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A New Procedure for Hydronic Balancing of Heating Circuits

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Abstract
A new procedure for hydronic balancing of heating circuits is presented. By measuring the differential pressure and adjusting the pump speed in all heating circuits a big share of pump electricity is being saved. TRNSYS simulations of a multi-family house with five different heating circuits reveal electricity savings of 40-65 % in comparison to standard mechanical differential pressure regulators in the course of a year. The influence of valve authority and flow resistance of the boiler circuit is investigated.

Keywords – hydronic balancing, electronic differential pressure regulator, trnsys

1. Introduction

The hydronic balancing of radiators is a cost-effective method to reduce the fuel consumption of temperature sensitive heaters as well as the pump electricity consumption. As it is quite complex a lot of companies have developed methods to simplify it (e. g. Afriso, Danfoss, Grundfos, Viessmann). Up to now, the solutions mainly focus on radiators (or floor heating systems respectively) but not on heating circuits.

In this paper a new procedure for the hydronic balancing of heating circuits is presented and compared to standard mechanical differential pressure regulators. In order to assess the electricity saving potential TRNSYS simulations of a multi-family house are investigated.

2. Fundamentals

Fig. 1 shows a distribution manifold for three heating circuits each with a circulation pump and a mixing valve at design heat load. By using a (small) pump in every circuit, varying heating characteristics and different reduction times can be set and the reliability of supply is improved. The radiators of each heating circuit are balanced but not the heating circuits. The heat demand of the heating circuit on the left is not fulfilled and the heating circuit on the right causes noise because the differential pressure or the flow rate respectively is too high. Thus, the benefit of the balanced radiators is reduced. A balanced distribution manifold is a necessary condition for an energy (fuel and electricity) efficient heating system.

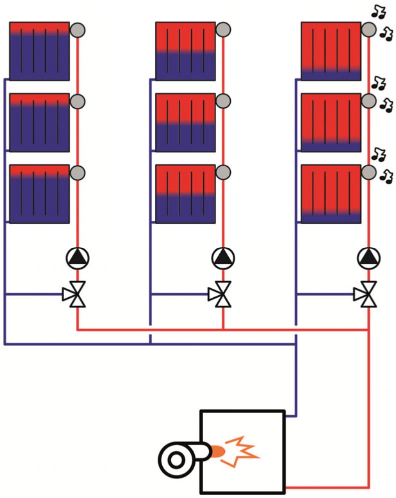

Fig. 1: Heating system with balanced radiators and self-controlled pumps

The circuits interact because of the pressure losses of the heater circuit. Fig. 2 shows two simplified schemes of a heating system with a distribution manifold and three heating circuits. The mixing valves are omitted and the radiators are summed up in order to simplify the scheme for further considerations. The values in this chapter are only examples.

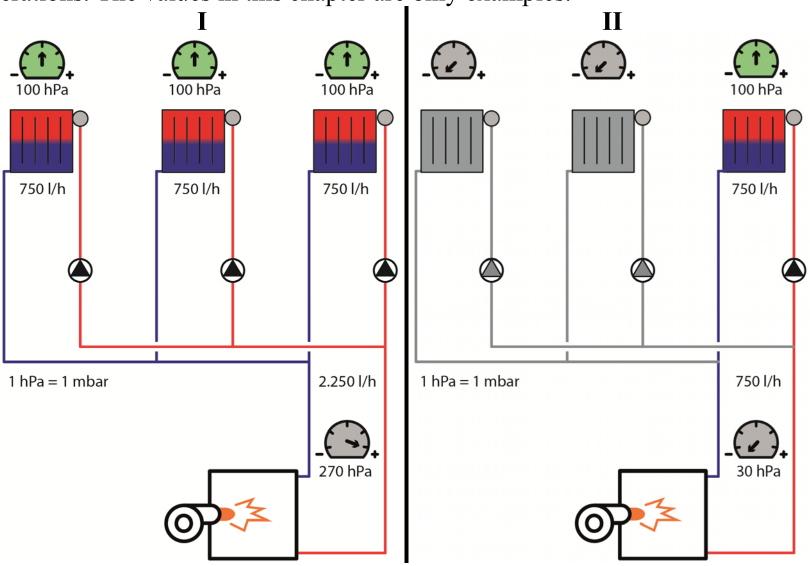

Fig. 2: Comparison of parallel (left) and single (right) operation of three heating circuits

In single operation (see II in fig. 2) the pressure loss in the heater circuit is low, e. g. 30 hPa and the system curve is flat. At the design point for this heating circuit the circulation pump has to deliver a nominal flow rate of 750 l/h with a head of 1.33 m wc (=130 hPa). In parallel operation (see I in fig. 2) the system curve of each heating circuit gets steeper, as the pressure loss in the heater circuit rises. Due to its quadratic behavior the pressure loss is increased by a factor of 9 when the volume flow rate is tripled. In order to deliver 750 l/h, every circulation pump has to increase its head to 3.77 m wc (370 hPa).

Remark: In order to avoid confusion between the differential pressure of the heating circuit and the pump, pump head (in m wc (meter water column) or hPa) is used for the differential pressure of the pump.

Although the design flow rate of parallel operation will occur very seldom in the course of a year, the installer will adjust the pump control curve for that point in order to have satisfied customers. (In practice the installer has to choose the nearest control curve, as the number of control curves in pumps is limited.)

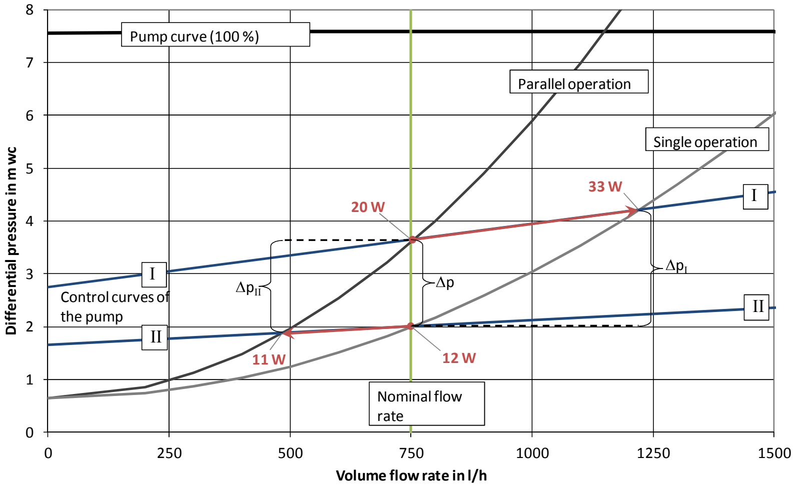

Fig. 3: Oversupply of single operation and undersupply of parallel operation for two possible control curves of the pump (same flow rate in each heating circuit)

Fig. 3 shows the control curve **I** in the pump diagram that delivers 750 l/h in parallel operation. At this operating point the pump consumes an electric power of 20 W. If the other heating circuits are switched off (single operation) the operating point moves to the right. The self-controlled pump interprets that effect as if the heat demand has been increased and raises its speed. It consumes 33 W, delivers 1200 l/h instead of 750 l/h and increases the differential pressure of the heating circuit by Δp_I of 2.2 m wc (215 hPa). This oversupply will cause whistling noise at some thermostatic valves, too.

On the other hand, undersupply results if the installer picks the control curve **II** in order to save electricity. In single operation the circulation pump takes 12 W and delivers 750 l/h. But, in parallel operation the system curve becomes steeper and the self-controlled pump interprets that as if the heat demand has been decreased. It reduces the pump speed, takes only 11 W, but delivers only 500 l/h. The differential pressure is far lower Δp_{II} than it should be. For further information on pump control please see e. g. [1]. If the flow rates are not equally distributed, the situation will even become worse for the heating circuit with the lowest demand, as its flow rate can even drop to zero.

In both cases the self-controlled pumps react in a wrong way, as they assume that a reduction of volume flow rate corresponds with a reduction of heat demand. But on a distribution manifold this can as well correspond with an increasing heat demand of another circuit.

Consequently this effect confuses the automatic adaption of the pump control curve as it uses the same assumption (see [2]). Thus, it is not possible to balance the whole system without additional equipment.

3. State of the Art

Basically, the installer has two options in order to balance the distribution manifold dynamically, even in part load situations. First, is the use of a hydraulic separator and second, is the use of a mechanical **d**ifferential **p**ressure **r**egulator (DPR) (see fig. 4).

The **hydraulic separator** reduces the differential pressure of the distribution manifold so that the interaction of the heating circuits can be neglected. The circulation pumps can operate at a low control curve of about 1.5 m wc. However, an extra circulation pump is needed to supply the system with the heat from the heater. If the circulation pump of the heater fails the heat supply falls out as well. Furthermore, the volume flow rates of the heater and the heating circuits are not balanced so that the return temperature to the heater is higher than the return temperature of the heating circuits. As this contradicts the benefit of the hydronic balancing of the whole system, this solution will not be regarded further.

The **mechanical DPR** is typically installed in the return pipe and connected to the flow pipe via a capillary (see fig. 4). This leads the static pressure of the flow pipe to the outer side of a membrane. The set value can be adjusted by the force of a spring. If the differential pressure changes, the membrane opens or closes the flow area.

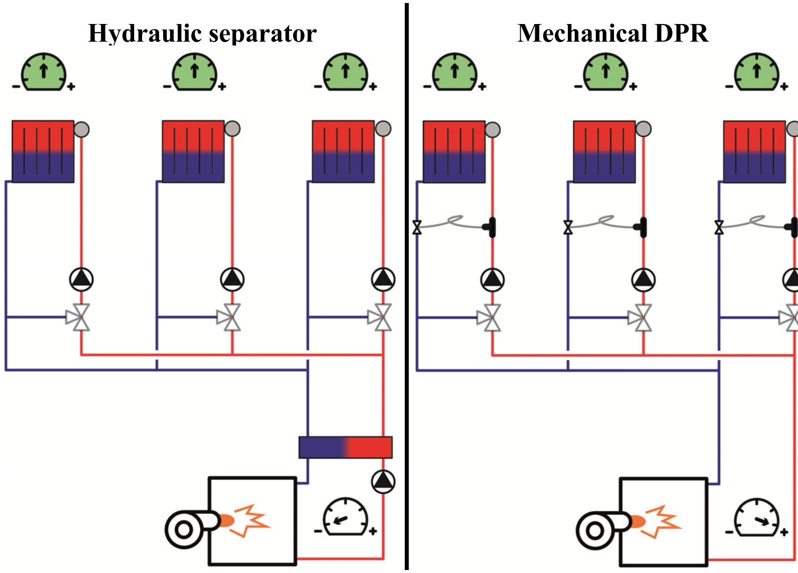

Fig. 4: Heating system with three heating circuits with hydraulic separator (left) and a mechanical DPR in each circuit (right)

To guarantee a sufficient valve authority of the mechanical DPR it is recommended that the pressure loss of the valve exceeds at least 50 % of the set value at design flow rate. The system curve becomes steeper and the control curve has to be increased even further (see fig. 5).

In the example from above, the pump consumes 28 W in order to deliver 750 l/h of volume flow rate. It has to be pointed out, that now its power consumption is independent from the amount of operating heating circuits (same system curve). In single operation the pressure loss of the valve is increased in order to keep the design flow rate and fulfill the demand.

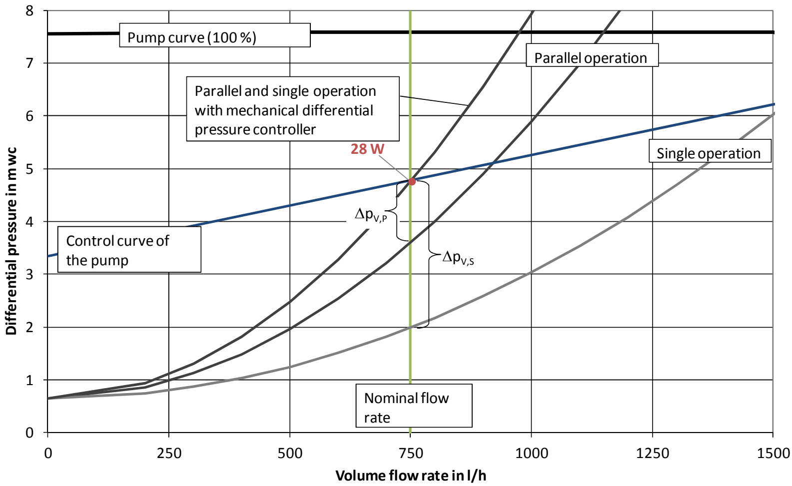

Fig. 5: Higher power consumption of the pump due to a mechanical DPR in single and parallel operation with higher control curve (same flow rate in each heating circuit)

If the flow rate decreases in the course of the year (heating season), the operating point moves on the control curve to the left. The mechanical DPR adapts dynamically to the sunken demand but its pressure loss increases. As the design flow rate occurs only a few times a year (if at all), a big amount of the pump energy consumption is dissipated in the mechanical DPR. The annual energy consumption is further investigated in chapter 5.

4. Electronic Differential Pressure Regulator

The new procedure describes a product of the PAW GmbH & Co. KG in Hamelin, Germany. It uses an electronic DPR integrated into a preassembled fitting group for heating circuits, called HeatBloC MC. The differential pressure between flow and return line is measured with a differential pressure sensor (DPS) of GRUNDFOS Holding A/S and a high-efficient circulation pump controlled via a PWM signal (see fig. 6).

Furthermore the controller allows system monitoring and easy commissioning via a smartphone app.

The electronic DPR does not add further pressure losses to the system, so the system curves stay unchanged, compare fig. 7 to fig. 3. That is why the pump delivers 750 l/h in single operation with a power consumption of only 12 W. In parallel operation the pump speed is increased so that the design flow rate stays constant. Now, the pump consumes 20 W (see fig. 7).

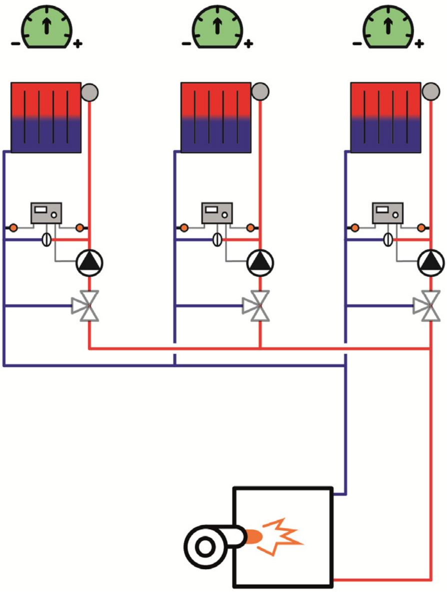

Fig. 6: Heating system with three heating circuits with an electronic DPR in each circuit

In contrast to the self-controlled pump, there is a control area for the pump. The pump speed is modulated in relation to the heat demand.

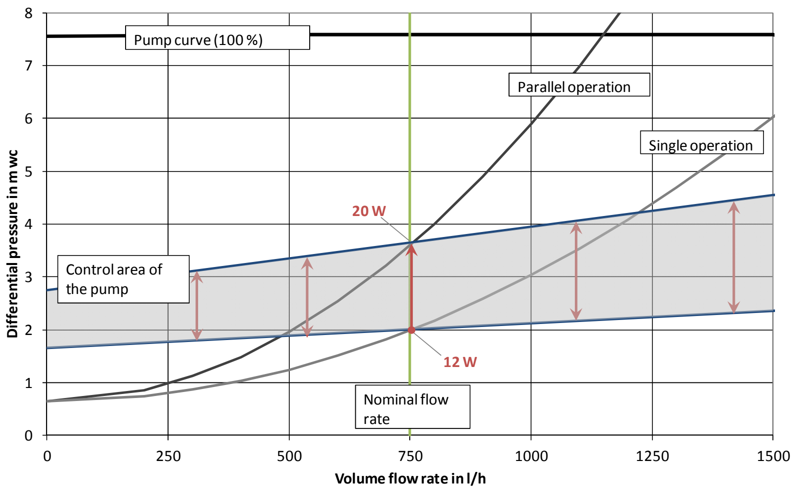

Fig. 7: Electronic DPR for single and parallel operation in the pump diagram

In order to assess the annual energy savings compared to the mechanical DPR realistic operating conditions have to be known.

5. Investigated system in TRNSYS

The simulated building is an old multi-family house with a heated living area of about 500 m². Every apartment has five rooms (living room LR, children's room CR, parents room PR, kitchen KI and bath room BR).

Table 1: Design data of the heating circuits

Heating circuit…	LR	CR	PR	KI	BR
Heated floor area in m²	159	118	92	63	30
Max. flow rate in l/h	1067	697	510	319	142
Max. heat load in kW	12.6	8.1	7.1	4.7	2.7

Every room of the building is simulated as a single thermal zone (plus one for the cellar). The set temperature of every room/zone is constant at 20 °C. The building has a heat load of 35 kW (at -10 °C) and a heat demand of 92 MWh.

There are five heating circuits, one for every kind of room, but there is only one heating characteristic and one user profile for the whole building.

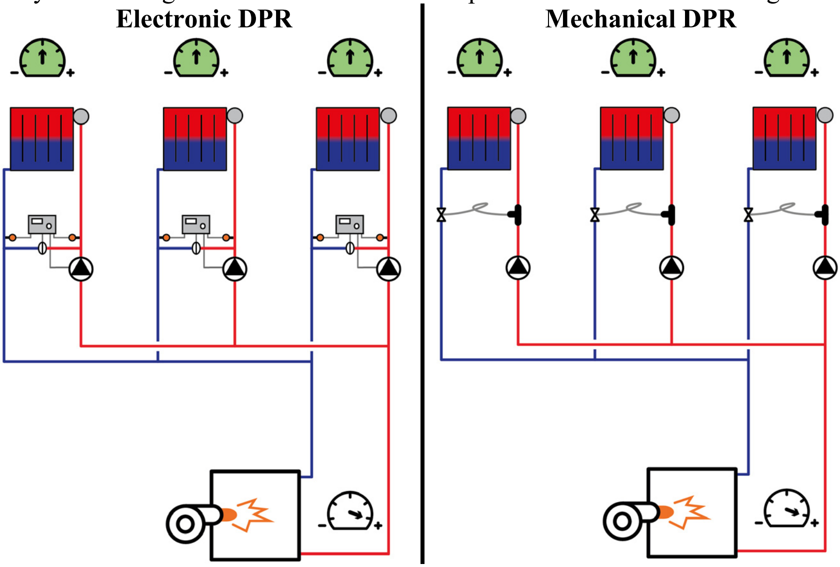

Fig. 8: Investigated systems with electronic and mechanical DPR
(in fact there are five heating circuits)

Thus, the heating circuits are simulated without mixing valve in every heating circuit. See fig. 8 for a hydraulic scheme of the simulated systems (in fact there are five heating circuits). The heater provides the required flow temperature by an internal mixing valve or by modulation.

The simulation is carried out with TRNSYS 17. The simulation time step is 1 min and the output data (temperatures and flow rates) have a resolution of 5 min.

The calculation is done according to the flow chart in fig. 9.

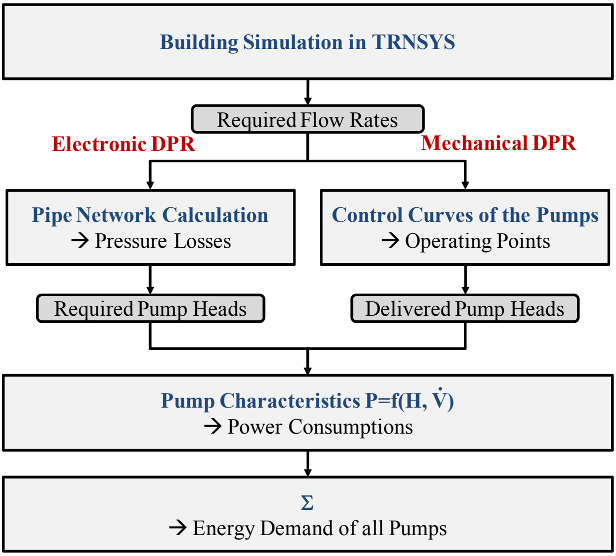

Fig. 9: Flow chart of the calculation of the energy demand of electronic (left) and mechanical (right) DPR

At first, the building simulation in TRNSYS delivers the required flow rates of each heating circuit. Then the calculation of electronic and mechanical DPR differs, as the pump control strategy is different:

- electronic DPR
  Via a pipe network calculation of the distribution manifold and the boiler circuit, the required pump heads are calculated, that are required to achieve the desired differential pressure between flow and return pipes.
- mechanical DPR
  The control curves of the pumps are specified by the design flow rates of each heating circuit (here equal to the maximum flow rate). At that point the pumps have to overcome the pressures losses of mechanical DPR, boiler circuit, fitting group, heating circuit and distribution manifold. The operation mode of the pump is H-v, which means that the pump head is variable and depending on the flow rate. At a flow rate of zero the pump head is assumed to be half of the value at full speed. Thus, the delivered pump head is calculated with the required flow rates.

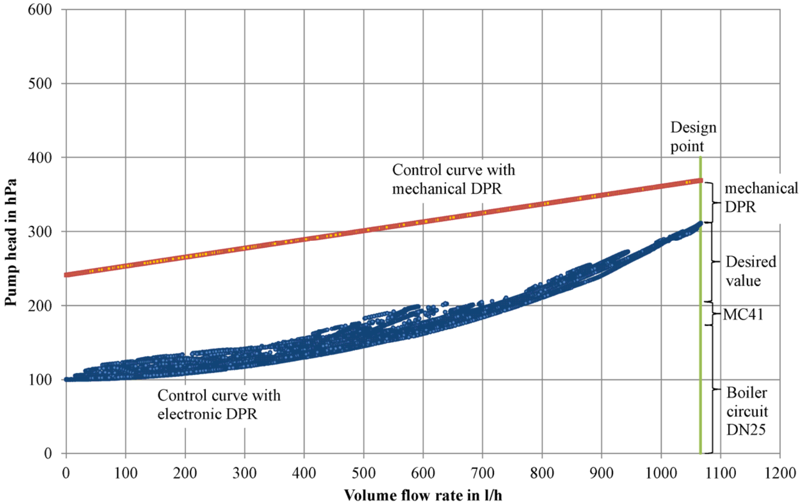

Fig. 10: Pump diagram for electronic and mechanical DPR in the heating circuit of the living room (LR)

Fig. 10 explains the difference of the calculated pump head for electronic and mechanical DPR in the pump diagram. The delivered pump head of the system with mechanical DPR is higher, as the control curve is determined by the pressure losses at design flow rate. By taking into account the total pipe network below the DPS, the electronic DPR delivers only the pump head that is needed to achieve the desired differential pressure. The difference between the curves is dissipated in the valve. Thus, the pressure loss in the valve increases in part-load situations.

With pump head and flow rate the power consumption of the pump can be calculated by the pump characteristics (see fig. 9 and 11). The investigated pump is the Grundfos UPM3 Hybrid 25-70. Fig. 11 shows, that the design flow rate, which is assumed to be the maximum value, occurs very seldom. About half of the year the volume flow rate is even below 350 l/h.

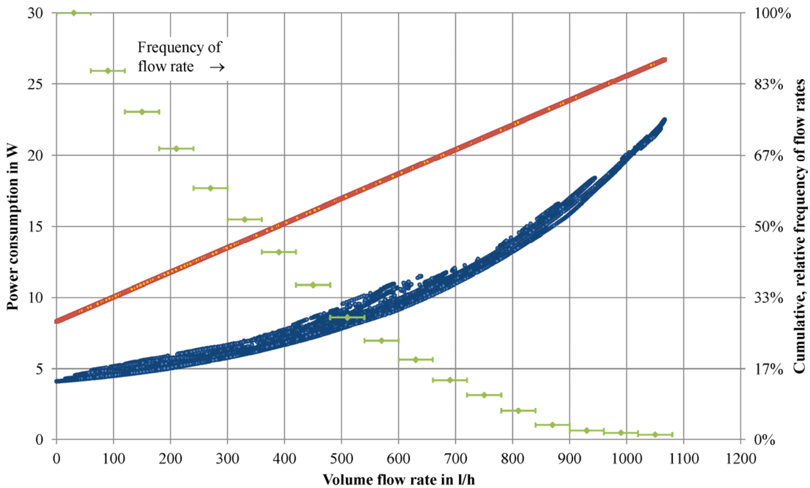

Fig. 11: Power consumption for electronic and meachanical DPR with the cumulative, relative frequency of the flow rate in the heating circuit of the living room LR

At last (see fig. 9), the power consumption is summed up to calculate the annual electricity demand. Obviously, the discrepancy in electricity demand depends on the pressure losses of the boiler circuit and the valve authority. Table 1 shows the pressure losses of the components and their variation. The desired differential pressure in the radiator circuit is 100 hPa.

Table 2: Pressure losses of components

Component	**Pressure losses in hPa at 1 m³/h**
Boiler	5
Distribution manifold to boiler circuit	1.2
5 m piping with 4 pipe elbows (DN 20/25/32 /40)	48.8/18.6/6.4/2.8
Boiler circuit (DN 20/25/32/40)	55.0/24.8/12.6/9.0
Fitting group without mixing valve (= MC41)	25.5
Distribution manifold to heating circuit	3.7
Radiator circuit (= desired value)	100
Heating circuit with electronic DPR	129.2
Mechanical DPR (valve authority 0.5/1/1.5)	50/100/150
Heating circuit with mechanical DPR (0.5/1/1.5)	179.2/229.2/279.2

6. Results

Fig. 12 shows the annual, relative electricity savings of the electronic DPR for four different valve authorities, each at design point. The lowest valve authority that can be achieved is 14 %, corresponding to the kvs values (fully open). However, it is recommended to have at least 50 % valve authority (see e. g. [3]). Thus, between 40 and 65 % of the electricity is being saved by the electronic DPR. The savings increase with the flow resistance of the boiler circuit and with the valve authority as well. In fig. 12 the pressure losses of the boiler circuit at 1 m³/h are varied between 9 and 55 hPa corresponding to different pipe diameters (see also table 2). The error indicator shows the variety of the five heating circuits. It is rather small although the design flow rates vary between 142 and 1066 l/h (see table 1), which is remarkable.

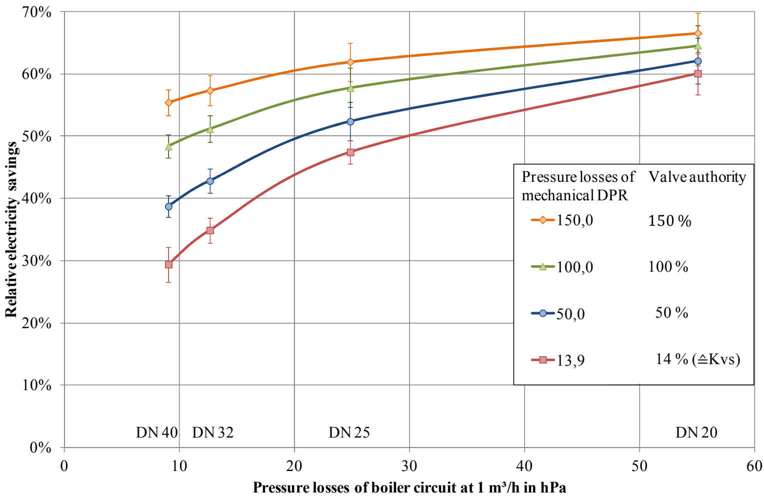

Fig. 12: Relative, electricity savings of the electronic DPR depending on pressure losses of boiler circuit and valve authority

With an electricity price in Germany of about 28 ct/kWh the annual cost savings vary between 40 and 170 € per year (see fig. 13). Although the flow rates and heat loads differ strongly, the error indicator shows a small variation of the cost savings of the five heating circuits. As the investment costs of both technologies, mechanical and electronic DPR, are comparable, the new product is profitable from the first day on.

In practice, the savings will even get higher, if we consider

- that the control curves of the pumps cannot be adjusted continuously (typically there are three setting options) and
- that the design flow rate comes from a static heat load calculation (incl. safety), which will seldom be reached (here the maximum value is used).

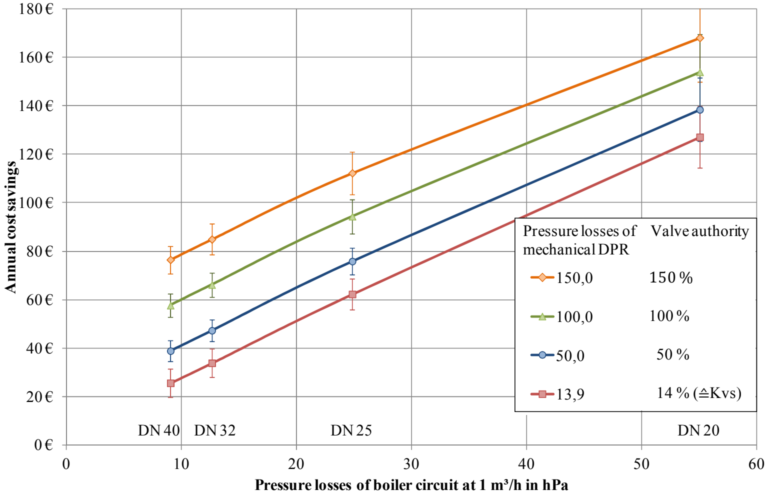

Fig. 13: Annual cost savings of the electronic DPR depending on pressure losses of boiler circuit and valve authority

7. Conclusion

The electronic DPR saves between 40 and 65 % of the electricity demand of the circulation pumps compared to mechanical DPR. For the investigated old multi-family house this leads to cost savings of 40 to 170 € per year and pays off from the first day. If safety margins on control curve and design flow rate were considered, the savings could even be higher.

The new product allows realizing high-efficient heat distribution systems without dissipation of energy in valves, without the need for storing heat in buffer tanks and without short circuit in the form of hydraulic separators.

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