Expert Report

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Planning fundamentals for optimum steam and heat generation

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Energy conservation and reduced emissions are not only political visions. Ultimately, they have also become the goal of every boiler operator for reasons of self-interest. With modern energy generation systems and effective waste heat recovery equipment, losses can be reduced to a minimum. However, dynamic influences are all too often disregarded. This article examines how the investment and running costs of steam and heat generators up to a capacity of 55 t/h or 38 MW/unit can be reduced for industry and municipalities.

Heat-up programmes instead of larger boilers

Careful calculation of heat/steam quantities is the cornerstone of any boiler optimization. Units which are dimensioned with greater capacity to cover infrequent start-up peaks are often uneconomical and environmentally-unfriendly during light load phases due to the frequent activation/deactivation of the firing equipment. By using consumption-based heat-up and start-up programmes with the ability to differentiate at certain times between priority and secondary consumers, it is possible to use a heat generator with less capacity. In this way, the control range for efficient utilization of the light load phases is also increased.

Separating production steam from building heating educes running costs

The heat consumer with the highest temperature/pressure level is decisive for the design pressure of the heat generator. As the design pressure increases, so does the cost of the overall system. Therefore, it is usually uneconomical to also cover the building heating with a production-oriented high-pressure steam generator. The low temperature level and the heating requirement outside production hours justify separate heat generation. Furthermore, there are cost savings for systems with a maximum temperature of 110 °C, since there are no requirements for supervision and monitoring. In certain circumstances, where there is a single consumer with a requirement for extremely high pressure and a comparatively low amount of heat, it may even make sense to allocate this consumer a dedicated steam generator.

An extremely low load calls for division of the overall output requirement

Besides security of supply, the spread between the smallest and largest heat consumption is another reason for dividing up the overall output requirement into several units. The smallest output requirement is often below the lowest load of a unit, so it makes sense to divide the output requirement on the basis of the lowest loads. Costly and environmentally-damaging activation and deactivation of the firing equipment and early wear-and-tear can be averted in this way. In large systems, the upper output limit of the heat generator determines the number of units. Dividing the total output requirement into structurally identical units is the optimum solution. Reduced spares inventories and the ability to swap parts are reason enough for this. An adapted low load unit should only be used if efficient operation with the smallest load cannot be fulfilled with the smallest unit calculated in this way.

Double-flame tube boilers are more cost effective when large outputs are required.

The output of a single-flame tube boiler is restricted by its structural possibilities and specifications. Bosch Industriekessel builds single-flame tube boilers up to capacities of approx. 19 MW or 28 t/h. When total outputs can no longer be met with one boiler, it is often more cost effective to use a double-flame tube boiler rather than several single-flame tube boilers. Lower installation, maintenance and testing costs are reason enough for this.

Double-flame tube boilers for independent operation of both firing units

Dynamic load matching for highly fluctuating consumption is required by most heat supply centers. Therefore, double-flame tube boilers, which are suitable and approved for unlimited independent burner operation, should be used. These double-flame tube boilers are not only equipped with separate flue gas ducts, but are also specifically constructed for 'single-flame tube operation' loading. The firing units are designed to be completely self-sufficient and can be operated independently or in parallel. With automatic activation and deactivation of the burners, depending on the heating needs with a sequence control circuit, a control range ranging from the low load of one burner to the maximum load of both burners is automatically available to each boiler unit. In this way, the

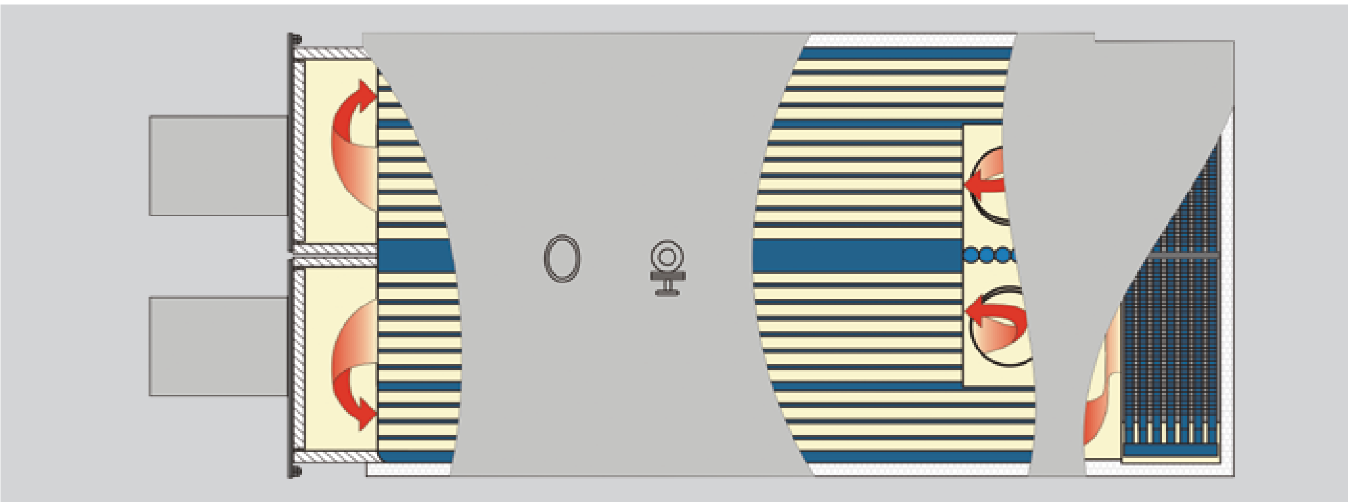


Figure 1: Three-pass double-flame smoke-tube boiler with separate flue gas ducts for independent burner operation and integrated economizer for heating feed water

modulating control range is doubled and the frequency with which the burner is activated during a light load is halved.
The non-stop supply of fuel over a large control range ensures the uninterrupted transfer of heat and continuous dynamic boiler water circulation. If there are faults with one firing unit, 50 % of the boiler capacity is still available (figure 1).

Finding the optimum boiler/burner combination increases customer benefits

A customer-oriented boiler manufacturer can offer various boiler/burner combinations for a given heat requirement. In order to find the boiler/burner combination with the greatest benefit for the customer, the alternatives must be examined. Two boiler types for a heat requirement of 1.800 kW, 90 /70 °C, natural gas heating, are compared in table 1.

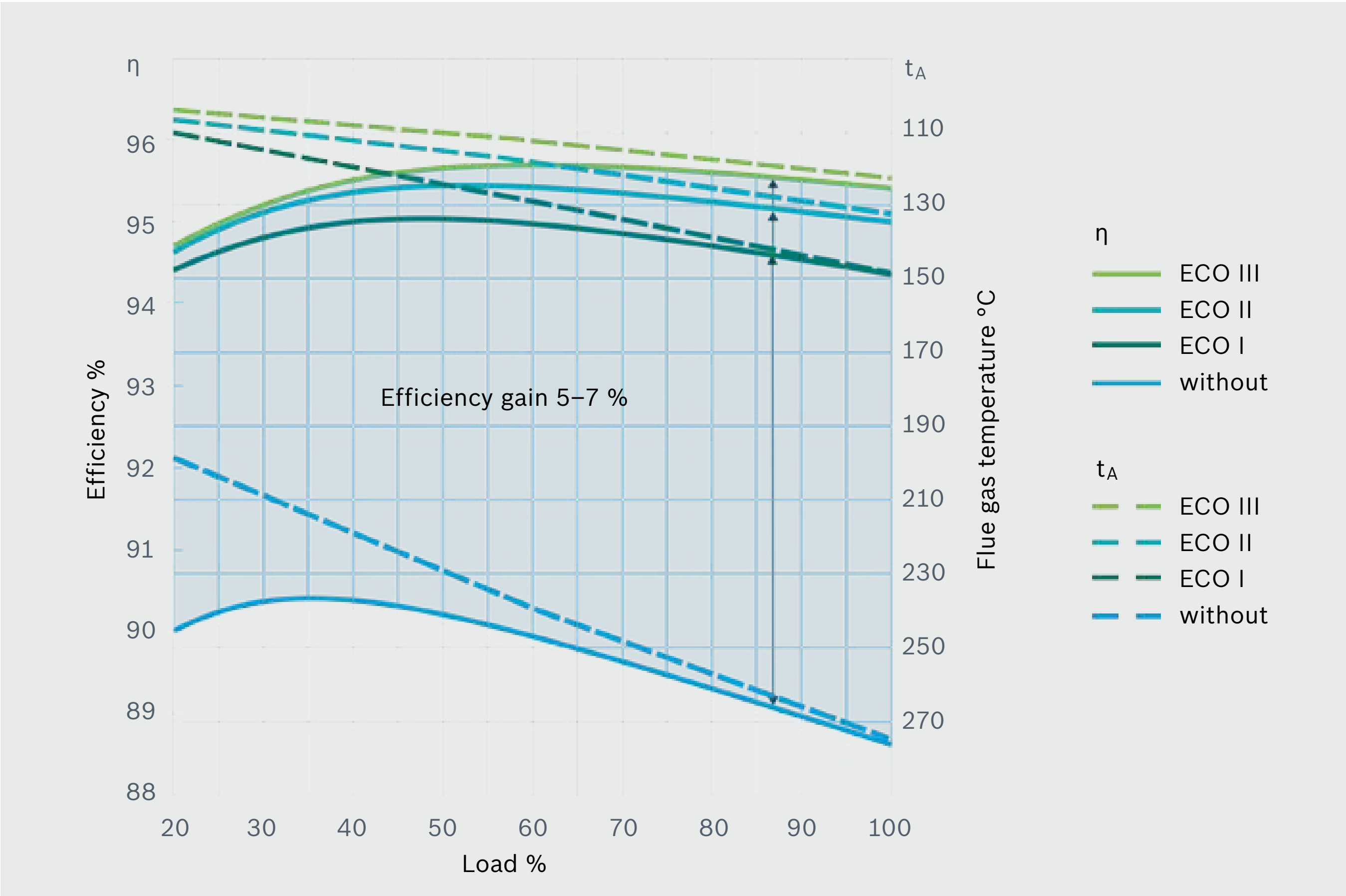
By using UT-L 16, the next largest boiler type with an upper thermal capacity limit of 2.000 kW, the customer can enjoy increased benefits due to the following:

- Use of a smaller burner
- Smaller burner motor connected load
- Larger burner control range
- Reduced activation frequency of the burner during light load phases
- Greater boiler efficiency
- Lower fuel consumption
- Lower harmful NO_X emissions in the flue gas
- Lower investment costs as the additional price for the boiler is compensated for by the lower burner price

Choosing the next largest boiler type does not always allow for the use of a smaller burner. Therefore, ways in which minor heat capacity reductions can be achieved, particularly with regard to distributing the overall heating capacity of multi-boiler systems into several units, should also be looked into.

Make money with flue gas heat exchangers

The use of a flue gas heat exchanger offers ideal ways to conserve energy and protect the environment.



Graphic 1: Achievable capacity optimisation from flue gas heat exchangers for „dry“ operation

Table 1: Comparison of two boiler/burner combinations		
Heating boiler/burner combination	**A**	**B**
Boiler type UT-L	14	16
Nominal output kW	1,800	1,800
Max. capacity kW	1,900	2,000
Boiler resistance mbar	7.5	5
Required burner type G	9	20
Burner motor kW	6.5	3
Burner control range	1 : 3.9	1 : 5.6
Boiler efficiency %	91.14	92.37
Amount of fuel m³/h	191	188
Spec. furnace loading MW/m³	1.77	1.08
NOx content in the flue gas mg/m³	150	130
Investment costs Boiler + burner %	100	93.2

Flue gas heat exchangers for 'dry' operation

Steam generators are usually supplied with fully deaerated feed water with a temperature of approx. 103 °C. The flue gas temperature at the boiler outlet depends on the boiler water temperature and the respective boiler load. In order to optimize output, the flue gas heat is fed through an economizer in the flue gas stream into the feed water.
In the case of the UNIVERSAL UL-S steam boiler (single-flame tube system up to 28 t/h)and the ZFR steam boiler (double-flame tube system up to 55 t/h) with integrated flue gas heat exchanger, the economizer is integrated into the thermally-insulated flue gas chamber and is pre-assembled ready-to-connect, provided this complies with the permitted transport dimensions. This removes the need for an additional foundation or on-site assembly. In the case of retrofits, the compact ECO-stand-alone flue gas heat exchanger can be set up and integrated directly behind the boiler.

The 'dry' mode of operation is suited to light fuel oil and natural gas, even in combination with chimneys susceptible to moisture. Passing below the dew point can be avoided by using a flue gas temperature regulator. Economizers with casings, flue gas channels and possible flue gas silencers can be designed in steel. Boiler efficiency levels of more than 95 % can be achieved with economizers in 'dry' operation (graphic 1).

High-pressure hot water generators for process or remote heating systems are usually operated at system return flow temperatures greater than 100 °C so that flue gas heat exchangers for 'dry' operation can also be used. In such cases, a partial flow from the return flow is usually fed via the flue gas heat exchanger. ECO systems for high-pressure hot water

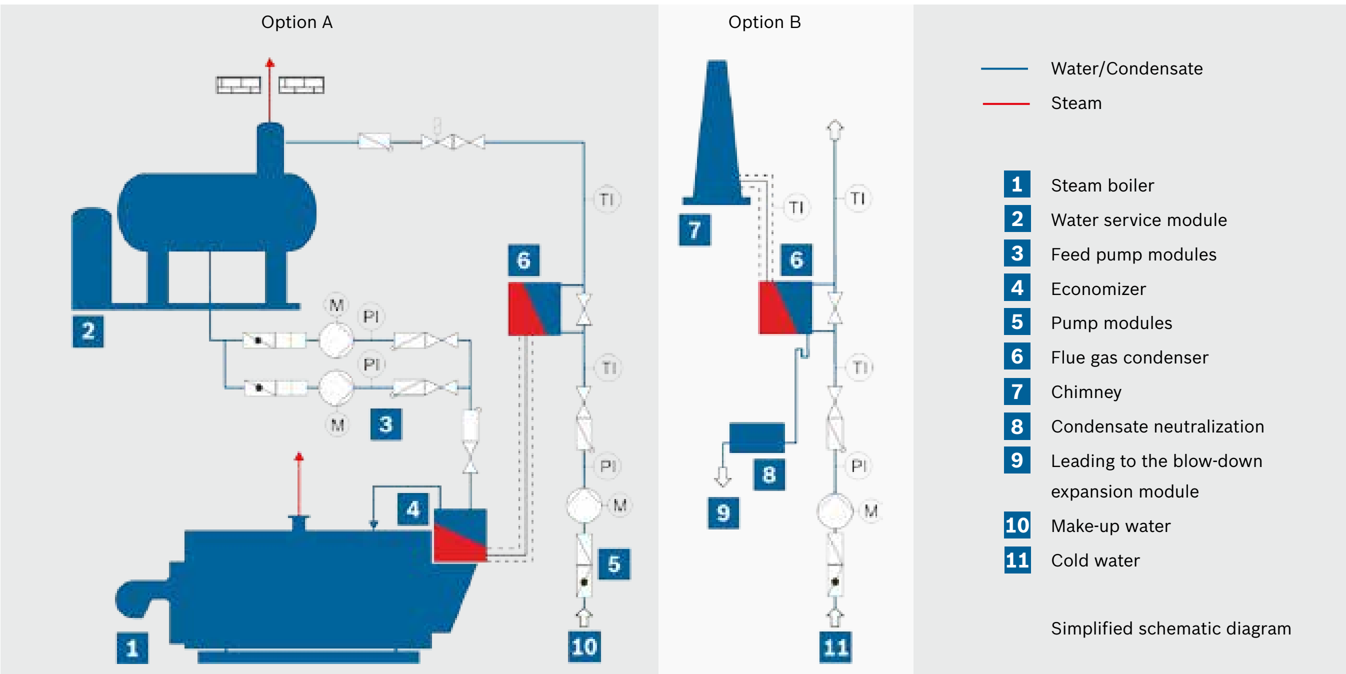


Figure 2: Steam generator with two-stage operation – economizer/flue gas condenser; capacity optimization of up to 15 % of the boiler capacity
Economizer: Boiler feed water preheater for 'dry' mode of operation
Flue gas condenser: Make-up/process water preheater for 'wet' mode of operation

generators are integrated into the flue gas chamber in new boilers and are available for set-up directly behind the boilers in the case of retrofits. They can be optionally equipped with water and/or flue gas-side temperature regulators to prevent passing below the dew point in the ECO and/or chimney.

Hot water generators for direct building heating are operated at the lowest temperature level possible. Depending on the boiler's supply and return flow temperatures and their spread, median boiler water temperatures of between 60–100 °C result. When boilers are operating efficiently, flue gas temperatures at the boiler outlet can reach 160–190 °C during full-load operation and 120–50 °C during low-load operation. Building heating boilers only operate at full output for a few days a year. The highest annual operating hours are in the medium to low load range.

The achievable boiler efficiency levels in these part-load ranges are already 93–94 %. A downstream flue gas heat exchanger for 'dry' operation can reduce the flue gas temperature downwards towards 75 °C and increase the efficiency further up to 98 %.

Flue gas heat exchangers for "wet" operation

Natural gas-heated heat generators produce flue gas free of soot and sulphur. Low sulphur fuel oil (sulphur content of max. 50 ppm = 0.005 weight percentage) which achieves a residue-free combustion similar to natural gas is now also available comprehensively. In the case of these flue gases, the condensation heat can also be used as heating output.

In industrial steam generators, a second stainless steel heat exchanger is used as a flue gas condenser in addition to the economizer in 'dry' operation for feed water heating. All flue gas ducts downstream of this are also made of stainless steel and equipped with corrosion-resistant condensate lines. Low-temperature consumers are a pre-requisite for flue gas condensation use.

Example: In heat-intensive production operations with direct steam consumers, without condensate return flow, the chemically treated make-up water can be heated up and/or process water generated or pre-heated (figure 2).

Flue gas condensation cannot be used for high-pressure hot water generators as the network return flow temperatures are well above the dew point.

Hot water generators with natural gas heating or heating with lowsulphur fuel oil can also be equipped with flue gas heat exchangers for 'wet' operation in order to optimise output (figure 3). Low-temperature heating circuits pass over stainless steel flue gas heat exchangers, bringing about the flue gas condensation.

Depending on the return flow temperature, boiler efficiency can be increased to more than 105 %, based on the net fuel calorific value (graphic 2). During selective heating with dual fuel gas/oil firing, the flue gas heat exchanger is equipped with a flue gas-side bypass and regulating flap to circumvent the heat exchanger with sulphurous oil.

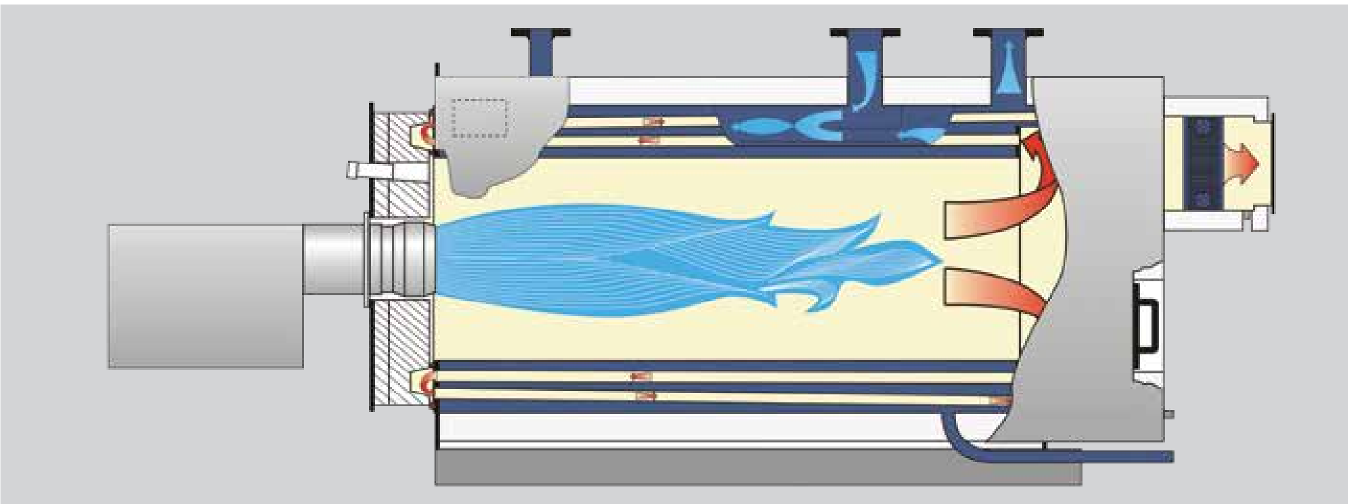
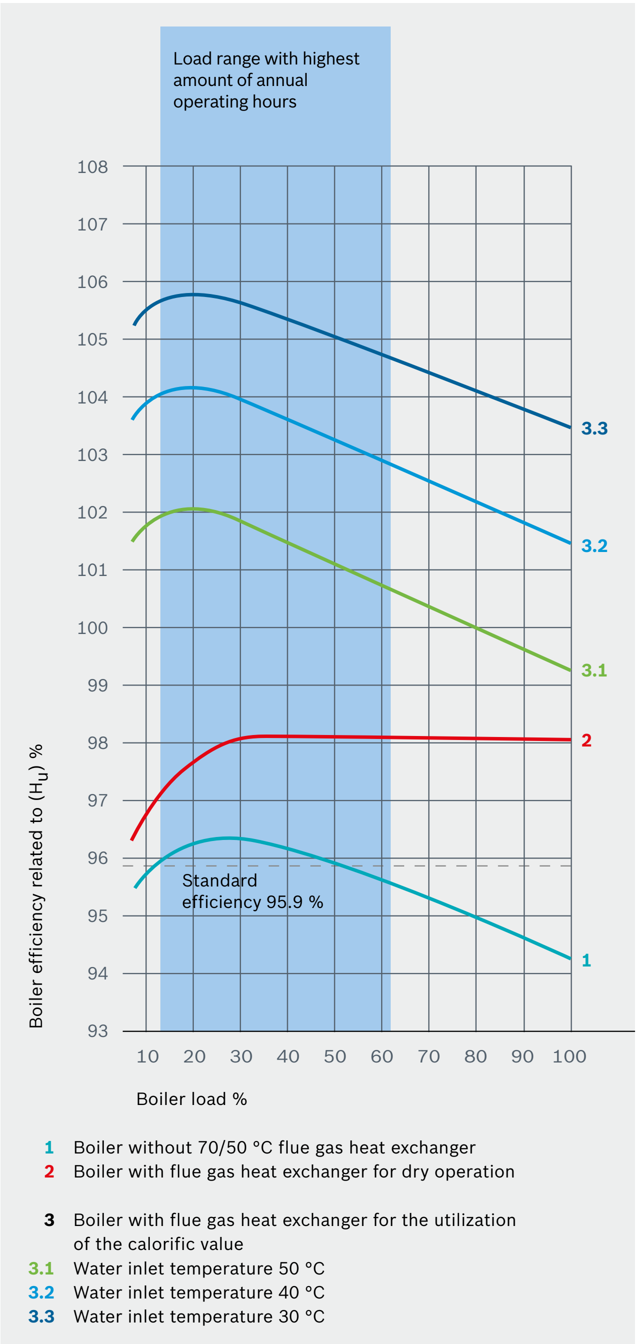


Figure 3: Single-flame smoke-tube hot water boiler designed according to the three-pass principle with flue gas heat exchanger

Condensate disposal

Taking the pH value as the acidity for liquids, flue gas condensate has a pH value of between 2.8 and 4.9 from the combustion of natural gas and a pH value of between 1.8 and 3.7 from the combustion of low-sulphur fuel oil. Condensate temperatures range from 25 °C to 55 °C. Filters with renewable dolomite filling for small systems and containers with dosing devices for caustic soda in the case of large-scale systems are used for the neutralisation. Given the right selection and dimensioning of the neutralisation equipment, it is possible to adhere to the permissible values for feeding into the public waste water networks. The inflow must be approved by the competent authorities.



Graphic 2: Efficiency graphs for UNIMAT hot water boilers with 70/50 °C boiler supply/return flows

Multi-boiler systems with optimised sequence control circuits

The design of multi-boiler systems provides ways in which overall efficiency can be increased and capacity optimized. A multi-boiler system for building heating is shown as an example. Compared with a single boiler system, increased demands are placed on the hydraulic and control circuitry.

Heating circuit control

Consumers require the best possible adjustment to the respective heating requirement with the greatest security of supply. Fluctuating heat quantities are best provided with constant volume streams and variable temperatures. Three-way mixers in the heating circuits for leading return flow water into the supply flow are used for this. The control of the heating circuit supply flow temperature, based on atmospheric conditions, affects the control elements of the three-way mixer and supplies the consumers with the heating temperature required at that moment for a sufficient amount of heat.

Boiler circuit control

Hot water boilers primarily require the maintenance of a minimum return flow temperature in order to avoid passing below the dew point. Three-way mixers to feed supply water into the return flow, for example, are used in hydraulic boiler circuits for this (return flow temperature maintenance). The heating quantity to be generated by one or more hot water boilers is increased or decreased depending on the external temperature, the system supply flow temperature and the system supply/return flow temperature spread.

If the heating quantity of the primary boiler is not sufficient, the boiler circuit pump and burner of the next boiler in the sequence are activated. The next boiler is initially heated-up in the boiler circuit to the minimum return flow temperature. Following this, heat is emitted via the three-way mixer into the system supply flow (figure 4). When less heat is required, the burner capacity is reduced. To avoid frequent activations, there is a time-delay on the activation and deactivation of the burners (stages).

Volumetric flows

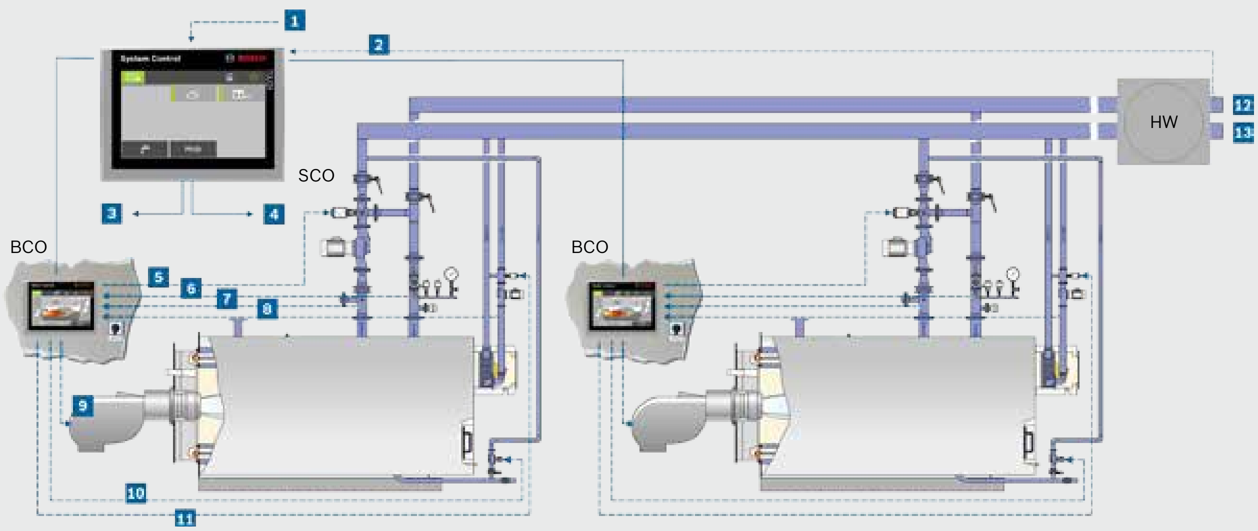
Different primary (through the boiler circuit control) and secondary (from the heating circuit control) volume flows, which can influence each another, result from the hydraulic circuitry of this multi-boiler system. When the primary and secondary sides are connected in a ‘fixed’ sequence, e.g. through heating circuit mixer inlets, the primary volume flow can go towards zero so that the requirement for a minimum volume stream for the hot water boiler and constant loading of the supply flow sensor for the boiler sequence cannot be met.

Hydraulic separator

One absolutely reliable way to solve this problem is to use a hydraulic separator. By doing so, the volume streams on the primary and secondary sides can be completely decoupled hydraulically and a counteracting influence ruled out. By aligning the common supply flow sensor at the secondary outlet, sensor loading with the first heat requirement is ensured. Boilers that are not operating are hydraulically locked as per the German Regulation on Heating Systems (Heizanlagenverordnung). Each boiler is loaded with a roughly constant volume flow. The boiler circuit pumps should be divided up according to the nominal outputs of the hot water boilers. Their overall feed rate should be at least 1.1 times and max. 1.5 times the overall heating circuit volume flow.

Control

A powerful control system is required if a multi-boiler system is to function reliably and for there to be the possibility of optimization. Besides carrying out the appropriate control tasks, the lowest possible energy consumption with the best possible environmental protection should be achieved. The control system should be in a position to manage the boiler system according to the atmospheric conditions in a sequence control circuit (regulated to the network supply flow temperature or depending on the heat quantities). The respective boiler circuit control should monitor the hot water boiler as well as control, activate and deactivate the burners and boiler circuit pumps. There is constant data exchange from the individual Boiler Control (BCO) boiler control systems to the superordinate System Control (SCO) management system via a common bus system so that the system can be automatically operated to meet the highest requirement.



1 Ambient temperature
2 System supply flow temperature for boiler sequence control
3 Remote access
4 Central control and communication system
5 Return temperature fusing
6 Flow temperature
7 Return temperature
8 ECO/inlet temperature
9 Output control
10 Heat maintenance system
11 ECO/outlet temperature controller
12 Supply flow
13 Return flow

Figure 4: Hot water boiler system with hydraulic separator controlled on the basis of atmospheric conditions

Summary

Output optimization begins with systematic logging of the output parameters of heating quantity, pressure and temperature. The peak and light load requirements are significant. Output is distributed across several boiler units with adapted outputs in line with these. The issue of separating production and thermal heating is crucial.

In the case of large outputs, the use of double-flame smoke-tube boilers for the independent operation of both firing units has optimization benefits. The boiler and burner should be considered a functional unit so that the boiler manufacturer can determine the optimal boiler/burner combination based on needs. Depending on the fuels available, different flue gas heat recovery systems can be used.

The greatest output optimization is achieved by fully utilizing flue gas condensation. Multi-boiler systems also offer various possibilities for output optimisation through the use of programmable controllers. Hot water boilers can be operated at the best efficiency based on atmospheric conditions if hydraulic circuitry is chosen accordingly.

There is a multitude of ways in which plant designers can optimize the output of heat generation systems. There should be detailed individual consideration of different alternatives with material and energy balancing.

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