BOA-Systronic

KSB

Contents

Intelligent pump and valve management saves energy

The new BOA-Systronic system solution improves the supply temperature control of heating circuits. It opens up a previously unused potential for saving electrical energy used by the circulator pump.

1
Heating circuit

Every heating circuit consists of several control components such as the circulator pump and the control valve, which are connected by pipes. The circulator pump conveys the heating water from the heat generator (boiler) to the consumer installations, and the control valve adjusts the volume flow rate pumped through the consumer installations. Conventional heating set-ups can be characterized as follows:

THE CONTROL COMPONENTS IN CONVENTIONAL HEATING SYSTEMS ARE NOT COORDINATED

- The circulator pump and the control valve fitted in conventional, mixing or injection-type systems operate independently, without coordination between the two components. There is no system knowledge about the hydraulic conditions in the heating circuit, so that some of the hydraulic energy supplied by the circulator pump may actually be destroyed by valves and differential pressure control elements elsewhere in the heating circuit.
- Mixing or injection-type systems produce a *constant volume flow rate through the consumer installations*[1]. As a result, part-load conditions – which account for more than 95% of the operating period – result in the circulator pump handling predominantly cold return water most of the time.
- In a mixing or injection-type system, the discharge head of the variable-speed circulator pump remains constant, irrespective of the actual load conditions, i.e. irrespective of external temperature. Only external heat gains will result in energy savings, depending on the set pump characteristic curve (Δp = constant or Δp = variable).
- If several heating circuits of a mixing or injection-type system branch off a main feed circuit, they must be balanced manually.

[1] *Constant volume flow rate through consumer installations: results from the hydraulic configuration of the main feed circuit (e.g. 3-way mixing valve). Whether the system is operating under nominal load or part-load conditions, the circulator pump will always deliver the nominal volume flow rate calculated for the design point. Only when external heat is acting on the consumer installations will the level of this volume flow rate be adjusted by the control function of the thermostats.*

2
System concept

An analysis of this situation resulted in the BOA-Systronic system concept, which has the clearly defined benefit of reducing the running costs of the heating circuit.

SAVINGS POTENTIAL BY SYSTEM CONCEPT

BOA-Systronic coordinates the operation of circulator pump and control valve. Depending on the control signal issued by the higher-level heating controller the two BOA-CVE SuperCompact control valves adjust the resulting volume flow rate pumped through the consumer installations. At the same time, the appropriate discharge head setpoint is transmitted to the variable-speed drive of the circulator pump.

BOA-Systronic transforms the conventional, constant-flow mixing or injection-type system into a variable-flow system, and adjusts the discharge head of the circulator pump to the reduced volume flow rates via the system control curve.
The radiator diagram illustrates the physical fact that – at identical heat output – the volume flow rates provided to the consumer installations can be reduced if the supply temperature is increased at the same time.

The supply temperature is increased by the higher-level controller. This results in hydraulic savings regarding both volume flow rate ΔQ and discharge head ΔH, whose product is proportional to the corresponding *electrical power savings for the circulator pump*[2].

A positive side effect is that static hydraulic balancing at the main feed manifold is now automatically performed via the circulator pump, which reduces commissioning costs for the heating circuit. When the heating circuit of a conventional mixing or injection-type system is commissioned, the temperature difference between supply and return (temperature differential) is set for the design point using the balancing valve, usu-

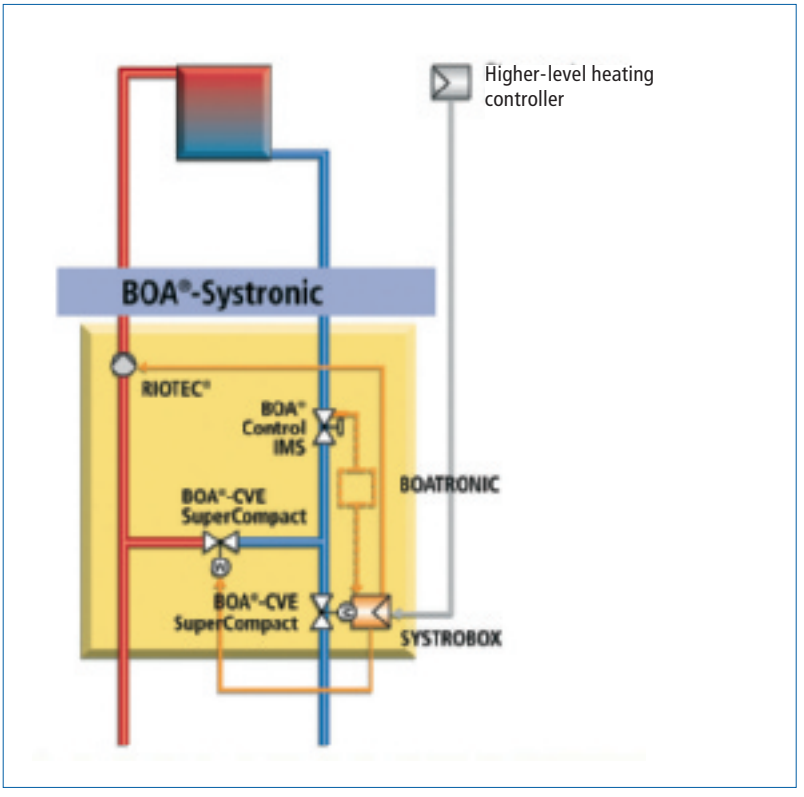

Fig. 01 Hydraulics schematics of BOA-Systronic

[2] *Electrical power input of circulator pump:* $P_{electr.} = constant \cdot \int_{t1}^{t2} Q(t) \cdot H(t)dt.$

The constant describes the efficiency of circulator pump and frequency inverter as well as water density and acceleration due to gravity.

ally by throttling this valve. The pressure drop across the valve may amount to several tenths of bar. With BOA-Systronic, this step is dispensed with.
As BOA-Systronic produces only the discharge head actually required to overcome system resistance, flow noises are prevented, even with external heat input, and expensive differential pressure control elements are not required for balancing the heating circuits. For hydraulic balancing of branch circuits, they can even be replaced by more cost-effective balancing valves. Variable volume flow rate control by BOA-Systronic has no influence on the hydraulic balancing of the branch circuits, which is performed for the design point.

KNOWLEDGE ABOUT PIPING CHARACTERISTIC OF HEATING CIRCUIT

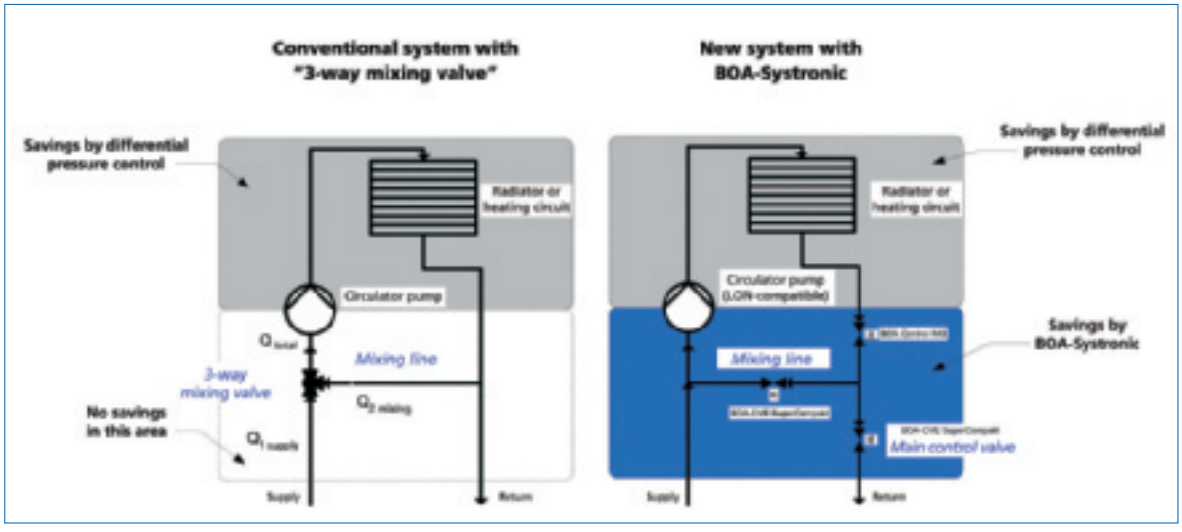

Fig. 02 Comparison of systems

Conclusion

The savings realised by BOA-Systronic result from knowledge about the hydraulic conditions in the heating circuit. They are completely independent from differential pressure control of the circulator pump. With BOA-Systronic, differential pressure control of the circulator pump is effected as before.

3
Components

The transformation into a system with variable volume flow presupposes that the partial volume flows are hydraulically decoupled and that information about the flow rates required in the heating circuit is available. For this reason, BOA-Systronic comprises three valves. The two BOA-CVE SuperCompact control valves are used for adjusting volume flow through the consumer installations depending on the actual load (external temperature).
The control unit is mounted on the main control valve at the factory. The *BOA-Control IMS*[4] valve is used here to measure the volume flow rate at the main feed manifold during commissioning. This measuring signal is used to determine the discharge head of the circulator pump for the design point as well as the system control curve and thus the hydraulic resistance of the heating circuit. The measuring valve remains fully open both during commissioning and over the entire operating range and – due to its very low ζ-coefficient – acts just like a piece of pipe. The measuring computer is not included in the system scope of supply.

Fig. 03 BOA-Systronic components

[3] *BOA-CVE SuperCompact: Automated shut-off and control valve for HVAC applications with smart electric actuator. The valve is produced in nominal sizes from DN20 to DN150 and nominal pressure class PN6/10/16. Thanks to its compact design, it is the smallest and lightest valve of this pressure class manufactured in series production today, enabling the space-saving design of air-conditioning and heating centrals. Due to its low weight, the valve is easy to install and handle. The self-calibration feature of the actuator is another benefit, which does away with the adjustment of limit switches.*

[4] *BOA-Control IMS: The valve measures volume flow rates independently from valve travel positions and minimum differential pressures. Unlike on conventional valve models, the measurement accuracy is constant across the entire valve travel. The measuring signal is read and processed by a measuring computer. Valves of this kind are often insulated, and any identification on their bodies may be difficult to read. After start-up, the computer display therefore first shows the nominal diameter of the connected valve. The operator can then choose via two keys whether the current flow rate is to be indicated [in m³/h] or the temperature of the fluid handled [in C°]. Volume flow rates can be checked within a matter of seconds in this way. BOA-Control IMS, which has a linear characteristic, can also be used as shut-off valve. Thanks to a travel stop with a protective cap, the valve can be set exactly to its original position once the shut-off process has been completed.*

[5] *ζ-coefficient: describes the resistance a valve offers to the fluid passing through it. The ζ-coefficient depends on the valve type and design.*

4
Control

BOA-Systronic is a control system which is installed downstream of the heating system's control unit. It does not replace the higher-level controller.

HIGHER-LEVEL CONTROLLER IS RETAINED

Supply temperature control remains the task of the higher-level controller. Input signals for this controller are, among others, the external temperature measured and the supply temperature measured in the heating circuit. With the help of the heating curve stored in the higher-level control unit, the setpoint for the supply temperature of the heating circuit is generated on the basis of the external temperature measured. Based on this setpoint and the supply temperature measured, the higher-level controller generates the control error signal, which is the input of the (PI or PID) control algorithm. This control algorithm generates a signal, which – in conventional mixing / injection-type systems – is then transmitted to the control valve.
This output control signal from the higher-level controller is the input for BOA-Systronic, i.e. it is transmitted to the Systrobox control unit. With the help of the system control curves determined during commissioning, Systrobox translates the control signal into two separate control signals for the two *BOA-CVE SuperCompact* control valves and into a discharge head setpoint for the circulator pump.

5 Volume flow rates

Thermal output of the heating circuit is calculated for the design point as the product of volume flow rate Q and temperature differential ΔT.

$$P_{th} = 1.163 \cdot Q \cdot \Delta T$$

Conventional systems

Owing to their hydraulic configuration, conventional *mixing or injection-type systems*[6] can provide the consumer installations only with a constant volume flow rate, irrespective of the heating controller's signal. The volume flow in the supply line is coupled with the volume flow of the cold return water pumped through the mixing line (Fig. 04).

$$Q_{total} = Q_{1supply} + Q_{2mixing}$$

So thermal output of the heating circuit can only be regulated via the temperature differential in conventional mixing / injection-type systems. **As a result, predominantly cold return water is pumped through the heating circuit under part-load conditions.**
The volume flow rate through the heating circuit is only reduced by the regulating function of the thermostatic valves (external heat load compensation).

BOA-Systronic

The innovative control concept of BOA-Systronic regulates thermal output by **variation of the temperature differential and the volume flow rate**, considerably reducing the water volume to be pumped through the heating circuit. This is possible because the two BOA-CVE *SuperCompact* control valves decouple the volume of heating water coming from the supply line from the volume of cold return water pumped through the mixing line.
The main control valve installed in the supply or return line regulates the volume of heating water, whereas the control valve in the mixing line adjusts the volume of cold return water to be mixed in. The additional optimizing effect of external heat load compensation by the thermostatic valves remains unaffected.
The radiator diagram illustrates that volume flow rate can be reduced while thermal output at the consumer installations stays the same, if the supply temperature is increased accordingly. Two methods can be used, which can be realized by making use of a standard function offered by the heating controller.

Parallel shift of heating curve

The controller's heating curve is shifted parallel by a fixed amount towards higher supply temperatures. The controller adds the fixed amount ΔT to the supply temperature setpoint (parallel shift of the heating curve). Due to the increased temperature differential, the

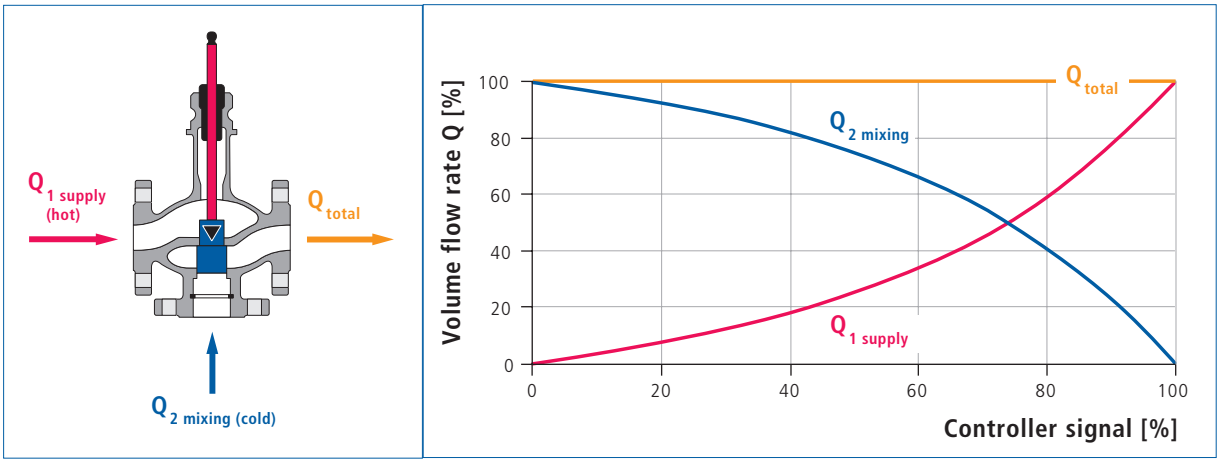

Fig. 04 Volume flow rates of 3-way valve

[6] *3-way configuration: In a 3-way mixing valve, the fluids to be mixed enter the valve via two input ports and the sum of their flow exits through a single output port. The ratio between the flow rates through both inlet ports is determined by the stem position. The sum of the throttling cross-sections on both inlet ports is constant over the entire valve travel. The valve therefore provides a constant volume flow at its outlet port, independent of stem position.*

nominal volume flow rate is reduced by 25% in all cases, resulting in a new design point for the circulator pump (Fig. 05)

INCREASED SUPPLY TEMPERATURE BY PARALLEL SHIFT OR SLOPE MODIFICATION OF HEATING CURVE

Thanks to the new design point, investment costs for the circulator pump and the valves in the heating circuit can be reduced considerably.

- Normally, a circulator pump with a lower output rating can be selected
  Benefit: Substantially reduced investment costs for the circulator pump
- The nominal diameter of the heating circuit can usually be chosen one nominal diameter smaller.
  Benefit: Reduced investment costs for piping, shut-off valves and strainers, including insulation.

In principle, this new design point can also be achieved with a conventional hydraulic configuration. However, BOA-Systronic offers a number of benefits.

- The consultant can size the consumer installations of the heating circuit as usual
- The consultant can use the benefits offered by BOA-Systronic without changing his planning
- The consultant saves planning work and thus time and costs

Slope modification of heating curve

The controller' s heating curve is shifted towards higher supply temperatures only if the system is running under part-load conditions. Depending on the value of the control signal, the controller internally adds an amount ΔT to the supply temperature setpoint (slope modification of heating curve). The nominal volume flow rate and thus the design point of the circulator pump remain unchanged. In this case, the investment costs for the circulator pump and the other valves cannot be reduced.

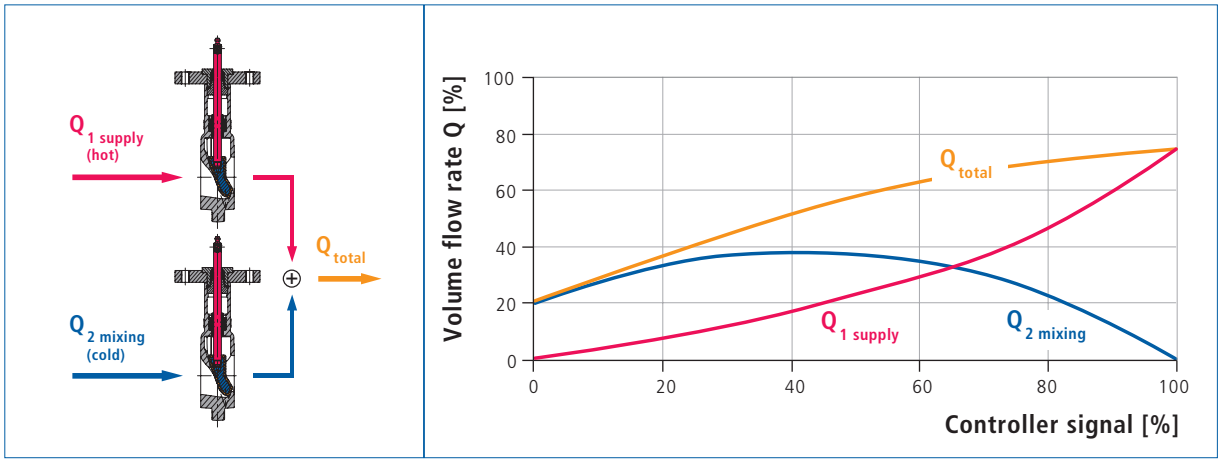

Fig. 05 Reduced volume flow rates of BOA-Systronic

6 Circulator pump heads

Owing to the hydraulic configuration of conventional mixing or injection-type systems, the circulator pump head cannot be matched to the **system control curve**. The circulator pump can only **react** to reduced volume flow rates resulting from the control function of the thermostatic valves at the consumer installations. Depending on the pump curve selected, the discharge head either remains constant (Δp = constant) or is reduced accordingly (Δp = variable).

BOA-SYSTRONIC CONTROLS THE PUMP AS A FUNCTION OF THE SYSTEM CURVE OF THE HEATING CIRCUIT

BOA-Systronic, by means of the two control valves, adjusts the volume flow rate as a function of external temperature and measures the **system curve of the heating circuit** during commissioning. As a result, the circulator's discharge head can be matched to the volume flow rate to be pumped. This is done by means of the **system control curve** (Fig. 6). The system control curve is automatically determined by measuring the volume flow rate during commissioning; it is limited by the minimum discharge head of the circulator pump. The *BOA-Control IMS* valve measures the volume flow rate in the heating circuit and thus determines the required nominal discharge head of the circulator at the design point. The values obtained are then used to determine the system constant of the heating circuit. As a result, the hydraulic resistance of the heating circuit is known, and the control unit knows the circulator head required for the individual load conditions.

The H/Q diagram on page 11 shows an **example** of the possible discharge heads of a differential pressure controlled pump. The diagram shows the H/Q data of a pump controlled independently of throughflow (Δp = constant) and offers a comparison between a conventional system and a system equipped with BOA-Systronic.

The design point is represented by the intersection of the system curve of the heating circuit with the characteristic curve of the circulator pump.

The system curve describes the resistance the volume flow has to overcome, and corresponds to the discharge head required of the circulator pump. It depends on the length and nominal diameter of the supply and return lines in the heating circuit, the pressure losses in the consumer installations, balancing valves, differential pressure control elements, strainers as well as thermostatic and shut-off valves.
The volume flow rate and discharge head are shown in normalized representation here.
The circulator pump of a mixing or injection-type system can only respond to reduced volume flow rates (external heat gain) with a constant discharge head, thus saving a certain amount of energy.

NEW DESIGN POINT FOR THE PUMP

With BOA-Systronic, parallel shift of the heating curve results in the new nominal volume flow rate

$$Q_{new} = 0.75 \cdot Q_{old}$$

and, by application of the affinity law, yields the associated discharge head of the circulator pump:
(see equation below)

$$H_{new} = H_{old} \cdot \left(\frac{Q_{new}}{Q_{old}}\right)^2 = 100\% \cdot \left(\frac{75\%}{100\%}\right)^2 \cdot H_{old} = 0.56 \cdot H_{old}$$

The valve authority of the main control valve must then be added to this value. It describes the pressure drop at the control valve, in relation to the differential pressure to be produced by the pump (overall pressure drop in the system). With BOA-

Systronic, valve authority is constant over the entire operating range. This correlation is reflected in the system control curve and explains why the system control curve runs parallel to the system curve, at a slightly higher level (Fig. 6)

In our example, a new design point is established for the circulator pump: the nominal volume flow rate is reduced by 25%, and the nominal discharge head of the circulator pump is reduced accordingly. As a result, a circulator pump with a lower performance rating can be selected.

Depending on the external temperature, the operating point of the BOA-Systronic controlled circulator pump moves along the system control curve. As external temperature rises, the operating point moves towards lower volume flow rates and lower discharge heads.

ALL FEATURES OF THE VARIABLE SPEED PUMP ARE RETAINED

The diagram also illustrates the effect the control function of the thermostatic valves has on various operating points (external heat load). Under the influence of external heat load, the operating point also moves along the characteristic curve of the differential pressure controlled pump. Depending on the pump curve set, the discharge head either remains constant (Δp=constant) or decreases with decreasing volume flow rate (Δp=variable). All the familiar features of the variable-speed pump and the thermostatic valves are retained.

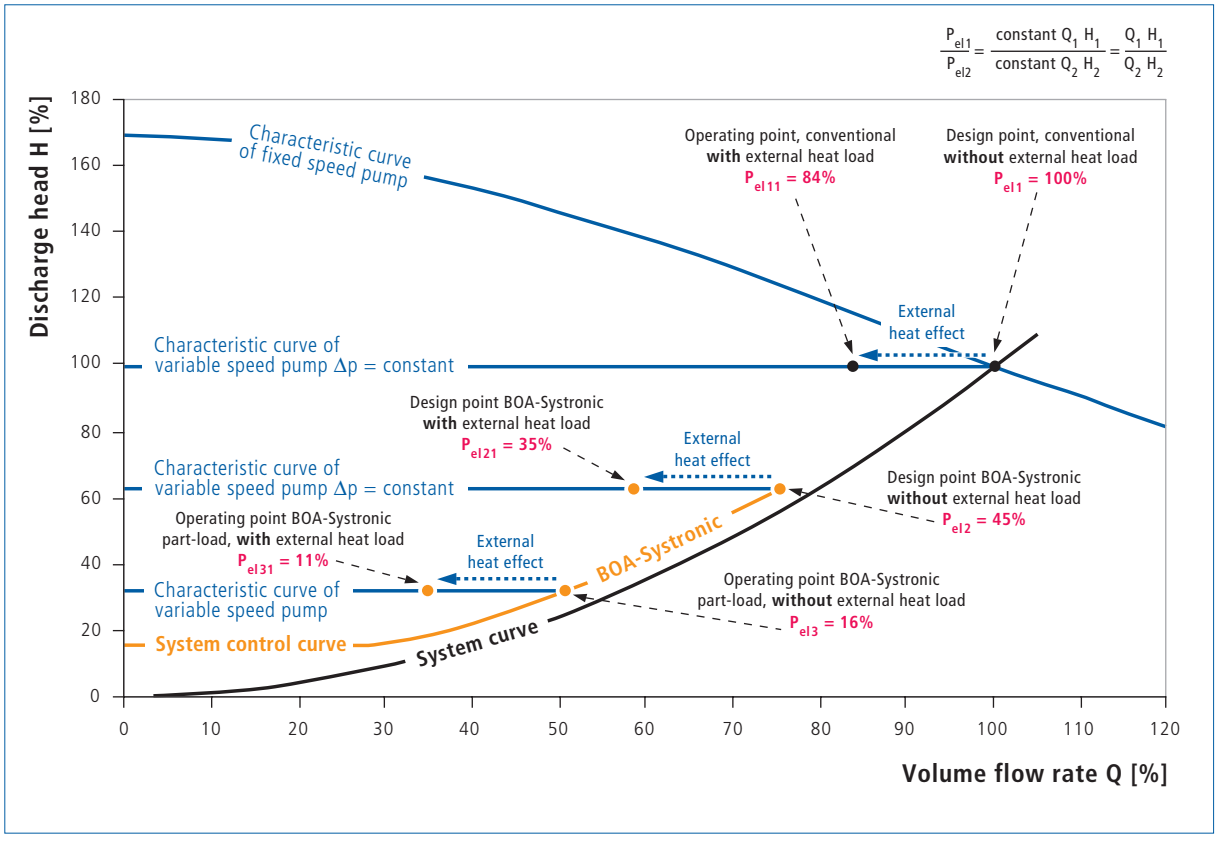

Fig. 06 Circulator pump heads (example)

7 Hydraulic balancing of branch circuits

BOA-Systronic operates the heating circuit with variable volume flow rates. The question therefore arises whether the branch circuits are hydraulically balanced for these variable operating points.

The branch circuits are hydraulically balanced for the design point (nominal load). This ensures adequate heat supply to the consumer installations in the individual branch circuits. In the following, the nominal load case is indexed $_N$, whereas the part-load case is indexed $_T$.

The following is to show that variable volume flow control by BOA-Systronic has no influence on branch circuit balancing.

The volume flow rates in branch circuits 1, 2 and 3 are adjusted by means of balancing valves BV1, BV2 and BV3. What is of interest is the ratio of the pressure drops at the balancing valves at nominal load

(e.g. $\frac{\Delta p_{N2}}{\Delta p_{N1}}$) and

part load (e.g. $\frac{\Delta p_{T2}}{\Delta p_{T1}}$).

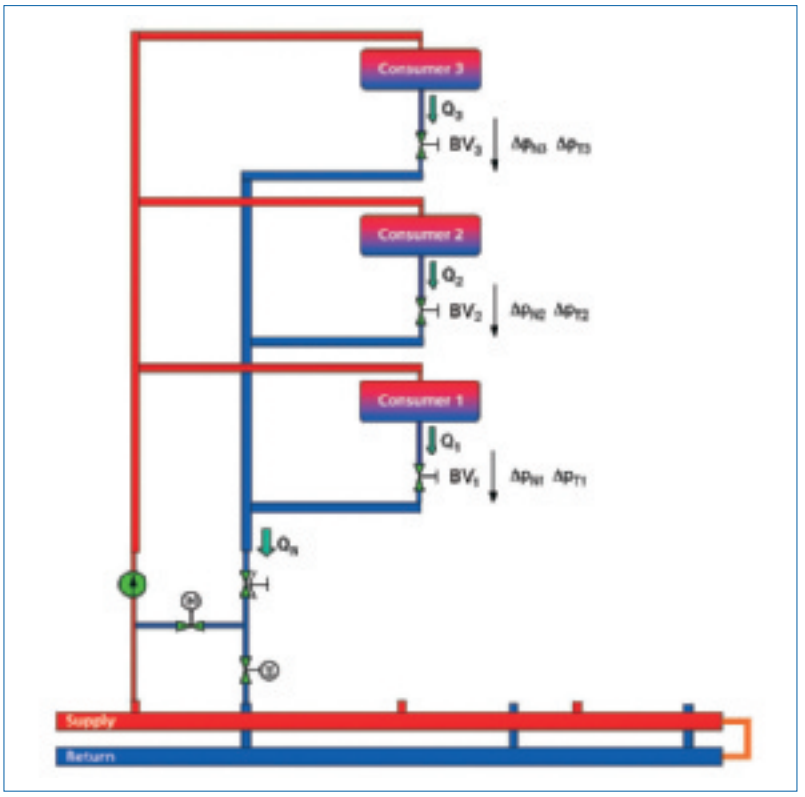

Fig. 07 Heating circuit with branch circuits

At the design point (nominal load), the differential pressure at the balancing valve of the branch circuit drops as follows:

Differential pressure at nominal load:

$$\Delta p_N = \frac{1}{2} \cdot \rho \cdot \zeta \cdot w^2 = \frac{1}{2} \cdot \rho \cdot \zeta \cdot \left(\frac{Q_N}{A}\right)^2$$

Equation 1

where ρ is the water density, ζ is the valve's zeta coefficient, w is the flow velocity of the water, A is the flow cross-section at the throttling point, and Q_N is the volume flow rate at design point.

Hydraulic balancing of the branch circuit is performed for the design point (nominal load). After that, the throttling position of the balancing valve remains unchanged. The pressure drop at the valve then only depends on the volume flow rate (Q).

The opening cross-section (A) and the zeta coefficient (ζ) of the valve remain unchanged.

$$\frac{1}{2} \cdot \rho \cdot \zeta \cdot \left(\frac{1}{A}\right)^2 = \text{constant} = c$$

Equation 2

Differential pressure at the balancing valve therefore only depends on a factor (c) which describes the valve and the volume flow rate (Q):

Differential pressure at nominal load:

$$\Delta p_N = c \cdot Q^2_N$$

Equation 3

Under part-load conditions, the differential pressure at the balancing valve (BV) is reduced as follows:

Differential pressure at parl load:

$$\Delta p_T = c \cdot (F \cdot Q_N)^2$$

Equation 4

where factor F describes the part-load level (0-100)%. Inserting equation 3 in equation 4 yields

$$\Delta p_T = F^2 \cdot \Delta p_N$$

Equation 5

resulting in the following differential pressures at nominal and part-load for branch circuits 1, 2 and 3:

Differential pressure BV1

$$\Delta p_{T1} = F^2 \cdot \Delta p_{N1}$$

Equation 6

Differential pressure BV2

$$\Delta p_{T2} = F^2 \cdot \Delta p_{N2}$$

Equation 7

Differential pressure BV3

$$\Delta p_{T3} = F^2 \cdot \Delta p_{N3}$$

Equation 8

Therefore, the ratios of these differential pressures are as follows:

$$\frac{\Delta p_{T2}}{\Delta p_{T1}} = \frac{\Delta p_{N2}}{\Delta p_{N1}}$$

Equation 9

Conclusion

The same law governing differential pressures in the branch circuits can be established for part load conditions as for nominal load conditions. It is therefore ensured that the branch circuits are actually supplied with the necessary volume flow rate for the thermal output required.

8 Differential pressure control elements

If external heat is acting on a room – sunlight, for instance – the thermostatic valves will reduce the volume flows passing through the radiators in this room. If volume flow rates are reduced, the circulator pump of a conventional heating system will either be operated with a constant or variable discharge head, depending on the set pump curve. The reduced volume flow rate will result in a reduced pressure drop in the piping. The excess differential pressure produced by the circulator pump can only drop at the thermostatic valve, which causes considerable flow noise or whistling. Differential pressure control elements are often used to prevent this. Their function limits the increase in differential pressure across the thermostatic valve, thus preventing flow noise. In conventional systems, therefore, part of the discharge head provided by the circulator pump is immediately reduced by the differential pressure control valve in many cases! By way of example, the H/Q diagram in fig. 08 compares the influence of external heat gain on the operating behaviour of a fixed speed circulator pump, a differential pressure controlled circulator pump of a mixing or injection-type system, and a differential pressure controlled pump controlled by BOA-Systronic. The diagram shows that the BOA-Systronic controlled pump generates only little excess differential pressure, which drops at the thermostatic valve.

NO DIFFERENTIAL PRESSURE CONTROL ELEMENTS REQUIRED

This differential pressure results from the hydraulic resistance of the heating circuit and the discharge head of the circulator pump controlled by BOA-Systronic. The differential pressure controlled pump of a mixing or injection-type system, by contrast, produces a much higher excess discharge head at the thermostatic valve (Δp_2), as does the fixed speed pump (Δp_1).

Conclusion

BOA-Systronic provides the circulator pump with the discharge head required for the actual load conditions. No excess discharge heads are produced under part load conditions, nor flow noises at the consumers. Expensive differential pressure control elements for balancing the heating circuits can be dispensed with. For hydraulic balancing of branch circuits, they can even be replaced by lower priced balancing valves.

9 Commissioning

If parallel shift of the heating curve is planned, BOA-Systronic will always reduce the volume flow rate for the design point by 25 %, based on the volume flow rate the system designer has calculated for a conventional mixing or injection-type system. BOA-Systronic has to be configured prior to commissioning. This is done by entering the value of the volume flow rate determined for a conventional mixing or injection-type system into the commissioning software, together with the nominal system diameter of BOA-Systronic (parameterization). The nominal diameter of the *BOA-Control IMS* measurement valve corresponds to this nominal system diameter. BOA-Systronic automatically determines the circulator's discharge head required for the design point. To do so, the circulator pump is started up with its minimum discharge head. A corresponding volume flow rate is produced in the heating circuit, which is measured by the *BOA-Control IMS* valve at the main feed manifold. The *BOATRONIC M-420* measuring computer converts this measured value into an analog (4-20)mA current signal and transmits it to the *Systrobox* control unit, where it is compared against the value for the (new) nominal volume flow rate. The circulator's discharge head is increased step by step, until the difference between setpoint and measured value falls below a certain limit. When this procedure has been completed, the system knows the circulator's discharge head for the design point and the system constant of the heating circuit, and thus its system curve. Therefore, the correlation between discharge head and volume flow rate for the heating circuit is known.

BOA-SYSTRONIC AUTOMATICALLY DETERMINES THE OPTIMUM PUMP HEAD

With the data stored for the volume flow rate at part load conditions, BOA-Systronic then generates the system control curve as well as the two valve control curves.

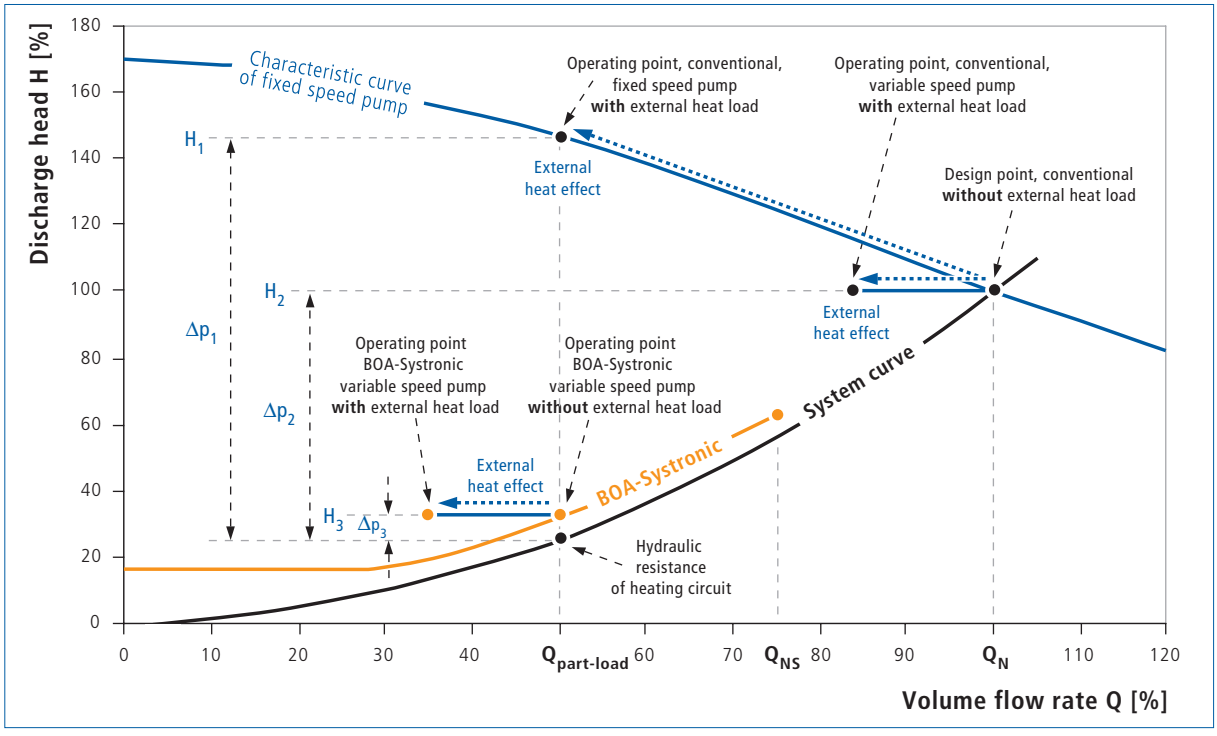

Fig. 08 Excess circulator pump heads (example)

Q_N Design point of heating circuit with 3-way valve
$Q_{N\ Sys}$ Design point of heating circuit with BOA-Systronic
Q_T Part load condition (example)

Δp1 Differential pressure at thermostatic valve (fixed speed pump)
Δp2 Differential pressure at thermostatic valve (variable speed pump Δp=const.)
Δp3 Differential pressure at thermostatic valve (BOA-Systronic)

10 Practical testing

10.1 Plant

BOA-Systronic has been in use in the office building of DeTe-Immobilien in Heidelberg, Germany, since 2001. The heating water is produced in a two-boiler system with a thermal output of approx. 2 MW. Each boiler is equipped with a 2-stage burner. The main feed manifold is connected directly to the boilers (without hydraulic separator) and feeds 4 heating circuits plus several other hot water circuits. Four heating controllers control supply temperature in the four building sections. The controllers are fitted in a separate control cabinet in the plant room.

FOUR HEATING CIRCUITS HEAT THE BUILDING

BOA-Systronic supplies heat to the West wing of the building. The East wing is equipped with a conventional mixing system. Both building sections require the same heat output. The "Stat. Heizung West" heating controller transmits its control signal (for the control valve) to the control unit of BOA-Systronic, where it is converted into the load-dependent discharge head setpoint for the circulator pump and two separate control signals for the two control valves. In both building sections, any disturbances in room temperature (external heat gain) are re-adjusted by means of the radiators' thermostatic valves. Both circulator pumps are differential pressure controlled (Δp = constant). Table 01 demonstrates the benefits of BOA-Systronic by comparing the performance data of the two heating circuits.

Fig. 09 Two-boiler system

CONTROLLER TRANSMITS CONTROL SIGNAL TO BOA-SYSTRONIC

The main control valve is supplied in nominal system diameter DN50 (Fig. 15). Fitted with an EA-C40 actuator, it is installed in the supply line of the heating circuit. The designation EA-C40 means that this actuator has an actuation force of

Fig. 10 Return manifold

4,000 N. The photo shows the terminal box for cable connection and the black handwheel for emergency operation in the event of a power failure. The smart actuator makes it possible to select either a linear or an equal-percentage valve characteristic. Configuration is performed exclusively by means of the parameterization software.

Fig. 11 Control cabinet

al-position feedback (2-10)VDC. When combined with BOA-Systronic, it is configured with a linear valve characteristic and fed by an analog (2-10) VDC voltage signal.

EA-C40 FOR NOMINAL SYSTEM DIAMETERS FROM DN 65

The mixing valve is always selected two nominal diameters smaller than the nominal system diameter and replaces the swing check valve in the mixing line (Fig. 16).

Parameter	East wing (3-way configuration)	West wing (BOA-Systronic)	Unit
Thermal output	300.00	300.00	kW
Temperature differential	20.00	27.00	K
Volume flow rate (max.)	13.00	9.75	m^3/h
Discharge head (max.)	8.00	4.50	m
Circulator pump	Riotec 65-100	Riotec 50-100	
Differential pressure control	Δp = constant	Δp = constant	
Nom. diameter of main heating circuit	DN65	DN50	
Parallel shift of heating curve	No	+3.5	K

Table 01: Performance data of main feed circuits

2 ACTUATOR TYPES FOR DIFFERENT NOMINAL SYSTEM DIAMETERS

The actuator can either be supplied with 24 VAC/DC or 230 VAC/DC. As standard, it is capable of processing 230/24 VAC 3-point control signals as well as analog (0/4-20) mA current or (0/2-10) VDC voltage signals and features active actu-

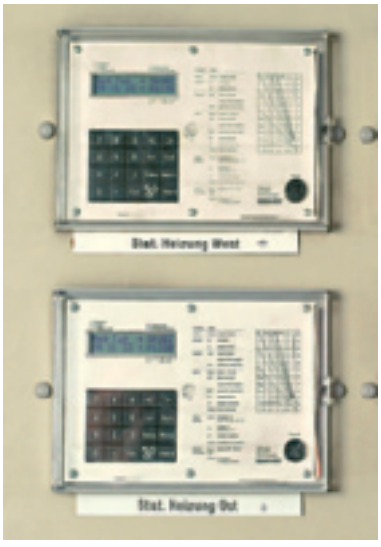

Fig. 12 Heating controllers for West and East wings

Fig. 13 Main feed manifold, West and East wings

Fig. 14 Main feed circuit with BOA-Systronic

It adjusts the volume flow rate in the mixing line in accordance with the valve control curve stored in the Systrobox. In this case, it is of nominal size DN32 and therefore equipped with actuator type EA-B12, which has an actuating force of 1,200 N.

In the event of a power failure, the valve can be actuated by means of an Allen key.

EA-B12 FOR NOMINAL SYSTEM DIAMETERS UP TO DN50

For applications other than BOA-Systronic, this actuator also offers the option of setting a linear or equal-percentage valve curve.
A five-core cable supplies the actuator with supply and control voltage. As the terminals are located inside the actuator, the cover must be removed prior to installation. Operating on a 24 VAC/DC voltage supply, the actuator requires an analog (0/2-10)V control signal and provides (2-10)VDC active actual-position feedback. When combined with BOA-Systronic, it is configured with a linear valve characteristic and addressed by an analog voltage signal (2-10) VDC.

The *Systrobox* is the "heart" of BOA-Systronic. The control unit stores the two valve control curves for the main control valve and the mixing valve, as well as the system control curve for the pump.

SYSTROBOX IS THE "HEART" OF BOA-SYSTRONIC. IT RECEIVES AND TRANSMITS ALL SIGNALS.

The control unit is powered by 24 VAC. It contains the interface for powering the *BOA-TRONIC* measuring computer and for receiving and processing its measuring signal. As interface with the (higher-level) controller, it receives the controller's control signal and transmits the three control sig-

Fig. 15 Main control valve BOA-Systronic

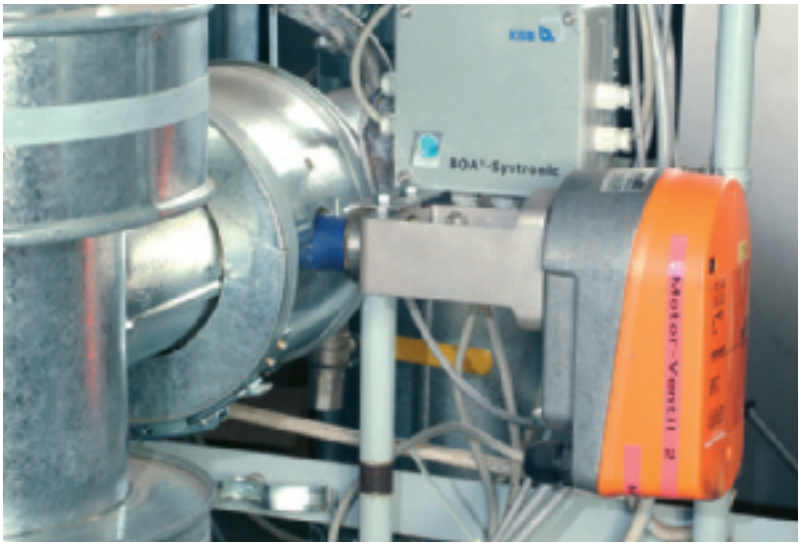

Fig. 16 Mixing valve BOA-Systronic

nals simultaneously to the pump and the control valves.

The control valves receive a separate analog (2-10)VDC control signal each, whereas the integrated FTT10 transceiver sends the currently required discharge head as digital signal to the pump via LON bus. A second pair of integrated LON terminals serves to transmit the LON output variables of BOA-Systronic as well as any other nodes of the LON bus to a higher-level building management system.

Systrobox comes pre-assembled to the main control valve as standard. However, it can also be mounted on the mixing valve, as in the present case, or in the control cabinet.

Fig. 17 Control unit of BOA-Systronic (Systrobox

10.2 Circulator selection for BOA-Systronic

The following analysis shows that the Riotec 50-100 circulator pump selected, which is controlled by BOA-Systronic, is oversized. The system curve of the heating circuit is calculated as the quotient of the pump head (H) and the square of the volume flow rate (Q):

$$k_{\text{heating circuit}} = \frac{H}{Q^2}$$

Equation 10

The volume flow rate for the design point of the conventionally equipped main feed circuit is $Q_{nom} = 13 m^3/h$. At this volume flow rate, the Riotec 65-100 pump can provide a maximum head of approx. H=8m (see pump catalogue). For this maximum case, the following system constant is calculated for the heating circuit:

$$k_{\text{heating circuit}} = \frac{8}{13^2} = 0.0473$$

Equation 11

The example is based on a temperature differential of ΔT = 20K, and the heating curve of the higher-level controller was shifted by 3.5K (parallel shift), resulting in a new design point: the nominal volume flow rate is reduced by 25%.

(Equation 12: see below)

For selecting the circulator pump operated with BOA-Systronic, the required discharge head is calculated for the design point, including equations 2 and 3.

(Equation 13: see below)

This new design point [Q/H] = [9.75m³/h / 4.5m] can be handled by a Riotec 50-60 pump. For the present example, investment costs for the circulator pump are reduced as follows:

$$Q_{N,Systronic} = 0.75 \cdot Q_{N,conv} = 0.75 \cdot 13\,m^3/h = 9.75\,m^3/h$$

Equation 12

$$H_{N,Systronic} = k_{\text{heating circuit}} \cdot Q^2_{N,Systronic} = 0.0473 \cdot 9.75\,m^2 = 4.5\,m$$

Equation 13

Pump	Catalogue price 2005 [€]	Difference [€]
Riotec 65 – 100	1,825.11	
Riotec 50 – 60	1,223.20	**602.91**

Table 02: Reduced investment costs for circulator pump

10.3 Measurements

To verify the function of the BOA-Systronic system, the following quantities were measured, among others. (Table 03)

Heating circuit East (3-way mixing configuration)	Heating circuit West (BOA-Systronic)
External temperature	External temperature
Volume flow rate at main feed manifold	Volume flow rate at main feed manifold
Differential pump pressure	Differential pump pressure
Electrical power input	Electrical power input

Tab. 03: Measured quantities

Measurements were taken on 545 days in the period from 2000 to 2002. The measured values were recorded at two-minute intervals, resulting in 711 values per day (24 hours), from which the day mean values were calculated for each measured quantity.

10.4 External temperature

The external temperatures measured were plotted for the measuring period 2000 to 2002. The diagram shows an average external temperature of approx. 10°C in the period monitored. Depending on the location, the heating circuits are selected for an external temperature of approx. –12°C to –15°C. Regulations stipulate that the building must be heated until the external temperature reaches approx. 16°C. The temperature difference between the design point and the switch-off temperature of the heating system is [(-12°C) – (+16°C)] = 28°C. The temperature difference between the design point and the average temperature is [(-12°C) – (+10°C)] = 22°C. The ratio between both values is 22/28 = 0.79. This means that **in the monitored period both heating circuits on average only require about 21% of the thermal output they were selected for.** This theory should be confirmed by a comparison

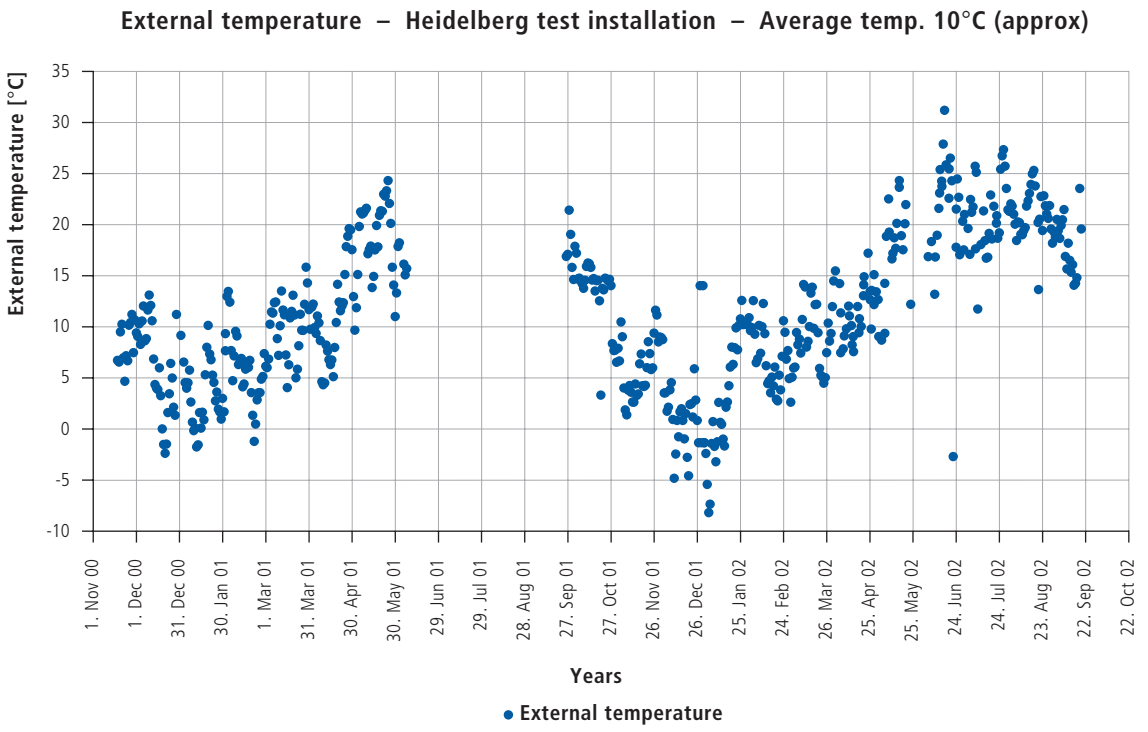

Fig. 18 External temperatures measured at the test installation in 2000 – 2002

of the volume flow rates measured, the differential pump pressures and the pump power consumption of both systems.

10.5 Volume flow rates

The conventional, mixing-type system must provide a thermal output P_{th} = 300 kW at the design point. Based on a temperature differential ΔT = 20K, the required volume flow rate Q_{nom} for the design point is calculated as follows:

$$Q_{nom} = \frac{P_{th}}{1.163 \cdot \Delta T} = \frac{300}{1.163 \cdot 20}\ m^3/h = 13\,m^3/h.$$

Equation 14

This value is confirmed by the measurements (Fig. 19). Irrespective of its degree of opening, the three-way control valve of the conventional, mixing-type system always supplies the nominal volume flow rate to the heating circuit (constant-flow system). BOA-Systronic, by contrast, adjusts the resulting volume flow rate in the main feed circuit depending on the opening degree of the two control valves and thus depending on the control signal issued by the heating controller. As expected, the volume flow rate supplied to the heating circuit by BOA-Systronic during the utilization period is considerably smaller than the volume flow rate the conventional, mixing-type system provides to its heating circuit. Fig. 19 shows that the measured nominal volume flow rates supplied by the conventional, mixing-type system do not quite reach the theoretical, calculated values. This is due to the control function of the thermostatic valves under the influence of external heat input to the heating circuit. The equation

$$\text{water volume flow} = \int_{t1}^{t2} Q(t)\,dt$$

is used to calculate the amounts

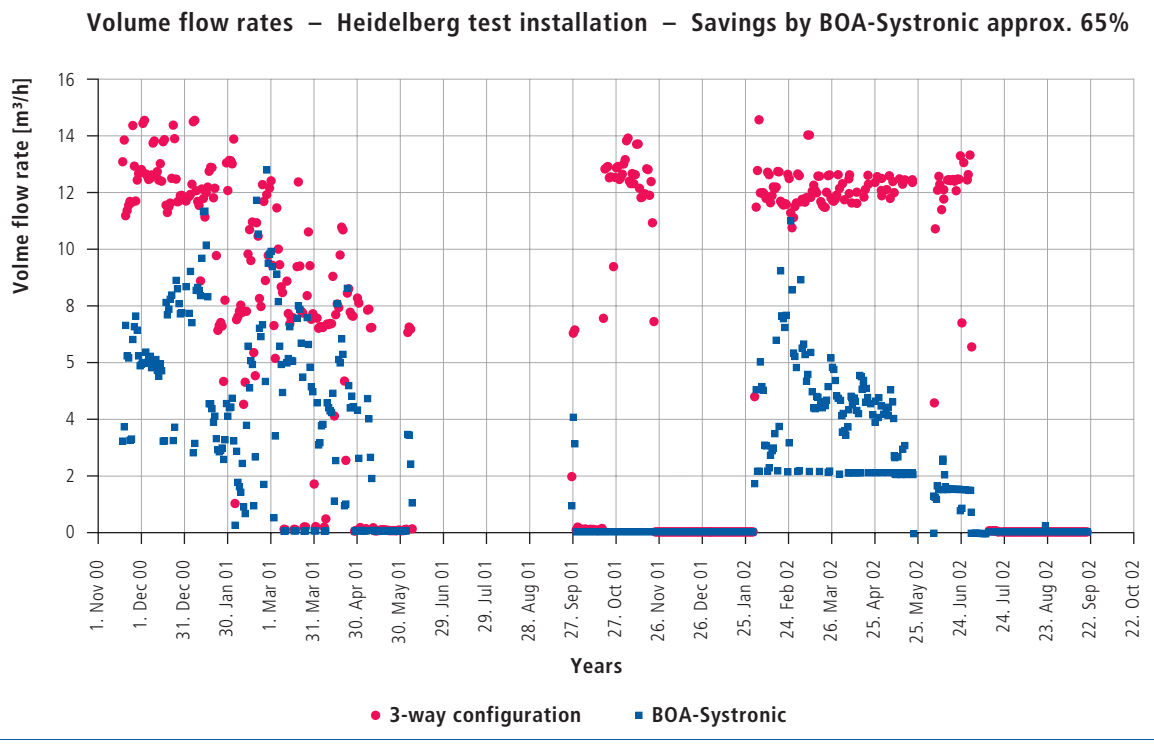

Fig. 19 Volume flow rates measured at the main feed manifold in 2000 – 2002

of water (volume flow rates) pumped through the two heating circuits, respectively. The mean values of the volume flow rates measured in the two heating circuits are calculated.

At identical thermal output, BOA-Systronic was shown to pump only 40 % of the water volume through the heating circuit, compared to the conventionally equipped heating circuit.

Measured Quantity	Volume flow rate (Q)		Ratio
Heating circuit	3-way configuration	BOA-Systronic	$Q_{Systronic}/Q_{3\text{-way configuration}}$
Unit	[m³/h]	[m³/h]	
Mean value	11.2	3.2	0.29

Table 4: Analysis of volume flow rates in 2000-2002

10.6 Differential pressures of the pumps

With BOA-Systronic, the pump is operated on average at only about 66% of the nominal discharge head at design point.

Measured Quantity	Differential pressure (H)		Ratio
Heating circuit	3-way configuration	BOA-Systronic	$H_{Systronic}/H_{3\text{-way configuration}}$
Unit	[m]	[m]	
Mean value	4.4	2.9	0.66

Table 5: Analysis of differential pump pressures in 2000-2002

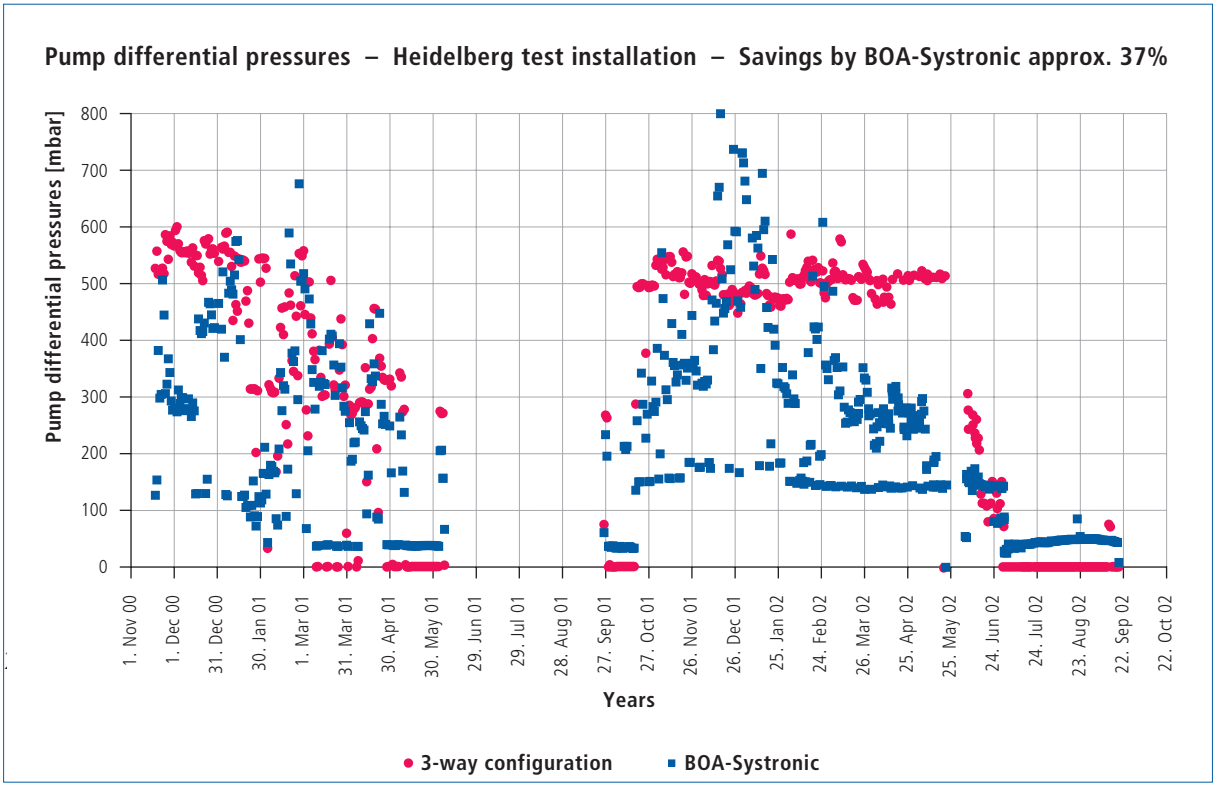

Fig. 20 Differential pressures of the circulators measured in 2000 – 2002

10.7 Pump input power

The pump input power, and thus its power consumption, is proportional to the product of the discharge head and volume flow rate. As BOA-Systronic operates the pump at reduced volume flow rates and discharge heads, the pump draws much less power from the electricity grid. BOA-Systronic was shown to save approx. 70% in electrical energy.

Measured quantity	Pump input power (P)		Ratio
Heating circuit Unit	3-way configuration [W]	BOA-Systronic [W]	$P_{Systronic}/P_{3\text{-way configuration}}$
Mean value	561	184	0.33

Table 6: Savings in pump power consumption

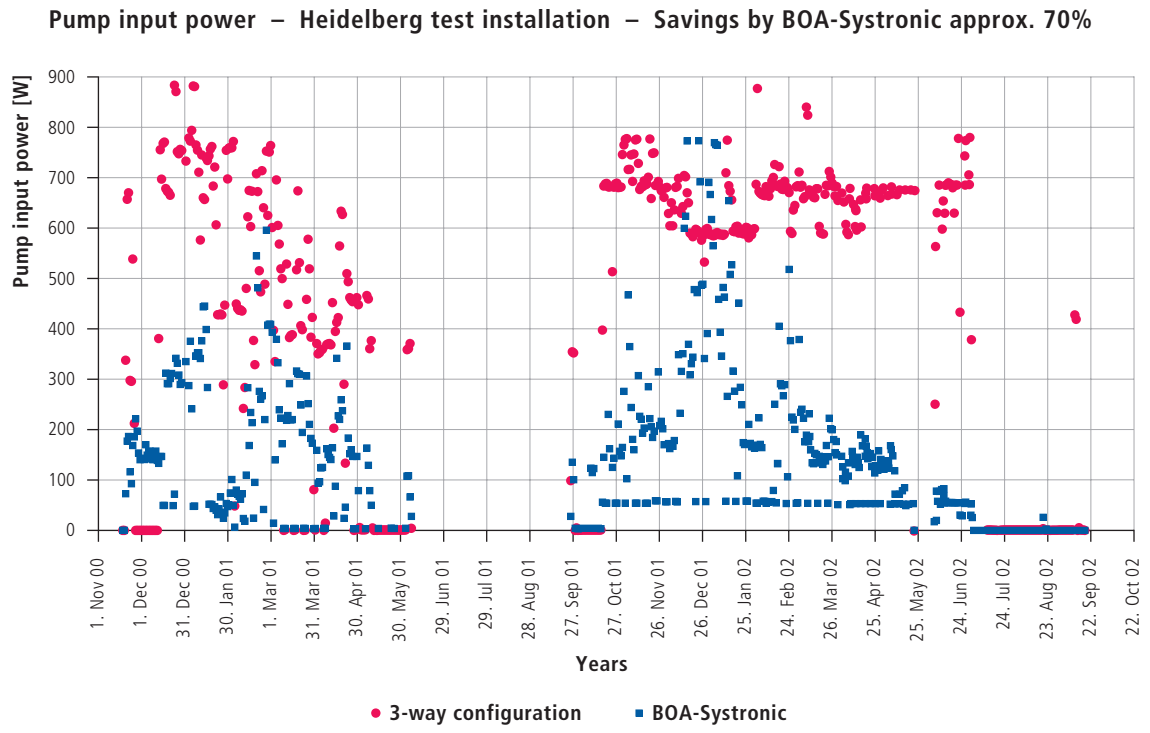

Fig. 21 Pump power input in 2000 – 2002

Conclusion

In our example, both heating circuits on average require only 21% of the thermal output at design point. By comparison, BOA-Systronic consumes only about 30% of the electricity required by the conventional set-up (here: 3-way mixing system).

11 Payback period for BOA-Systronic

11.1 Control valve investment and energy savings

With BOA-Systronic, the nominal diameter of the heating circuit components can be smaller than usual. This is due to the combined effect of increased temperature differential (difference between supply and return temperature) and reduced volume flow rates at design point, so that

1. the main feed pipe is one nominal diameter smaller
2. the shut-off valves in the main feed circuit are one nominal diameter smaller
3. the strainers in the main feed circuit are one nominal diameter smaller
4. a smaller circulator pump can be chosen
5. the measurement and control valves are one nominal diameter smaller
6. differential pressure controllers for balancing the heating circuits are not required
7. commissioning costs are reduced thanks to automatic initialization of the control valves and the pump as well as automatic hydraulic balancing at the main feed manifold.

Items (1) to (5) can also be planned and achieved in a conventional system by increasing the temperature differential at design point. Items (6) and (7), however, can only be realized with BOA-Systronic.

To compare the prices of the two systems, the average price for a conventional, mixing-type system of nominal diameter DN65 was determined on the basis of the catalogue prices given by 5 competitors. The mixing-type configuration comprises the following components:

- 3-way control valve
- swing check valve in the mixing line
- balancing valve

The gross price of BOA-Systronic, by contrast, is somewhat higher than the average price of a conventional mixing-type configuration, the differences depending on the nominal system diameter of the main feed circuit (table 07).

In the present example, a main feed circuit with a thermal output of 300 kW was equipped with BOA-Systronic of nominal system diameter DN50, whereas a nominal diameter of DN65 was selected for the conventional set-up of identical thermal output (table 08).

A simulation (version 1.21) was used to estimate the energy costs incurred for the glandless Riotec 50-100 pump during the heating period (table 10). Compared to the average price of a mixing-type system, the investment costs for BOA-Systronic would be approx. € 402 higher in this case. If this extra price is deducted from the electricity savings realized per heating period, **investment in BOA-Systronic will pay back after roughly one year.**

Nominal system diameter	Average extra price compared to 3-way mixing configuration in [%]
DN25 to DN50	11 %
DN65 to DN80	4 %
DN100 to DN150	13 %

Tab. 07: Average extra prices for BOA-Systronic

Heating circuit	Unit	Value	Difference
Average gross price of 3-way mixing configuration, DN65 (prices of 2005)	€	1,673	
Gross price of BOA-Systronic, DN50 (prices of 2005)	€	1,858	
Gross price of LON module for Riotec pump, pre-initialized	€	217	+402

Tab. 08: Extra price for BOA-Systronic with Riotec pump (example: DN50)

Heating circuit	Unit	Value	Difference
Average gross price of 3-way mixing configuration, DN65 (prices of 2005)	€	1,673	
Gross price of BOA-Systronic, DN50 (prices of 2005)	€	1,858	
Gross price of LON-module forRio-Eco pump, non-initialized	€	187	+372

Table 09: Extra price for BOA-Systronic with Rio-Eco pump (example: DN 50)

Cost factor	Unit	Value	Difference
Average price of electricity	€/kWh	0.11	
Average operating hours per heating period	h	6,800	
Average efficiency η of Riotec circulator pump	%	35	
Average pump power consumption/heating period; conv., mixing-type system DN65	kWh	5,000	
Average pump power consumption/heating period; BOA-Systronic DN50	kWh	1,200	-3,800
Average price of electricity/heating period; conv., mixing-type system DN65	€	548	
Average price of electricity/heating period; BOA-Systronic DN50	€	131	-417

Table 10: Energy costs in first year (example: DN 50)

11.2 Investment costs for heating circuit with Riotec pump

By utilizing all saving potentials offered by BOA-Systronic, the investment costs of the present heating circuit can be reduced by € 1,059.

If the extra price for BOA-Systronic is deducted from the reduced investment costs (€ 1,059–€ 402), the investment costs for the main feed circuit will be reduced to € 657 in this case. In addition, automated commissioning further reduces the commissioning costs per heating circuit by one hour. At present hourly rates (2005), this results in an additional € 45 saved.

Investment in BOA-Systronic would, therefore, pay back immediately, and the investment and commissioning costs for the heating circuit would be reduced substantially.

Cost factor	Unit	Difference
(1) Smaller nominal diameter of main feed pipe	€	-75
(2) 3 shut-off valves of smaller DN in main feed circuit	€	-123
(3) 1 strainer (standard mesh) of smaller DN in main feed circuit	€	-29
(4) 1 Riotec 50-60 circulator pump instead of Riotec 65-100	€	-602
(5) Measurement and control valves one DN smaller (BOA-Systronic)	€	see above
(6) No differential pressure controller required (1 no. per heating circuit, 1.5-inch)	€	-230
Sum total of factors (1) to (6)	€	-1,059

Tab. 11: Reduced investment costs for heating circuit with Riotec pump, example (prices 2005)

11.3 Investment costs for heating circuit with Rio-Eco pump

By utilizing all saving potentials offered by BOA-Systronic, the investment costs of the present heating circuit can be reduced by € 933.
(Table 12)

If the extra price for BOA-Systronic is deducted from the reduced investment costs (€ 933–€ 372), the investment costs for the main feed circuit are reduced to € 561 in this case. In addition, automated commissioning reduces the commissioning costs per heating circuit by one hour. At present hourly rates (2005), this saves an additional € 45.

Investment in BOA-Systronic would, therefore, pay back immediately, and the investment and commissioning costs for the heating circuit would be reduced substantially.

Cost factor	Unit	Difference
(1) Smaller nominal diameter of main feed pipe	€	-75
(2) 3 shut-off valves of smaller DN in main feed circuit	€	-123
(3) 1 strainer (standard mesh) of smaller DN in main feed circuit	€	-29
(4) 1 Rio-Eco 40-80 circulator pump instead of Riotec 65-100	€	-476
(5) Measurement and control valves one DN smaller (BOA-Systronic)	€	see above
(6) No differential pressure controller required (1 no. per heating circuit, 1.5-inch)	€	-230
Sum total of factors (1) to (6)	€	-933

Table 12: Reduced investment costs for heating circuit with Rio-Eco pump, example (prices 2005)

11.4 Total savings comparison Riotec/Rio-Eco

In the present example, the Rio-Eco pump could be expected to pay back after approximately three years, compared to the Riotec pump.

Period	Riotec (η=35%)							Rio-Eco (η=50%)								
	Reduced investment costs for heating circuit (1)–(6) [€]	Extra price for BOA-Systronic [€]	Reduced commissioning costs for heating circuit [€]	Reduced operating costs [€]	Savings [€]	Interest on savings (3%) [€]	Savings plus interest [€]	Reduced investment costs for heating circuit (1)–(6) [€]	Extra price for BOA-Systronic [€]	Reduced commissioning costs for heating circuit [€]	Reduced operating costs [€]	Savings [€]	Interest on savings (3%) [€]	Savings plus interest [€]	Price of electricity [€/kWh]	Pump operating hours [h]
Year 01	-1,059	402	-45	-417	-1,119	-34	-1,503	-933	372	-45	-456	-1,062	-32	-1,094	0,11	6,800
Year 02				-455	-1,608	-48	-1,656				-498	-1,592	-48	-1,640	0.12	6,800
Year 03				-455	-2,111	-63	-2,174				-498	-2,138	-64	-2,202	0.12	6,800
Year 04				-493	-2,667	-80	-2,747				-539	-2,741	-82	-2,283	0.13	6,800
Year 05				-493	-3,240	-97	-3,337				-539	-3,362	-101	-3,463	0.13	6,800
Year 06				-531	-3,868	-116	-3,984				-581	-4,044	-121	-4,165	0.14	6,800
Year 07				-531	-4,515	-135	-4,651				-581	-4,746	-142	-4,889	0.14	6,800
Year 08				-569	-5,220	-157	-5,376				-622	-5,511	-165	-5,676	0.15	6,800
Year 09				-569	-5,945	-178	-6,124				-622	-6,298	-189	-6,487	0.15	6,800
Year 10				-607	-6,731	-202	-6,933				-664	-7,151	-215	-7,365	0.16	6,800
Year 11				-607	-7,540	-226	-7,766				-664	-8,029	-241	-8,270	0.16	6,800
Year 12				-645	-8,411	-252	-8,663				-705	-8,975	-269	-9,244	0.17	6,800
Year 13				-645	-9,308	-279	-9,588				-705	-9,949	-298	-10,248	0.17	6,800
Year 14				-682	-10,270	-308	-10,578				-747	-10,995	-330	-11,325	0.18	6,800
Year 15				-682	-11,260	-338	-11,597				-747	-12,072	-362	-12,434	0.18	6,800
Year 16				-720	-12,317	-370	-12,687				-788	-13,222	-397	-13,619	0.19	6,800
Year 17				-720	-13,407	-402	-13,809				-788	-14,407	-432	-14,839	0.19	6,800
Year 18				-758	-14,567	-437	-15,004				-830	-15,669	-470	-16,139	0.20	6,800
Year 19				-758	-15,762	-473	-16,235				-830	-16,969	-509	-17,478	0.20	6,800
Year 20				-758	-16,993	-510	-17,503				-830	-18,308	-549	-18,857	0.20	6,800

Table 13: Outline of costs expected in 20 years of useful life

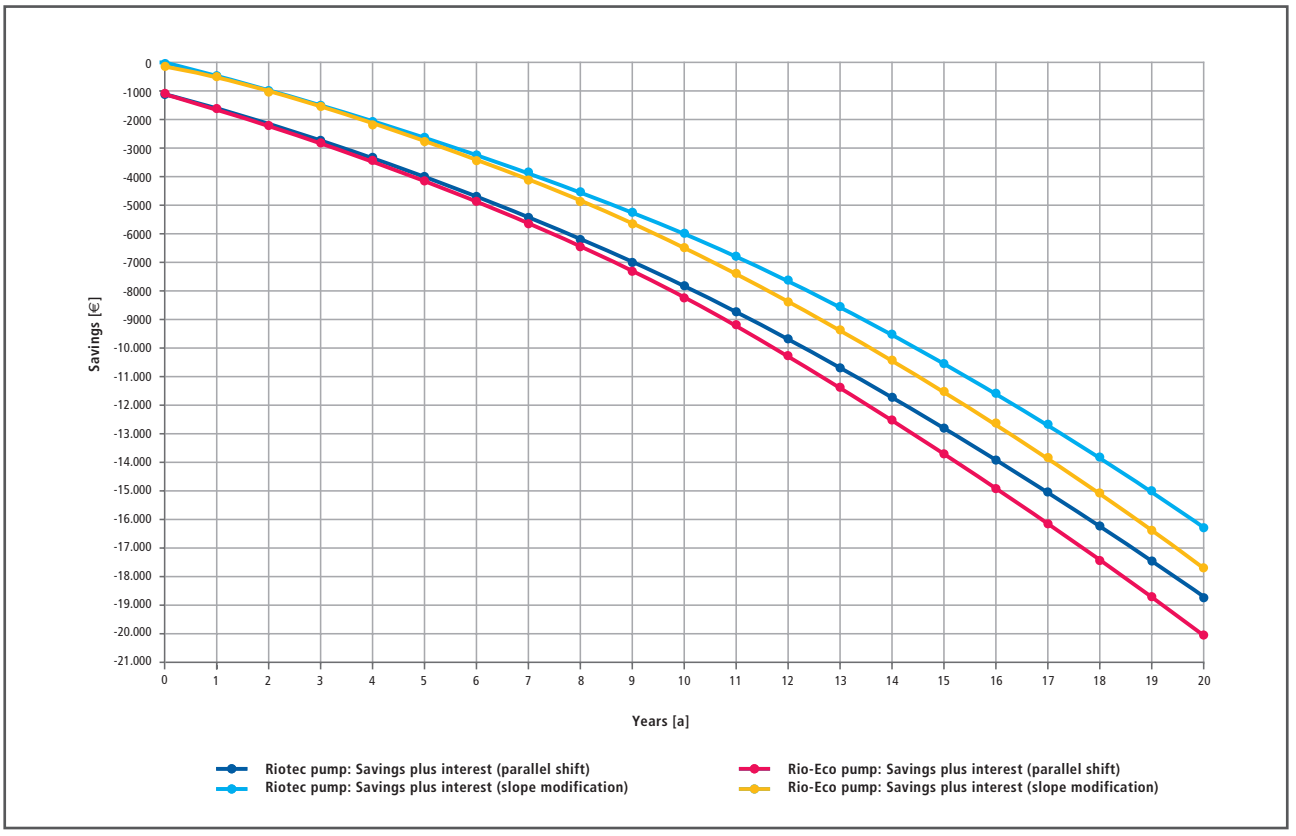

Fig. 22 Savings realized by Riotec and Rio-Eco pumps with slope modification and parallel shift (example)

Period [a]	Reduced costs	Unit	Riotec	Rio-Eco	Difference
5	Investment and commissioning	€	-702	-606	96
	Pump operation	€	-2,313	-2,530	-217
	Interest on savings (3 %)	€	-322	-327	-4
	Total	€	**-3,337**	**-3,463**	**-125**
	Annual savings	€	**-667**	**-693**	**-25**
10	Investment and commissioning	€	-702	-606	96
	Pump operation	€	-5,120	-5,600	-480
	Interest on savings (3 %)	€	-1,111	-1,159	-49
	Total	€	**-6,933**	**-7,365**	**-433**
	Annual savings	€	**-693**	**-737**	**-43**
15	Investment and commissioning	€	-702	-606	-96
	Pump operation	€	-8,381	-9,168	-787
	Interest on savings (3 %)	€	-2,514	-2,660	-146
	Total	€	**-11,597**	**-12,434**	**-837**
	Annual savings	€	**-773**	**-829**	**-56**
20	Investment and commissioning	€	-702	-606	-96
	Pump operation	€	-12,095	-13,234	-1,139
	Interest on savings (3 %)	€	-4,706	-5,017	-311
	Total	€	**-17,503**	**-18,857**	**-1,354**
	Annual savings	€	**-875**	**-943**	**-68**

Tab. 14: Total savings

12 References

Since being released for sale in 2003, BOA-Systronic has been in operation in many heating systems in public and industrial buildings throughout Germany.

The photo below shows three heating circuits equipped with BOA-Systronic systems of nominal diameter DN32.

Fig. 23 Heating circuits with BOA-Systronic DN32

13 Conclusion

BOA-Systronic reduces operating costs.

An analysis of load profiles in heating systems revealed that heating circuits operate under part-load conditions for more than 95% of their operating time. From this finding, it is safe to conclude that in conventional mixing or injection-type systems cold return water is being circulated through the heating circuit most of the time. BOA-Systronic, by contrast, provides only the volume flow actually required and can thus save an average of 70% electricity costs for the circulator pump over the heating period, which – depending on the thermal output of the heating circuit – may amount to several hundreds of Euros in electricity savings per year.

BOA-Systronic reduces the investment costs for the heating circuit.

In new or replacement installations, the investment costs for the main feed circuit can be reduced without modifying the original planning. Differential pressure control valves for balancing the heating circuits are not required. They can be replaced by balancing valves, which are less expensive. Even in heating circuits already equipped with a LON-compatible variable speed pump, investment in BOA-Systronic will pay back in less than two years.

BOA-Systronic reduces the commissioning costs for the heating circuit.

The circulator pump and the control valves are initialized automatically. Static balancing at the main feed manifold is performed automatically by the pump. The hydraulic operation of the heating circuit is optimized. The system immediately detects any air in the piping and thus prevents unnecessary commissioning work. Altogether, the costs for heating circuit commissioning are reduced.

BOA-Systronic offers increased comfort of use.

The hydraulic operation of the heating circuit is optimized thanks to substantially reduced discharge heads and volume flow rates. Excessive discharge heads under part-load conditions are prevented, and flow noises at the consumer points are avoided.

BOA-Systronic is gentle on the environment.

Electricity is something you cannot produce and store for later use, but it must be available at the exact moment when it is needed. Burning fossil fuels produces CO_2 emissions of roughly 0.53 kg per 1 kWh of electrical energy produced. Thanks to the drastic reduction in power consumption, BOA-Systronic therefore makes a positive contribution to environmental protection.

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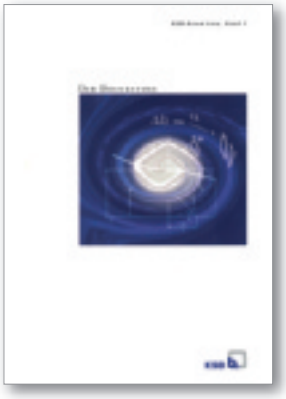

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