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SERIES **15** | MODULE **02** | **BOILERS & BURNERS**

Energy-efficient boilers and burners

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Over a third of the UK's greenhouse gas emissions and nearly half of the energy we use is heating-related. Approximately 9m UK boilers are classed as inefficient; particularly commercial boiler plant, so boiler plant efficiency is a key area for consideration when undertaking an energy efficiency programme.

In this article we will cover boiler technology with a focus on low temperature hot water (LTHW) boilers, efficiencies and how to achieve energy saving opportunities.

A boiler is an appliance that burns a fuel, raising the temperature of a medium (typically air or water) via a heat exchange process, providing space heating, hot water or for industrial processes.

A LTHW boiler comprises:
- a fuel inlet;
- burner;
- heat exchanger;
- a pump for circulating water;
- the input water feed;
- a hot water outlet;
- an exhaust flue (chimney); and
- controls.

The boiler controls set the required temperature and pressure of the outlet water. If the outlet water is at a lower temperature than required, the burner 'fires' a controlled mixture of fuel and air to generate hot combustion gases. The heat is then transferred to the circulating water via the heat exchanger.

In the UK gas-fired boilers are most prevalent. Oil and LPG are more expensive than gas and burner

Table 1. The Non-Domestic Building Compliance Guide provides a minimum level of boiler efficiency

New Buildings	System	Boiler Seasonal Efficiency (gross)
Gas	Single boiler system ≤2 MW	91 per cent
	Single boiler system > 2 MW	86 per cent
	Multiple-boiler system	82 per cent for individual boiler 86 per cent for overall multi-boiler system
LPG	Single boiler system ≤2 MW	93 per cent
	Single boiler system > 2 MW	87 per cent
	Multiple-boiler system	82 per cent for individual boiler 87 per cent for overall multi-boiler system
Oil	Single boiler system	84 per cent
	Multiple-boiler system	82 per cent for individual boiler 84 per cent for overall system
Existing Buildings		**Boiler Seasonal Efficiency (gross)**
Gas	All systems	82 per cent
LPG		83 per cent
Oil		84 per cent

conversions to gas can be pursued to achieve cost savings.

Biomass boilers using wood or organic waste for fuel are growing in popularity as they produce fewer carbon emissions; although fuel storage remains a consideration.

LTHW boilers produce hot water up to 90oC. Medium/high temperature and steam boilers generate water or steam at higher temperatures, and tend to be found on larger sites or industrial premises.

Four types of boilers

There are four main types of boilers: conventional, high-efficiency, condensing and combi boilers.

Conventional boilers - referred to as standard boilers and are in excess of 20 years old where still being used. Their efficiency ranges from 70 per cent in good condition, to 50 – 60 per cent in poorer condition. They either employ atmospheric burners taking air from the open surroundings, or use forced draught burners which use a fan to force air into the boiler and out through the flue. These can be identified by fans fitted to the front of the boiler.

High-efficiency boilers - widely used since the late 1990s as new installs and replacements for conventional models. They have lower water content, large heat exchanger surface area and increased insulation to the boiler shell. Expected efficiencies are in the region of 70 - 80 per cent.

Condensing boilers - have larger heat exchanger surface areas, often two heat exchangers. The larger surface area recovers extra sensible heat from waste heat and returns it into the system. This reduces the temperature of exhaust gases causing the water vapour to condense, which is drained out via a pipe. Condensing boilers are the most efficient at about 90 per cent; they also have good part-load performance.

Combination ('combi') boiler - a secondary heat exchanger integrated within the boiler housing is used to generate hot water instantaneously, eliminating the need for a hot water storage cylinder and feeder tank. They are beneficial where space is limited and are used mainly in domestic buildings and smaller commercial properties where hot water demand is limited to taps.

Boilers can be installed as single or multiple boiler systems, combining to deliver larger heat loads. A benefit of multi-boiler systems is the ability to sequence boiler operation to meet varying heat loads at different times of the day and season. Condensing boilers are recommended as lead boilers in a multi-boiler system.

Table 2. Key boiler service actions

Action	Purpose	Impact
Flue gas analysis	Ensure fuel-to-air ratio follows manufacturer's recommendation. Too little air means insufficient oxygen for complete combustion to occur, resulting in a build-up of potentially dangerous carbon monoxide in the flue; too much air leads to energy waste in trying to heat the excess.	A well-tuned boiler will experience annual savings of around 2 per cent.
Controls calibration	Ensure sensors and gauges are calibrated.	Wrong flow/return and boiler firing temperatures will distort optimal performance leading to energy waste.
Burner cleaning	Incomplete combustion leads to soot creation on the burner side inhibiting heat flow.	A 1mm layer of soot will cause a 10 per cent increase in boiler energy input to meet the same heat demand.
Limescale treatment	Lime scale build-up on the water-side of the heat exchanger creates an insulating layer that inhibits heat transfer.	A 1mm layer of lime scale will cause 5-7 per cent increase in energy required by the boiler to meet the same heat demand. Chemical treatment may be required in hard-water areas.

Boiler efficiency

The efficiency of a boiler is important as it determines how much of the fuel input is converted into useful heat output. No boiler is 100 per cent efficient, as heat is lost via the flue and the casing of the boiler itself.

Figures for heating efficiency are often quoted close to 100 per cent, but a more accurate measure is the 'boiler seasonal efficiency'. This takes into account all characteristics of a boiler and is averaged over a season or year. It is a weighted average of the gross efficiencies of the boiler at 30 per cent and 100 per cent of the boiler output. The equation below (Fig.1) calculates boiler seasonal efficiency for single boilers <400kW, or multiple-boiler systems with identical individual boilers of <400kW each.

Based on CIBSE figures, boilers and burners have a life expectancy of around 20 years. End of service life could occur for reasons including: obsolescence, excessive maintenance costs, changed system requirements and environmental considerations.

Fig. 1

$$\textbf{Boiler seasonal efficiency} = 0.81\eta 30 \text{ per cent} + 0.19\eta 100 \text{ per cent}$$

Where η30 per cent is gross boiler efficiency measured at 30 per cent load
η100 per cent is gross boiler efficiency measured at 100 per cent load

Energy-saving measures

The most appropriate energy-saving solution will depend on the type of boiler and heating system installed, the business needs and budget. The measures can be grouped into management actions, low cost and capex actions.

Management actions

Regular effective maintenance - Absence of an effective maintenance regime can lead to a significant drop in a boiler's efficiency or breakdown. A minimum annual service is recommended with other key boiler service actions.

Match boiler operation and occupancy - The benefits of controls is to ensure boiler operation only when required. Often boilers operate during weekends and holidays when a building is not occupied and there is no process heat requirement. Sometimes adjusted control settings to cover temporary extended hours are not returned to their original settings. A regular check will prevent energy being wasted in this way. Savings of up to 12 per cent are possible.

Boiler controls monitoring - A simple way of assessing boiler control effectiveness is to chart monthly or weekly heating energy consumption and compare with building operating hours and outside weather conditions (degree day analysis). This will reveal high energy use out-of-hours or high heating load in mild conditions, indications that control settings are inaccurate or insufficient.

It is also worth comparing the building's heating performance to similar building types using published benchmarks for the building type. The annual performance is calculated by dividing the annual heating energy used by the area of the building to gain a 'benchmark' in kWh/m2.

Low-cost actions

Boiler and pipework insulation - Heat loss from the body of a modern insulated boiler is approximately 1-2 per cent of total fuel input, and up to 10 per cent on older boilers with poor insulation. Heat loss from exposed pipes and flanges can contribute a further 10 per cent. It is common for valves and flanged to be left un-insulated because of future access but inexpensive Velcro or string fastening valve jackets can be used to circumvent this.

Insulation should be added where insufficient, or replaced if missing or deteriorating. The Non-Domestic Building Compliance Guide sets maximum permissible heat loss levels for heating pipes based on the pipe thickness.

Install flue dampers - It is common for the flue to cause a flow of air through the boiler, even if not firing, particularly in larger boilers. This cools the boiler, losing valuable heat to the atmosphere, known as 'standing losses'. A flue damper can be used to close off the flue automatically when the boiler is not firing, preventing such losses. Building regulations require boilers to have improved efficiencies at both full and part-loads, leading to lower standing losses in modern boilers. Retrofitting flue dampers is suitable for older, conventional boilers with a large load (typically >100kW).

Sequence control - In a multi-boiler system an absence of sequence control is indicated by all boilers firing up and switching off at the same time under mild conditions i.e. spring and autumn.

Good sequence control ensures that only the minimum number of boilers required to meet the heat demand actually fire, and that these boilers are used to full capacity rather than part-load. The order in which the boilers fire can also be rotated to minimise maintenance costs. Good sequence control could save 5-10 per cent of the overall energy consumption of the boiler plant. Where not already installed, sequence control should be retrofitted to multiple boiler applications with a variable load pattern. A condensing boiler should take the lead where a mix of conventional and condensing boilers are installed.

Boiler interlock - Sometimes boilers fire but don't actively heat the water in the system or contribute to the building's space heating; this is known as 'dry cycling'. Dry cycling can be confirmed by turning off radiators and the distribution system -if the boilers continue to fire when no load is required, dry-cycling is occurring.

Linking the boiler controls with the heating system controls (such as room thermostats) via an interlock will prevent dry-cycling, otherwise through the installation of specialised intelligent boiler load optimisation controller. The best option will be determined by the size and location of the boiler and controls. Interlock control is appropriate for all types of boilers, with savings of around 15 per cent achieved on some large boilers.

Optimised start/stop - A time switch is used to control the start and stop time of most heating systems, corresponding to the buildings occupancy requirement; this can be improved with an optimiser.

An optimiser is a sophisticated time switch linked to the internal and external thermostats of the heating system, which switches the boiler on at exactly the right time to ensure that the building reaches the required internal temperature in time for occupation. Similarly, the boiler is switched off early so that the internal temperature is maintained only when required. Optimisers will 'study' the building for some weeks before achieving the optimum start and stop times. Savings of 5-10 per cent of the overall energy consumption of the boiler plant could be achieved. The optimiser can be integrated into the building management system (BMS).

Weather compensation - Weather compensation control goes a step further than optimisation, by varying the flow water temperature in relation to outdoor temperatures, thus modulating the performance of the heating system to ensure room temperature is at set-point.

The compensator measures the outdoor temperature, the indoor temperature and temperature of flow water feeding the heat emitters. It then assesses whether the indoor temperature set point is being maintained.

For example when outdoor temperature is 5°C, the flow water to radiators may be 70°C. If the outdoor temperature rises to 12°C, the flow temperature could then be reduced to 60°C, based on a predetermined heating curve adjustment, thus saving on heating fuel.

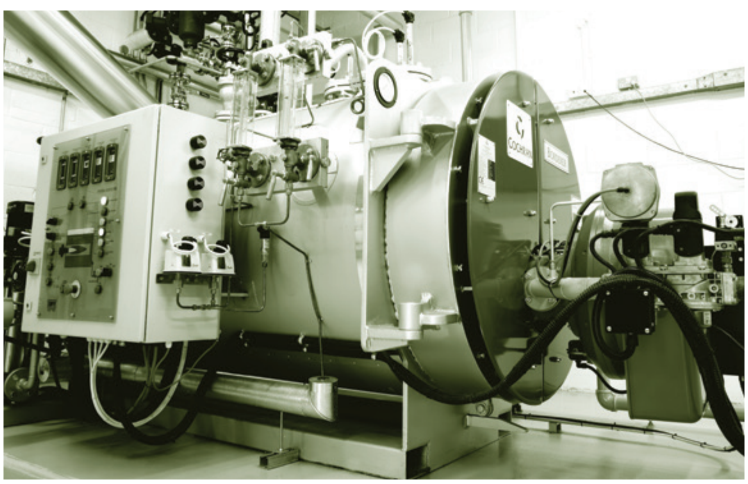
Weather compensation has limitations for constant temperature systems such as fan convectors or air handling units, because variable temperature strategy is not applicable, therefore separate controls will be required for constant and variable temperature circuits.

Capex Measures

Boiler replacement with condensing units - Older standard boilers and non-condensing boilers i.e. installed before the 2005 legislative mandatory requirement for all new boiler installations to be of the condensing configuration, will benefit from replacement. Many boilers were installed slightly oversized. Over time the size of the building served by boilers may have significantly reduced, or fabric upgrade may have occurred, reducing heat demand. In these scenarios like-for-like replacement should not be pursued. An analysis of the actual thermal demand and boiler size should take place with advice taken from a qualified building services engineer or boiler technician.

An existing standard boiler with efficiency in the region of 60 per cent being replaced with a new condensing boiler of 90 per cent efficiency will deliver a significant energy saving, with simple paybacks of 3 – 5 years in many cases. Often the new condensing boilers will have improved control features thus increasing the overall benefit.

Modulating burners - The simplest form of burner control is single-stage or 'on-off' control and is the type of control found on most older, standard boilers. Single stage burners simply switch on to full capacity and off again, in a continuous inefficient fashion irrespective of load conditions. Some boilers have two-stage 'high-low' burners (low being typically about 40 per cent load), which offers some benefit over single stage burners, as it reduces the number of times the burner switches on/off and the number of air purges, thus improved boiler efficiency under part-load conditions.



Modulating burners regulate the fuel input and air supplies to exactly match the required heat demand. This ensures good efficiency across the whole heat output range of the boiler, as modulation can vary between 10 – 100 per cent of boiler capacity. Modulating burners are best suited for older boilers with variable heat loads.

Variable speed drive - Most heating systems use the same amount of energy for pumping, regardless of the load on the system, but they normally require maximum flow for only a limited time of the day, usually peak morning period when the heating has just come on.

For forced/induced-draught boilers, a variable speed drive (VSD) can be installed on the fan. This enables the fan to operate at lower speeds when less air flow is required. A reduction in fan speed of 10 per cent can result in fan energy consumption savings of around 20 per cent, a reduction in fan speed of 20 per cent will save up to 40 per cent.

For systems with large flow pumps, typically over 4kW, VSDs will enable variable water flow control on a similar principle. Savings of 25-50 per cent of annual pumping energy consumption can be achieved depending on the duration of low load. Retrofitting of variable speed drives and pumps is best suited to larger systems having variable loads.

Recover heat from exhaust gases - In conventional boilers, the heat contained within the exhaust gases is lost to the atmosphere. If replacement with a condensing boiler is not possible, this heat can be recovered through the use of an external heat exchanger. The recovered heat can be used to pre-heat the return water or the combustion air. Increasing the temperature of the combustion air by 20oC can improve the overall efficiency of the boiler by 1 per cent.

This technology is best suited to conventional and high efficiency boilers with flue gases of a sufficient temperature, and most economical when applied to larger systems.

References and further reading

CIBSE Guide F Energy efficiency in buildings

CTV008 Low temperature hot water boilers

Non-domestic building compliance guide

CTV046 HVAC overview guide

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BOILERS & BURNERS

Please mark your answers on the sheet below by placing a cross in the box next to the correct answer. Only mark one box for each question. You may find it helpful to mark the answers in pencil first before filling in the final answers in ink. Once you have completed the answer sheet in ink, return it to the address below. Photocopies are acceptable.

QUESTIONS

1 Heat loss from the body of an un-insulated older boiler can be up to?
- ☐ 75 per cent
- ☐ 10 per cent
- ☐ 50 per cent
- ☐ 0.5 per cent

2 Which boiler fuel is most prevalent in the UK.
- ☐ Biomass
- ☐ Hydrogen
- ☐ Gas
- ☐ Oil

3 What type of burner provides only a simple on/off boiler burner action?
- ☐ Modulation burners
- ☐ Single stage burners
- ☐ Two stage burners
- ☐ Micro burners

4 Weather compensation control varies which of the following?
- ☐ Flow water temperature
- ☐ Rocket boost
- ☐ Soot formation
- ☐ Rainfall

5 What is the minimum permitted boiler seasonal efficiency for a gas boiler ≤2 MW in a new non-domestic building?
- ☐ 50 per cent
- ☐ 79 per cent
- ☐ 91 per cent
- ☐ 65 per cent

6 Which of the following is not a basic component of a boiler?
- ☐ Burner
- ☐ Heat exchanger
- ☐ Ultra speed booster
- ☐ Flue

7 Low temperature hot water boilers (LTHW) produce hot water at what temperature
- ☐ Around 2000C
- ☐ Around 900C
- ☐ Below 200C
- ☐ Over 3500C

8 What is the minimum permitted boiler seasonal efficiency for an Oil boiler in an existing non domestic building?
- ☐ 50 per cent
- ☐ 95 per cent
- ☐ 84 per cent
- ☐ 65 per cent

9 What is the minimum permitted boiler seasonal efficiency for a gas boiler in an existing non domestic building?
- ☐ 55 per cent
- ☐ 82 per cent
- ☐ 89 per cent
- ☐ 99 per cent

10 Which of the following is not a type of boiler
- ☐ Variable speed drive
- ☐ High efficiency boiler
- ☐ Combi boiler
- ☐ Condensing boiler

Please complete your details below in block capitals

Name .... (Mr. Mrs, Ms)..........

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