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ENERGY EFFICIENCY ACCELERATOR

Energy efficiency guidance for the food & beverage sector

Introducing energy savings opportunities in boilers and heat distribution

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Boilers and heat distribution

Almost all of the sub-sectors in the food and beverage processing industry need some form of process heating for, for example, pasteurization, sterilization, blanching, peeling, evaporation, washing products and the cleaning of production halls and equipment. The required thermal energy is usually supplied by on-site boilers installed to supply hot water or steam at various temperatures and pressures depending on the process requirements.

In the F&B sector, heat is also needed for the conversion of starch to glucose, distillation columns, extraction, drying and for cleaning of bottles, jars and cases used when packaging the final products. Depending on process requirements, plant (utility) steam will be used for indirect heating, culinary steam for direct-contact processes and pure (hygienic) steam used to produce organic products. Low temperature hot water (e.g. <90°C) and medium temperature hot water (e.g. <180°) needs are commonly satisfied using steam-to-water heat exchangers or from separate boilers.

Technology overview

Steam boilers

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

1. Shell type – where the hot combustion gases pass down a tube and into subsequent bundles of tubes immersed below water level. The heat from these gases is then transferred to heat the water to produce steam. Most steam and hot water boilers are derivatives of the shell type, which are also referred to as 'fire tube' boilers.
2. Water tube type – where the water is contained in tubes and the hot combustion gases pass around them to heat the water to produce steam.

In either case, the heat must transfer across the surface of the tubes containing the water or combustion gases. Therefore, these tubes are made of materials with good heat-transfer properties. After use, the combustion gases exit the boiler via a chimney known as a flue. The output steam will be fed out of the boiler into a distribution system. This is a network of insulated pipes that transfer the steam to the point(s) at which it is used. Overall thermal efficiency will vary according to system configuration and the nature of the heat using processes, however a combustion efficiency of ~84% is typically deemed good for a natural-gas fuelled boiler.

Hot water boilers

There are three main types of hot water boiler: conventional, high-efficiency and condensing. These can be used separately or combined together within systems.

1. Conventional - these are often cast iron and larger than other boilers. Most use atmospheric burners, where the air required for combustion is drawn from around the boiler through natural convection. Seasonal energy efficiency levels are generally poor at <70%.
2. High-efficiency - these boilers have a low water content, a large heat exchanger surface area and increased insulation to the boiler shell. They tend to be smaller than conventional boilers and operate at efficiency levels of up to ~82%.
3. Condensing - even in modern high-efficiency boilers, waste heat in the exhaust gases is lost to the atmosphere via the boiler flue. Water vapour makes up some of these exhaust gases. In condensing boilers, a second heat exchanger is used to extract much of the waste heat and return it to the system allowing efficiencies of up to ~90% to be achieved for some low temperature systems.

The controls on hot water boilers set the required flow temperature of the water. If the return water is at a lower temperature than required, the boiler must 'fire' to produce heat, i.e. it must burn fuel. The hot combustion gases pass over the heat exchanger to heat the circulating water within and the resultant hot water is distributed to the heating system via a circulating pump with the exhaust gases discharged to atmosphere via a flue.

Types of fuel used in boilers

There are a wide range of fuels used. Boilers commonly burn standard hydrocarbon fuels, such as natural-gas, LPG, oil and coal, but some burn tallow or waste materials. Some boilers, known as dual-fuel boilers, can burn gas or oil which is useful in instances where an interruptible gas supply contract is held. Coal burners can be a variety of designs mainly centring on how the coal is fed to the boiler and burnt.

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Biomass boilers are becoming more popular. Biomass is any solid non-fossil-based organic fuel and includes wood (either grown specifically as a fuel or as waste material), straw, types of grass and many other organic by-products. The mechanisms for handling and burning fuel differ markedly for solid, liquid and gaseous fuels, and the design of a boiler depends on the intended fuel type(s). However, as many of the general principles for saving energy are the same, this guide does not distinguish between fuel types.

Low(er) carbon alternatives

In response to rising fuel costs and environmental concerns, an increasing number of companies are seeking to incorporate and integrate a range of low and zero carbon (LZC) technologies into their facilities in order to reduce the thermal load and fuel usage by their boilers including those outlined below.

Solar thermal – Solar thermal systems use solar collectors to absorb energy from the sun and transfer it, using heat exchangers, to heat water. For industrial process heating applications, solar thermal systems can be used to provide hot water at temperatures of between 30°C and 300°C. Although a relatively mature technology with enormous technical potential, it is massively under-exploited.

There are two main types of solar heating collector that are particularly suited to the 30°-150°C hot water temperatures commonly demanded within the F&B sector:

- Flat-plate collectors – These are relatively low cost and low maintenance and are suitable for delivering thermal energy at between 30°C to 80°C. Construction typically comprises absorber plates, insulation layers, recuperating tubes filled with a heat transfer medium, such as water or water/glycol mixture, encased with glazing covers. The operation of the flat plate collector is simple: when the solar irradiation hit the surface of the collector, the radiation passes through the transparent glazing cover and reaches the absorber plate. The radiation is then absorbed by the plate and converted into thermal energy which is then transferred to the heat transfer fluid. Thermal efficiency of flat-plate collectors is typically ~70%.
- Evacuated tube collectors – This is the predominant solar thermal collector technology worldwide with a market share >65 % chiefly due to their largescale manufacture and deployment in China which accounts for more than 70% of global installed solar thermal capacity. Evacuated tube collectors are designed to operate at higher temperature than flat plate collector commonly ranging from 50°C to 130°C. The manufacturing process, mechanical complexity and material selection of evacuated tube collectors make them more expensive than for flat plate collectors. For example, the design of collectors' housing is made of a vacuum glass tubes to reduce and eliminate convection and conduction thermal losses. However, evacuated tubes are more efficient at around 80%.

Solar thermal systems can displace fossil fuel use by, for example, heating or pre-heating steam boiler feedwater or make-up water and/or increasing the return temperature of closed loop hot water systems serving drying, washing or heat treatment processes.

Combined heat and power (CHP) – Also referred to as co-generation, CHP systems

Technology overview

capture usable waste heat that is produced in the process of generating electricity. By so doing, CHP plants can achieve energy efficiency levels in excess of 80% at the point of use, reducing carbon emissions and energy costs. As most F&B companies have significant simultaneous demands for electricity and thermal energy (heating and cooling), CHP is commonly deployed within the sector.

CHP systems can use either turbines or engines, according to power demands and heat-to-power ratios, with reciprocating engine-based prime movers generally best suited to applications below 5MW of electricity generation capacity.

Typically, the engine directly drives a generator to produce electrical power and heat is recovered from the engine jacket, the oil cooler and the exhaust gases and, if the heat required is at low enough temperature, from the intercooler. This type of CHP was developed in the 1980s and is usually supplied as a fully packaged unit. Turbines have higher capital cost and have lower electrical efficiency, but have a smaller physical footprint, can provide higher temperature heat and can have greater reliability.

A CHP unit typically operates in parallel with the public supply with additional electricity imported as required. The heat output is commonly supplemented with boiler plant to ensure delivery of required service temperatures and at times of peak demand. A thermal store can be included to smoothen the heat demand, reduce the need for peak boiler use and maximise electricity production at times of higher electricity prices. It is also possible to use heat from a CHP system to generate cooling via absorption chillers to deliver a tri-generation solution i.e. electricity, heating and cooling.

For facilities with limited year-round heat requirements but with large year-round cooling needs, this option would lower the site's electrical load by displacing the electrical demand of conventional chiller plant.

The boilers and public electricity supply connections are normally sized to meet the peak demands of the building when the CHP is not operating, as the CHP unit requires regular maintenance. The CHP units are normally maintained by the supplier under a long-term maintenance contract with remote monitoring of the operation allowing faults to be identified and visits scheduled to maximise availability.

It is important that other energy savings measures are fully considered before the viability of a CHP scheme is evaluated. Failure to do so may result in the benefit of the CHP scheme being undermined by the later application of other energy efficiency measures.

As an energy generation process, CHP is 'fuel neutral'. This means that a CHP process can be applied to both renewables like biomass and biogas and fossil fuels like natural gas and oil. Indeed, within certain F&B sub-sectors, where there is a significant quantity of unavoidable organic 'waste' co-product, such as fruit and vegetable peelings, the deployment of an anaerobic digester to breakdown the organic matter into a methane-rich biogas, can provide a sustainable, low carbon fuel supply to the CHP system (and/or boilers).

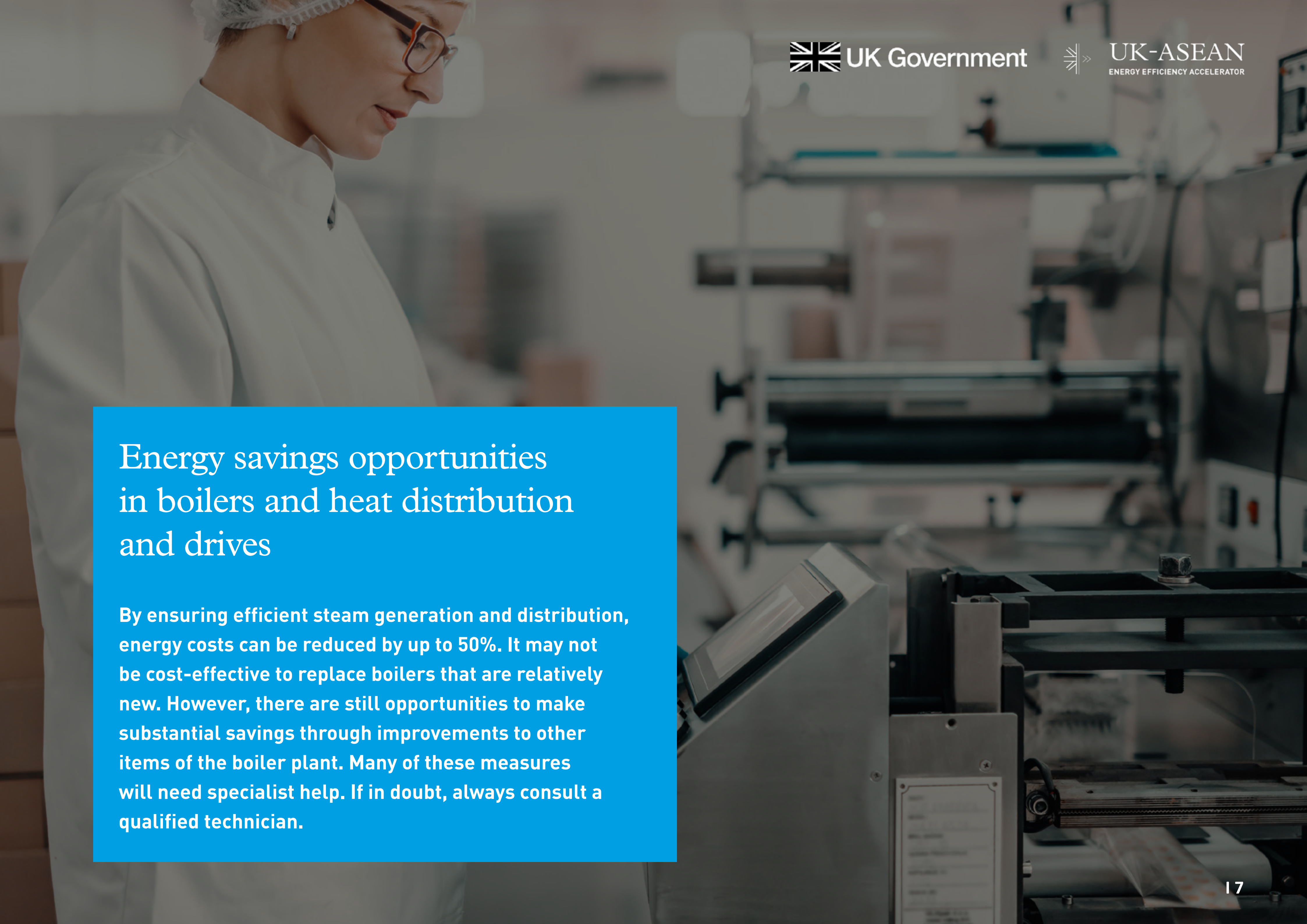
Heat pumps – A heat pump may be thought of as a refrigerator designed to work in reverse i.e. to effectively upgrade a low temperature waste heat stream to a useful high temperature heat stream. The mechanical heat pump is the most widely used in industry and has just four main components: evaporator, compressor, condenser and expansion device.

Technology overview

The refrigerant is the working fluid that passes through all these components in a closed circuit. In the evaporator heat is extracted from a waste heat source e.g. the humid waste air stream from a dryer, causing the refrigerant to evaporate from a liquid state to a gas. Following compression to a higher temperature and pressure, the recovered heat along with the electrical energy input to the compressor can be exchanged in the condenser and delivered to the consumer. Giving up its energy causes the refrigerant to condense. By passing through an expansion device the refrigerant changes back to a low pressure liquid state then circulates to the evaporator allowing the cycle to repeat.

The efficiency of the heat pump is denoted by its coefficient of performance (COP), defined as the ratio of total heat delivered by the heat pump to the amount of electricity needed to drive the heat pump. Heat pumps operating in the F&B sector routinely achieve COPs of >5 i.e. every one unit of electricity used by the compressor delivers >5 kWh of useful heat. Potential waste heat streams include condenser heat from refrigeration systems, dryers and waste water streams.

As for solar thermal and CHP systems, heat pumps can be integrated with existing systems and services to operate in series or parallel to provide part of the thermal loads with boiler (or other systems) providing the remainder.



Energy savings opportunities in boilers and heat distribution and drives

By ensuring efficient steam generation and distribution, energy costs can be reduced by up to 50%. It may not be cost-effective to replace boilers that are relatively new. However, there are still opportunities to make substantial savings through improvements to other items of the boiler plant. Many of these measures will need specialist help. If in doubt, always consult a qualified technician.

Inspect and maintain boilers

Make sure that boilers are formally checked at least weekly between services. Common signs of boiler inefficiency are warning lights, pressure drops, and damage, such as burn marks and increased noise levels. Every time a warning sign is ignored, energy is being wasted. Gas leaks are a serious safety issue and should be reported immediately.

Boilers should be serviced at least once a year by a qualified technician. If in heavy use then servicing should be carried out more often, for example, boilers used to provide a base heat load on a continuous basis.

> *A poorly maintained industrial boiler can consume 10% more energy than one that has been well maintained.*

The engineer should replace worn parts and clean the burners and any heat exchangers to remove the build-up of deposits. The service should also include a combustion and/or flue gas test and an adjustment to the fuel/air mix so that the boiler burns fuel efficiently.

> *A 2% reduction in flue gas level will give a fuel saving of 1.2%*

Match boiler outputs to process and/or site requirements

Before product changeover or scheduled stoppage, make sure that the boiler operatives know about the step changes in output capacity of steam or hot water. Matching supply to demands will help to save boiler fuel.

Fit insulation and inspect it regularly

Make sure that all distribution networks (such as pipes, valves, flanges) are suitably insulated and that the insulation is in good condition. Reducing heat loss will cut running costs.

> *Around 10% of the heat produced in steam boilers can be lost through insufficient or ineffective insulation on the distribution system.*

Do not lose heat on standby

When a boiler is on standby, the heat loss through the flue can be significant. Installing an isolation damper can eliminate this heat loss and fuel savings of up to 12% are possible. There is also the added benefit of reducing harmful emissions.

Look at water quality

Poor water quality can lead to scale, deposition and corrosion, which all reduce boiler efficiency. Consider using automatic water treatment and analysis. Generally treatment consists of adding chemicals to the water.

> *An automatic water treatment system can save 2% of the fuel requirement.*

Investigate the potential for recovering waste heat

Waste heat from boiler flue gases can be used to preheat the combustion air for boilers or the boiler feedwater, therefore reducing the overall amount of energy required in the process. These measures can save between 2 and 5% of fuel in sectors such as breweries, distilling, soft drinks, canned foods and confectionery manufacture.

Investigate installing automatic controls and use isolation procedures

Boilers are at their most efficient at the maximum firing rate. If a site needs varying rates of heat for different processes, it might be worth considering having several smaller boilers to cover the site load and utilising sequencing controls to ensure the varying requirements are met using the most efficient configuration.

Boiler replacement

Where boilers are coming up for major refurbishment or replacement, it is worth undertaking a detailed appraisal of current and planned thermal requirements to ensure replacement boilers are properly sized and to consider the merits of incorporating low and zero carbon technologies into the design e.g. solar thermal, CHP and heat pumps.

Condensing boilers are more expensive than non-condensing designs and if you have a number of boilers, it can often be more cost-effective to install just one or two condensing boilers to act as the lead boilers. The rest can be non-condensing types for back-up and peak load top-up.

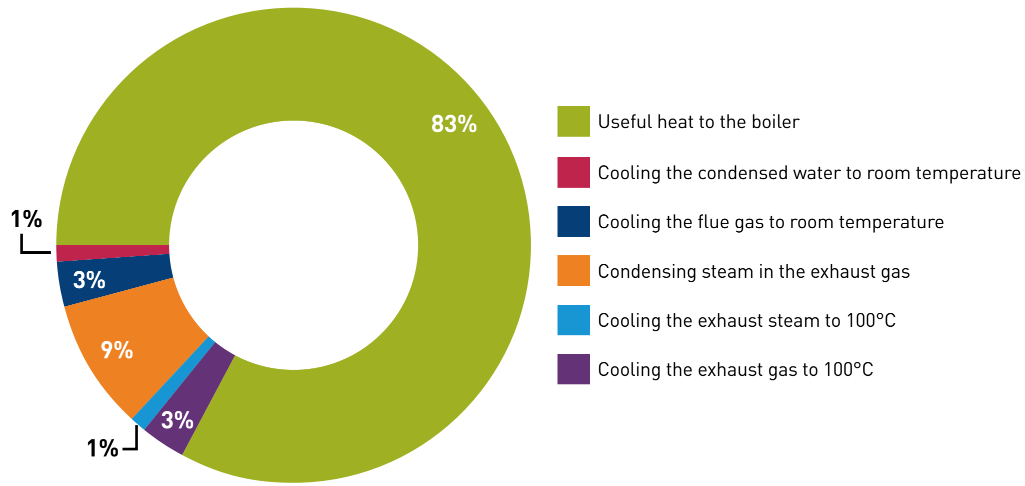
All steam boilers and hot water boilers over 500 kW should be professionally commissioned by the manufacturer or their approved agent. They should:

- Confirm steam/water flow rates
- Measure combustion efficiency across the full range of firing and give you a copy of the results
- Give you the commissioning certificate and warranty forms
- Provide training to the facilities staff during handover.

In installations with more than one boiler, it's also important to commission the sequence or step controls to make sure the number of boilers operating match the heat load. This is particularly important when one or more is a condensing boiler. In these cases, the sequence controller needs to make sure the condensing boiler always operates as the lead.

Flue Gas Heat Recovery

Even in larger well-controlled gas boilers ~17% or more of the energy in the fuel can be wasted (see chart below for the breakdown of losses). The largest component of that wasted energy is the heat of the water vapour present in the exhaust gas. Condensing boilers and economiser can often be configured to recover that energy be it as an addition to a new build or a retrofit.



Case study 1:

A Bakery in the UK[1]

A UK bakery producing more than two million products every day installed a 1MW Combined Heat and Power (CHP) unit in its newest plant.

Through this installation, electricity is produced at low-voltage, then increased to a high-voltage for connection to the site's 11kV ring main. Exhaust gases from the engine are used to generate the site's base steam load requirements, and hot water is recovered from the engine, stored, then re-used by other equipment on the site.

The CHP unit is helping the new plant to save 1,000 tonnes of carbon emissions annually. Energy costs will be reduced by approximately £400,000 per year, allowing the company to pay for the CHP unit in around three years.

1. https://cdn.centricabusinesssolutions.com/sites/g/files/qehiga126/files/CBS_UK_Bakery.pdf

Case study 2:

Nestle Malaysia[2]

In 2017, Nestle received support from GreenTech Malaysia to perform audits for three of their factories: Shah Alam, Chembong and Petaling Jaya. The energy audit had found that due to the implementation of energy saving projects at the Chembong factory, at least 797,212 kWh of electricity can be saved in a year.

Some of the energy savings opportunities being implemented by the factory related to boilers included:

- Strengthening standard routines for steam traps and condensate recovery management as part of maintenance to prevent unnecessary losses.
- Installing energy recovery equipment in boilers i.e. Economisers, which have the capability of increasing boiler efficiencies by 3 to 5%.
- Installing new equipment with lower energy usage such as water treatment for boilers.
- Including an energy efficient criteria in the selection of equipment for boilers.

Case study 3:

Kellogg, UK[3]

Kellogg's manufacturing plant in Manchester, United Kingdom, contains a 4.9 MWe (megawatt electrical) Combined Heat and Power (CHP) plant that supplies 85% of the plant's current steam demand and approximately 50% of electricity demand. The use of the CHP plant reduces CO2 emissions by approximately 12% annually.

2. https://www.nestle.com.my/sites/g/files/pydnoa251/files/201909/Nestle_in_Society_Report_2018.pdf

3. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=COM/TAD/CA/ENV/EPOC(2016)19/FINAL&docLanguage=En

Checklist and tips for efficient operation of steam thermal systems

This checklist summarises the key criteria and characteristics of energy efficient steam thermal systems. If you are unable to indicate "YES" to all questions, it is likely that the efficiency of your system could be improved, saving you money and reducing your carbon emissions.

Checklist and tips

Ref	Best practice criteria	Response	Feedback
1	**Do burners operate with trim control to keep excess O_2 levels <3% across firing range?**	[yes]/[no]	Retrofitting modern, modulating burners with exhaust gas trim control typically reduces fuel consumption by 10-15% and burner electricity consumption by >30%. Simple payback commonly achieved in <2 years.
2	**Is the boiler water level controlled by a modulating feedwater control system?**	[yes]/[no]	'On/off' control systems can lead to unstable boiler operation as pressures can quickly fall and rapidly recover during periods of light-loading. The installation of full feedwater modulation control can reduce short cycling and improve efficiency. Fuel savings >5% and paybacks of ~3-years are common.
3	**Are boilers fitted with automatic TDS controls?**	[yes]/[no]	Installing closed-loop automatic controls can provide closer control of TDS levels at reduced blowdown rates. Fuel savings of >1% and paybacks <3-years are common.
4	**Are flue gas discharge temperatures <200°C?**	[yes]/[no]	If flue gas temperatures are >200°C, an economiser can be fitted to extract energy from the hot flue gases and use it to preheat boiler feedwater. Fuel savings of 4-6% are commonly achieved with a payback of ~4-years.
5	**Are boilers operated at their design pressure (as opposed to a lesser required system pressure)?**	[yes]/[no]	If not, the diminished 'store' of energy within the boiler water risks short cycling which can reduce effective boiler efficiency levels to below 50%. With no CAPEX necessary, 'payback' is instant!
6	**Is the flash steam from TDS blowdown being recovered to the feedwater tank via a deaerator head?**	[yes]/[no]	Doing so can recover 10-15% of blowdown water (saving water and chemical costs) and >40% of blowdown energy content. Simple payback commonly achieved in <3-years.
7	**Is energy recovered from residual blowdown effluent?**	[yes]/[no]	Using a plate heat exchanger to pre-heat cold boiler make-up water can extract a further 40-50% of total available blowdown energy. Simple payback commonly achieved in <3-years.
8	**Is the feedwater tank maintained at a temperature >85°C?**	[yes]/[no]	Supplying water to a boiler at a high temperature of >85°C not only reduces thermal stresses on the boiler and helps maintain its output it also significantly reduces the amount of oxygen scavenging chemicals required.
9	**Is at least 85% of condensate being recovered and returned to the feedwater tank?**	[yes]/[no]	A well design and operated steam and condensate system should enable >85% of condensate to be returned to the feedwater tank, thereby saving on water, chemicals and fuel costs. Each 6°C rise in feedwater temperature achieved from improved condensate return rates will deliver a 1% improvement in system efficiency. Simple payback commonly achieved in <1-year.
10	**Are all sections of steam and condensate pipework, valves, vessels and fittings effectively insulated?**	[yes]/[no]	Ensuring that all hot surfaces are properly insulated to keep surface temperatures below 40°C is highly cost effective. Fitting flexible, removable covers to valves typically paybacks in under 2-years.

The Carbon Trust is an independent company with a mission to accelerate the move to a sustainable, low-carbon economy. The Carbon Trust:

- advises businesses, governments and the public sector on opportunities in a sustainable, low-carbon world;
- measures and certifies the environmental footprint of organisations, products and services;
- helps develop and deploy low-carbon technologies and solutions, from energy efficiency to renewable power.

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