Research Report

Potential Energy Savings and Economic Evaluation of Hydronic Balancing in Technical Building Systems

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1 Introduction

For many years, improving the energy efficiency of buildings has been an important part of the energy transformation in Germany. The energy conservation legislation arising from this and the ongoing development of energy-related requirements based on economic efficiency criteria play a significant role in this. The intended goal of these developments is a building stock that is, as much as possible, climate-neutral by 2050.

However, there are currently two essential statutes in which energy-related requirements for existing and new buildings are defined. The first of these is the *Energieeinspargesetz* (EnEG) [Energy Conservation Act] [1] with the related implementation provisions of the *Energie-Einsparverordnung* (EnEV) [Energy Conservation Ordinance] [2], which contains requirements for the building envelope and for technical building systems. The second essential statute is the *Erneuerbare-Energien-Wärmegesetz* (EEWärmeG) [Renewable Energies Heat Act][3], which specifies how renewable energies are to be used to meet the heat demand of new buildings and existing buildings in the public sector. However, the current state-of-affairs is that the two statutes are not optimally aligned to each other, which in practice repeatedly leaves room for interpretation.

At the European level, the Member States have undertaken in accordance with Article 9 of Directive 2010/31/EU (Energy Performance of Buildings) [4] to make the nearly zero energy building standard mandatory for all new buildings by 2021 and for non-residential buildings in the public sector by 2019. This action initiated at the European level has led to a reform of energy conservation legislation in Germany. The objective of the reform is to merge the EnEG and the EEWärmeG into a single act with the title

Gesetz zur Vereinheitlichung des Energieeinsparrechts für Gebäude – GEG [Act for the Harmonization of Energy Conservation Legislation for Buildings – Buildings Energy Act].

The proposed GEG is intended to contain a uniform set of requirements in which energy efficiency and renewable energies are integrated. All requirements mentioned in the GEG are subject to the economic efficiency principle.

Directive 2010/31/EU was amended by Directive (EU) 2018/844 [5], which among other things addresses system requirements for the overall energy efficiency of technical buildings systems and inspections. These amendments are motivated in part by the previous lack of adequate consideration of hydronic balancing, as well as the necessity to optimize the energy efficiency of buildings under real-life, dynamically varying part-load operating conditions.

The specific aim of the present study is therefore to analyze the aspect of hydronic balancing from an energy and efficiency perspective and to determine whether it can be implemented directly in the GEG.

2 Definition of hydronic balancing

2.1 Basic considerations

The primary objective of heating systems for building energy technology is to ensure adequate supply to the property matching demand, which means that the energy balance of the system must be maintained under the required boundary conditions (thermal comfort), both spatially and temporally. The thermal power to be provided by the hydronic system is defined as:

$$\dot{Q} = \dot{m} \cdot c_p \cdot (\vartheta_{VL} - \vartheta_{RL}) \tag{1}$$

where

$\dot{Q}$	heat flow [W]
$\dot{m}$	mass flow [kg/s]
c_p	specific heat capacity [kJ/(kg K)]
ϑ_S	supply flow temperature [°C]
ϑ_R	return temperature [°C]

The significant factors in Eq. (1) are the mass flow to be maintained ($\dot{m}$) and the temperature difference to be maintained ($\Delta\vartheta = \vartheta_S - \vartheta_R$). If either of these two criteria is not satisfied, the result is insufficient thermal supply by the heating system, either spatially or temporally. This is shown by example in Fig. 1.

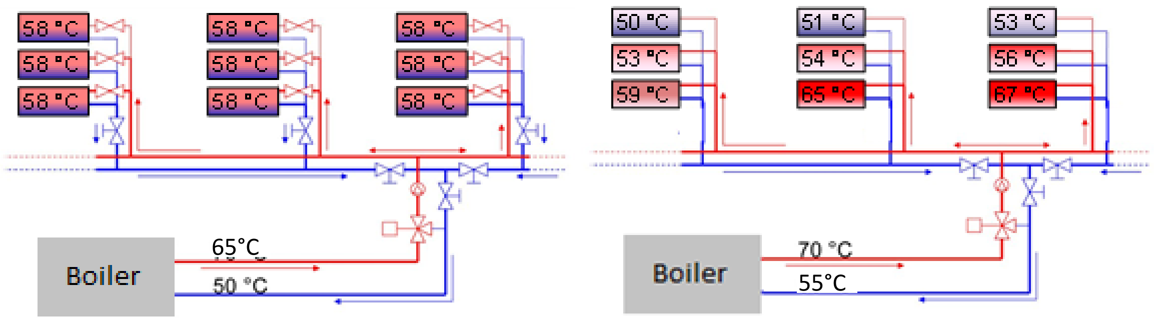


Fig. 1 Adequately (left) and inadequately (right) supplied heating systems (examples)

With regard to adequate supply, the term *hydronic balancing* has been established in the past. Definitions of hydronic balancing can be found in various publications.

Table 1 gives an overview of the most important formulations documented in the literature.

Table 1 Definitions of hydronic balancing in various literature sources

Literature source	Author	Definition
[6]	*VDZ Technical Rules*	*"Hydronic balancing is the process of matching the volume flows in the individual subsystems to the target volume flows calculated in the design. Hydronic balancing ensures that all heating surfaces are supplied with the necessary volume flows of the heat transfer medium at the right time. Maximum reduction of the system temperatures is only possible with hydronic balancing."*
[7]	*SAENA*	*"The objective of hydronic balancing is to adjust the technically required flow volumes."*
[8] / [9]	*Schweikhardt et al.*	*"Hydronic balancing ensures that the required volume of hot water flows through every radiator."*
[10]	*ASUE*	*"Hydronic balancing restricts the hot water volume flows so that the amount of heat fed to each radiator is limited to the amount necessary for uniform heating. This is done on the basis of a room-per-room calculation of the heat load and the design parameters specific to the heat generator (supply and return temperatures, pressure difference at the thermostatic valve)."*
[11]	*DENA*	*"Hydronic balancing ensures that the radiators or heating circuits for wall or floor heating are adequately supplied. For this purpose, in the entire system the volume flow of hot water is set individually for each room."*

All definitions in Table 1 refer more or less directly to hydronic aspects, and thus in particular to the pressure loss and the resulting mass flows. The following generally valid classic definition of hydronic balancing can be derived from these definitions:

"The term <u>hydronic balancing</u> is understood to mean the calculation and setting of resistance values (pressure losses) with the objective of achieving the target volume flow distribution." [12][1]

The classic definition of hydronic balancing focuses solely on hydraulics and provision of the mass flows, because in practice this is a relatively economical solution. Newer approaches for ensuring adequate supply of heating systems extend the meaning of the term and also allow consideration of thermal adaptation ($\Delta\vartheta$) in the analysis.

The documented definition of hydronic balancing is formulated very generally and therefore provides leeway with regard to implementation, i.e. whether it relates to static balancing (i.e. settings referenced to a design operating point) or a dynamic process that is performed continuously. For static hydronic balancing, the reference to the setting of pressure losses under the design conditions (nominal mass flow) is unambiguously defined. With regard to the terms

[1] In the context of the present study, the term "hydronic balancing" relates to water-based systems. However, the basic findings apply equally well to air-based systems. Furthermore, a distinction is made between static and dynamic forms of hydronic balancing.

of reference for dynamic hydronic balancing, there is no uniform definition. Instead, a constant differential pressure under full or partial load or a maximum value as a criterion for the mass flow is used.

This means that the dynamic systems provide “order” for example in a dynamic heating scenario, which leads to balanced load across the entire system.

The effect of not carrying out hydronic balancing in a heating system can also be discussed based on Eq. (1). If the mass flow at the consumer is inadequate, then with the same supply and return temperatures the emitted heat flow ($\dot{Q}$) will be inadequate. The lower mass flow can be offset by a larger temperature difference ($\Delta\vartheta$), but that leads to different temperature levels in the distribution system and at the heat generation system. That can result in a higher final energy expenditure, such as higher thermal losses. On the other hand, the unbalanced supply can be balanced by a higher pressure from the pump (with higher electrical expenditures). The energy differences between a system with hydronic balancing carried out according to the stated definition and a system that is not hydronically balanced are compiled in the following sections. The analysis is based on data from the literature.

2.2 Components for hydronic balancing

A variety of components can be used to carry out hydronic balancing. In relatively large buildings, the individual risers are adjusted relative to each other by means of so-called group balancing valves so that the same Δp values are present at the supply point between the individual riser branches. This allows hydronic balancing to be ensured between the risers. Within a branch, *pre-settable thermostatic valves* or *return temperature limiters* are used for adjustment. Both devices create an additional pressure loss, thereby limiting the mass flow. They are among the technical devices that are used for *static hydronic balancing.*

Under dynamic conditions, extended components are used as local control devices and are often combined with TRVs. In terms of operation, these components combine conventional TRV systems with a differential pressure regulator or a mass flow limiter. A mass flow limiter prevents the mass flow from rising above a pre-settable limit. A differential pressure regulator additionally limits the differential pressure over the valve under part load conditions, which also prevents undesirable noise. A consequence of these technologies is that especially during heating up and under part load conditions the mass flows or differential pressures cannot exceed the design values, avoiding unbalanced distribution in these systems. The combination of a TRV and a differential pressure controller or mass flow limiter is one of the components that can be used for *dynamic hydronic balancing*.

3 Literature analysis

A large number of publications on the subject of hydronic balancing are currently available. In the following analyses, only those publications are considered that:

- clearly list the boundary conditions;
- can withstand a scientific analysis.

All reports without an unambiguous relationship to the significant physical parameters are not considered in the following analyses.
Extensive information on hydronic balancing is provided by *Wolf and Jagnow* in [13] (*Optimus study*) and [14]. The analysis covers multi-family buildings, for which savings of 8 kWh/m²a (space heating energy savings) could be achieved compared to an unbalanced system. *Irrek* [15] analyzes the electrical energy consumption of central circulation pumps in connection with hydronic balancing issues. He finds that the electricity consumption of the described systems can be up to 50% lower with properly implemented static hydraulic balancing. Furthermore, [15] reports that with hydronically balanced systems, additional thermal energy savings of up to 10 to 15% compared to systems that are not hydronically balanced can be achieved through lower thermal losses or optimized control parameters.
In [16], *Felsmann and Hirschberg* study the influence of the absence of hydronic balancing on the part-load behaviour of electrical circulation pumps. In qualitative terms, they conclude that part load behaviour is by far the most typical case in central hot water heating systems and that this case should be considered with priority. In a second research project [17], *Hirschberg and Felsmann* analyze the influence of the absence of hydronic balancing along the demand chain (heat emission, heat distribution, heat generation). For the heat emission subdomain, differences of 2.5 to 3% between balanced and unbalanced systems are found (space heating energy). For heat generation, the absence of hydronic balancing leads to an additional expenditure of up to 8%. With regard to the power consumption of the central circulation pump, electrical energy savings of up to 25% compared to an unbalanced system are stated for a balanced system. In [18] *Hirschberg* again analyzes aspects of hydronic balancing. In particular, the analyses focus on the impact of pre-set TRVs. In these analyses, the absence of hydronic balancing raises the average mass flow in the system by 8%. If pre-set TRVs are used, this elevated mass flow can be reduced to a value of 1.5%.
Guzek also performs extensive numerical analyses on hydronic balancing in [19]. Continuous and intermittent operating modes are analyzed for a single-family dwelling and a multi-family dwelling. The influence of hydronic balancing was found to be very low in continuous operating mode. This can be explained by the part load behaviour of the system, in which the TRVs cause a reduction in the mass flow. The conditions in intermittent operation mode, which is also analyzed, are regarded as critical. Here an additional energy expenditure of 7% for heat emission is found in [19]. For the central circulation pump, an additional expenditure of order of up to 26%[2] for electrical energy is documented. The additional expenditure for heating en-

[2] With regard to the absolute parameters, it should be noted that the electrical savings in kWh are distinctly lower than the absolute savings in thermal energy.

ergy and electrical energy was due to compensation measures that were carried out on a hydronically unbalanced system (raising the heating curve $\Delta\vartheta$ and shifting the pump characteristic curve)[3].

A paper on hydronic balancing that has not yet been published in scientific journals was authored by *Seifert et al.* [20] 2014, in which in particular continuous and intermittent operating modes were analyzed as well as local dynamic mass flow limiters and static pre-settable valves. In the results of this study it is clearly concluded that continuous operation is not significant with regard to hydronic balancing. By contrast, significant differences between the analyzed systems were seen under intermittent operation. In particular, systems with an integrated function for mass flow limiting act in a "regulatory" manner during heating-up operation. Energy savings in the range of 0 to 6% relative to the thermal energy emitted in the heating network are seen in [20]. If the heat generator is included in the analysis, final energy savings of 0 to 7.5% are documented in [20]. The mentioned energy parameters were considered in the discussion on the revision of *DIN V 18599* [21] and *EN 15316-2* [22].
An analysis of various buildings used for social purposes in [8] can be regarded as a recent field study. With reference to this study, a field test is proposed to characterize potential energy savings with various buildings. The energy differences along the demand chain (emission, distribution, generation) are not distinguished in [8]. Instead, summary quantities are stated in [8]. With regard to thermal energy demand, potential savings of 12.5 to 29% are stated, as well as up to 85% for electrical energy for the pump. However, here it should be clearly pointed out that the energy savings consist of a mixture of:

- Altered user behaviour
- Static and dynamic hydronic balancing
- Replacement of the circulation pump

It should also be noted that the results only cover a very short measurement period and do not allow distinction between individual measures. Further analyses can be seen in [9], whereby in comparison to [8] the analysis period was several years. With regard to thermal energy savings, an average potential of 8 to 11% is indicated. The parameters are subdivided by building class and building age. It should also be noted that in [9] additional energy consumption was also found after hydronic balancing. A noteworthy aspect of [9] is that it also provides a comparison of embedded and free heating surfaces, with only small savings for systems integrated into building elements. Compared to an unbalanced system, they are in the range of up to 2% relative to the space heating energy.
The influence of hydronic balancing of a floor heating installation on the COP of a heat pump is studied in current measurements and analyses by *Thalfeldt et al.* [23]. The relationship between the COP of the heat pump and the hydronic system is discussed, but currently no reliable results regarding energy savings can be derived at this stage from this study. According to the authors, the studies are not yet completed and must be further elaborated.

[3] The goal of the introduction of compensation measures is to ensure the required thermal comfort in all rooms, both spatially and temporally.

Aside from the previously mentioned scientific papers, there is a large number of publications that also address the subject of hydronic balancing. The work by *Oschatz et al*. [24], which derives evaluation methods for hydronic balancing that have been incorporated in *DIN V 18599* [21], can be regarded as essential in connection with evaluation for standardization purposes. Parameters for space heat emission were determined and were updated for the revision of that standard in 2016/2017. They therefore are not further documented. In [24] a method using a load factor is proposed for heat distribution. The corresponding formula is:

$$\beta_{h,d} = \frac{Q_{h,b} + Q_{h,ce}}{\dot{Q}_{h,max} \cdot t_h} \cdot f_{hydr} \tag{2}$$

The state of the hydronic network is taken into account in Eq. 2 as follows[4]:

- Balanced hydronic network: $f_{hydr} = 1{,}0$
- Unbalanced hydronic network: $f_{hydr} = 1{,}2$

In this connection, $\beta_{h,d}$ is understood to mean the hydronic load factor. The effect on distribution and heat generator systems can be indicated by a thermal load factor. The thermal load factor influences the supply and return temperatures and thereby also indirectly influences the utilization factor of the heat generator. The corresponding equations are:

$$\vartheta_{R,a}(\beta_i) = \left(\vartheta_{RD} - \vartheta_{i,h,set}\right) \cdot \beta_i^{1/n} + \vartheta_{i,h,set} \tag{3}$$

$$\vartheta_{S,a}(\beta_i) = \left(\vartheta_{SD} - \vartheta_{i,h,set}\right) \cdot \beta_i^{1/n} + \vartheta_{i,h,set} \qquad (4)^5$$

Parameters for hydronic balancing are not directly proposed in [24].
The thermal and electrical energy savings derived from the literature research are summarized in Table 2.

Table 2 Summary of literature research – savings in systems with hydronic balancing versus systems without hydronic balancing[6] – energy demand including heat generator losses

Literature source	Author	Final energy savings		Electrical energy savings		Building type
		Old building	New building	Old building	New building	
[9]	*Schweikhardt et al.*	8 – 11% [7]		-		Non-residential building (church)
[13] / [14]	*Wolff and Jagnow*	8 kWh/m²	18 kWh/m² [8]	13%		Multi-family building
[15]	*Irrek*	10 – 15%			50% (90%)	Multi-family building

[4] The parameters documented in [24] are recorded in [21].
[5] Validity for two-pipe distribution system
[6] The final energy savings documented in Table 2 relate to systems with radiators (open heating surfaces). EnEV 2002 is regarded as the boundary for distinguishing between old and new buildings. This means that buildings erected before EnEV 2002 are old buildings, while those constructed after EnEV 2002 are new buildings.
[7] Analysis of buildings constructed from 1978 onward (WSchVO 1977)
[8] Construction later than 1994

[16] / [17]	*Hirschberg and Felsmann*	8% [9]			25%	Single-family building
[19]	*Guzek*[10]	≤ 7%	(≤ 1.2%)	26%	12%	Single-family building
[20]	*Seifert et al.*	0 – 2.8%	0 – 7.5%	-		Single-family building

With the exception of reference [20], the energy savings listed in Table 2 relate to static hydronic balancing. However, technical solutions that enable dynamic hydronic balancing are increasingly available, but these solutions are not yet backed up by detailed measurements or scientific analysis. A first simplified field test carried out in [25] showed potential energy savings of up to 15% (dynamic hydronic balancing compared to static hydronic balancing). Since these analyses have not yet been scientifically evaluated, the parameters for dynamic hydronic balancing currently reported in the standards should be used in the following analyses (see section 4.1).

[9] No differentiation by building age class
[10] Due to the selected boundary conditions, the trends in this case are different.

4 Standards and technical rules

4.1 Standard parameters

Current energy-related parameters for hydronic balancing are anchored in various standards. The most extensive data is available in DIN V 18599 [21], which provides energy-related data for hydronic balancing along the demand chain (heat emission, heat distribution, heat generation). A direct relationship to the deployed useful energy is made for heat emission. The calculation is based on representing the additional energy expenditures as temperature changes (higher room temperatures). Table 3[11] contains the corresponding values. The applicable equation for the calculation is:

$$\Delta\vartheta_{ce} = \Delta\vartheta_{str} + \Delta\vartheta_{ctr} + \Delta\vartheta_{emb} + \Delta\vartheta_{rad} + \Delta\vartheta_{im} + \Delta\vartheta_{hydr} + \Delta\vartheta_{roomaut} \quad (5)$$

Table 3 Temperature variations in heat emission versus hydronic balancing in degrees K (hydronic balancing performed with manufacturer declaration for balancing and in coordination with EN 14336 [26])

Single-pipe system	$\Delta\vartheta_{hydr}$	Two-pipe system	*n ≤ 10 $\Delta\vartheta_{hydr}$	*n > 10 $\Delta\vartheta_{hydr}$
No hydronic balancing	0.7	No hydronic balancing	0.6	
Statically balanced per circuit	0.4	Static balancing per radiator/heating surface without group balance	0.3	0.4
Dynamically balanced per circuit (e.g. with automatic flow limiters)	0.3	Static balancing per radiator/ heating surface and static group balancing (e.g. with balancing valve)	0.2	0.3
Dynamically balanced per circuit (e.g. with automatic flow limiters) and dynamically controlled depending on its load (e.g. with return temperature limitation)	0.2	Static balancing per radiator or heating panel and dynamic group balancing (e.g. with differential pressure controller)	0.1	0.2
Dynamically balanced per circuit (e.g. with automatic flow limiters) and dynamically controlled depending on its load (spread supply-return temperature)	0.1	Dynamic balancing per radiator or heating panel (e.g. with flow limiters and/or differential pressure controller)	0.0	
		* Number of radiators/heating surfaces per group		

A factor (f_{hydr}) is also used for the hydronic analysis, and in particular for determination of the load factor of the heat generator, the storage tank and the distribution network. The corresponding parameters can be found in Table 4.

[11] In the framework of the normative evaluation, flow limiters and dynamic valves are treated as the same for calculation, despite having different operating mechanisms from a technical perspective.

Table 4 Factors for hydronic balancing of heat generation according to DIN V 18599-5 [21]

Single-pipe system	Two-pipe system	f_{hydr}
No hydronic balancing		1.06
Hydronic balancing performed with manufacture declaration on the balancing and in coordination with EN 14336 and		1.02
flow regulators or exclusively statically balanced systems	With more than eight radiators / heating surfaces per automatic differential pressure controller, or exclusively statically balanced systems	
Flow regulators, flow in single-pipe branch dynamically controlled depending on its load	At most eight radiators / heating surfaces per automatic differential pressure controller and / or flow regulator	1.0

With regard to the electrical energy demand of the circulation pump, the calculation in DIN V 18599-5 [21] is implemented using an expenditure factor $e_{h,d,aux}$.

$$e_{h,d,aux} = f_e \cdot (C_{P1} + C_{P2} \cdot \beta_{h,d}^{-1}) \cdot \frac{EEI}{0{,}25} \tag{6}$$

The efficiency factor f_e in Eq. (6) is determined as follows with an unknown pump:

$$f_e = \left(1{,}25 + \left(\frac{200}{P_{hydr}}\right)^{0{,}5}\right) \cdot b \tag{7}$$

If the pump is not designed for the demand or the pump is set to a higher head due to the absence of hydronic balancing, $b = 2$ must be used in the calculation. In this way the expenditure factor, and with it the electrical expenditure (see Eq. (8)), is doubled per default if the hydronic network is not balanced.

$$W_{h,d} = W_{h,d,hydr} \cdot e_{h,d,aus} \tag{8}$$

4.2 Technical rules

The current regulations for carrying out hydronic balancing are analyzed below.

EPBD: Directive 2010/31/EU on the energy performance of buildings [4]

The European directive on the energy performance of buildings (EPBD) stipulates that:
"Article 8
Technical building systems, electromobility and smart readiness indicator

1. Member States shall, for the purpose of optimizing the energy use of technical building systems, set system requirements in respect of the overall energy performance, the proper installation, and the appropriate dimensioning, adjustment and control of the technical building systems which are installed in existing buildings. Member States may also apply these system requirements to new buildings.
System requirements shall be set for new, replacement and upgrading of technical building systems and shall be applied in so far as they are technically, economically and functionally feasible.
Member States shall require new buildings, where technically and economically feasible, to be equipped with self-regulating devices for the separate regulation of the temperature in each room or, where justified, in a designated heated zone of the building unit. In existing buildings, the installation of such self-regulating devices shall be required when heat generators are replaced, where technically and economically feasible."
"Article 14
Inspection of heating systems
1. Member States shall lay down the necessary measures to establish regular inspections of the accessible parts of heating systems or of systems for combined space heating and ventilation, with an effective rated output of over 70 kW, such as the heat generator, control system and circulation pump(s) used for heating buildings. The inspection shall include an assessment of the efficiency and sizing of the heat generator compared with the heating requirements of the building and, where relevant, consider the capabilities of the heating system or of the system for combined space heating and ventilation to optimize its performance under typical or average operating conditions."

EnEV 2014: Energy Conservation Ordinance [2]

Although the EnEV does not formulate any specific requirements for carrying out hydronic balancing, hydronic balancing is foreseen in the calculation method defined in DIN V 18599 and DIN V 4701.
The EnEV reference buildings are supplied by a hydronically balanced heating system.

KfW and BAFA subsidy
A prerequisite for a KfW or BAFA subsidy is hydronic balancing according to the VdZ technical rules document "Optimization of Heating Systems in Existing Buildings." A distinction is made between individual measures that can be performed as part of a renovation with either method A or method B, and confirmation for a KfW efficiency house for which hydronic balancing can only be performed with method B. Confirmation is provided by means of the relevant VdZ confirmation forms.

VdZ Technical Rules for the Optimization of Heating Systems in Existing Buildings [6]
The technical rules are primarily applicable to the renovation of existing buildings. The simplifications made for old buildings are not used for new buildings. In conjunction with the confirmation forms, this rule defines a technical standard that is subdivided as follows:

- Method A

Method A (standard service) is in general to be regarded as a contractual standard service and derives its validity from VOB-C. In the context of the subsidy, the method may only be used up to a maximum of 500 m² living area or useful floor area per heating circuit with its own pump / differential pressure controller. This method is subject to the relevant guidelines, and there are restrictions on its eligibility for KfW or BAFA subsidy.

- Method B

Method B must be requested separately as a premium service and is currently always valid for KfW or BAFA subsidy.

The technical implementation of methods A and B are described in Annex A - Hydronic balancing measures according to VdZ.

VOB-C (DIN 18380) [27]
"3.1.1 The components of space heating systems and domestic hot water systems shall be matched to each other such that the required service is provided, operational reliability is assured, and economical and efficient operation is possible."
"3.5.1 The contractor shall configure the system components such that the planned functions and services are provided and the legal requirements are fulfilled. Hydronic balancing shall be performed with the settings determined by calculation such that during normal operation all heat consumers are supplied with hot water according to their heat loads, including for example also after lowering of the room temperature or shutdowns of the heating system." (DIN 18380:2016-09)

EN 15378: Inspection of boilers and heating systems [28]
The procedure for a heating inspection is explained according to the requirements of the EPBD. This also includes checking the hydronic balancing.
A simplified method for the inspection of heating systems (“heating system check”) is described in the national annex DIN SPEC 15378. Among other things, the heating check includes a procedure that facilitates quick determination of whether or not hydronic balancing has been carried out in an existing heating system.

DIN V 18599: Energy performance of buildings - Calculation of the net, final and primary energy demand for heating, cooling, ventilation, domestic hot water and lighting - Part 5: Final energy demand of heating systems [21]
DIN V 4701-10: Energy performance of heating and ventilation systems in buildings - Part 10: Heating, domestic hot water supply, ventilation [29]
Both standards regard hydronic balancing as a prerequisite for proper operation. DIN V 18599-5 also provides for a correction factor for systems that are not hydraulically balanced.
"Proper operation of the heating systems according to the generally accepted technical rules is presumed. Separate instructions in this regard, for example for hydronic balancing of hot water heating systems, can be found in VDMA 24199." (DIN V 18599-5)
"This presumes normal operation of the heating and ventilation systems according to the generally accepted technical rules. Separate instructions in this regard, for example for the hydronic balancing of hot water heating systems, can be found in the VDMA specification *Regelungstechnische Anforderungen an die Hydraulik bei Planung und Ausführung von Heizungs-, Trinkwassererwärmungs- und Raumlufttechnischen Anlagen* [Hydraulic control requirements for the design and implementation of heating, domestic hot water and ventilation systems]." (DIN V 4701-10)

EN 14336: Heating systems in buildings - Installation and commissioning of water-based heating systems [26]
The standard contains the following passage regarding hydronic balancing:
"The water flow volumes must be hydronically balanced and correspond to the design specifications."

VDMA 24199 *Regelungstechnische Anforderungen an die Hydraulik bei Planung und Ausführung von Heizungs-, Kälte-, Trinkwarmwasser- Raumlufttechnischen Anlagen* [Hydraulic control requirements for the design and implementation of heating, cooling, domestic hot water and ventilation systems] [30]
The VDMA specification is intended to support project engineering and design and to present possible procedures for hydronic balancing. Furthermore, both DIN V 4701-10 and DIN V 18599-5 refer to VDMA specification 24199 as accepted technical rules.

<u>Prerequisites</u>
- System flushed and unpolluted
- System components filled
- System components de-aired
- All circuits filled with flowing media or connected as foreseen in operation
- Dirt traps and/or filters cleaned

<u>New systems</u>
The pipe network calculation forms the basis for hydronic balancing. Valves must be provided for hydronic balancing, such as:
- Pre-settable thermostatic valves
- Pre-settable return flow limiters in combination with non-pre-settable thermostatic valves
- Group balancing valves
- Differential pressure controller (variable-flow circuits) should be used in case of excessive flow noise due to high differential pressure
- Flow regulators (constant-flow and variable-flow circuits)

The valves must then be adjusted according to the calculations, and the values recorded and added to the inspection documents.
Additional checks can be made by measurement. For this the pumps must be ready for use and adjusted for constant operating conditions, and thermal control valves must be adjusted according to the calculations, or if this is not possible it must be taken into account for the measurement. After steady-state operating conditions are reached, the parts of the system to be checked are measured and compared to the calculated values. Deviations must be corrected by adjusting the settings of the control valves or differential pressure regulators. This adjustment influences other parts of the system and must be taken into account. Here as well the measured values and pre-set values must be recorded and added to the inspection documents.

Old systems
Calculation is difficult or impossible in the absence of documentation.
First the actual and target flows are determined, for example by:

- Calculated dimensioning using system simulation
- Recording network characteristics with a measurement pump
- Measuring flows with measurement valves

Then static or dynamic hydronic balancing can be carried out

Static balancing with the aid of measurement valves and manual throttle valves
Valves shall be provided that enable adjustment of the system components and, in the case of relatively large systems, measurement of the system components. It must be ensured in advance that the pumps are ready for use and adjusted for constant operating conditions, and that all adjustable valves are set according to experience or target flow so that the specified steady-state operating conditions can be achieved.
Various measurement methods can be used:

- **Iterative method**
  Repeated measurement at each hydronic measurement point and adjustment of the corresponding control valves until the desired values are obtained.
- **Compensation/proportional method**
  The least favourable point of the system must be known. That determines the minimum pump head. A minimum pressure difference at the target flow must be present at the least favourable part of the system. For measurement reasons, it should not be less than 3 kPa. While the part of the system with the least favourable point is kept at the minimum pressure loss by a main valve, the other parts of the system are measured and adjusted.
- **Balance method**
  Hydronic balancing is performed using a measurement computer and balance method software.

The components of the system to be checked are measured and compared to the foreseen target flow. Then the deviations are corrected by adjusting the control valves or differential pressure regulators. It must be borne in mind that these adjustments affect other parts of the system. The measurement and pre-set values must be recorded.

Dynamic balancing by differential pressure controllers in variable-flow systems or by flow regulators in constant-flow systems

If differential pressure regulators are used for every circuit in variable-flow systems (e.g. two-pipe systems), hydronic balancing is performed dynamically because the target flow is controlled by the regulated differential pressure and the pre-set throttle settings at the individual emitters.
In constant-flow systems, hydronic balancing is performed dynamically if flow regulators are used in every circuit, since they compensate for the interactions between the different circuits.
If the system is extended, it is not necessary to check and/or change the dynamic balancing in the existing circuits.

ZVSHK technical information on hydronic balancing

The technical data is informative and provides suggestions for carrying out hydronic balancing and in particular for compliance with VOB-C.

New systems

First the heat load must be determined for each room. Then the system temperatures must be determined (specification of supply and return temperatures). Using this data, the heating surfaces are laid out and the volume flows are calculated. The pipe network is dimensioned for a pressure loss between 30 and 100 Pa/m (pipe network calculation). If necessary, group balancing valves need to be used, calculated and adjusted. The pre-set values of thermostatic valves and the pump head must be determined. In addition, differential pressure controls are required if the pressure difference in the network is greater than 200 mbar. Finally, the thermostatic valves must be pre-set.

Old systems

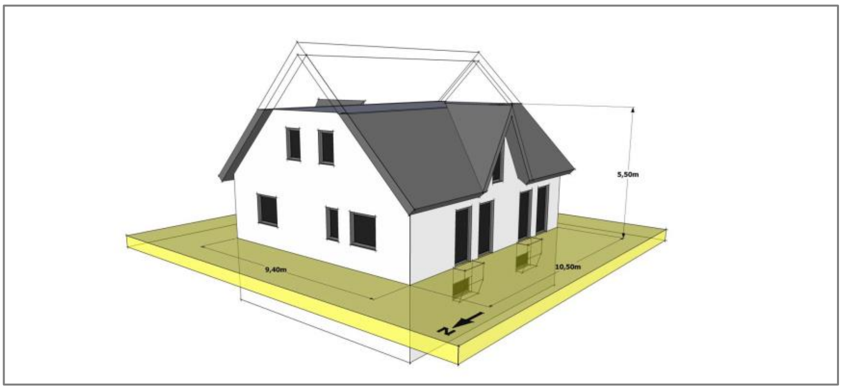
The procedure is largely similar to that for new systems. The heat demand for each room may be estimated. Then the system temperatures are determined or measured. The dimensioning of the heating surfaces is checked, and the flows are determined from a predefined temperature difference and the heat demand. The pipe network must be included in the determination of the pressure losses in the entire system. If necessary, group balancing valves have to be used, the settings must be determined, and the valves must then be adjusted accordingly. Differential pressure controllers should also be used if the pressure difference in the network exceeds 200 mbar. The existing circulation pump is checked and replaced if necessary. Then the pre-setting values of the thermostatic valves are determined, based on 100 mbar at the valve as a design guideline. These values are then pre-set.

5 Cost-benefit analysis

5.1 Boundary conditions

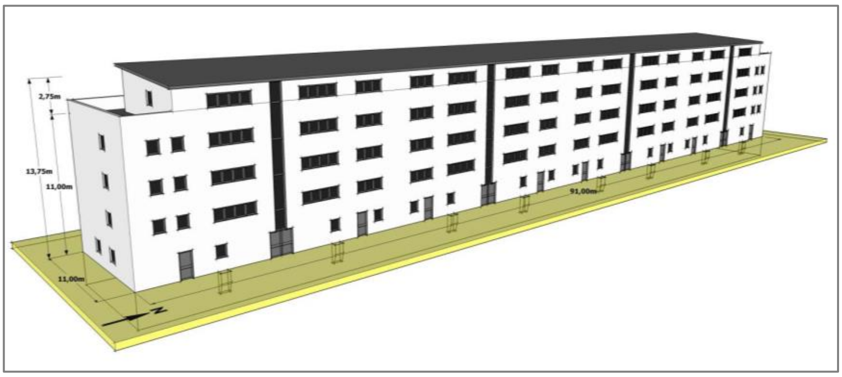
5.1.1 Definition of typical application cases

The analyses are made for a single-family dwelling and a multi-family dwelling with 40 building units according to the ZUB catalogue of model buildings [31].



Useful floor area	148.8 m²
Living area	110 m²
Number of radiators	
Old building	11
New building	9
Surface heating	
Floor heating circuits	6
Radiators	3

Fig. 2 Single-family dwelling with basement [31]



Useful floor area	3,800 m²
Living area	2,850 m²
Number of radiators	
Old building	250
New building	200
Number of branches	8

Fig. 3 Multi-family dwelling with 40 building units [31]

A distinction is made between existing buildings and new buildings, with all buildings erected since EnEV 2002 regarded as new buildings.

Typical consumption data for existing buildings depending on renovation status and energy carrier is available in the BMVSB online publication *Vergleichswerte für Verbrauch bei Wohngebäuden* [Comparative consumption values for residential buildings] [32]. Adjusted for the domestic water heating, the specific final space heating energy consumption (only heating, referenced to the living area) is, for example, 170 kWh/m² per year for an unrenovated single-family dwelling[12] using natural gas or heating oil, or for a large unrenovated multi-family dwelling[12] 130 kWh/m² per year [33].

The following installation systems are analyzed:

Small single-family dwelling with heated basement	Condensing boiler and radiators
	Air/water heat pump and floor heating (only new buildings)
Large multi-family dwelling (40 building units)	Condensing boiler and radiators
	District heating and radiators
	District heating and floor heating (only new buildings)

[12] Construction earlier than 1984

The existing adjustable pump for hydronic balancing can be either a multi-speed pump or a high-efficiency pump. Accordingly, two cases are considered for the residential buildings: multi-speed pump and high-efficiency pump. Due to the low electricity consumption of high-efficiency pumps, the absolute electricity savings are lower.

5.1.2 Methodology and boundary conditions of cost-benefit analysis

According to the *Energieeinsparungsgesetz* (EnEG) [Energy Conservation Act] Section 5(1) [1], requirements are regarded as economically justified if the necessary expenditures can be amortized by the resulting savings within the normal useful lifetime of the building or its building units. The expected remaining useful lifetime must be considered for existing buildings. This means that a measure is regarded as economically feasible if the determined amortization time is shorter than the calculated useful lifetime T_N.
The static amortization time J and the amortization time T_A taking dynamic price trends into account are calculated according to the following amortization method [34]:

$$J = \frac{\text{Investment cost}}{\text{Annual energy cost saving}} \tag{9}$$

$$T_A = \frac{\ln\big(1 - J \cdot (q - r)\big)}{\ln \frac{r}{q}} \tag{10}$$

J static amortization time
T_A amortization time in years (depending on price increase and interest rate)
q interest factor; $q = 1 + \frac{p}{100}$; p = interest rate [%]
r price adjustment factor; $r = 1 + \frac{P_V}{100}$; P_V = annual price adjustment [%]

The static amortization time is the ratio of the investment cost for implementation of hydronic balancing to the annual savings in energy costs.
Current energy prices and expected energy price increases, as well as the interest rate for mortgage loans, are relevant for the calculation of energy cost savings. The energy prices for residential buildings are based on the data in [35][13] and have been extrapolated to the 2018 price level.

Table 5 Energy prices used in the calculation

Fuel	Per-kWh price [€/kWh]	
	Single Family	Multifamily
Natural gas	0.056	0.053
District heating	0.069	0.068
Electricity: heat pump tariff	0.195	-
Electricity: household tariff for auxiliary electricity	0.271	0.271

The price increase and interest rate are used in accordance with Reference [36] and its Table 6. Regarding applicable interest rate it states:
"For determination of the interest rate for calculation purposes, it is proposed to take into account both the current situation and medium-term trends up to the year 2020. Nominal interest rates for construction loans with 10-year fixed interest rates have again dropped slightly in the last two years and are currently (as of October 2017) slightly above 1%. The forecasted

[13] BDEW heating cost comparison for old buildings, 2017: Germany-wide annual averages for the period of October 2015 to September 2016.

increase in consumer prices in Germany in 2017 is 1.8%, following several years when it was below 1%.
Taking into account the equation for determination of the interest rate:

interest rate = (1 + nominal construction loan interest rate) / (1 + consumer price index) - 1

a further drop in the costing interest rate to below 0% could be justified in light of the present situation. Nevertheless, in our view it is likely that the interest rate level will rise again when inflation stabilizes around 2%.
In order to take the current situation into account, while at the same time being able to reflect a potential rise in interest rates in the coming years, in consultation with the client an interest rate of 0% is assumed."

For the price increase with the natural gas and district heating variants, for simplicity the same price increase is used for auxiliary energy as for natural gas and district heating because auxiliary energy has only a small share.

Table 6 Price increase and interest rate

Price increase and interest rate		
Price increase	Natural gas / district heating including auxiliary energy	1.0%
	Electricity for heat pumps including auxiliary energy	0.25%
Interest rate		0%

Useful lifetimes of heating systems are given in VDI 2067 Part 1 [37]. No data is included for the hydronic balancing of central heating systems. In [37] 10 years is stated for circulation pumps and 15 years for thermostatic radiator valves. Based on these system components, which are required for hydronic balancing, hydronic balancing can be regarded as economical if the amortization time is less than 15 years.

5.1.3 Technical solutions and cost analysis

The following cases are distinguished for the cost-benefit analysis:

- Static hydronic balancing
  (1) Hydronic balancing with existing pre-settable valves, thermostatic sensors and group balancing valves in the multi-family dwelling
  (2) Hydronic balancing with the installation of pre-settable valves and thermostatic sensors as well as group balancing valves in the multi-family dwelling
- Dynamic hydronic balancing
  (3) Static hydronic balancing per radiator with existing pre-settable valves, thermostatic sensors and the new installation of dynamic group balancing in the multi-family dwelling
  (4) Hydronic balancing with the installation of dynamic valves and thermostatic sensors

The costs and potential energy savings differ accordingly. As both regulated multi-speed circulation pumps and regulated high-efficiency pumps may be present, two cases are considered.

The cost of carrying out hydronic balancing includes the following tasks performed by a heating system specialist:

- Data collection (radiator sizes, insulation standard, etc.)
- Calculation or estimation of the heat load and the pre-setting values for each room and radiator
- Depending on the variant:
  - Installation of new thermostatic valves and thermostatic sensors
  - Installation of static group balancing valves
  - Installation of group differential pressure controllers
- Adjusting the thermostatic valves, pump and heating curve
- Documentation
- Time/cost for covering the distance to the house[14]

Note: When setting up new heating systems, carrying out hydronic balancing according to the technical rules is mandatory. Compared to the retrofit of hydronic balancing, works are limited to pre-setting the thermostatic valves, because balancing is performed on the basis of readily available building planning as part of the installation process.

[14] Here it is assumed that hydronic balancing is performed as an independent task. If other tasks are performed at the same time, this cost component is reduced proportionally.

5.1.4 Derivation of possible savings for the cost-benefit analysis

Based on the literature analysis and the evaluation criteria according to the standard, the potential savings for the residential buildings are specified for the cost-benefit analysis according to building type, variant and building age (existing or new); see Table 7.
The energy saving values take into account that hydronic balancing tends to be more significant in extended pipe networks than in small networks because the differences of pressure at the heating surfaces are larger. This effect is only partially captured in the evaluation according to the standard. Dynamic balancing has an additional advantage here because at least some of the relatively complex calculations are not needed.
In addition, the standard does not adequately differentiate between heat transfer by radiators and surface heating for the evaluation of hydronic balancing. The values in the standard (see Table 3, section 4.1) were determined for radiator heating. The expected savings potential is lower with surface heating systems because the relationships are different to those for radiator heating:

- All floor heating circuits of a distribution manifold (per floor or apartment) have the same pressure available.
- The pipe length per floor heating circuit from the distribution manifold is limited, which implies only small differences between the floor heating circuits.
- Operation of floor heating systems is usually continuous.

The energy savings for surface heating systems are also included in Table 7. There it is assumed that operation is continuous, physiological heat criteria are met (the temperature does not drop below the setpoint room temperature), and compensation measures have been taken in the form of higher supply temperatures, longer start-up heating times and higher pump characteristic curve settings for systems that are not hydronically balanced.

With variants (2) and (4), it is assumed that existing valves with thermostatic sensors have been replaced by new valves with new thermostatic sensors, resulting in further savings. Depending on the age of the existing valves, these can be as much as 7% [38]. The savings considered for Table 7 relate to existing buildings and corresponding heating systems of average age, and therefore to average potential savings. With even older existing systems (installed before 1988), larger savings can be achieved by replacing the valves and sensors[15].

Where a floor heating distribution manifold has no pre-setting, the manifold has to be replaced. As an alternative, hydronic balancing can be done with an electronic controller (e.g. individual room temperature control), if equipped with the necessary functionalities. This case is not further considered. For accurate control under part load conditions the dynamic variant of hydronic balancing is required. It can be achieved “in front of” the distribution manifold, e.g. by a differential pressure controller. For the additional energy saving no further data, beyond the standardized values in DIN V 18599-5, is available yet.

In addition, **electrical energy savings** of 25% compared to an unbalanced system are taken into account for the residential buildings.

[15] In DIN V 18599, this is taken into account in the determination of temperature variations. For determination of the final energy savings with these variantt, 4 kWh/m² per year for the single-family dwelling or 3 kWh/m² per year for the multi-family dwelling are included.

Table 7 Energy savings: balanced versus unbalanced systems in residential buildings

Variant			Final energy savings [kWh/m²y]			
			Single-family dwelling		Multi-family dwelling	
			Old building	New building	Old building	New building
			Up to 2001	2002 – 2008	Up to 2001	2002 – 2008
(1)	Static hydronic balancing per radiator and static group balancing; existing TRVs (and group balancing valves in the MFD) are only adjusted	Condensing boiler and radiators	5.0	6.0	8.0	9.0
		District heating and radiators			7.0	8.0
	Static hydronic balancing per heating surface (floor heating)	Heat pump and floor heating		2.5		
		District heating and floor heating				5.0
(2)	Static balancing per radiator and static group balancing with installation of new valves/TRVs (and new group balancing valves in the MFD)	Condensing boiler and radiators	9.0	10.0	11.0	12.0
		District heating and radiators			10.0	11.0
	Static hydronic balancing per heating surface (floor heating)	Heat pump and floor heating		2.5		
		District heating and floor heating				5.0
(3)	Static balancing per radiator (existing valves/TRVs) and dynamic group balancing with installation of new group differential pressure controllers	Condensing boiler and radiators			11.0	12.0
		District heating and radiators			10.0	11.0
(4)	Dynamic balancing per radiator with installation of dynamic radiator valves and new thermostatic sensors	Condensing boiler and radiators	13.0	14.0	15.0	16.0
		District heating and radiators			14.0	15.0

5.2 Results

Table 8 Results of static hydronic balancing: existing pre-settable valves – small single-family dwelling

(1) Static hydronic balancing – existing pre-settable valves		Heating system	**Condensing boiler and radiators**				**Air/water heat pump + Floor heating**	
Small single-family dwelling (heated basement)		Building age class	Old building		New building		New building	
			Up to 2001		From 2002 to 2008		From 2002 to 2008	
		Current situation	Multi-speed pump	HE pump	Multi-speed pump	HE pump	Multi-speed pump	HE pump
Useful floor area A_N		m²	148.8					
Living area A_{Wfl}		m²	110.0					
Specific heat savings		kWh/m²a	5		6		2.5	
Absolute heat savings		kWh/a	550		660		275	
Energy cost savings for heat		€/a	31		37		54	
Auxiliary energy consumption without hydronic balancing		kWh/a	65	30	65	30	170	90
Potential electrical energy savings		%	25%		25%		25%	
Auxiliary energy savings		kWh/a	16	8	16	8	43	23
Energy cost savings – electricity for auxiliary energy		€/a	4	2	4	2	12	6
Total energy cost savings		**€/a**	**35**	**33**	**41**	**39**	**65**	**60**
No hydronic balancing		€	290		250		250	
Static amortization time [a]		**a**	**8.2 a**	**8.8 a**	**6.0 a**	**6.4 a**	**3.8 a**	**4.2 a**
Amortization period T_A	Price increase for natural gas	1.0%	**8.0 a**	**8.5 a**	**5.9 a**	**6.2 a**	**3.8 a**	**4.2 a**
	Price increase for heat pump electricity	0.25%						
	Interest rate	0.0%						

Table 9 Results of static hydronic balancing: installation of new pre-settable valves – small single-family dwelling

(2) Static hydronic balancing – new pre-settable valves		Heating system	**Condensing boiler and radiators**				**Air/water heat pump + Floor heating**	
		Building age class	Old building		New building		New building	
Small single-family dwelling (heated basement)			Up to 2001		From 2002 to 2008		From 2002 to 2008	
		Current situation	Multi-speed pump	HE pump	Multi-speed pump	HE pump	Multi-speed pump	HE pump
Useful floor area A_N		m²	148.8					
Living area A_{Wfl}		m²	110.0					
Specific heat savings		kWh/m²y	9		10		2.5	
Absolute heat savings		kWh/y	990		1,100		275	
Energy cost savings for heat		€/y	55		62		54	
Auxiliary energy consumption without hydronic balancing		kWh/a	65	30	65	30	170	90
Potential electrical energy savings		%	25%		25%		25%	
Auxiliary energy savings		kWh/a	16	8	16	8	43	23
Energy cost savings – electricity for auxiliary energy		€/a	4	2	4	2	12	6
Total energy cost savings		**€/a**	**60**	**57**	**66**	**64**	**65**	**60**
No hydronic balancing		€	900		700		1,500	
Static amortization time [a]		**a**	**15.0 a**	**15.7 a**	**10.6 a**	**11.0 a**	**23.0 a**	**25.1 a**
Amortization period T_A	Price increase for natural gas	1.0%	**14.1 a**	**14.6 a**	**10.1 a**	**10.5 a**	**22.4 a**	**24.4 a**
	Price increase for heat pump electricity	0.25%						
	Interest rate	0.0%						

Table 10 Results of dynamic hydronic balancing: installation of new TRV with differential pressure controller or volume flow limiter – small single-family dwelling

(4) Dynamic hydronic balancing – new TRV with differential pressure controller or volume flow limiter		Heating system	Condensing boiler and radiators			
		Building age class	Old building		New building	
Small single-family dwelling (heated basement)			Up to 2001		From 2002 to 2008	
		Current situation	Multi-speed pump	HE pump	Multi-speed pump	HE pump
Useful floor area A_N		m²	148.8			
Living area A_{Wfl}		m²	110.0			
Specific heat savings		kWh/m²a	13		14	
Absolute heat savings		kWh/a	1,430		1,540	
Energy cost savings for heat		€/a	80		86	
Auxiliary energy consumption without hydronic balancing		kWh/a	65	30	65	30
Potential electrical energy savings		%	25%		25%	
Auxiliary energy savings		kWh/a	16	8	16	8
Energy cost savings – electricity for auxiliary energy		€/a	4	2	4	2
Total energy cost savings		**€/a**	**84**	**82**	**91**	**88**
No hydronic balancing		€	1,000		800	
Static amortization time [a]		**a**	**11.8 a**	**12.2 a**	**8.8 a**	**9.1 a**
Amortization period T_A	Price increase for natural gas	1.0%	**11.2 a**	**11.5 a**	**8.5 a**	**8.7 a**
	Interest rate	0.0%				

Table 11 Results of static hydronic balancing: existing pre-settable valves and group balancing valves – MFD with 40 units

(1) Static hydronic balancing – existing pre-settable valves and group balancing valves	Heating system	Condensing boiler and radiators				District heating and radiators				District heating and floor heating	
Multi-family dwelling (40 residential units)	Building age class	Old building		New building		Old building		New building		New building	
		Up to 2001		From 2002 to 2008		Up to 2001		From 2002 to 2008		From 2002 to 2008	
	Current situation	Multi-speed pump	HE pump	Multi-speed pump	HE pump	Multi-speed pump	HE pump	Multi-speed pump	HE pump	Multi-speed pump	HE pump
Useful floor area A_N	m²	3,800									
Living area A_{Wfl}	m²	2,850									
Specific heat savings	kWh/m²a	8		9		7		8		5	
Absolute heat savings	kWh/a	22,800		25,650		19,950		22,800		14,250	
Energy cost savings for heat	€/a	1,208		1,359		1,357		1,550		969	
Auxiliary energy consumption without hydronic balancing	kWh/a	615	390	615	390	615	390	615	390	1,470	1,135
Potential electrical energy savings	%	25%		25%		25%		25%		25%	
Auxiliary energy savings	kWh/a	154	98	154	98	154	98	154	98	368	284
Energy cost savings – electricity for auxiliary energy	€/a	42	26	42	26	42	26	42	26	100	77
Total energy cost savings	**€/a**	**1,250**	**1,235**	**1,401**	**1,386**	**1,398**	**1,383**	**1,592**	**1,577**	**1,069**	**1,046**
No hydronic balancing	€	4,900		4,000		4,900		4,000		3,500	
Static amortization time [a]	**a**	**3.9 a**	**4.0 a**	**2.9 a**	**2.9 a**	**3.5 a**	**3.5 a**	**2.5 a**	**2.5 a**	**3.3 a**	**3.3 a**
Amortization period T_A – Price increase for natural gas / district heating	1.0%	**3.9 a**	**3.9 a**	**2.8 a**	**2.9 a**	**3.5 a**	**3.5 a**	**2.5 a**	**2.5 a**	**3.2 a**	**3.3 a**
Amortization period T_A – Interest rate	0.0%										

Table 12 Results of static hydronic balancing: Installation of new pre-settable valves and group balancing valves – MFD with 40 units

(2) Static hydronic balancing – new pre-settable valves and group balancing valves	Heating system	**Condensing boiler and radiators**				**District heating and radiators**			
	Building age class	Old building		New building		Old building		New building	
		Up to 2001		From 2002 to 2008		Up to 2001		From 2002 to 2008	
Multi-family dwelling (40 residential units)	Current situation	Multi-speed pump	HE pump	Multi-speed pump	HE pump	Multi-speed pump	HE pump	Multi-speed pump	HE pump
Useful floor area A_N	m²	3,800							
Living area A_{Wfl}	m²	2,850							
Specific heat savings	kWh/m²a	11		12		10		11	
Absolute heat savings	kWh/a	31,350		34,200		28,500		31,350	
Energy cost savings for heat	€/a	1,662		1,813		1,938		2,132	
Auxiliary energy consumption without hydronic balancing	kWh/a	615	390	615	390	615	390	615	390
Potential electrical energy savings	%	25%		25%		25%		25%	
Auxiliary energy savings	kWh/a	154	98	154	98	154	98	154	98
Energy cost savings – electricity for auxiliary energy	€/a	42	26	42	26	42	26	42	26
Total energy cost savings	**€/a**	**1,703**	**1,688**	**1,854**	**1,839**	**1,980**	**1,964**	**2,173**	**2,158**
No hydronic balancing	€	16,900		13,900		16,900		13,900	
Static amortization time [a]	**a**	**9.9 a**	**10.0 a**	**7.5 a**	**7.6 a**	**8.5 a**	**8.6 a**	**6.4 a**	**6.4 a**
Amortization period T_A – Price increase for natural gas / district heating	1.0%	**9.5 a**	**9.6 a**	**7.3 a**	**7.3 a**	**8.2 a**	**8.3 a**	**6.2 a**	**6.3 a**
Amortization period T_A – Interest rate	0.0%								

Table 13 Results of static hydronic balancing per radiator and dynamic group balancing with new differential pressure controllers – MFD with 40 units

(3) Static hydronic balancing – with existing pre-settable TRVs and dynamic group balancing with new installation of differential pressure controllers	Heating system	**Condensing boiler and radiators**				**District heating and radiators**			
	Building age class	Old building		New building		Old building		New building	
Multi-family dwelling (40 residential units)		Up to 2001		From 2002 to 2008		Up to 2001		From 2002 to 2008	
	Current situation	Multi-speed pump	HE pump	Multi-speed pump	HE pump	Multi-speed pump	HE pump	Multi-speed pump	HE pump
Useful floor area A_N	m²	3,800							
Living area A_{Wfl}	m²	2,850							
Specific heat savings	kWh/m²a	11		12		10		11	
Absolute heat savings	kWh/a	31,350		34,200		28,500		31,350	
Energy cost savings for heat	€/a	1,662		1,813		1,938		2,132	
Auxiliary energy consumption without hydronic balancing	kWh/a	615	390	615	390	615	390	615	390
Potential electrical energy savings	%	25%		25%		25%		25%	
Auxiliary energy savings	kWh/a	154	98	154	98	154	98	154	98
Energy cost savings – electricity for auxiliary energy	€/a	42	26	42	26	42	26	42	26
Total energy cost savings	**€/a**	**1,703**	**1,688**	**1,854**	**1,839**	**1,980**	**1,964**	**2,173**	**2,158**
No hydronic balancing	€	6,700		6,000		6,700		6,000	
Static amortization time [a]	**a**	**3.9 a**	**4.0 a**	**3.2 a**	**3.3 a**	**3.4 a**	**3.4 a**	**2.8 a**	**2.8 a**
Amortization period T_A – Price increase for natural gas / district heating	1.0%	**3.9 a**	**3.9 a**	**3.2 a**	**3.2 a**	**3.3 a**	**3.4 a**	**2.7 a**	**2.8 a**
Interest rate	0.0%								

Table 14 Results of dynamic hydronic balancing: installation of new TRV with differential pressure controller or volume flow limiter – MFD with 40 units

(4) Dynamic hydronic balancing – new TRV with differential pressure controller or volume flow limiter	Heating system	Condensing boiler and radiators				District heating and radiators			
	Building age class	Old building		New building		Old building		New building	
Multi-family dwelling (40 residential units)		Up to 2001		From 2002 to 2008		Up to 2001		From 2002 to 2008	
	Current situation	Multi-speed pump	HE pump	Multi-speed pump	HE pump	Multi-speed pump	HE pump	Multi-speed pump	HE pump
Useful floor area A_N	m²	3,800							
Living area A_{Wfl}	m²	2,850							
Specific heat savings	kWh/m²a	15		16		14		15	
Absolute heat savings	kWh/a	42,750		45,600		39,900		42,750	
Energy cost savings for heat	€/a	2,266		2,417		2,713		2,907	
Auxiliary energy consumption without hydronic balancing	kWh/a	615	390	615	390	615	390	615	390
Potential electrical energy savings	%	25%		25%		25%		25%	
Auxiliary energy savings	kWh/a	154	98	154	98	154	98	154	98
Energy cost savings – electricity for auxiliary energy	€/a	42	26	42	26	42	26	42	26
Total energy cost savings	**€/a**	**2,307**	**2,292**	**2,458**	**2,443**	**2,755**	**2,740**	**2,949**	**2,933**
No hydronic balancing	€	18,700		15,100		18,700		15,100	
Static amortization time [a]	**a**	**8.1 a**	**8.2 a**	**6.1 a**	**6.2 a**	**6.8 a**	**6.8 a**	**5.1 a**	**5.1 a**
Amortization period T_A – Price increase for natural gas / district heating	1.0%	**7.8 a**	**7.9 a**	**6.0 a**	**6.0 a**	**6.6 a**	**6.6 a**	**5.0 a**	**5.0 a**
Interest rate	0.0%								

6 Simplified estimation of potential savings at macroeconomic level

In Germany there are at present about 18.9 million residential buildings [39], of which approximately 84% are supplied by a central heating system (including district heating) [40]. According to the statistical evaluation in Annex B – Current statistics on implemented hydronic balancing, 85% of residential buildings do not have hydronic balancing.

The dena Report on Buildings 2018 shows greenhouse gas emissions due to energy consumption for building heating of 190.2 million t CO_2 equivalent [41]. With average potential savings of 5 to 10%, greenhouse gas emissions could thus be reduced by 6.8 to 13.5 million $t_{CO2\_equivalent}$ (see Table 15). If we take the average value of 7.5%, the potential annual reduction from complete implementation of hydronic balancing in existing buildings is approximately 10 million $t_{CO2\_equivalent}$.

Table 15 Estimated total potential economic efficiency savings through hydronic balancing

Greenhouse gas emissions from building heating			190,200,000	$t_{CO2\_equivalent}$	[41]
of which from central heating systems (including district heating)		83.6%	159,007,200	$t_{CO2\_equivalent}$	[40]
of which from not hydronically balanced central heating systems		85.0%	135,156,120	$t_{CO2\_equivalent}$	Annex B
Reductions in greenhouse gas emissions by hydronic balancing	**from**	**5.0%**	**6,757,806**	$t_{CO2\_equivalent}$	
	to	**10.0%**	**13,515,612**	$t_{CO2\_equivalent}$	
	medium	**7.5%**	**10,136,709**	$t_{CO2\_equivalent}$	

7 Conclusion

The present study provides an assessment of of energy-related and economic impacts of methods for hydronic balancing. The main goal of the study is to find a realistic estimation for systems that achieve static and dynamic hydronic balancing.

For this purpose, the present study is divided into two parts. The first part presents an overview of currently available most important literature related to hydronic balancing. It was found that the available literature sources differ significantly with regard to study approach (simulation, measurement, field test), results, and quality of the work. The authors of this study therefore decided to select those sources that have been precisely balanced both thermodynamically and hydronically and in which the essential boundary conditions are understandably documented.

Based on these criteria, it can be stated that the range of potential thermal energy savings documented in the literature is 0 to 15% relative to the respective initial situation. Larger variations can be seen with regard to electrical savings, which lie in a range of 12 to 50%. For residential buildings with radiator heating, a reliable database is available for conventional hydronic balancing methods.

By contrast, conclusions regarding the differentiation of potential savings for different building types and sizes, for heating surfaces integrated into building elements, and for additional improvements through dynamic hydronic balancing are only available to a limited extent. To allow a reliable conclusion with regard to economic feasibility, the values from the literature have been complemented by current normative values from the standards DIN V 18599 / EN 15316-2. This applies in particular to issues regarding system design and layout and replacement of control equipment and valves.

With regard to economic issues, the analyses in the scope of the study clearly show that amortization periods strongly depend on the installation expenditure. With existing pre-settable valves for which calculation and adjustment must be performed, the amortization time for existing residential buildings with radiator heating is 6 to 9 years in the single-family dwelling and 2.5 to 4 years in the multi-family dwelling considered in the analysis. With the multi-family dwelling, if dynamic group balancing with installation of new differential pressure controllers is carried out in addition to adjustment of existing pre-settable valves, the potential savings rise while the amortization times remain within comparable ranges. If the pre-settable valves must first be installed, the corresponding payback time for the investment increases. Larger savings can be achieved if dynamic hydronic balancing is carried out by the installation of valves with differential pressure controllers or volume flow limiters on the radiators. Despite higher costs, the amortization times compared to the installation of pre-settable valves drop to 8.5 to 12.2 years in the single-family dwelling or 5 to 8.1 years in the multi-family dwelling considered in the analysis.

The evaluated statistical surveys show that approximately 85% of residential buildings in Germany do not have hydronic balancing. Assuming average energy savings of 7.5%, greenhouse gas emissions could be reduced by approximately 10 million $t_{CO2\_equivalent}$ per year by carrying out hydronic balancing.

In summary, from the present study it can be concluded that hydronic balancing has a positive energy effect on the heat consumption and electrical auxiliary energy consumption of heating systems. The relative and absolute savings differ depending on the initial situation and the implemented measures for hydronic balancing.

Savings of 2.5 to 16 kWh/m²a[16] are typically achieved for thermal energy consumption (final energy), and 25% for auxiliary energy consumption (electricity).
For existing residential buildings with radiator heating and existing pre-settable thermostatic valves, these energy savings lead to amortization times of approximately 8 to 9 years (single-family dwelling) or approximately 3.5 to 4 years (multi-family dwelling) for retrofit of hydronic balancing. The calculated useful life is 15 years. Retrofit hydronic balancing of an existing network is therefore economically feasible in the sense of Section 5 of the Energy Conservation Act (Germany).
In new heating systems, hydronic balancing is indispensable for the installation of a heating system that conforms to the technical specifications. It is performed in the course of the necessary design and installation process.
Dynamic hydronic balancing delivers additional potential energy savings compared to static balancing. If installation of new thermostatic valves is necessary for carrying out hydronic balancing, it results in more favourable amortization times than static balancing.

Complete implementation of hydronic balancing in existing buildings would enable a potential reduction of approximately 10 million $t_{CO2\_equivalent}$ per year.

[16] The higher savings values also include savings arising from the replacement of thermal control valves for carrying out hydronic balancing.

8 Bibliography

[1] *Energieeinsparungsgesetz in der Fassung der Bekanntmachung vom 1. September 2005 (BGBl. I S. 2684), das durch Artikel 1 des Gesetzes vom 4. Juli 2013 (BGBl. I S. 2197) geändert worden ist.*

[2] *Zweite Verordnung zur Änderung der Energieeinsparverordnung vom 16. Oktober 2013 (Energieeinsparverordnung - EnEV 2014).*

[3] *Gesetz zur Förderung Erneuerbarer Energien im Wärmebereich (Erneuerbare-Energien-Wärmegesetz - EEWärmeG) in der seit 1. Mai 2011 geltenden Fassung.*

[4] *RICHTLINIE 2010/31/EU DES EUROPÄISCHEN PARLAMENTS UND DES RATES vom 19. Mai 2010 über die Gesamtenergieeffizienz von Gebäuden (Neufassung), Änderung vom 30. Mai 2018 durch RICHTLINIE (EU) 2018/844 DES EUROPÄISCHEN PARLAMENTS UND DES RATES.*

[5] RICHTLINIE (EU) 2018/844 DES EUROPÄISCHEN PARLAMENTS UND DES RATES vom 30. Mai 2018 zur Änderung der Richtlinie 2010/31/EU über die Gesamtenergieeffizienz von Gebäuden und der Richtlinie 2012/27/EU über Energieeffizienz.

[6] *VDZ: Fachregel – Optimierung von Heizungsanlagen im Bestand, VDZ – Spitzenverband der Gebäudetechnik, Berlin.*

[7] *SAENA: Hydraulischer Abgleich für Heizungssysteme, Sächsische Energieagentur GmbH SAENA, 2012.*

[8] *Schweikhardt, F.: Hydraulischer Abgleich und Heizungspumpentausch – Ein Pilotprojekt der Evangelischen Landeskirche in Baden, Evangelische Landeskirche in Baden, 2014.*

[9] *Schweikhardt, F.: Hydraulischer Abgleich und Heizungspumpentausch – Ein Pilotprojekt der Evangelischen Landeskirche in Baden, Evangelische Landeskirche in Baden, 2017 - Abschlussbericht.*

[10] *ASUE: Hydraulischer Abgleich von Heizungsanlagen in Frage und Antwort – Für Wohnungseigentümer, Hausbesitzer und Wohnungsverwaltungen, ASUE Arbeitsgemeinschaft für sparsamen und umweltfreundlichen Energieverbrauch e.V., 2017.*

[11] *DENA: Hydraulischer Abgleich - So wird es behaglich! Effizient geheizt mit dem hydraulischen Abgleich, Deutsche Energie-Agentur GmbH (dena), Berlin, 02/2017.*

[12] *Recknagel, Sprenger, Albers: Taschenbuch für Heizungs + Klimatechnik, 78. Auflage, 2017/2018.*

[13] *Wolff, D.; Jagnow, K.: Optimus - Umweltkommunikation in der mittelständischen Wirtschaft am Beispiel der Optimierung von Heizungssystemen durch Information und Qualikation zur nachhaltigen Nutzung von Energieeinsparpotenzialen / Deutsche Bundesstiftung.*

[14] *Jagnow, K.: Verfahren zur energetischen und wirtschaftlichen Bewertung von Qualitätssicherungsmaßnahmen in der Heizungsanlagentechnik, Universität Dortmund, Dissertation, 2004.*

[15] *Irrek, W.: Optimierung der Heizungssysteme und hocheffiziente Umwälzpumpen in größeren Gebäuden / Wuppertal Institut für Klima, Umwelt, Energie GmbH im Wissenschaftszentrum Nordrhein-Westfalen - Abschlussbericht. 2005. _ Forschungsbericht.*

[16] *Felsmann, C.; Hirschberg, R.: Das Rohrnetz in Heizungsanlagen - Eine Analyse des Teillastverhaltens und der Effizienz von Rohrnetzen. VDI Verlag Düsseldorf, 2007., ISBN 978 3 18 315519 4.*

[17] *Hirschberg, R.: Vom Heizkessel zum Heizkörper - ohne Wärmeverteilung geht nichts. In: TGA-Kongress (2007).*

[18] *Hirschberg, R.: Auslegung und dynamischer Betrieb von Wärmeverteilsystemen. In: TGA Kongress (2007).*

[19] *Guzek, G.: Zur Energieeinsparung in Heizungsanlagen durch den hydraulischen Abgleich, Dissertation TU Dresden (2009).*

[20] *Seifert, J.; Meinzenbach, A., Knorr, M. Perschk, A.: Energetischer Vergleich von thermostatischen Heizkörperventilen mit und ohne Durchflussregelung, TU Dresden (unveröffentlichter Forschungsbericht), 2014.*

[21] *DIN V 18599:2016-10. Energetische Bewertung von Gebäuden - Berechnung des Nutz-, End- und Primärenergiebedarfs für Heizung, Kühlung, Lüftung, Trinkwarmwasser und Beleuchtung (11 Normenteile), Beuth Verlag GmbH.*

[22] *DIN EN 15316-2: Energetische Bewertung von Gebäuden – Verfahren zur Berechnung der Energieanforderungen und Nutzungsgrade der Anlagen – Teil 2: Wärmeübergabesysteme (Raumheizung und -kühlung), Modul M3-5, M4-5; 2017, Beuth Verlag GmbH.*

[23] *Thalfeldt, M.; Simson, R.; Kurnitski, J.: The effect of hydronic balancing on room temperature and heat pump efficiency of a building with underfloor heating In: Energy Procedia 96 (2016) 467 – 477.*

[24] *Oschatz, B.; Felsmann, C.: Hydraulischer Abgleich in DIN V 18599 – Überarbeitung der Kennwerte für den hydraulischen Abgleich in Rohrleitungen, ITG Dresden 2007.*

[25] *Osojnik, M; Kolb, S.; Chambris, A.; Schramm, H.: Hydronic balacing and control - how to overcome the global cvhallenge of reducing energy use in multifamily housing, ECEEE 2017 summer study, 2017 (https://www.eceee.org/summerstudy/).*

[26] *EN 14336: Heizungsanlagen in Gebäuden – Installation und Abnahme der Warmwasser-Heizungsanlagen; 2005, Beuth Verlag GmbH.*

[27] *DIN 18380:2012-09: VOB Vergabe- und Vertragsordnung für Bauleistungen - Teil C: Allgemeine Technische Vertragsbedingungen für Bauleistungen (ATV) - Heizanlagen und zentrale Wassererwärmungsanlagen.*

[28] *DIN EN 15378:2008-07: Heizungssysteme in Gebäuden - Inspektion von Kesseln und Heizungssystemen; Deutsche Fassung.*

[29] *DIN V 4701-10:2003-08. Energetische Bewertung heiz- und raumlufttechnischer Anlagen - Heizung, Trinkwassererwärmung, Lüftung.*

[30] *VDMA 24199: Regelungstechnische Anforderungen an die Hydraulik bei Planung und Ausführung von Heizungs-, Kälte-, Trinkwarmwasser- Raumlufttechnischen Anlagen, Mai 2005.*

[31] *ZUB Kassel e.V. im Auftrag des BMVBS/BBSR: Entwicklung einer Datenbank mit Modellgebäuden für energiebezogene Untersuchungen, insbesondere der Wirtschaftlichkeit, Oktober 2010.*

[32] *BMVBS-Online-Publikation, Nr. 11/2012: Vergleichswerte für Verbrauch bei Wohngebäuden, Juni 2012.*

[33] *ITG Dresden: Wirtschaftlichkeit von Systemen zur Erfassung und Abrechnung des Wärmeverbrauchs, Januar 2014 im Auftrag des Bundesinstituts für Bau-, Stadt- und Raumforschung (BBSR).*

[34] *VDI 6025 2012-11: Betriebswirtschaftliche Berechnungen für Investitionsgüter und Anlagen, November 2012.*

[35] *BDEW-Heizkostenvergleich Altbau 2017, Stand Januar 2017.*

[36] *IB Hauser u.a.: Kurzgutachten zur Aktualisierung und Fortschrei-bung der vorliegenden Wirtschaftlichkeitsuntersu-chung sowie zu Flexibilisierungsoptionen, im Auftrag des BMWi, April 2018.*

[37] *VDI 2067 Blatt 1: Wirtschaftlichkeit gebäudetechnischer Anlagen, Grundlagen und Kostenberechnung,* September 2012.

[38] *Seifert, J.; Meinzenbach, A., Haupt, J. Perschk, A.: Energieeinsparung durch den Austausch von thermostatischen Reglern, HLH Bd. 62 2011.*

[39] *Gebäude und Wohnungen Bestand an Wohnungen und Wohngebäuden 2017, Statistisches Bundesamt (Destatis), 2018.*

[40] *BDEW-Studie zum Hiezungsmarkt: Wie heizt Deutschland?, Berlin Juli 2015.*

[41] *dena-GEBÄUDEREPORT KOMPAKT 2018: Statistiken und Analysen zur Energieeffizienz im Gebäudebestand, 04/2018.*

9 List of symbols

b	overdimensioning factor	-
f_{hydr}	hydronic factor	-
c_p	specific heat capacity	kJ/(kg K)
C_{P1}, C_{P2}	Constants	-
$e_{h,d,aux}$	expenditure factor for heating pump operation	-
EEI	energy efficiency index	-
f_e	pump efficiency factor	-
J	static amortization time	y
$\dot{m}$	mass flow	kg/s
n	heating area exponent	-
P_{hydr}	hydronic output	W
p	interest rate	%
P_V	annual price adjustment	%
$Q_{h,b}$	heat distribution	kWh
Q_{ce}	heat transfer	kWh
$\dot{Q}$	heat flow	W
$\dot{Q}_{h,max}$	maximum heat output	W
q	interest factor	-
r	price adjustment factor	-
T_A	amortization time	a
T_N	calculated useful life	a
t_h	operating time	h
$W_{h,d}$	electrical expenditure	kWh
$W_{h,d,hydr}$	hydronic energy demand	kWh
$\beta_{h,d}$	hydronic load factor	-
β_i	thermal load factor	-
$\vartheta_{i,h,set}$	indoor setpoint temperature	°C
ϑ_R	return temperature	°C
$\vartheta_{R,a}$	average return temperature	°C
ϑ_{RD}	design return temperature	°C
ϑ_S	supply temperature	°C
$\vartheta_{S,a}$	average supply temperature	°C
ϑ_{SD}	design supply temperature	°C
$\Delta\vartheta$	temperature difference	K
$\Delta\vartheta_{ce}$	total temperature variation	K
$\Delta\vartheta_{ctr}$	temperature variation due to control deviation	K
$\Delta\vartheta_{emb}$	temperature variation due to additional heat loss	K
$\Delta\vartheta_{hydr}$	temperature variation due to lack of hydronic balancing	K
$\Delta\vartheta_{im}$	temperature variation due to intermittent operation	K
$\Delta\vartheta_{rad}$	temperature variation due to radiation of the heat transfer system	K
$\Delta\vartheta_{roomaut}$	temperature variation due to room automation	K
$\Delta\vartheta_{str}$	temperature variation due to stratification	K

Annex A – Hydronic balancing measures according to VdZ

In recent years an evaluation matrix for hydronic balancing was developed in the framework of the various activities of heating technology associations. This matrix has been published by the lead association for building services, VdZ, which acts a forum for energy efficiency in building services. The method is used as a basis for evaluation in the framework of KfW subsidy programs. It is briefly described below.

There are basically two methods that can be used to achieve hydronic balancing: method A and method B. They are described in detail in Table 16.

Table 16 Methods for performing hydronic balancing (two-pipe heating system with radiators) – individual measures

	Method A (Approximation method allowed with heated useful floor area up to 500 m² per heating circuit equipped with a pump, differential pressure controller or flow controller; see also technical rules, minimum output)	**Method B** (usually: software calculation, for all system sizes; see also technical rules, recommended)
For use with subsidy measures:	**Approved for:** - Replacement of heat generator - Heating optimization - Insulation upgrades	**Required for:** - Heating package

Services to be documented:	- Determination of heating surface flows based on estimated heat load (according to building age class (W/m²), installed heating surface size, etc.)
	- Thermostatic valves with conventional presetting: Determination of pre-set values by means of heating surface flow and assumed differential pressure
	- Thermostatic valve with automatic flow limiting: Pre-set value = determined heating surface flow
	- Approximate determination of:
	  ○ System temperature
	  ○ Pump head
	  ○ Total flow
	  ○ Settings for group valves and/or differential pressure controllers, as appropriate
		- Room-by-room heat load calculation based on EN 12831 and relevant supplements. Simplifications are possible (e.g. U values based on types)
		- Heating surface layout: Calculation of heating surface flows depending on the design flow and return temperatures and heating surface sizes
		- Determination (usually by pipe network calculation) of:
		  ○ Pre-set values for thermostatic valves
		  ○ Pump head
		  ○ Total flow
		  ○ As appropriate, settings of group valves and/or differential pressure controllers
		  ○ Optimization of supply temperature for heating surfaces in existing buildings
		- If the majority of the existing piping installation is concealed, the pre-set values can be determined based on assumed pipe lengths and nominal diameters.

Specifically for floor heating installations and single-pipe heating systems, additional requirements are stated:

Services to be documented with single-pipe heating systems:

- Determination of individual single-pipe heating circuit flows: The heat load is determined according to the building age class (method A) or according to method B.
- Balancing of the single-pipe heating circuit by means of flow limiting or flow regulation and return temperature limiting
- Determination of the necessary pump head and the total flow
- Adjusting the heating circuit circulation pump(s)
- Exposed pipes must be insulated (check eligibility of the relevant subsidy program)
- Note: Changing to a two-pipe system with radiators is recommended and is eligible for a subsidy

Services to be documented with floor heating:

- The individual heating circuits must be equipped with pre-settable balancing equipment, volume flow sensors, or flow regulators or limiters.
- Method A or method B is used.

In addition to the described methods, technical guidelines for carrying out hydronic balancing in non-residential buildings and efficiency houses (new construction) are available from VdZ. They fit into the Table 6 scheme.

Annex B – Current statistics on implemented hydronic balancing

In the scope of a statistical survey conducted by the Internet portal *www.energiesparclub.de* and *co2online gGmbH*, 23,000 buildings were analyzed with regard to hydronic balancing. The share of buildings with hydronic balancing per German federal state is shown in Table 17. The number of residential buildings per federal state with hydronic balancing in all of Germany has been determined by Destatis [39].

Table 17 Percentage of buildings with hydronic balancing

Federal state	Percentage of buildings with hydronic balancing	Total number of residential buildings	Number of residential buildings with hydronic balancing
Saxony	24.3%	822,586	199,888
Brandenburg	20.7%	665,899	137,841
Thuringia	19.0%	528,318	100,380
Mecklenburg-West Pomerania	18.6%	392,676	73,038
Saxony-Anhalt	18.5%	574,780	106,334
Berlin	16.0%	324,681	51,949
Rhineland-Palatinate	15.6%	1,181,157	184,260
Baden-Württemberg	15.3%	2,414,446	369,410
Bavaria	15.3%	3,040,234	465,156
Hessen	15.2%	1,387,704	210,931
Hamburg	15.1%	250,872	37,882
Saarland	15.0%	304,717	45,708
North Rhine-Westphalia	13.6%	3,868,712	526,145
Schleswig-Holstein	12.4%	815,222	101,088
Lower Saxony	12.1%	2,236,433	270,608
Bremen	11.8%	139,544	16,466
Percentage of residential buildings in Germany with hydronic balancing (rounded)		18,947,981	2,897,085
		15%	

Based on these statistics, it can be shown that in the entire federal territory there is still considerable potential with buildings where hydronic balancing can be carried out. It can also be seen that in the former East German states there is a higher percentage of buildings where hydronic balancing has been carried out, due to the many new buildings constructed after the reunification.