The challenge for energy-efficient boilers and burners

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Last summer the government finally unveiled amendments to Part L of the Building Regulations to be introduced next April. Part L covers the requirements for the conservation of fuel and power and the amendments will reduce the carbon dioxide target for non-domestic buildings by 9 per cent compared with the 2010 standard. This revision to Part L is seen by Government as the next step towards the 2019 zero carbon target for new non-domestic buildings (2016 is the zero carbon target for homes).

The Government also has an objective to make an 80 per cent reduction in carbon emissions by 2050 and according to the Building Research Establishment, of all the buildings that will be in use in 2050 60 per cent are already built and 40 per cent will pre-date 1985, the year when Part L was first introduced to address building energy efficiency. This makes the challenge to increase the efficiency of the existing building stock as important.

Space and water heating

Efficient boilers and heating systems are important because Carbon Trust figures show that space and water heating accounts for around 60 per cent of a building's total energy consumption and around 40 per cent of the UK's Greenhouse Gas emissions. Boilers and burners are also employed in industrial applications where efficiency is as important because of cost and legislation pressure.

The most common type of boiler for space and water heating is the low temperature hot water (LTHW) boiler providing heat at around 80OC for radiators and other emitters. Condensing boilers are now common but the efficiency of this type of boiler is better when applied with low temperature heating such as underfloor heating systems. Steam boilers are seen in large sites such as hospitals or universities or for industrial process applications where the much higher heat transfer capability of steam is beneficial. Less common, compared with LTHW plant, are medium (MTHW) or high temperature (HTHW) boilers.

Natural gas is the most common fuel for space heating boilers although oil is still used.

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There are different grades of oil classified by their viscosity. Light kerosene and fuel oil is used in smaller commercial buildings while heavy fuel oil is usually restricted to larger boilers. Liquid Petroleum Gas (LPG) is an option where the clean combustion properties of gas are required outside the natural gas supply area but the cost of LPG is higher than natural gas. Biomass fuels such as wood chip or pellets and to a certain extent bio-fuels are becoming more popular because of the lower carbon emissions.

The two fundamental components of a boiler are the burner and the heat exchanger. There is a wide variety of burner and heat exchanger types and their design is fundamental to the overall efficiency of the boiler.

Efficient combustion

The key requirement for the design of any burner is to provide efficient combustion. The burner needs to achieve effective mixing of the correct proportions of fuel and air and needs to allow sufficient time for complete combustion to take place. The ratio of air and fuel required for complete combustion is known as the stoichiometric ratio and its control is perhaps the most important factor in determining burner efficiency. Practical considerations means that the burner must be designed to introduce more air than the ideal ratio (known as excess air) to ensure complete combustion, in order to eliminate the formation of harmful combustion products. On the other hand the level of excess air must be minimised to reduce the reduction in burner efficiency

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by heating unnecessary air.

There are three main categories of gas burner. Atmospheric burners (or natural draught burners) where gas is injected through the burner to entrain the air needed for combustion. This is the most basic and least efficient burner type because it is only the action of the gas jet and the diffusion of the surrounding air that causes mixing of the air and fuel and this makes it difficult to design for minimum levels of excess air. There has been a move away from this type of simple and low cost burner driven by the need for higher efficiency.

The second type of burner is the forced draught burner where a motor-driven fan introduces the combustion air into the burner so that the air fuel mixing is well controlled and a compact flame produced. The third type is the pre-mixed burner where the gas and air are mixed before combustion in a mixing chamber. The main advantage being that the combustion air can be controlled very closely to achieve the correct ratio of air and gas at all times, in order, to maintain combustion efficiency.

For combustion of the grades of oil used in burners for space heating boilers the fuel has to be broken down into tiny droplets to yield a large surface area for the fuel and air to mix - this process is called atomisation. The most common oil-fired burner is the pressure jet burner which supplies fuel to a nozzle at sufficient pressure to atomise the oil into fine droplets ready for combustion. The flame from the combustion of oil is characterised by a more yellow luminous flame and has a higher radiant heat output compared with flames from the combustion of gaseous fuels.

Burner control basics

There are three main approaches to burner control. The most basic is a simple on-off control. At part load, the burner cycles on and off to achieve the necessary level of heat output. With a two-stage or high-low burner control there

is a low firing rate followed by a step change to the high firing rate when required to satisfy the demand. This provides two stages of thermal output and allows the burner to match the thermal load more closely for greater efficiency. A fully modulating control adjusts both the fuel and combustion air to maintain optimum combustion efficiency at all loads. It provides close matching between the burner output and heat demand and is the most energy efficient control method.

There is often confusion about efficiency based on gross and net calorific value of the fuel.

The gross (or higher) calorific value (CV) can be defined as the total heat liberated by the complete combustion of the fuel. It is determined by measuring the heat removed when cooling the products of combustion to a standard reference temperature, and includes latent heat recovered from condensation of the water vapour component. This water vapour forms as a result of the combustion of any hydrogen molecules contained within the fuel, and the vaporisation of any moisture present.

The net (or lower) value equals the gross calorific value minus the latent heat of the water vapour formed from the combustion of hydrogen and from any moisture present in the fuel. The ratio

> **"There is confusion about efficiency based on gross and net calorific value of the fuel. The gross calorific value is defined as heat liberated by the total combustion of the fuel"**

between gross and net CV varies between fuels, for example it is 1.109 for natural gas and 1.067 for gas oil. Condensing boilers recover some of the heat in the water vapour so it is possible to achieve efficiencies greater than 100 per cent net efficiency.

Space heating boilers operate for much of the time at less than full load, which means boiler efficiency should be considered across a range of likely loads not just at rated output. Quoted instantaneous boiler efficiencies are generally not representative of practical situations in buildings.

The seasonal (or annual) efficiency provides a better measure of the true operation, averaged over a season or year, based on the total useful heat output compared with the total energy input over the period in question. This means boilers with good part load efficiency will significantly improve the seasonal efficiency. The EU Boiler Efficiency Directive first set requirements for minimum boiler efficiency at full and part load, as far back as the late 1990s.

History of cast iron

Hot water boilers for space and process heating are available in a wide range of designs but basically comprise a burner and a heat exchanger. Cast iron has long been the choice of material for the manufacture of boilers, dating back to the late 19th century when the first coal-fired boilers were produced. Cast iron was chosen for its tolerance to sulphurous flue gases, a by-product released as a result of burning coal. Once natural gas became available its clean combustion properties meant different construction metals could be used.

Although the efficiency of cast iron boilers has been improved the drive for higher efficiency means the market developed many other designs. For example the use of cast aluminium or copper finned tube heat exchangers designed to achieve higher heat transfer rates has reduced boiler sizes and thermal mass. Burner design has been refined to improve combustion efficiency and boiler insulation levels have been improved. Larger boilers have been designed around pressure jet and forced draught burners firing into a steel combustion chamber and steel heat tube heat exchangers.

The switch from cast iron boilers to condensing models has been one of the most spectacular shifts within the commercial heating industry. A leading supplier quotes that in 2002, cast iron heat exchangers represented 70 per cent of all new commercial boiler sales but today, that stands at just 18 per cent. In a mirror image, condensing boilers are now 80 per cent of commercial boiler sales, compared to 20 per cent 2002.

Reduce thermal losses

There are many designs available but common characteristics are

low water content and thermal mass to reduce thermal inertia efficiency losses. Larger heat exchangers designed to increase heat transfer rates and high levels of insulation to reduce case losses. In many cases the atmospheric burner has been replaced by the forced draught or premix burners. Typically they achieve efficiencies around 80 to 85 per cent at full load.

These have an additional heat exchanger to extract extra heat by condensing water vapour from the products of combustion. They can achieve full load efficiencies in the range 85-95 per cent when in the condensing mode depending upon the return water temperature.

Condensation occurs at return water temperatures below 55^{O}C (depending upon the level of excess air) and the lower the return temperature the more efficient the boiler operates. In an underfloor heating system operating at 30 to 40^{O}C a condensing boiler can achieve seasonal efficiencies over 90 per cent. However, in the more common radiator heating system seasonal efficiencies of up to 87 per cent can be achieved provided variable temperature (weather compensation) controls are used. With constant temperature emitters (80^{O}C flow systems) such as fan coils or air handling units the efficiency will be lower because the boiler will not operate in the condensing mode for much of the time.

A characteristic of condensing boilers is that the efficiency often increases when operating between full and around 50 per cent loading. Other than low temperature systems, combinations of condensing and non-condensing boilers can be more cost effective than all condensing boilers. Specifying the lead boiler as condensing, with a lower cost non-condensing boiler to top-up can optimise capital cost while still maintaining overall plant efficiency.

Using multiple boilers (modules) in one installation can improve seasonal efficiency by enabling a better match between boiler output and system demand. During periods of lower demand only a proportion of the boilers will be required to supply heat. There may be a capital and maintenance cost penalty for installations with too many modules. Condensing boilers should always be controlled to be the 'lead' boiler in multiple boiler installations.

It is difficult to separate the boiler plant from the heating system as the two interact with each other. The most efficient heating systems have not only efficient boilers but also well designed heat distribution systems and effective controls. A well-designed system can perform badly with poor controls and conversely a poor heating design can't be fixed by just adding controls.

Essential not to over-size

It is essential to ensure boilers are not oversized. Apart from capital cost implications an over-sized boiler operates further down the part load curve and hence at lower efficiencies. Where possible consider splitting domestic hot water from space heating in order to avoid poor summertime efficiencies. Plant sized to meet both space and water heating will be too large for the hot water thermal loads during the summer period and this can significantly reduce seasonal efficiency.

> **"Regularly carrying out boiler maintenance is essential to ensure continual high efficiencies. This includes cleaning and adjusting the burner"**

Regularly carrying out boiler maintenance is essential to ensure continual high efficiencies. This includes cleaning and adjusting the burner, cleaning the heat exchanger to ensure good heat transfer and setting the boiler controls correctly.

The impending Energy Related Products (ErP) Directive covers a wide range of products for domestic and commercial use, including electrical powered products, boilers and water heaters. It is aimed at phasing out the lower performing energy using products from the market. The final directive is due to come into force in 2015 and details of the outlined efficiency requirements have only recently been released.

The requirements for fossil fuel boilers with 70kW to 400kW rated input, will have a significant impact on the commercial boiler market. The Directive will effectively eliminate from the market all high efficiency non-condensing boilers up to 400kW, which includes atmospheric, pre-mix and pressure jet boilers. If Building Regulations Part L formulae for calculating gross seasonal efficiency are applied to the requirements (94 per cent part load and 86 per cent full load), the equivalent seasonal efficiency is 92.5 per cent without differentiation between new or existing buildings. To reach these levels small to medium size installation projects will require a condensing boiler solution and for refurbishment projects it will mean that heating system replacement rather than simply boiler replacement will have to be considered. The next two years will, therefore, see another significant shift in the efficiency of commercial heating systems.

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MARK THROWER, MANAGING EDITOR

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SERIES 11 MODULE 7: QUESTIONS

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.

1 What percentage reduction in the carbon target for non-domestic buildings is expected from the latest revision to the Building Regulations?
☐ 2 per cent ☐ 5 per cent ☐ 9 per cent ☐ 12 per cent

2 What is the zero carbon target date for new non-domestic buildings?
☐ 2015 ☐ 2019 ☐ 2020 ☐ 2050

3 Which is not a requirement for the design of any burner?
☐ to condense the flue products
☐ to provide efficient combustion
☐ to achieve effective mixing of the correct proportions of fuel and air
☐ to allow sufficient time for complete combustion to take place

4 Which of the following is not considered to be renewable energy for boilers?
☐ Wood chip ☐ Wood pellet ☐ Biogas ☐ LPG

5 Which of the following is not one of the main types of gas burner?
☐ Atmospheric
☐ Forced draught
☐ Pressure jet
☐ Premix

6 What is the most efficient mode of burner operation?
☐ High/low
☐ On/off
☐ Reverse return
☐ Fully modulating

7 Which of the following statements about seasonal efficiency is not correct?
☐ It always has the same value as the instantaneous full load efficiency
☐ It is the ratio of useful heat output to total energy input over a given period
☐ It provides a better measure of true operation than the full lead instantaneous efficiency
☐ Boilers with good part load efficiency will significantly improve the seasonal efficiency

8 What is an ideal application for condensing boilers?
☐ Underfloor heating systems at 40OC flow temperature
☐ Steam condensate systems
☐ High temperature hot water systems
☐ Fixed 80OC flow temperature systems with including fan coils and air handling units

9 Which measure of boiler efficiency can reach over 100 per cent?
☐ Forward ☐ Net ☐ Standard ☐ Gross

10 At approximately what return water temperature does a condensing boiler start to condense water vapour condensation in the flue products?
☐ below 10°C ☐ below 30°C ☐ below 55°C ☐ above 75°C