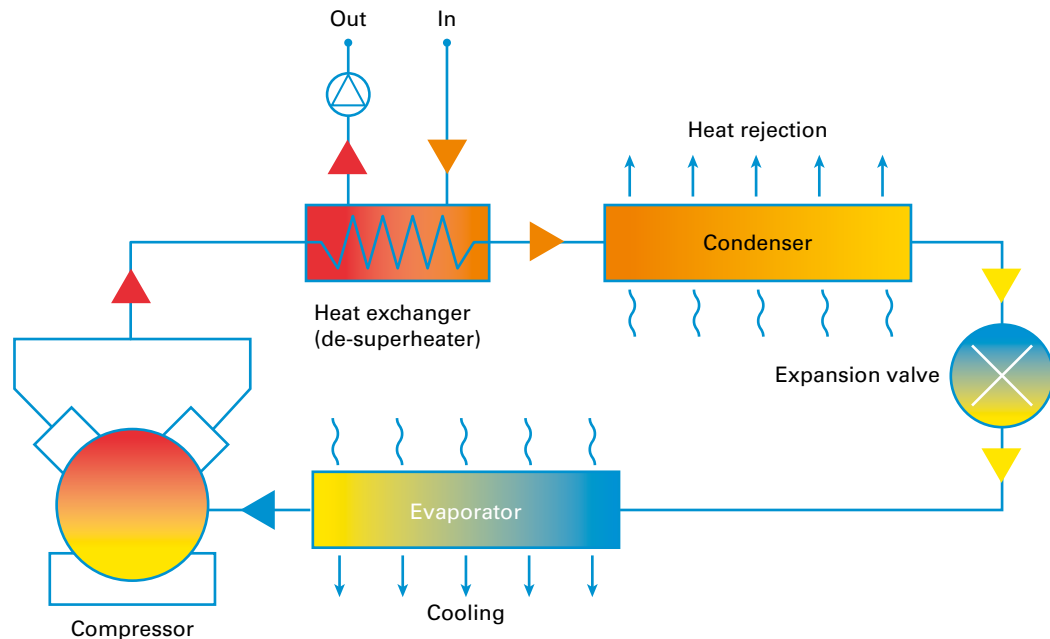
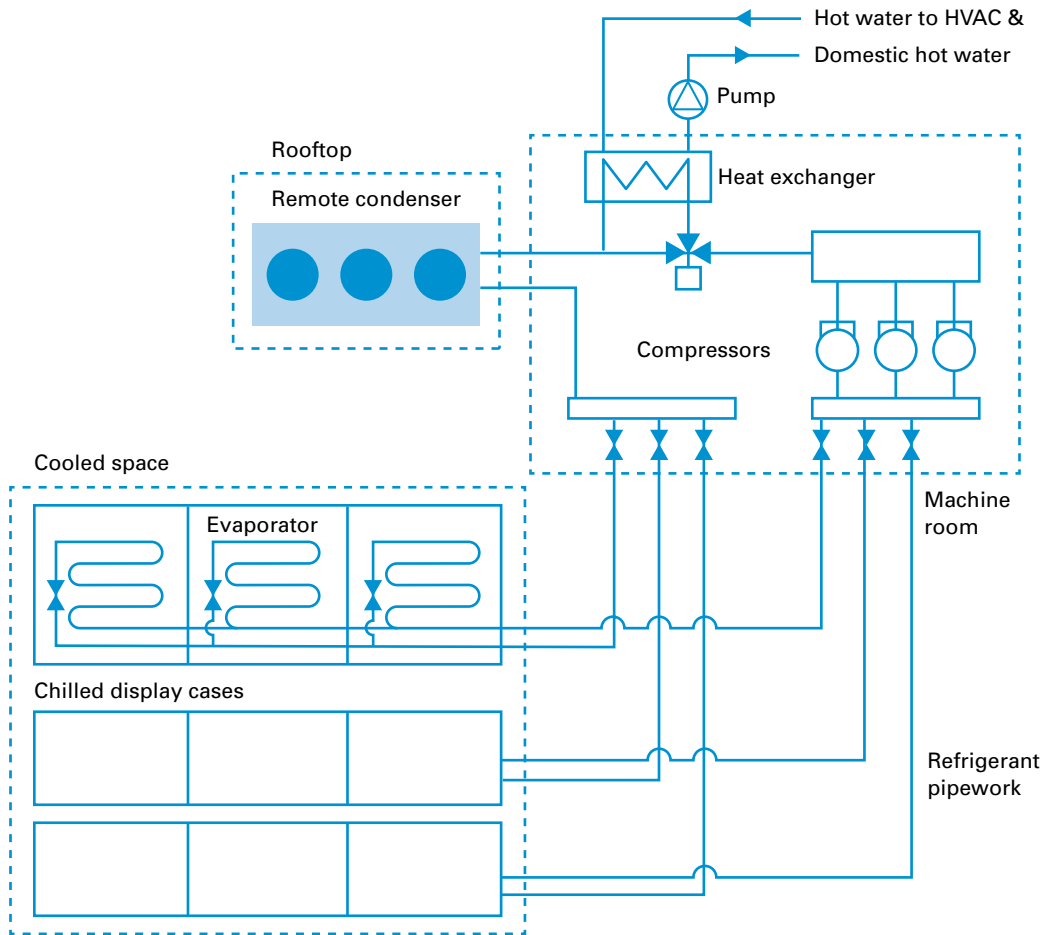


Figure 11 De-superheater used on larger centralised system



The same principle can be used on large central refrigeration systems with multiple compressors (see Figure 11).

The large amount of heat rejected by the refrigeration system in a typical supermarket offers an attractive resource for use in store space heating, with around 10% of rejected heat being available at high grade. Much of the remaining heat could also be recovered but as low grade.

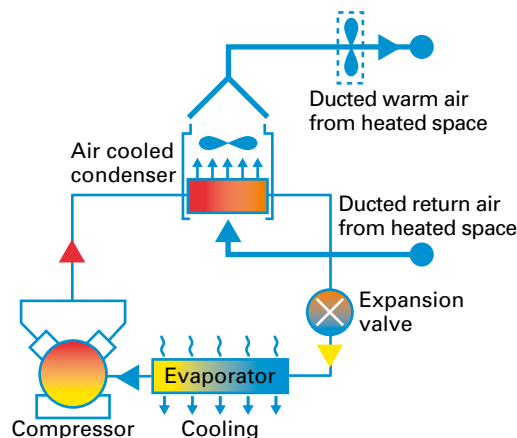
## Low-grade heat recovery from the condenser

The condenser in your cooling system rejects heat, normally directly to atmosphere. If you have a coincident cooling and heating demand, you could make good use of this heat despite it being low grade.

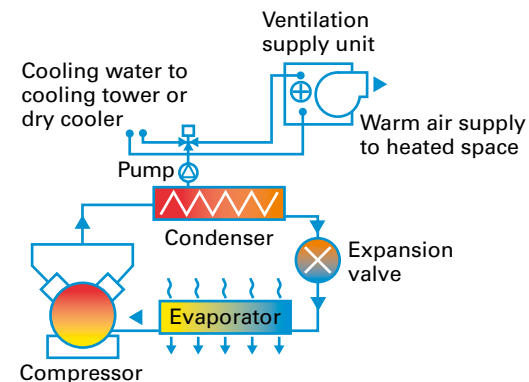
Typically for refrigeration systems in the UK, the condensers will operate at ambient air temperatures of between 20°C and 40°C. The heat rejected could be used for alternative heating purposes, local to the refrigeration plant.

Where air-cooled condensers are used (see *Figure 12*), the simplest method of recovering the waste heat is to use the warm air discharge for space heating purposes. This can be achieved either by ducting the air from the condensers directly into the space that requires heating or potentially physically re-locating the condenser within the space that requires heating providing a direct supply.

*Figure 12 Low-grade heat recovery: air-cooled condenser*



*Figure 13 Low-grade heat recovery: water-cooled condenser*



Ducting the heat from the condenser will probably require the installation of a supplementary fan and, whichever method is adopted, it may be necessary to provide bypass ducting to discharge warm air to outside, when the space heating is not required.

Low-grade heat recovered from condensers can be upgraded to a higher grade through the use of heat pumps and then used for applications such as space heating or pre-heating domestic hot water.

Where water-cooled condensers are used (see *Figure 13*) the cooling water could, for example, be supplied to a warm air heater coil within a ventilation system.

## Server rooms

An increasing number of computers in office spaces demands a proportional increase in the number of servers. The servers produce a significant amount of heat, which can affect their operation if left unchecked. Therefore this results in an increasing demand for 24-hour cooling in the server rooms in order to maintain their correct operation.

Where refrigerant cooling is used the resulting waste heat from the condensing units could be captured and used elsewhere in the building for space or hot water heating.



## Benefits

In a supermarket, you could supply 75% to 90% of hot water demand from heat recovered from refrigeration. This could account for 2% to 3% of the building's total CO<sub>2</sub> emissions.

# Heat recovery applications: ventilation

In modern buildings you need to balance the requirements for ventilation systems to provide sufficient fresh air with efficient energy consumption. Heat recovery through the ventilation system, which would otherwise be lost, can reduce energy consumption.

## Principles

The 'air tightness' of spaces in buildings is increasingly being targeted to improve building efficiencies.

This has resulted in contemporary ventilation systems being required to deliver more fresh air than before, usually to a greater occupancy and internal comfort level whilst ensuring that energy is not being wasted and indoor air quality is at the correct levels.

The cost of installing a heating, ventilation and air conditioning (HVAC) heat recovery system depends on the size and complexity of installation. In an average installation, without any huge complications and where plant operates continuously, you could recoup the cost within two years. For plant that runs for just 40 hours a week, the payback period would be around five years.

## Efficiency of heat recovery

The most effective way of recovering energy from ventilation and air-conditioning systems is to make use of recirculated air.

## Where ventilation heat recovery can be applied

There are many applications of heat recovery technology in ventilating and air-conditioning systems, but they are based on a few simple techniques. The principal ones are thermal wheels, plate heat exchangers, heat pipes and the run around system.

Heat recovery can potentially be applied to any HVAC system that uses ductwork to supply and extract ventilation air. You can commonly find opportunities in:

- offices
- lecture theatres
- hospital wards
- swimming pool halls
- manufacturing areas.

It's worth noting that installations in new buildings where mechanical ventilation is being provided are almost certain to contain some form of heat recovery. This is because current building regulations demand a level of efficiency which is very difficult to achieve without it and such techniques are now commonly adopted.

This section will be useful in informing the debate about which sort of heat recovery to include in new builds and should be particularly useful to anyone wanting to retro-fit to an existing system.

A qualified engineer will be able to talk you through the various systems and advise on their specific requirements. As the efficiencies are so similar and the costs (particularly for new build projects) not hugely varied, considerations such as space and maintenance may be just as important in your decision of which technology to opt for as financial performance.

Ventilation heat recovery – efficiencies

The efficiencies shown below are useful in comparing the range of technologies available for heat recovery in ventilation systems:

- Plate heat exchanger: typically 55%-65%, maximum 80%
- Thermal wheel: typically 65%-75%, maximum 80%
- Run around coil: typically 45%-50%, maximum 55%
- Heat pump: typically 35%-50%, maximum 60%
- Heat pipes: typically 50%-65%, maximum 75%

Further references

[How to implement heat recovery in heating, air conditioning and ventilation systems \(CTL051\)](#)

[Air to air energy recovery: A guide to equipment eligible for Enhanced Capital Allowances \(ECA771\)](#)

[How to implement de-stratification fans \(CTL023\)](#)

Ventilation heat recovery applications

|   |         |
|---|---------|
| Thermal wheel technology                      | Page 32 |
| Plate heat exchanger (recuperator) technology | Page 34 |
| Heat pump technology                          | Page 36 |
| Run around coil (closed loop) technology      | Page 41 |
| Heat pipe technology                          | Page 40 |



## Tips for implementation

A key consideration when installing heat recovery in a ventilation system is to recognise that the introduction of the heat recovery equipment will cause a pressure drop on the supply and extract fans. Some fans may be able to cope, but it is essential that this is checked at design stage to ensure the overall performance of the system isn't compromised.

In general, heat recovery in ventilation systems can't be easily applied to contaminated air streams, such as cooker hoods or some industrial extraction systems, because the heat exchanger can become fouled with particulates in the extract air stream. This is also important where either smells or substances which may be harmful to health could be present in the exhaust air stream.

When installing heat recovery in an existing HVAC system, you need to consider the available space in the ductwork and whether your fan power is adequate.

Ideally, supply and extract AHUs and ductwork are usually stacked on top of one another, but there are still opportunities for heat recovery if they are not. However, technologies like run around coils only tend to be economical if the ducts are in the same plant room.

Once installed, it's important that a proper maintenance regime is undertaken. The regime should cover:

- blocked filters
- dirty heat exchange surfaces
- dirty ductwork
- blocked condensate drains

- damaged damper seals
- seized damper actuators
- poorly calibrated controls
- recommissioning of systems after alterations.

It's worth noting that installations in new buildings where mechanical ventilation is being provided are almost certain to contain some form of heat recovery. This is because current building regulations demand a level of efficiency which is very difficult to achieve without it and such techniques are now commonly adopted.

This section will be useful in informing the debate about which sort of heat recovery to include in new builds and should be particularly useful to anyone wanting to retro-fit to an existing system.

## Thermal wheel

Thermal wheel technology offers you the greatest percentage of heat recovery within an air system, and therefore the greatest reduction in energy and carbon. However, there are limitations due to the physical size of the unit as well potential for cross-contamination of the air streams. Additional heat recovery can be advantageous, especially where there is high latent temperature in the return air.

A thermal wheel, also known as a 'rotary' or 'regenerative' heat exchanger, is a system of heat transfer which involves a single rotating wheel with high thermal capacity located within the supply and exhaust air streams of an air handling unit (AHU). Its rotation allows the recovery of energy from air that would otherwise be lost to the atmosphere, and the energy to be used to pre-heat (or cool) the incoming fresh air.

The use of this technology will reduce the amount of energy needed to heat (or cool) the supply air to the required temperature with a corresponding reduction in carbon emissions.



Thermal wheel installed in an AHU (Image courtesy of Nuaire Ltd)

A thermal wheel typically comprises a circular wheel with a matrix or honeycomb material of a large surface area through which air can pass. The wheel sits with one half in the exhaust air stream and the other half in the supply air stream of the AHU.

As the thermal wheel rotates, energy from the exhaust air stream is captured within the honeycomb structure. The heat exchanger honeycomb rotates and the energy is transferred to the fresh air stream in the other half of the AHU. Supply and exhaust air streams must be flowing in opposite directions to maximise heat recovery and supply air temperature.

The rotary heat exchanger honeycomb is normally manufactured from aluminium, which has good heat transfer properties, but it can also be manufactured from plastic or paper material. The wheel is rotated by a small electric motor and belt drive system.

### Benefits

With the high efficiencies of thermal wheels, your investment could pay back within two years.



## Investment and payback

When specifying new ventilation equipment for an office building of 2500m<sup>2</sup>, operating within normal office hours, a thermal wheel is likely to add around £7,000 to £9,000 to the capital cost but should pay back in around two years. If you were considering retro-fitting a thermal wheel to existing equipment, assuming you have the space and there are no significant complications, you should expect to pay more but still achieve a payback in the region of three years.

The speed of rotation of the thermal wheel can be controlled with a variable speed motor for improved control of the temperature transfer. If no heat (or cool) transfer is required, the motor can be stopped and the air flow will pass straight through the honeycomb matrix without any transfer of energy to the other compartment.

## Advantages and disadvantages

Thermal wheels are available to capture either 'sensible' or 'total heat' (ie sensible and latent heat) from the exhaust air stream and transfer the captured energy into the supply air stream. The benefit of the total heat version is that it also captures latent heat (water vapour) and transfers this additional energy into the supply air stream as well as sensible heat.

The speed of rotation will determine the amount of energy transferred between the two air streams; however, total heat thermal wheels can achieve efficiencies of up to 85%.

The thermal wheel has to be installed in the AHU, so the size of the unit can be very large, especially as air flow volume increases. You should consider the space you have available, as this will increase the complexity of coordination of ductwork.

## Tips for implementation

Remember these issues if considering a thermal wheel for your site:

- Using a thermal wheel in an AHU leads to the supply and exhaust air streams mixing to a small degree. If this isn't acceptable, because the exhaust air is contaminated in some way, you can reduce the effect by using physical seals and purge sections within the air handling unit. However, this may not stop the mixing completely.
- In addition, air entering the wheel from either side must be filtered to prevent the wheel becoming fouled with particulates in the air streams.
- You'll also need to ensure that good access for maintenance is provided as part of the installation, and considering the space requirements of a thermal wheel, this may be an important issue in determining whether the project is feasible.

## Plate heat exchanger or recuperator

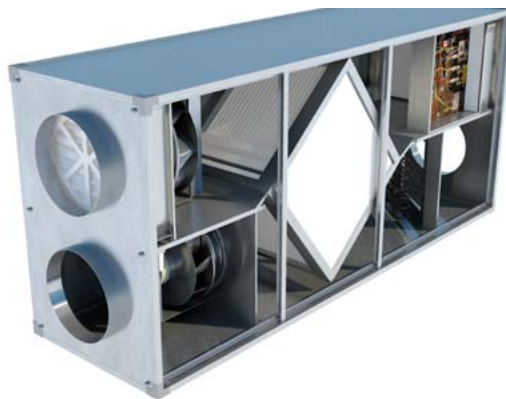
Recuperator technology is by far the most common form of air-to-air heat recovery and is used in a variety of air handling units with different air volumes. This technology can be linked with additional heating and cooling coils to reduce the amount of energy required to maintain internal conditions.

A plate heat exchanger (or recuperator) transfers heat between the supply and exhaust streams of an air handling unit. It recovers energy from extracted air that would otherwise be lost to the atmosphere and uses it to pre-heat (or cool) the incoming fresh air. *Figure 14* and the image below demonstrate the principle and structure of the heat exchanger type.

The use of a plate heat exchanger reduces the amount of energy needed to heat (or cool) the supply air to the required temperature with a corresponding reduction in carbon emissions.

A plate heat exchanger is typically comprised of a series of parallel plates of aluminium, plastic, stainless steel or synthetic fibre, which direct the intake (supply) air and exhaust (return) air. The supply and extract air streams cross over each

*Figure 14 Principle of operation of a recuperator*



A plate heat exchanger within an AHU  
(Image courtesy of Nuair Ltd)

other, but are separated by the parallel plates, which allow energy to be transferred from the exhaust air to the incoming air supply.

As the intake and exhaust air streams are physically separated and energy is transferred through the plates, their material, thickness and surface area affect the transfer efficiencies of the equipment. Manufacturers claim gross efficiencies between 50% and 80% depending on the specification of the unit.

In traditional plate heat exchangers, sensible heat (containing no moisture) will pass through the plates dividing the two air streams. Newer plate heat exchangers, constructed from a semi-permeable membrane, will allow both sensible and latent heat to transfer between the two air streams, providing a greater energy saving.

### Benefits

A 70% efficient plate heat exchanger in a typical office could save you 38% of your total gas consumption.

## Advantages and disadvantages

If heat recovery through the plate heat exchanger is not required, for example in summer conditions, and the exhaust air is at a higher temperature than the incoming supply air, a mechanical bypass damper can divert the air around the plate heat exchanger. This prevents unwanted heat being transferred to the supply air.

### Investment and payback

Plate heat exchangers are a relatively simple approach to heat recovery and, other than ongoing maintenance, are not a significant operative cost. For a typical office of 2,500m<sup>2</sup> with normal working hours, you should expect to pay around an extra £6,000 to £8,000 for the inclusion of a plate heat exchanger in a new build project, which should pay back in well under two years. If you want to retro-fit an exchanger to a similar sized system, the cost is likely to be about £12,000 with a payback period of around three years.

## Tips for implementation

Since the two streams are physically separated from each other there is a low risk of contamination transfer between the supply and exhaust air flows making this application of this technology quite flexible and broadly applicable to many different industries.

Depending upon the material of the plate heat exchanger, the cold incoming air from outside may need to be temperature

controlled to ensure that the air flow is above 0°C. Water freezing on the plates can result in either loss of performance or damage to the plates themselves.

If one of the air streams is cooler than the dew point of the other air stream, there is a chance of condensation and therefore condensate drains should be provided to the ventilation unit.

As the plate heat exchanger must be installed within the air handling unit, the physical size of the air handling unit can be large, especially as air flow volumes increase. Access for maintenance is also required, adding to the overall plant space required.

Due to the need to recover the exhaust air energy and pre-heat the incoming supply air, the ductwork associated with the various air paths must be co-ordinated within one area. Allowances must be made for routing of the

ductwork through the building as four different air paths must be coordinated within one area.

## Heat pumps

Heat pump coils remove heat or cool energy from one location and direct it to another. They are used to avoid cross-contamination of air or when the systems can not be located within the same air handling unit. This system can be added retrospectively within an existing and separate air handling unit.

A ventilation heat pump heat recovery system is built for efficient energy transfer from one air stream to another where the two systems are physically independent from each other. Heat pumps can provide either heating or cooling energy to the coil located within the supply air stream.

Heat pump systems operate on the same principle as a basic refrigeration cycle. They use both coils within the air handling unit air stream as either a condenser or an evaporator for heating or cooling purposes. Refrigerant pipework connects supply and extract coils within the air streams of the separate air handling units. A compressor and expansion device is located between the two coils.

## Heat pump – heating mode

Figure 15 shows that if the supply air requires heating, heat energy is fed directly from the compressor via the refrigerant pipework into the supply air coil (condenser) located within the supply air stream of the AHU. This heats the cooler incoming air and leaves the condenser as a cooled refrigerant liquid.

The cooled liquid is reduced in pressure by passing through an expansion device and enters the exhaust air coil (evaporator) located within the exhaust air stream. In the evaporator the refrigerant evaporates (boils) to a vapour state. This is where the cooling takes place. The refrigerant re-enters the compressor and the cycle starts again.

## Heat pump – cooling mode

Figure 16 shows that when cooling is required the reverse occurs and heat energy is fed directly from the compressor into the exhaust air coil (condenser) located within the exhaust air stream of the AHU.

The cooled liquid is reduced in pressure after passing through an expansion device and enters the supply air coil (evaporator) located within the supply air stream. In the evaporator the refrigerant evaporates (boils) to a vapour state. This is where the cooling of the incoming supply air takes place. The refrigerant then re-enters the compressor and the refrigerant cycle starts again.

Figure 15 Heat pump in heating mode

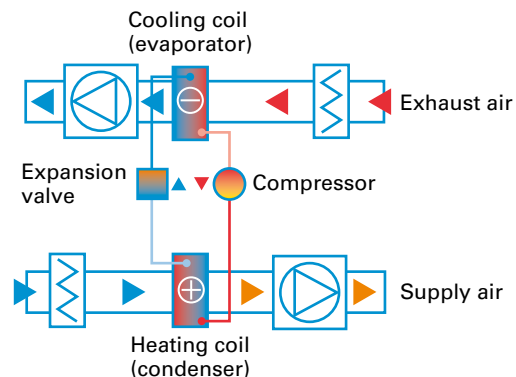
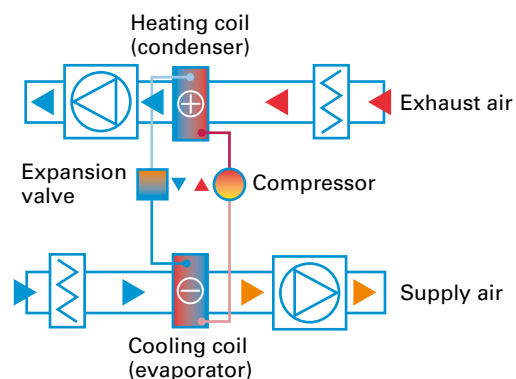


Figure 16 Heat pump in cooling mode



## Advantages and disadvantages

The heat pump efficiency, of up to 60%, is usually controlled by adjusting the speed of the compressor.

The major advantage of this system is that it provides a means of heat recovery where two air streams are not close enough for alternative and more efficient heat recovery methods. This can assist with the position of the air handling units and reduction in the interconnecting ductwork within the air system.

Due to the separation of the air streams via the coils and pipework, there is no risk of cross-contamination within the air streams.

## Tips for implementation

Don't forget to consider these issues when looking into heat pumps as your chosen heat recovery method:

- Although heat pumps provide a way of transferring energy between two separate air streams, overall efficiency will be reduced where long distances are involved.
- The heat pump system can be a solution for retro-fit as well as new build where space constraints mean other, more efficient methods can't be used.

## Investment and payback

Heat pumps should save you a significant amount off your heating energy bill – in some cases as much as 60%. In a typical UK office of 250 people, that could be as much as £3,500 a year.

## Benefits

By using heat pumps with an efficiency of 50% to provide cooling as well as heating, you could save up to 12% of total building CO<sub>2</sub> in a typical office.

## Run around coil

Run around coils are a process where heat or cool energy is removed from one location and directed to another where the systems cannot be located within the same air handling unit or to avoid cross-contamination of air. This system can be added retrospectively within existing and separate air handling units.

A run around coil system is built to enable efficient energy transfer from one air system to another, where the two systems are physically independent.

This process involves a heat transfer coil in each of the supply and exhaust air streams, but, unlike the thermal wheel and plate heat exchanger, a run around coil system does not require the air streams to be located within the same AHU. These coils recover energy from the extracted air that would otherwise be lost to atmosphere. This recovered energy can then be used to pre-heat (or cool) the incoming fresh air stream. This reduces the amount of energy needed to heat (or cool) the supply air to the required temperature with a corresponding reduction in carbon emissions.

The possibility of exchanging heat between remote air streams is due to the coils being connected to each other by a pumped pipework circuit. This pumping will use a small amount of energy but this will be less than that being saved by installing the system.

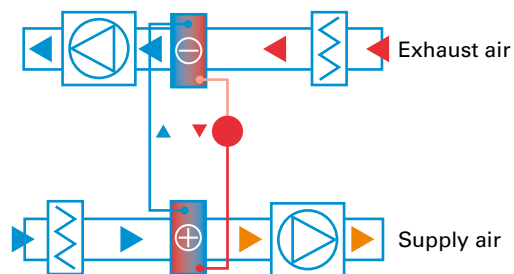
The pipework is charged with a circulating fluid, normally water or glycol, which flows around the circuit between the coils within the two air streams. Hence the closed loop system or run around coil terminology (see *Figure 17*).

Run around coil systems cannot transfer moisture from one air stream to another and therefore only sensible heat can be captured. For the most cost-effective operation, with equal airflow rates and no condensation, typical effectiveness values range from 45% to 55%.

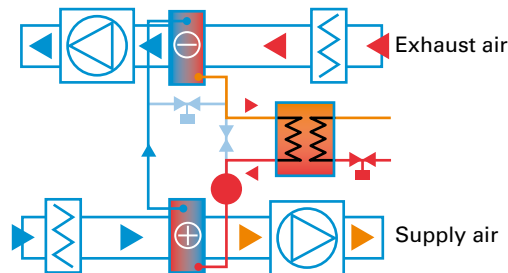
The fluid pipework distribution circuit connecting the supply and exhaust coils, as well as containing the circulating pump, requires the following components:

- an expansion vessel
- an automatic fill device to ensure the system remains charged

**Figure 17** Run around coil system installed between supply and extract AHUs



**Figure 18** The efficiencies of run around coils can be enhanced significantly by connecting to a secondary heat source as shown below



## Tips for implementation

In very cold weather, ice may form on the coils so you'll need to ensure that your specialist considers the use of frost protection in the system.

You can use this approach as a retro-fit option in existing separate supply and extract systems without significant modification to the ductwork but remember that for it to be viable the distance between supply and extract ducts shouldn't be too great.

## Investment and payback

In a typical office building of around 2,500m<sup>2</sup>, which operates on weekdays and some early evenings, installation of a run around coil system might cost £5,000 to £7,000 and give payback in the region of two years. Retro-fitting run around coils is unlikely to cost a significant amount more than in new build.

- controls to bypass and shut down the system when not required
- various other safety devices and ancillaries.

## Advantages and disadvantages

- Provides heat recovery where air streams are not close enough for alternative and more efficient methods. Using a run around system can assist with positioning air handling units and reduce the interconnecting ductwork.
- Additional energy efficiencies, up to 75%, can be introduced to the run around coil configuration if linked to a separate heat source.
- Glycol in the fluid system will reduce efficiency and increase pump power consumption.
- The separation of the air streams means there is no risk of cross-contamination between the air streams.
- Multiple air streams in a building can be used to further improve energy transfer. Exhaust heat recovery coils can be focused on high-energy areas where dedicated ventilation services are provided (such as datacentres, kitchens and process ventilation) to maximise additional energy recovery.

## Benefits

You could achieve up to an 8% reduction in electricity use in a general retail store by installing a run around coil with 45% to 55% efficiency.

## Heat pipes

Heat pipes can only be used where the supply and extract air streams are contained in the same air handling unit. However, the energy efficiency and lack of mechanical moving parts make them suitable for a majority of applications within new air handling units.

Heat pipes are simple, low maintenance devices that can transfer heat from one point to another without having to use either an external power supply or moving parts (i.e. pumps or compressors). In this context, a heat pipe heat exchanger is used for efficient energy transfer from one air path to another. This process involves sealed tubes, sometimes internally lined with a wick, charged with a refrigerant. In heating, ventilation and air-conditioning systems, heat pipes are located within the supply and exhaust air streams of an air handling unit.



## Run around coils versus heat pumps

These two types of heat recovery system appear quite similar but in fact use different approaches to achieve similar results.

Both systems can be used where supply and exhaust air streams are not physically close by connecting the streams with pipework, but here the similarity ends.

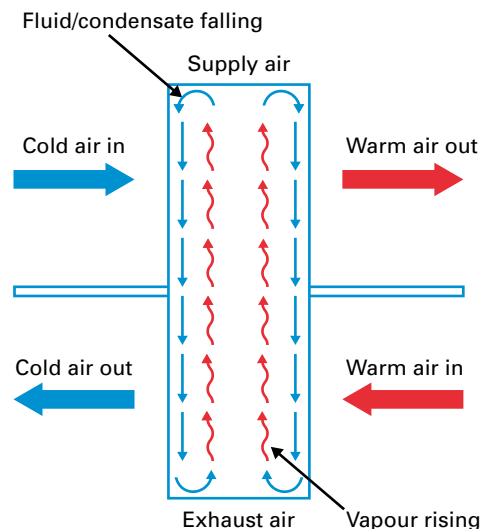
Run around systems are simple: the pump is the only mechanical part and their efficiency is limited due to the heat transfer medium being used. Heat pumps, on the other hand, operate like a refrigerant circuit and often use refrigerant fluid rather than a simple water/glycol mix. Using a compressor and expansion valve provides greater control which, whilst increasing complexity, also increases efficiency.

The heat pipes are usually a continuous pipe, which passes through both the supply and extract air streams.

Within the tube system, the sealed refrigerant located at the bottom of the tube absorbs the energy (heat) from the exhaust air stream. As the refrigerant within the tube heats up, it changes from a liquid to a vapour. The high temperature vapour rises vertically within the tube to the other end located within the cooler incoming supply air stream. The energy (heat) within the tube heats up the incoming air stream. As the temperature of the refrigerant within the tube decreases it changes back to a liquid which falls back down the pipe walls to the bottom of the tube in the exhaust air stream. Then the cycle starts over again. *Figure 19* illustrates this operation.

By using wicks within the heat pipe tubes, it is possible to locate the tubes horizontally as the wick allows the migration of the liquid via the wick rather than through buoyancy and gravity. That said, greater efficiencies can be achieved if the heat pipe tubes are mounted vertically, allowing vapour to naturally migrate up and the cooler liquid to fall down via gravity.

**Figure 19** Heat pipes – principle of conversion



However, in this vertical configuration, the heat pipes are reliant on the arrangement of the AHU sections (supply and exhaust). If the incoming supply air stream is to be heated by the warmer exhaust air (for example winter conditions) then the AHU must be configured so that the warmer exhaust air is at the bottom and the cooler incoming air is at the top, thus allowing



buoyancy and gravity to drive the movement of air and the heat recovery process to occur.

If the incoming supply air stream is required to be cooled from the cooler exhaust air then the AHU must be configured so that the cooler exhaust air is at the top and the warmer incoming air is at the bottom. Cool energy recovery can then occur.

## Advantages and disadvantages

As the air streams are not mixed as part of the process of transferring heat via the heat pipes, there is no risk of cross-contamination provided there is a physical divide between the supply and exhaust air sections within the air handling unit.

The supply air can be further controlled by means of a main heating or cooling coil following the heat transfer through the heat pipe heat exchanger.

The heat pipe system requires the AHU and associated ductwork to be arranged in a specific way. Allowances should be made for routing ductwork through the building plant room.

## Tips for implementation

Heat pipes have limited flexibility, so you need to bear these issues in mind if considering them for your site.

Due to the configuration of the heat pipe, they are unable to be controlled and isolated. So, if the heat recovery system is not required, for example in summer conditions, a mechanical bypass damper must be used to divert the air around the heat pipe coil.

As the heat pipe heat exchanger has to be installed within the air handling unit, the physical size of the AHU can be more than would otherwise be the case, especially as the air flow volume increases. Good access for maintenance is also required, again adding to the overall plant space required.

## Investment and payback

In an office housing around 250 people working typical UK hours, heat pipes could potentially save up to 50% on gas bills, which could equate to well over £4,000 a year.

## Benefits

Efficiencies of the heat pipe system can range from 50% to 55% on horizontal pipes and up to 75% on vertical pipes.

# Heat recovery applications: industrial processes

Process heating refers to types of heat transfer techniques such as drying, evaporating, separating, curing, heat treating, melting and controlling chemical reactions, used in a wide range of sectors, from laundries and food production to chemicals and foundries.

Recovery of heat used in industrial processes is frequently more complex than in other applications. You should use this section as an initial guide to help you identify whether you should undertake the kinds of processes where heat may be lost and the kinds of techniques which might be used to recover it.

## Energy use in industrial processes

The use of energy for industrial processes can be broadly classed into low and high temperature ranges. Low temperature covers processes that operate at or discharge at temperatures up to 400°C-500°C. Typically, you would find these processes in the chemicals, food and drink, paper and board and textiles and laundering sectors.

The high-temperature range covers any process operating or discharging above 500°C, generally associated with furnaces or kilns, in the metals, minerals, ceramics and glass sectors.

The most prevalent use of energy recovered from processes occurs in the low temperature range and is in fact typically between ambient and 200°C. Opportunities for heat recovery are based on operations which apply to many industrial sites, such as boilers, refrigeration plant, air compressors and prime movers (engines or turbines).

## Process heating

Delivery of heat to industrial processes has two key aspects: the release of heat from a fuel and the transfer of heat to the process. A wide range of fuels are used, including electricity, natural

gas, a range of oils, LPG and coal. Various approaches are taken to transferring heat to the process, including:

- flue gases heated directly by combustion
- hot water or steam generated in a boiler
- through radiation from electrical heating elements
- in air heated indirectly from combustion gases via a heat exchanger.

Each application requires both fuel to generate the heat and a mechanism to deliver the heat to the process. In combination, these arrangements are known as 'heat sources'.

## Steam

Steam is the most widespread process heat delivery medium. It is produced via combustion in boilers or as an output from a CHP plant. The main advantages of steam are its high heat capacity and flexibility. The main disadvantage is that it tends to be expensive to produce due to inefficiencies in boiler and distribution systems.

## Warm air

Warm air can be generated directly by electricity or indirectly by fuel combustion. Warm air is generally used for the lower temperature ranges of process heating, such as drying activities, where it supplies heat and acts as the carrier to remove water or other solvents from a product.

## Hot water

Hot water can be produced by electricity or any fossil fuel. It can also be produced by heat exchange with process fluids, as well as from waste heat. Water has a large capacity for retaining heat, which makes it more useful than other media, such as air. However, unless it is held under pressure, water will boil if heated beyond 100°C. Although it is easy and safe to use, this limits the range of activities for which water can be used as a heat-transfer medium.

## Thermal oil

Thermal oil is usually used where temperatures higher than those which can be readily achieved with water are required. Systems must be robustly maintained to prevent the leak of hot oil and, therefore, problems are rare.

## Direct combustion heat

Direct combustion heating, usually using natural gas or fuel oil, is used in many medium and higher temperature process-heating applications such as rotary kilns. The main advantages of this form of heating are the efficiency of heat transfer and the rapidity of response to heat input changes.

## Indirect combustion/electrical heating

This is where the combustion process is separated from the material to be heated by the structure of the furnace and many furnaces operate on this principle. Burners fire into a combustion chamber and heat is then transferred through the walls to the material to be heated. This process is less efficient than direct heating, but prevents contamination of the material. It can also be used where a product is flammable.

## Direct electrical heating

There are various direct electrical heating techniques. Arc furnaces use electric current to heat metals directly. Induction furnaces are used to heat a range of materials, including metals and glasses. Very high temperatures of up to 300 to 400°C can be achieved in inert atmospheres. Heating with microwaves (or radio frequency energy) is possible for some types of material.

## Specialist advice

The application of these techniques will often require a bespoke approach which fits with the specific context of the site, equipment and processes involved.

Heat recovery in industrial processes is a specialised area and you will need the services of a specialist.

As the efficiency of heat recovery in industrial processes can vary so widely,

it's difficult to give general advice on the level of investment required. However, the specialist with whom you engage should provide examples of other projects they have worked on, so you can make informed choices about the right solution for you.

See [page 55](#) for tips on finding a suitable organisation to help you with heat recovery.

minimises both heat exchanger surface areas and costs. For certain processes it may not be possible to find a suitable use for the available waste heat because of a lack of either an economic application or a viable heat recovery technology.

## Further references

[How to implement industrial heat recovery equipment \(CTL037\)](#)

[How to implement heat recovery in compressed air \(CTL166\)](#)

[Waste heat recovery in the process industries \(GPG141\)](#)

[Heat recovery from air compressors \(GPG238\)](#)

## Process heating – where heat is wasted

### High-temperature gases

Loss of heat through hot waste gases is inevitable in all processes involving high temperatures. The energy efficiency of the process can be improved by recovering heat from the waste gas stream or the waste heat can be used elsewhere to reduce primary energy use. However, several parameters must first be evaluated:

- the flow rate of the waste gas stream
- the temperature of the waste gases
- the composition of the waste gases.

Once these factors have been established, the means of heat recovery can be matched to its end use. Costs for waste heat recovery and use must also be assessed.

Heat transfer rates are highest at high temperature because of enhanced thermal conductivities and greater radiative heat transfer. Operating at high temperatures therefore

# Case study

## Packaging

Packaging companies have saved 20% of the energy consumption used for the provision of compressed air by upgrading their compressors and using a heat recovery system on exhausts.

The next few pages provide an overview of the common potential applications for heat recovery in relation to industrial processes.

### Low-temperature processes

There are considerable opportunities and potential for low-temperature waste heat recovery from the following typical plant and processes.

### Air compressors

Most of the electricity supplied to an air compressor (which can be up to 90%) is converted to heat. It is possible to recover anywhere from 50% to 90% of this thermal energy and use it to heat other air or water.

Air-cooled and water-cooled packaged rotary screw compressors are typically enclosed in cabinets and include heat exchangers and fans, but the waste heat discharged can be recovered.

### Distillation

Distillation is conventionally carried out in a column in which components of a liquid mixture are separated. By applying heat the component with the lower boiling point is evaporated. The waste heat manifests itself in the condenser, which is used for cooling the volatile component being boiled off.

## Specialist advice

### Low-temperature processes

|                                  |         |
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| Distillation                     | Page 45 |
| Drying                           | Page 46 |
| Dyeing and finishing             | Page 46 |
| Evaporation                      | Page 47 |
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### High-temperature processes

|                         |         |
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| Furnaces – recuperators | Page 50 |

### Uses for high-temperature heat recovery

|                        |         |
|------------------------|---------|
| Charge pre-heating     | Page 52 |
| Steam generation       | Page 53 |
| Electricity generation | Page 53 |
| Space heating          | Page 54 |

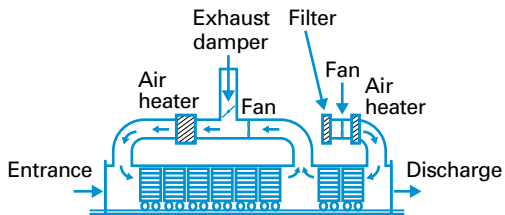
### Drying

Dryers are widely used in several industrial sectors. Rotary dryers are the principal energy consumers, with spray and band dryers also being significant consumers. Heat is normally discharged as warm humid air (see *Figure 20*).

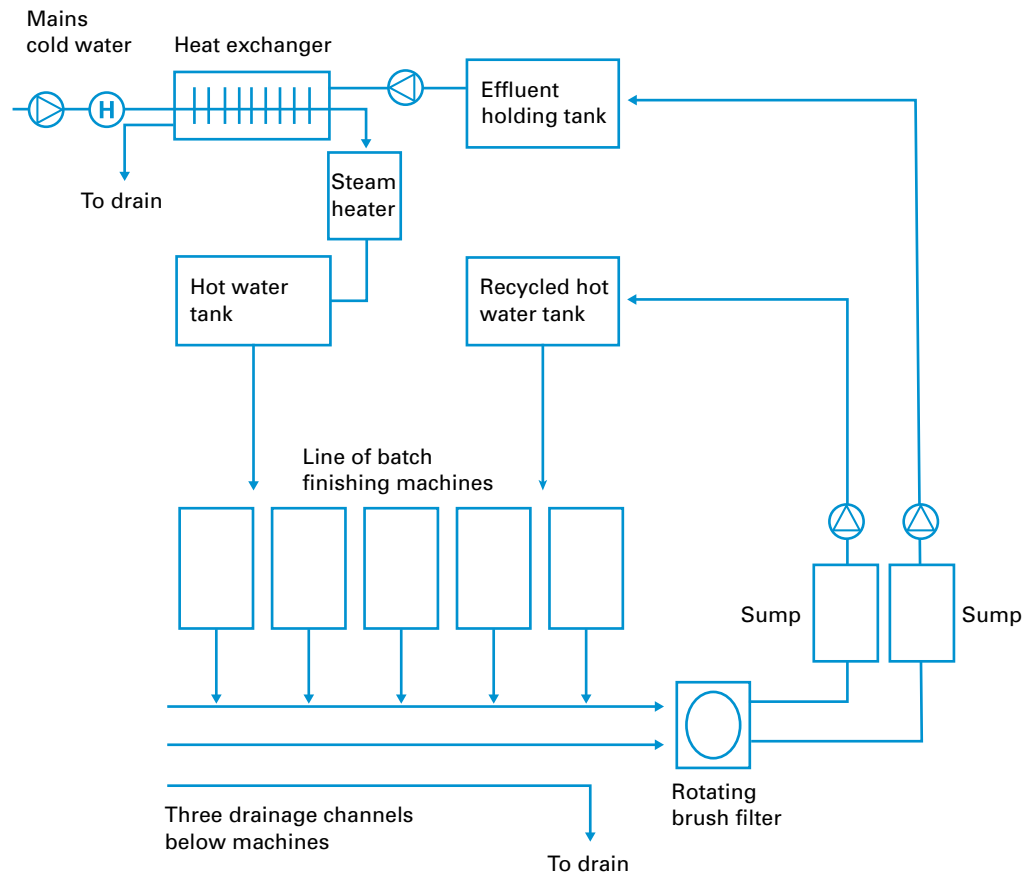
### Dyeing and finishing

Dyeing and finishing processes in the textile and fabric care sector provide good opportunities for waste heat recovery (see *Figure 21*). Warm effluents can be a source for pre-heating incoming cold water and heat exchangers can be used on effluent containing fibres.

*Figure 20* A sketch of a typical tunnel dryer with recirculation to direct exhaust gases back to the inlet of the process.



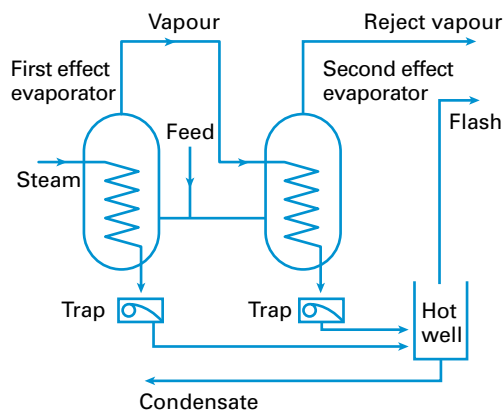
*Figure 21* A sketch of a typical finishing plant with heat recovery from the effluent discharge



## Evaporation

Evaporation is used to concentrate solutions of liquids (see *Figure 23*). Commonly this involves boiling off the water by the addition of heat. Concentrating the vapour leaving the mixture is the main source of heat loss, as in distillation. Evaporators are graded in terms of increasing efficiency and hence effective use of heat, ie single effect, multiple effect and mechanical recompression (MVR) evaporators.

*Figure 22 A sketch of a multiple effect evaporator. The waste heat is cascaded in temperature through a line of evaporator effects*



## Prime movers

A prime mover is a component in a system which converts other forms of energy into useful mechanical energy.

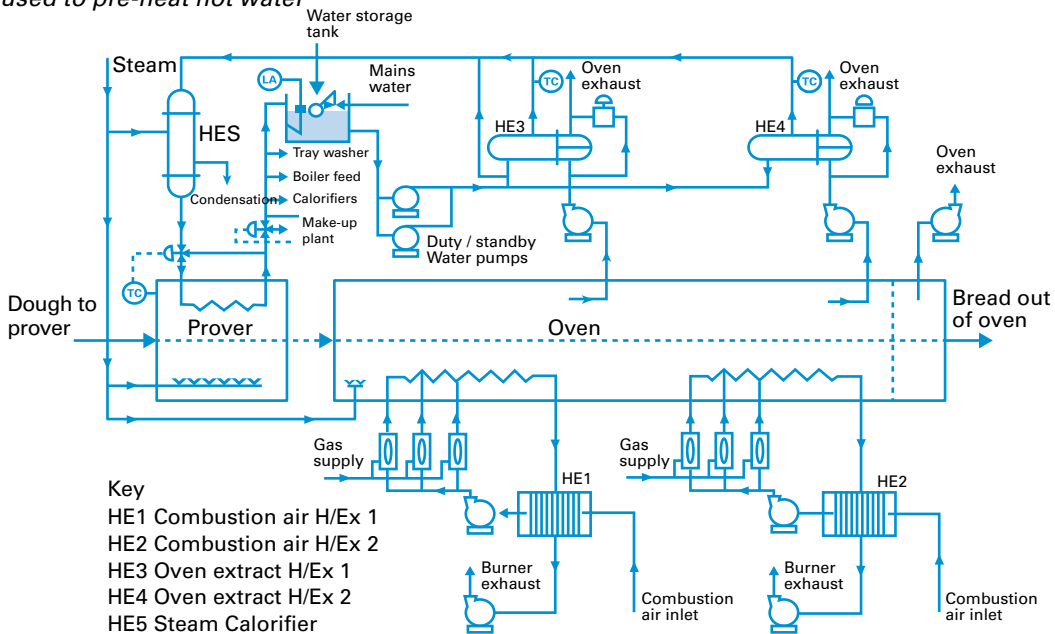
Many plants within industry use prime movers, such as reciprocating gas or diesel engines, gas turbines and steam turbines. The latter are sometimes used to recover thermal energy, for example as pressure reduction units. Reciprocating engines can be useful sources of heat at a variety of temperatures, ranging from moderate temperature exhaust gases to lower grade heat in the water cooling system and, in larger engines, the oil cooler. Gas turbine exhaust heat can be used for drying and can, via an absorption refrigeration system, provide cooling or refrigeration.

Ovens

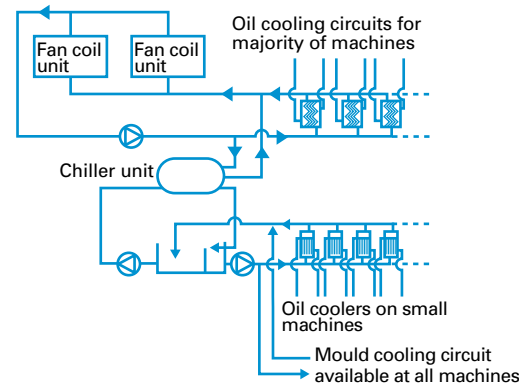
Ovens are commonly used in food ingredients and food derivatives industries. They can be either directly or indirectly fired. Heat can be

recovered from the oven exhaust and used typically for other purposes, for example tray washing, pre-heating boiler feed water, and so on (see *Figure 23*).

*Figure 23* A sketch of heat recovery on a bakery oven. Heat recovered from the burner exhaust is used for combustion air pre-heating and heat recovered from the oven exhaust is used to pre-heat hot water



*Figure 24* A sketch of plastics injection moulding machine cooling circuits with heat recovery used for space heating





### Pasteurisation and sterilisation

In the dairy industry, pasteurisation is already highly efficient in terms of heat recovery; however sterilisation, particularly bottle sterilisation, is energy intensive and provides more opportunity for waste heat recovery.

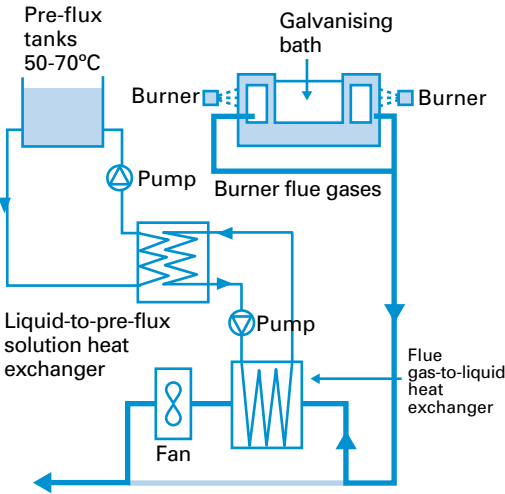
### Process cooling

Process cooling is widely employed for uses such as plastics injection moulding. Although regarded as a 'low grade' heat source, it can be viably used for space heating.

### Process heating

The largest consumer of energy in several industrial sectors is process heating (see *Figure 25*). Heat input is normally via steam, hot oil or direct firing. Process heating duties include heating feed materials to reaction temperatures, pipe and storage vessel heating, calcining, kilning and so on. The heat is commonly available as hot gases, or in the solid product being processed.

*Figure 25 Typical heat recovery on a galvanising plant. Liquid-to-liquid and gas-to-liquid heat exchangers are used to recover heat from the burner flue gases for pre-heating the pre-flux tanks*



## Case study

### Dairy industry

Waste heat from a CHP unit in a dairy processing factory was initially used on a spray drier. However, when the drier closed a few years later, a new scheme was developed to use the heat for process and space heating.

### Washing

In the fabric care industries, typically in laundering, large amounts of heat are used for washing. The warm effluents that are normally drained can be a source of heat for pre-heating incoming cold water.

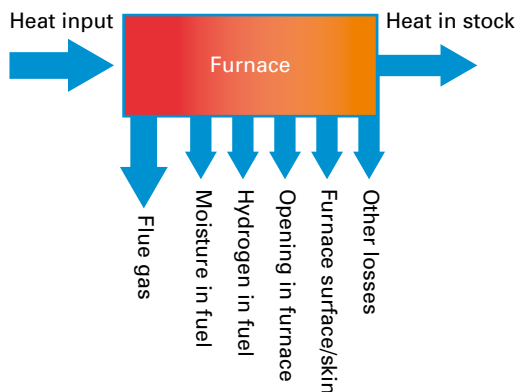
## High-temperature processes

The opportunities for heat recovery from high-temperature processes are significant and mainly revolve around the use of furnace-based operations.

### Furnaces

In any industrial furnace the combustion products leave the furnace at a temperature higher than the stock temperature (see *Figure 26*).

**Figure 26** Typical heat flows and losses in a furnace



Loss of heat through hot waste gases is inevitable and the energy efficiency of the process can be improved by recovering heat from the waste gas stream or the waste heat can be used elsewhere to reduce primary energy use. Several parameters must first be evaluated:

- the flow rate of the waste gas stream
- the temperature or 'quality' of the waste gases
- the composition of the waste gases.

Once these factors have been established, the means of heat recovery can be matched to its end use. Costs for waste heat recovery and use must also be assessed.

### Heat recovery applications

Waste heat in flue gases can be recovered for the following:

- preheating of combustion air
- charge pre-heating
- using waste heat as a heat source for other processes.

### Pre-heating combustion air

Pre-heating of combustion air is one of the most popular uses of waste heat from furnaces and kilns due to its high efficiency and reduction in primary fuel use. For a long time, fuel gases were only used for pre-heating combustion air for large boilers, metal-heating furnaces and high-temperature kilns. But pre-heating using heat from flue gases is now also applied to compact boilers and compact industrial furnaces.

Equipment for combustion air pre-heating can be divided into recuperators and regenerators.

**A recuperator** is a device for waste heat recovery that works by counter-flowing hot gases and cold air through a heat exchanger. External versions are most common, but other techniques such as self-recuperative burners are also used. A modern recuperator using furnace exhaust gas of 1,000°C can preheat the combustion air to over 500°C, which results in energy savings of up to 30% compared with using cold combustion air.

A regenerator is a cyclic heat storage device. The choice of equipment depends on the efficiency of the device and where it is placed in the furnace. It is recommended that, under

circumstances where temperature profiles are critical within a furnace or kiln, both physical and mathematical modelling of the furnace/ burner geometry is undertaken to establish optimum conditions.

Most conventional gas/air burners are only capable of operating with pre-heated air up to 300°C. Above this temperature, purpose-built burners must be used. While this adds to capital costs, combustion efficiencies are improved and operating costs are therefore lower.

High-temperature burners, coupled with either recuperators or regenerators, are now common in the UK metal, glass, pottery, refractory and chemical industries.

Combustion air pre-heating normally becomes attractive when furnaces or kilns operate above 500°C for an appreciable proportion of their cycle.

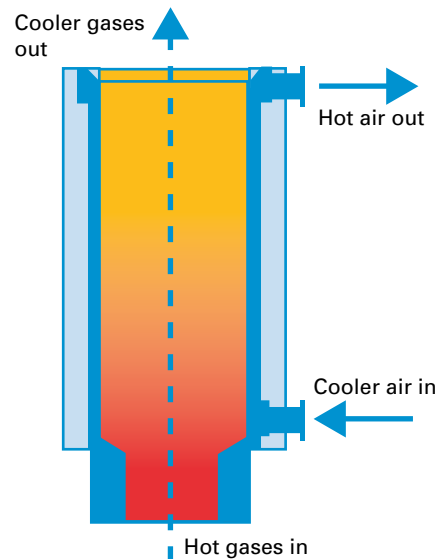
Increasing the temperature of combustion air also results in higher flame temperatures. These are associated with higher nitrogen oxide (NO<sub>x</sub>) emissions, which are subject to stringent standards. High efficiency burners with low NO<sub>x</sub> emissions have recently been developed.

Since the volume of combustion air increases when it is preheated, it is necessary to consider this when modifying air-duct diameters and blowers. It should be noted that pre-heating of combustion gases from high-density oils with a high sulphur content could cause clogging with dust or sulphides, corrosion or increases in NO<sub>x</sub>.

## Heat recuperators – radiation type

The cold air and hot waste gases counter-flow along concentric tubes (see *Figure 27*). Heat transfer is by radiation. The hot air out is ducted to the furnace burner combustion air inlet.

**Figure 27** A cross-section of a double shell radiation recuperator



This kind of exchange is most influenced by the temperature, so these recuperators are suitable when the temperature of the flue gases is higher than 1000°C, or when the components of the flue gases are aggressive or contain a high percentage of particles.

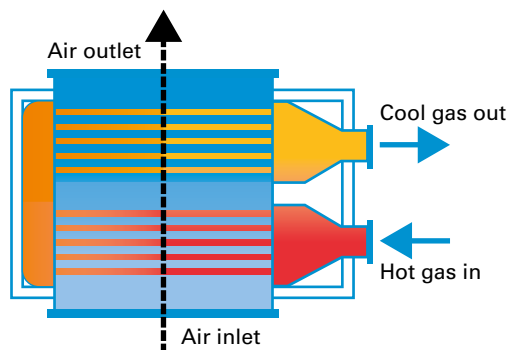
### Heat recuperators — convection type

In these recuperators the heat transfer between the primary and secondary fluids is done by convection (see figure 28). The hot air out is ducted to the furnace burner combustion air inlet.

Their main feature is the full contact between the gases and the tubes composing the recuperator, so that they are especially suitable when:

- the working temperature is lower than 1000°C
- the gas streams are fairly clean (with no particles) and without especially corrosive components.

**Figure 28** Two-step heat exchanger in parallel flows



### Charge pre-heating

When raw materials are pre-heated by exhaust gases before being placed in a heating furnace, the amount of fuel necessary to heat them in the furnace is reduced. As raw materials are usually at room temperature, they can be heated sufficiently using high-temperature flue gases, which noticeably reduce the fuel consumption rate.

With furnace pre-heating, gases from the furnace or kiln are directed to the incoming stock by means of ducting, or by extending the furnace. The economics of charge pre-heating depend heavily on the furnace, oven or kiln geometry.

Initial capital expenditure in extending the furnace or installing insulated ductwork may be high, but subsequent maintenance costs should be minimal. At its most efficient, charge pre-heating rivals the pre-heating of combustion air in economic viability. Charge pre-heating has the advantage of low maintenance costs, while combustion air pre-heating normally has lower capital costs.

Many furnaces, including blast furnaces and pottery tunnel kilns, incorporate charge recuperation in the furnace design. In these cases, waste gases emitted after recuperation are at relatively low temperatures (typically less than 400°C). In certain industries, for example aluminium and copper foundries, stock pre-heating has the additional advantage of removing the hazard of explosion caused by entrapped water vapour. Heat transfer efficiencies vary according to the geometry of the charge, its thermal conductivity, flow

rates and temperatures. Estimates of the fuel savings possible with this technique vary from 10%-30%.

## Steam generation

Waste heat boilers have been used for steam generation for many years in the UK chemical, copper, iron and steel industries. Steam generation using waste heat is only economically viable if there is a continuous supply of heat and a definite requirement for process steam and paybacks on investments of around three years can be achieved.

Waste heat boilers are highly energy efficient (typically around 80%). In using waste heat boilers, consideration should be given to the ease of installing the device and associated water treatment plant and the cost of regular maintenance. Use of waste heat boilers is generally considered only at the plant design stage and not when considering retro-fit opportunities.

Waste heat boiler plant is normally purchased on the basis of process steam requirements or, in a few cases, for a space heating requirement when a steam main is already employed.

### Other processes (to generate steam or hot water by a waste heat boiler)

The temperature of furnace exhaust gas can be 400°C to 600°C, even after heat has been recovered from it for pre-heating the charge or combustion air. One possibility is to install a waste heat boiler to produce steam or hot water from this heat, especially when large quantities of steam or hot water are needed.

Sometimes exhaust gas heat can be used for heating purposes in other equipment, but only if the heat quantity, temperature range, operation time and so on are suitable. Where this is the case, you could greatly reduce fuel consumption. One existing example is the use of exhaust gas from a quenching furnace as a heat source in a tempering furnace.

## Electricity generation

The generation of electricity using waste heat is well established in the UK chemical and petrochemical industry, where it forms an integral part of the chemical process stream. In this industry, processes are often uneconomic without this heat recovery facility. Examples can be found in ethylene cracking, ammonia

production and petrochemical refining, where there is a demand for both electricity and low pressure steam.

Power generation using waste heat requires:

- an almost continuous supply of waste heat:
- water pre-treatment
- regular maintenance
- high-pressure boiler and condensing steam turbine plant.

This last requirement results in high capital costs. Estimated payback periods are generally three to six years and this use for waste heat has therefore not found favour in the UK.

There is currently no example of a retro-fitted power generation system using high temperature waste gas streams in the UK.

The only exception is the use of gas turbine exhaust in waste heat boilers in a combined heat and power (CHP) plant. For further information, see Department for Energy and Climate Change documents ([www.decc.gov.uk](http://www.decc.gov.uk)).

## Uses for recovered heat from high-temperature processes

### Space heating

Although waste heat is frequently used for space heating, this use is often not as cost-effective as others and payback periods are typically three to five years.

Space heating has several disadvantages over other uses, such as combustion air pre-heating. If the source of the waste heat and the space to be heated are not adjacent, then long lengths of ducting combined with some form of air dilution are often required. The high cost of transmitting the heat can thus offset any economic advantage. Furthermore, if high temperature waste heat is used for space heating then, in general, only a fraction of the heat available is used. In the summer months, for example, all the waste heat is dumped. The economics are thus calculated for a heating season which lasts about seven months.

Space heating as an application for recovered waste heat should only be considered when other options are shown not to be technically viable.

Space heating becomes more attractive when:

- the source of waste heat is close to the area to be heated
- current heating systems are highly inefficient
- there is no other possible use for the waste heat and the heat generating process has been optimised
- the heat exchange technology is simple to install and cheap to purchase and maintain
- the supply of waste heat is coincident with the demand of the area to be heated.

Most of these criteria should be met before space heating is considered as a viable use for hot waste gases.

Use of waste heat for space heating can, however, be economic when it displaces obsolete heating systems or is used to heat new buildings – that is, as an alternative to other heating systems – and when some capital investment would have been necessary anyway. When space heating applications supplement existing heating plant, the economics are generally poor.

## Case study

### Diamond Power Specialty Ltd

Boiler cleaning and ash-handling systems producer Diamond Power paid back its heat recovery system in 3.3 years. The firm installed a simple mechanical ventilation system to remove the waste heat from the compressor room. The warm air contributes to the space heating in the workshop or is ducted outside in the warmer months.

# Next steps

By reading this overview guide, you should now have a good understanding of the types of processes that may be wasting heat unnecessarily in your business.

There are a number of things you can do next which will help you decide whether or not to invest in the implementation of one or more heat recovery systems in your building.

## Heat recovery checklist

If you haven't already, you can use the [Heat Recovery Checklist](#) to help you ask the right questions about the systems in your building. This includes the important step of ensuring your building services are already operating efficiently before considering heat recovery.

The checklist covers practical issues and key things to look out for in your building.

## Light manufacturing and warehousing heat recovery webinar

If your business is manufacturing on a smaller scale or warehousing, there is a [webinar](#) that can help you. The webinar will show you how you can reduce your energy bills by up to 30%, identify where heat is being wasted, where heat recovery can be retro-fitted and how you could potentially offset the capital cost of heat recovery against profits.

## Engage with a specialist

Once you've established that heat recovery is for you, you should engage a specialist to advise you by carrying out a more detailed feasibility study and providing an estimate of the work required.

For situations where the heat recovery system you are considering will be part of your building's inherent systems (such as ventilation, heating and so on), you should approach a building services engineer. If you don't have an existing relationship with an engineering practice, a good place to find a reputable company is [www.cibse.org](http://www.cibse.org), the website of the Chartered Institution of Building Services Engineers, which features a 'Find an expert' service. You could also contact the Combustion Engineering Association ([www.cea.org.uk](http://www.cea.org.uk)), which should be able to help with certain technologies.

If you are considering heat recovery to be incorporated into an industrial process, you'll need to choose a specialist carefully and ensure they have particular experience in the field. One way to do this is to make contact with equipment manufacturers.

Finally, heat recovery systems should always be installed by experienced and reputable contractors. If you don't have an existing relationship with a contractor you can contact the Heating and Ventilation Contractors' Association ([www.hvca.org.uk](http://www.hvca.org.uk)).

### Further reading

There are a number of other publications available through the Carbon Trust which might be of interest:

[Heat recovery from air compressors \(GPG238\)](#)

[Energy efficient operation of boiler plant \(GPG369\)](#)

[Low temperature hot water boilers – Introducing energy saving opportunities for business \(CTV008\)](#)

[How to recover heat from a compressed air system \(CTL051\)](#)

[Waste heat recovery in the process industries \(GPG141\)](#)

[How to implement industrial heat recovery equipment \(CTL037\)](#)

[Air-to-air heat recovery: a guide to equipment eligible for ECAs \(ECA771\)](#)

[Find products which qualify for Enhanced Capital Allowances](#)



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