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Boilers and burners

By Paul Stevenson, Larkdown Environmental Ltd

Boilers are everywhere. They fall into three main sectors:

• **residential and domestic:** generally small scale and often gas, but can be:
a) electric-powered, especially in high-density buildings;
b) electric/ oil/ solid-fuel/ bio-mass: mainly for buildings off the gas grid;
c) larger, central boiler with district heating systems (DHS - e.g. multi-storey or mixed-use buildings); more common in central/ east Europe, former Soviet states and China than UK;

• **commercial and service:** often larger, centralised boilers servicing the hot-water (HW) and space heating needs of offices, hospitals and care-homes, retail and warehousing, hotels, sports and leisure centres, etc; and

• **industry:** lots of large scale and bespoke boilers for chemicals, food and drink, metals, apparel and engineering sectors. Several industries have technical uses for steam or HW. This article does not cover energy efficiency (EE) in steam boilers.

This article focuses on moderate to large fossil-fuel boilers, used for HW and space heating found in the commercial and service sectors. Natural gas is the predominant fuel, because the unit cost per kWh is much lower than other fuels and its exhaust gases are "clean". It explores energy and CO2 savings technologies and techniques, covering:

• **improving efficiency away from the boiler:** what can one do to reduce the demand for space heating and HW? This should always be the first thing to consider in any energy-saving/ low-carbon initiative;

• **energy efficiency and gas boilers:** there are many gas-boilers that are going to be around for decades, so what can be done to improve their efficiency?;

• **boiler design:** if and when installing or replacing a (gas) boiler, what should one consider?; and

• **boilers of the future:** briefly exploration of the options for large scale de-carbonisation for space heating and HW. The UK Government recently pledged to ban fossil fuel boilers for all new residential builds from 2025; other sectors will likely follow.

Photo courtesy Remeha/Owen Mathias

There are many good publications, available on the internet, that will give a wider coverage of specific areas. Sources are provided towards the end of this article.

When carrying-out a general energy audit, it is good practice to work backwards from end-use(s), via the distribution system to the point of generation. Boilers and hot-water systems follow the same logic; for instance, it is pointless installing and operating a super-efficient boiler if the building is only part-occupied, has badly fitted windows and doors, hot-water is leaking from a tap, or much of the heat is lost via poorly insulated pipes. This may seem obvious, but the author has encountered numerous instances where focus was given solely to the boiler without first considering the end-uses and the distribution system that takes it there.

Attention should be given to the building fabric including: wall and roof insulation, double-glazing, draft-proofing. Clearly, it is better to design-in from the start rather than retrofit, but retrofits of older style windows (that need replacing anyway), enhanced loft insulation or cavity wall insulation and attention to external doors to ensure they close properly all help reduce the load on the boiler (and the air-con).

The boiler's performance over time should be monitored to compare its consumption against meaningful measures of activity, such as building occupancy and heating degree-days. This creates a good base line against which any progress can be measured.

Compare performance

A building energy management system (BEMS) that has the boiler and HW system as one of its key energy centres allows the energy manager to compare performance on a like-for-like basis as well as identify recurring issues that cause high consumption. This systematic approach also allows the energy manager to measure "before" and "after" performances. From this he/she can quantify the benefits, which is a key step in any formal energy management system (EnMS), such as ISO50001.

With the BEMS the energy manager should, where practical,

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disaggregate the building into meaningful zones. There is no point heating unoccupied or infrequently used areas. If it can't be controlled automatically, can it at least be controlled manually, for instance, are there valves to shut-off radiators or entire floors? In addition, the BEMS should be programmed to introduce a "dead-zone" – i.e. no heating or cooling between 20-24°C.

Both CIBSE and Carbon Trust advice is that warming should be needed only if temperatures fall below 19°C. Cooling should only kick in when temperatures rise above 24°C and there should be a "dead-band" between these temperatures where neither heating nor cooling takes place.

Temperature control should be automatic and tamper free, ideally controlled by the BEMS. This eliminates potential conflict - where the heating is trying to warm the building whilst the AC is trying to cool it. Yes, this does happen!

Engage with staff to explain what is being done and why. People need to be aware of their impact and understand how they can help; once aware they are more likely to "buy-in" and even replicate it at home.

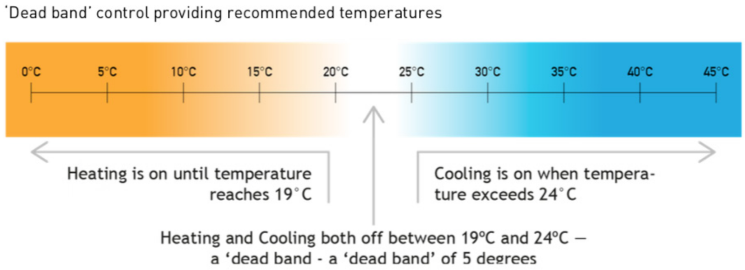
When it comes to hot-water distribution eliminate leaks and misuses of both water and heat e.g. washroom taps. Insulate pipework and HW tanks, introduce controls and sensors, such as passive infra-red (PIR) to prevent unnecessary room heating, etc. Again, all this sounds obvious, but there are plenty of examples where it doesn't happen.

Introduce a strategy to maximise heat recovery. Building heat-recovery is already well established, for instance plate heat exchangers, thermal wheels and run-around coils to pre-heat incoming air.

Hot water is not as easy, but for frequently used showers in sport and leisure facilities, hotels and homes, one can retrofit waste-water heat-recovery (WWHR), which captures heat from the discharge to pre-heat make-up water.

Attention to these opportunities offers excellent savings of 20-30 per cent or more, especially if the area hasn't had attention for many years. They also offer excellent financial returns, with paybacks typically < 5 years and sometimes < 1 year.

Figure 1: Use of the dead band can cut energy use



It also helps future-proof the building against ever-tightening legislation on efficiency minimums. For instance, "F" and "G" rated buildings will soon be unrentable; over the next 10-20 years this will likely apply to "E" then "D". The author's advice would be to consider what the requirements are likely to be needed 20-years hence, and make EE interventions that meet these requirements, even if the payback is between 5-10 years.

Finally, any new investment in a new boiler will now be correctly sized. The boiler no longer needs to be 20-30 per cent bigger to service 20-30 per cent avoidable waste!

Millions of gas boilers

There are millions of gas boilers in the UK and they are likely to be around for decades to come. An audit of the boiler can often identify numerous no/low-cost energy (and water) savings, typically between 5-20 per cent. If the boiler is very old, poorly sized for the site's current needs, or has not been properly maintained for years, then saving potential can be even greater.

Most equipment operates best when new. Regular and effective maintenance is needed to sustain optimum performance. Most boilers and their burners are serviced at least annually for continued safe operation. This is mandatory. The other reason for maintenance is optimum performance. This is not mandatory and therefore is considered less important, but attention can lead to reductions in energy and operation costs.

Maintenance needs to address three main areas where the efficiency can worsen over time:

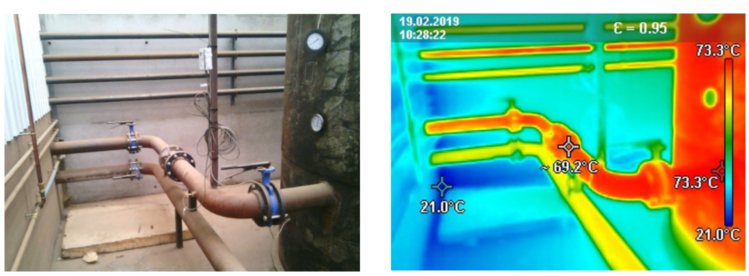
- combustion efficiency: releasing the heat from fuel, i.e. the burners;
- heat transfer efficiency: getting heat from products of combustion into the water; and
- reducing boiler heat loss.

A first step is to optimise burner's gas air ratio or balance. In effect, "tuning" the burners. Too little air, and one gets incomplete combustion, poisonous carbon monoxide emissions and poor efficiency. Too much air, one gets complete combustion, but lots of heat is lost in the excess air. Just right, and one has complete combustion but with minimum heat lost up the exhaust. Ideally, one wants to reduce excess air ideally to <5 per cent O_2 in exhaust.

One approach is oxygen trim control. This is an on-line analyser of O_2 in flue gas, with computerised control that opens/closes air damper. Boiler efficiency improves 1-5 per cent, with a typical payback <2 years.

Variable speed drive (VSD) motors for the air inlet (or exhaust – depending on the set-up) can be used to control the gas:air balance. Furthermore, VSD control reduces the electricity required to drive the fan, offering power savings of 10-30 per cent compared with valves or dampers.

Figure 2: Thermal imaging can identify areas of boiler heat loss



Flue-gas dampers should be considered. During boiler stand-by, natural convection creates air flow through the boiler to the flue, resulting in heat transfer from the water and equipment to this air, which is then lost via the chimney. If boilers are put on stand-by regularly, total losses can be large. A shut-off damper restricts airflow through the flue and prevents heat loss. Dampers are particularly suited to intermittent use, or where regular on/off boiler cycling is needed to maintain the required pressure/ temperature. Automatic, gas-tight, shut-off dampers or automatic, air-sealing damper at the combustion-air fan inlet are both widely available.

An "economiser" is a gas-to-water heat exchanger located in the exhaust gas flue. It captures heat from the exhaust, typically at 200°C, to pre-heat cold make-up water going into the boiler. During normal boiler operation, the economiser receives a continuous flow of make-up water, matching heat "source" with heat "sink". Typical energy savings are 3-5 per cent, with payback of 2-4 years.

Excess heat can also be used to pre-heat the air going to the burners. Raising the air temperature by 10°C offers approx 1 per cent boiler energy efficiency. This is more common in large, continuous industrial boilers.

Heat is lost from the surface of the boiler through a combination of convection and radiation heat loss. In a modern, efficient system, radiation loss from the boiler should be less than 1-2 per cent. However, this can reach 10 per cent for older boilers that have degraded, or with poor insulation/ loss of casing.

Renewable energy options

Explore renewable energy (RE) options: such as solar thermal or air-sourced or ground-sourced heat pumps (ASHP or GSHP) to pre-heat make-up water going to the boiler. Look at capturing heat from other sources to pre-heat water, such as refrigerant or air compressors.

Inevitably, a boiler will come to the end of its serviceable life. For the immediate future, most organisations are going to replace with gas boilers. The first thing to do is to pay attention to the system losses previously mentioned.

Then, ensure the boiler is correctly sized (capacity-rating) for its application, with a little (but not excessive) over-capacity. It's difficult for an oversized boiler to work close to its optimum efficiency if it is regularly operating at only 10-20 per cent of capacity.

Always target an "A" rated boiler, ideally on the enhanced capital allowance (ECA) scheme's energy technology list (ETL). This is a peer-reviewed list of the most efficient equipment, including boilers.

The ECA's Tax Credits Scheme has now come to an end. Although this eliminates the tax benefits, the assessment of high-performing equipment is still valuable.

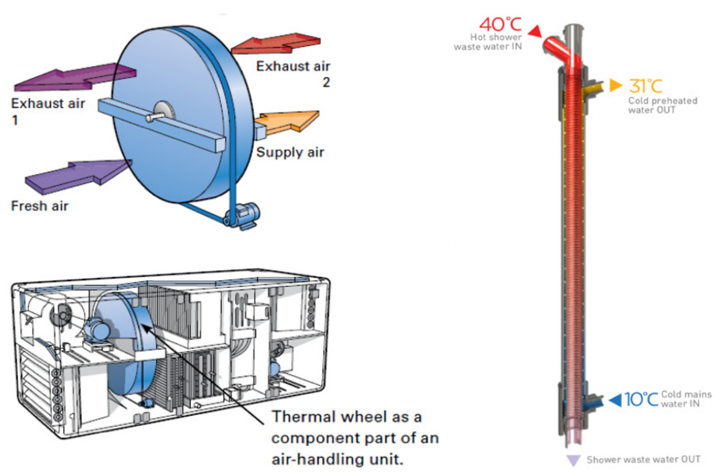
For organisations with large seasonal variations consider boiler "cascade" systems, which comprise two or more smaller boilers. These are set up in a modular manner to allow individual boilers to work closer to max efficiency. Also, one can carry out planned maintenance on one or two units while others are doing the work. An example is Worcester-Bosch GB162 (each unit 50-100kW thermal output). For larger heat demands, the GB162 can be set-up in any combination of 2 to 8 boilers either in-line or back-to-back, using the Bosch cascade kits.

These units can operate individually and are efficient at a high turn-down (i.e. can operate close to max efficiency at only 20 per cent capacity pull), which offers greater seasonal flexibility.

Consideration can be given to biomass boilers that generate heat from burning logs, wood chips or wood pellets. Properly sourced biomass is considered a renewable (i.e. carbon neutral) alternative to fossil-fuelled boilers and currently attracts the renewable heat incentive (RHI). This makes their uptake attractive, especially in areas not on the gas grid. To attract the RHI, the boilers must meet the current legislation controls for air quality, plus other Ofgem requirements.

Many countries, including UK, have committed to being "net zero" carbon by 2050. This is a challenging target, but it is achievable. Clearly, there will still be a need for HW and space heating, and most likely this

Figure 3: Boosting the temperature of boiler supply air can save energy



will still come from boilers. Looking forward, there are several routes towards no/ low CO_2 boilers.

Overall building efficiency

The first step is to take insulation and overall building efficiency to the next level as detailed earlier.

All-electric boilers - with electricity from RE sources - are on the horizon. Immersion heaters and inline/ instantaneous electric water heaters are an established technology. The reason they aren't widely adopted is cost. Electricity is 3-5 times the unit cost per kWh than natural gas.

However, the financial impact from CO_2 emissions is currently only being felt gently. The UK is constantly increasing its proportion of RE electricity, phasing out coal and gas-powered stations, so CO_2/kWh for electricity will continue to fall, but gas will remain at 0.185 kg/kWh (more like 0.20 – 0.24 per kWh thermal). For 2019, electricity emitted 0.256 kg/ kWh, compared to 0.460 in 2012 and >0.5 in 2008. It is predicted to fall below gas sometime in the 2020s.

Electric heating can be augmented with air-sourced and ground-sourced heat pumps (= renewable energy). These still use electricity, but generate between 2-4 times the thermal output per unit electricity. Realistically, they are only viable as underfloor heating in modern, well-insulated buildings. Also, their efficiency in the coldest parts of winter is poor and they will need some augmenting for HW.

The idea of using gas boilers with carbon capture and storage (CCS) is a non-starter. For CCS to work effectively, it needs large point sources of clean CO_2 emissions. Trying to capture the CO_2 from lots of smaller boilers will be impossible.

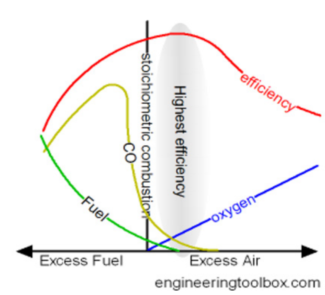
Bio-gases, such as syngas or anaerobic-digestion methane, are more likely to be generated large scale and applied to industrial processes where zero/low-carbon technologies - such as steel, ceramic or cement manufacture - are particularly "hard to reach".

Being part of a larger district heating scheme can make use of:
- energy-from waste schemes, either heat only or CHP;
- heat recovered from industrial sites or large heat-sinks, for example underground transport systems; and
- bio-gases and other RE sources.

These are happening, although as mentioned, the UK is not well geared-up for DHS.

Hydrogen-fuelled boilers have been much heralded (hyped?). It is more akin to gas-air burners, but hydrogen has very different flame characteristics, so the boilers would need new burners.

Figure 4: Creating combustion efficiency



In addition, one has to consider the source of hydrogen. The first method is steam methane reforming (SMR) of natural gas i.e. "blue" hydrogen. However, the SMR process is energy intense and not all the CO_2 is captured, so it's only low-carbon. Also, the CO_2 needs CCS: which is both energy intense and still unproven at large scale.

The second method is hydrolysis with RE electricity = "green" hydrogen. The issue this raises is: why not maximise direct use of this RE electricity and eliminate the intermediate processing?

Finally, there needs to be a method of delivering hydrogen to its to point-of-use. This would mean either taking over the gas network (huge logistical challenge), or compressed hydrogen cylinders at 300-700 bar. This would require extra energy for compressing then transporting the hydrogen.

Hydrogen could be used for cracking oil, ammonia manufacture, heavy goods/long-distance transport, perhaps metal refining, plus some accessible storage during winter months. But it isn't a panacea. Hydrogen will be energy intense and (for SMR + CCS) appears a risky route to de-carbonisation.

Further reading

"Steam and high temperature hot water boilers", Resource Efficiency Scotland. https://energy.zerowastescotland.org.uk/sites/default/files/Module%202%20%20Steam%20and%20High%20Temperature%20Hot%20Water%20Boilers%20-%20Energy%20Efficiency%20E-module.pdf

CTV052 "Steam and high temperature hot water boilers" Carbon Trust, 2012 (no web link)

GPG 382: "Energy efficient operation of heat distribution systems" Carbon Trust 2005 (no web link)

Energy Efficiency: Steam, Hot Water and Process Heating Systems, Victoria State, 2015. https://www.sustainability.vic.gov.au/-/media/SV/Publications/Business/Efficient-business-operations/Energy-efficiency-for-business/Energy-efficiency-best-practice-guidelines/SRSB-BPG-Heating-Manual-Mar-2015.pdf?la=en.

"Heat Pumps: Integrating technologies to decarbonise heating and cooling", Copper Alliance, 2018. https://www.ehpa.org/fileadmin/user_upload/White_Paper_Heat_pumps.pdf

"A Guide to Hydrogen" Energy Institute - Energy Essentials, 2020. https://knowledge.energyinst.org/__data/assets/pdf_file/0008/742625/Energy-Essentials,-A-User-Guide-to-Hydrogen,-Energy-Institute-2020.pdf#Energy%20Essentials%20PDF

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BOILERS & BURNERS

Please mark your answers below by placing a cross in the box. Don't forget that some questions might have more than one correct answer. 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, return it to the address below. Photocopies are acceptable.

QUESTIONS

1) What would be the most sensible order of actions to improve the overall efficiency of a building's thermal energy needs?

- ☐ "(a) Tune" existing boiler, (b) buy new boiler, (c) attention to EE at end-uses, (d) distribution system
- ☐ (a) Attention to EE at end-uses, (b) distribution system, (c) "tune" existing boiler, (d) buy new boiler
- ☐ (a) "Tune" existing boiler, (b) attention to EE at end-uses, (c) distribution system, (d) buy new boiler
- ☐ (a) Attention to EE at end-uses, (b) "tune" existing boiler, (c) buy new boiler, (d) distribution system

2) What savings might one reasonably expect from paying attention to the thermal system away from the boiler?

☐ 5-10% ☐ 10-20% ☐ 20-30% ☐ 30-50%

3) Which of these in NOT a good reason for paying attention to the space-heating and HW requirements of a building?

- ☐ Makes energy cost and CO2 emission reporting easier
- ☐ Helps future proof the organisation against tightening low-carbon legislation
- ☐ Means any new boiler purchase in the future will be correctly sized for its needs
- ☐ Saves energy costs and reduces site CO2 emissions

4) Currently, which of these EPC rating are considered minimum for most new rentals?

☐ Rating = D ☐ Rating = E
☐ Rating = F ☐ Rating = G

5) Which of these in NOT an energy-saving action?

- ☐ Fixing a dripping hot-water tap
- ☐ Waste-heat recovery from exhaust air via a thermal wheel
- ☐ Waste water heat recovery from showers
- ☐ Solar thermal panels to pre-heat boiler water

6) Which of the following would help improve the energy performance of a building?

- ☐ Establishing a formal EnMS with boilers and HW/ space heating as a key centre
- ☐ Attention to the BEMS, ideally with maximum feedback and minimum staff interference
- ☐ Regular servicing and maintenance of the boiler and HW system
- ☐ All of the above

7) What is the CIBSE and Carbon Trust recommended "dead band" or zone where not building heating of cooling should take place?

☐ 18-25°C ☐ 20-24°C ☐ 19-21°C ☐ 20-22°C

8) Which of the following is a mandatory EE intervention?

- ☐ Flue gas dampers for when boiler is on stand-by
- ☐ Regular maintenance and tuning of the boiler
- ☐ Variable speed drive fans for the inlet air
- ☐ Installing an economiser to recapture heat from the exhaust gases

9) What is "green" hydrogen?

- ☐ Hydrogen from hydrolysis using electricity
- ☐ Hydrogen from hydrolysis using RE electricity
- ☐ Hydrogen from steam methane reforming
- ☐ Hydrogen from steam methane reforming + CCS

10)Which of these is least likely to be seen as a boiler in 2050?

- ☐ Hydrogen boilers burning "blue" hydrogen
- ☐ All electric boilers: either immersion or inline/ instantaneous
- ☐ Biomass boilers
- ☐ Local CCS for capturing the boiler's CO2 emissions

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Business ....

Business Address ....

....

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.... Post Code ....

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