TP1: Experiments with software Lesosai

The thermal performance of this illustrated building project has been calculated with software Lesosai.

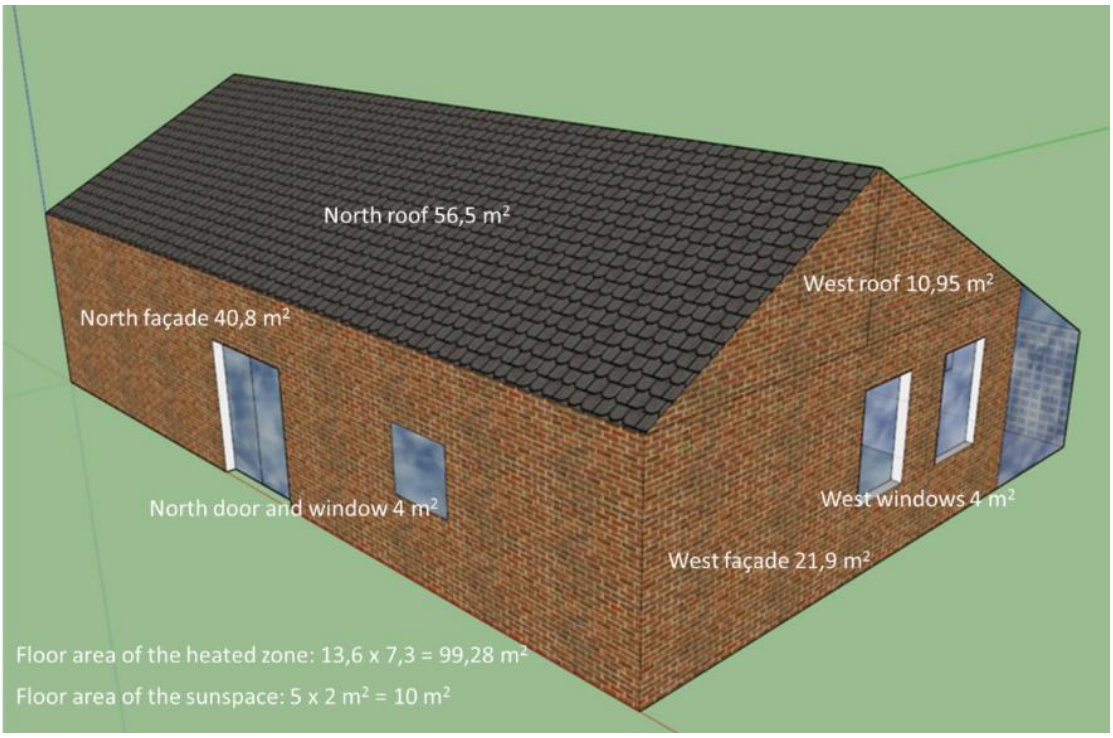


Fig. 1: North and west facade of the house

Fig. 2: South and east facade of the house

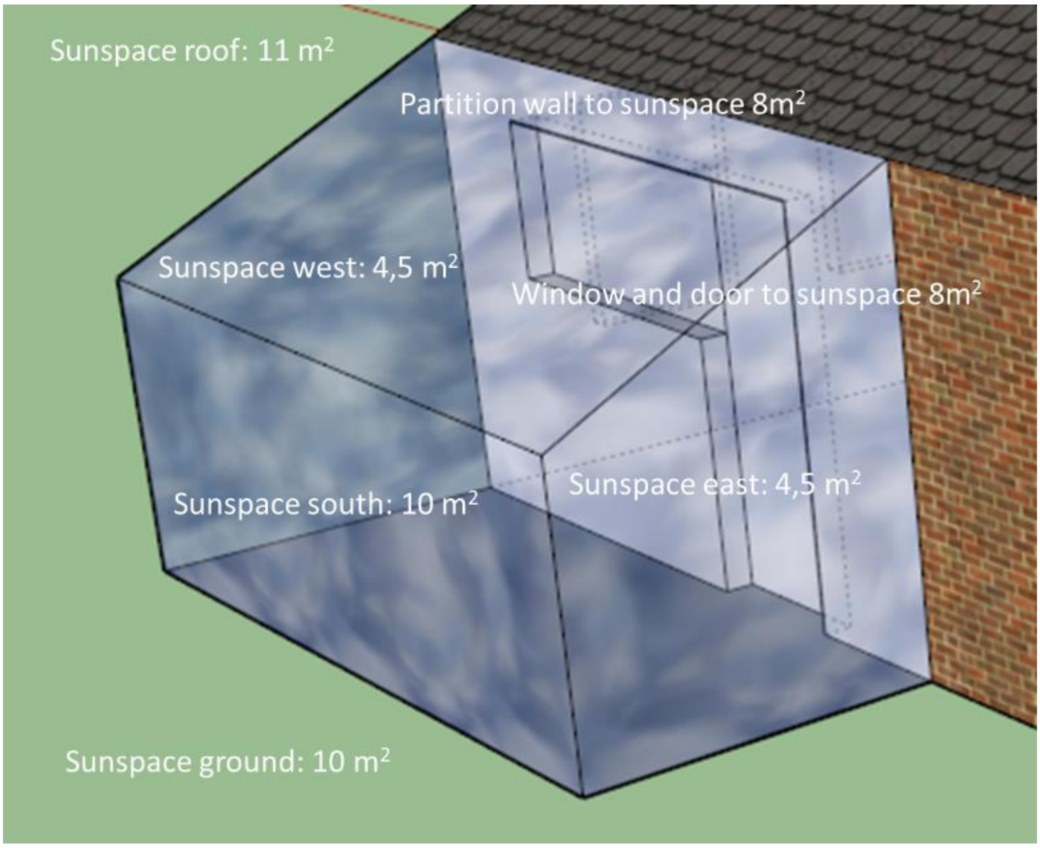


Fig. 3: Greenhouse

Following characteristics are given by the architect and the values have already been entered in Lesosai:

Internal temperature:	$20\ °C$
Average power of internal gains:	$250\ W$
Overall efficiency of the heating system (production, distribution, emission and control losses considered):	$75\ \%$
U-value of the ceiling:	$0{,}2\ W/(m^2K)$
U-value of the brick walls:	$0{,}3\ W/(m^2K)$
U-value of the roof: (not part of the heated area)	$5{,}0\ W/(m^2K)$
U-value of windows:	$2{,}0\ W/(m^2K)$
U-value of the partition wall to sunspace:	$0{,}3\ W/(m^2K)$
Resulting floor U-value of the heated zone:	$0{,}29\ W/(m^2K)$
Resulting floor U-value of the sunspace:	$0{,}87\ W/(m^2K)$

The climatic data for Lausanne, located at an altitude of $600\ m$ are used for the calculation.

Calculation of the energy balance of the building project (from annexe L of EN 832) by the software Lesosai

All the values of the house have already been entered in Lesosai and calculated according to the European Standard EN 13790, an extension of EN 832.

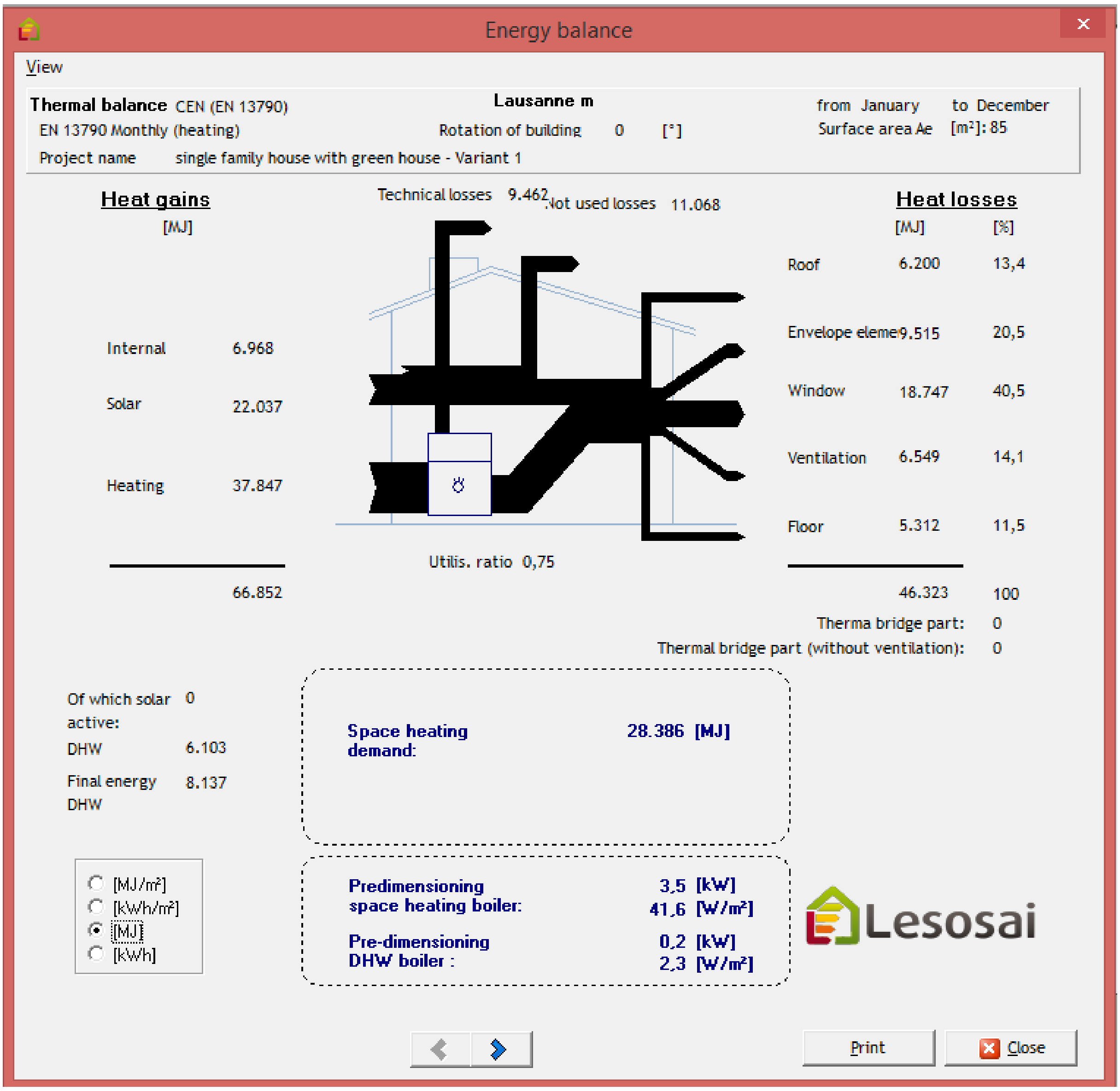


Fig. 4: Energy balance of the building

General data

Heating demand in MJ (January-December)	28386 MJ	100 %
Heating demand in kWh (January-December)	7885 kWh	100 %
Specific heating demand in MJ/m^2 (January-December)	333.9 MJ/m^2	100 %
Specific heating demand in kWh/m^2 (January-December)	92.8 kWh/m^2	100 %
Heating demand calculated by SIA 380/1	31165 MJ	110 %
Heating demand in the period from October to April	27455 MJ	97 %
Heating demand in the period from May to September	931 MJ	3 %
Heating demand for the same building in Bari (Italy) from January to December	8403 MJ	30 %
Heating demand for the same building in Zermatt (Switzerland) from January to December	47830 MJ	169 %
Heat losses in Zermatt	75450 MJ	
Heat losses in Lausanne	46323 MJ	
Solar gains in Zermatt	24249 MJ	
Solar gains in Lausanne	22037 MJ	

Heated zone data

Heating demand when the indoor temperature increase from 20° C to 21° C	31445 MJ	111 %
Heating demand when the indoor temperature decrease from 20° C to 19° C	25521 MJ	90 %
Heating demand when thermal inertia decrease from 100 kJ/m^2K to 50 kJ/m^2K	32655 MJ	115 %
Heating demand when thermal inertia increase from 100 kJ/m^2K to 125 kJ/m^2K	27941 MJ	99 %
Heating demand when the number of persons changes from 2 to 5	26840 MJ	95%
Heating demand when the mean heat release per person is 200 W instead of 70 W	26487 MJ	93 %

Heating demand when the reduction factor of heat gains of electrical installations is 90 %	27739 MJ	98 %
Heating demand in MJ when domestic hot water consumption is 50 l/day	32182 MJ	113 %
Heating demand in MJ when domestic hot water consumption is 200 l/day	43643 MJ	154 %

For comfort and hygienic reasons, a minimum ventilation rate is needed. The entered value for the house is $n_{min} = 0{,}5 \cdot h^{-1}$ during use corresponding to $\dot{V} = 120\ m^3/h$.

Heating demand without a mechanical ventilation and $n_{min} = 1 \cdot h^{-1}$ corresponding to $\dot{V} = 240\ m^3/h$	33214 MJ	117 %
Heating demand when the supply air flow rate and the exhaust air flow rate is $120\ m^3/h$ without a heat recovery efficiency (0 %) (mean wind exposure and high tightness)	31593 MJ	111 %
Heating demand with a heat recovery efficiency of 50 %	28757 MJ	101 %
Heating demand with a heat recovery efficiency of 80 %	27066 MJ	95 %
Heating demand with a heat recovery efficiency of 90 %	26505 MJ	93 %
Heating demand when the supply air flow rate and the exhaust air flow rate is $70\ m^3/h$ without a heat recovery efficiency (0 %) (mean wind exposure and high tightness)	29228 MJ	103 %
Heating demand with a heat recovery efficiency of 50 %	27582 MJ	97 %
Heating demand with a heat recovery efficiency of 80%	26598 MJ	94 %
Heating demand with a heat recovery efficiency of 90 %	26271 MJ	93 %
Heating demand without the sunspace	26684 MJ	94 %
Differences?		6 %
Heating demand when the U-value of the windows changes from 2,0 W/m^2K to 1,3 W/m^2K	23311 MJ	82 %

TP2: Laboratory experiments in heating systems

1. Basics about pumps/circulators

1.1. System characteristic

The system curve (network characteristic) shows the pressure loss in 3 different closed given pipeworks as a function of the volume flow.

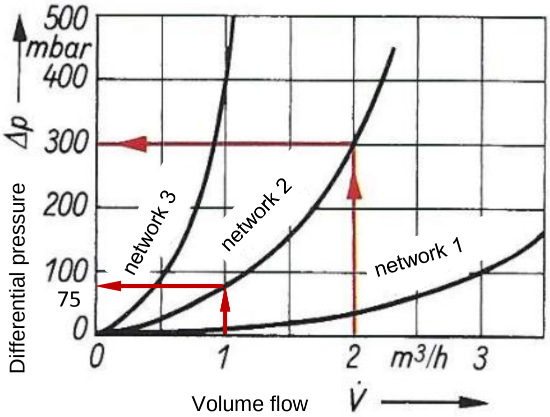


Fig. 1: Examples of system characteristics

The network losses are proportional to $\dot{V}^2$: $\frac{\Delta p_1}{\Delta p_2} = \left(\frac{\dot{V}_1}{\dot{V}_2}\right)^2$ $\frac{300}{75} = \left(\frac{2}{1}\right)^2$

When water velocity in the tube network is changing, also the friction or the system resistance varies. If the flow rate in the tube network is decreased to 50 %, the pressure is reduced to one fourth. If the flow rate is doubled, the pressure drop is increased by a factor of 4.

1.2. Pump characteristic

The pump characteristic shows the relationship pressure drop versus volume flow rate. The form of the pump characteristic depends on the particular pump and its design.

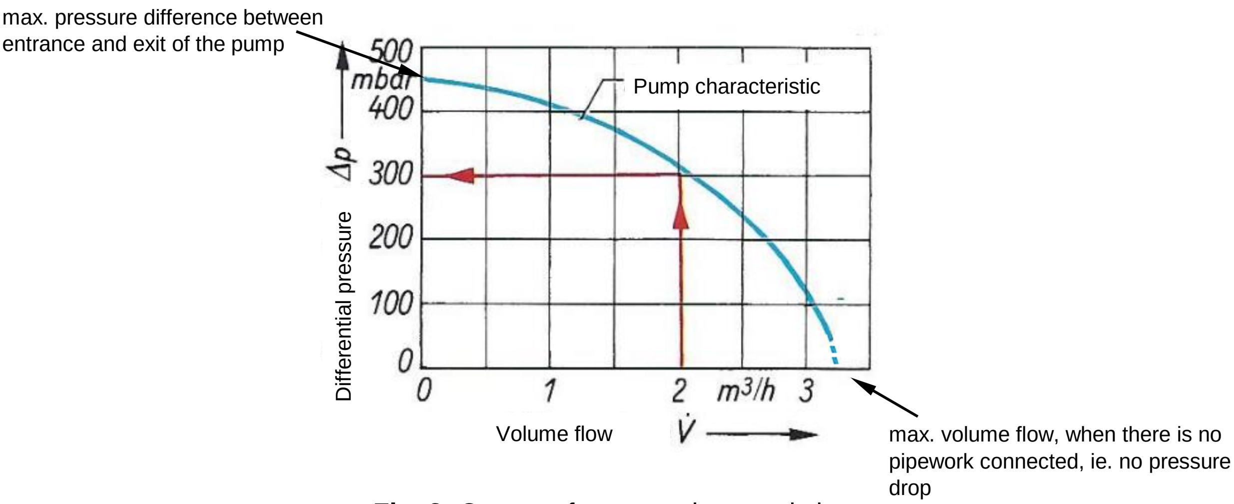


Fig. 2: Course of a pump characteristic

1.3. Operating point with the circulator

The operating point of a circulator is at the system characteristic and the pump characteristic intersection.

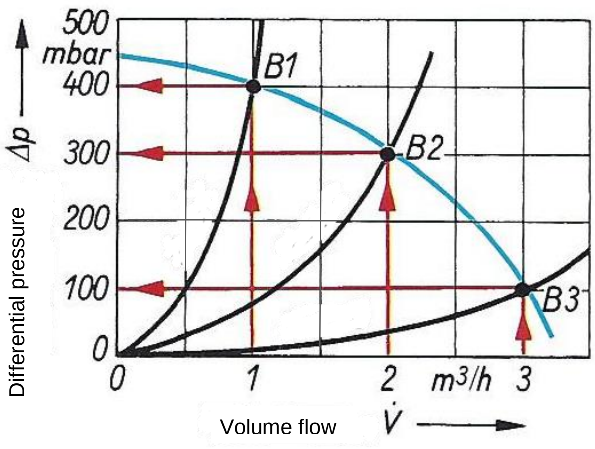


Fig. 3: Operating points of a circulator

The efficiency of a pump varies depending on the operating point. This point remains normally not constant over time because of the changing network characteristic and flow rates when the thermostatic valves are opened and closed, e.g. B3 when three radiators are open and B1 when only one radiator is open.

1.4. Throttling

By increasing the pressure drop (for example by closing thermostatic valves), the system curve becomes steeper, while the operating point also moves (B3-B2-B1).

1.5. Circulators with/without feed back control

Pumps without feedback control operate independently of the radiator valves of a building always at full power. They are often oversized, but they are still standard in most single-family houses. However, it is advisable to replace them by speed-controlled circulator pumps. The main difference between an uncontrolled and a controlled circulating pump is that the feed back controlled pump automatically adjusts its pressure difference to the changing hydraulic conditions of the heating system.

1.5.1. Differential pressure control of pumps

The aim of the differential pressure control is to counteract the pressure drop behavior of the thermostat valves to save energy. Nevertheless, it must be ensured that the minimum required differential pressure is always reached. The control of the pressure difference is for instance required if there are thermostatic valves which open or close. This means that sometimes more and sometimes less resistance is present. The pump identifies those pressure differences automatically and reacts with an increased or reduced pump performance. There are typically two different modes to control the pressure difference:

- Control at a constant differential pressure $\Delta p - c$ (reference value is constant)
- Control at a variable differential pressure $\Delta p - v$ (reference value is variable)

Which of these two pump modes should be used depends on the characteristics of the pipe network. A system with constant differential pressure is used preferably, when the resistance of the tubes is small compared to the individual resistances by e.g. thermostatic valves or other single elements. A variable differential pressure control is useful when the resistance of the pipework itself is similar to the resistance of the thermostatic valves (for example in undersized two-pipe systems).

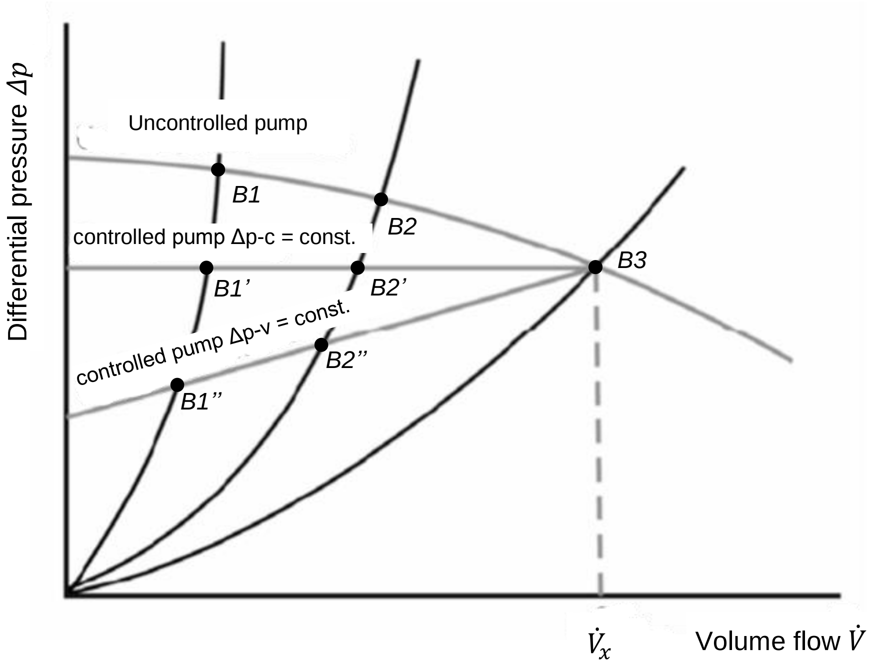


Fig. 4: Constant and variable differential pressure

1.5.2. Constant differential pressure control $\Delta p - c$

In this control mode, the central differential pressure control between pump input and output keeps the pressure difference at a constant value (Figure 4). Technically this is achieved by electronically controlled, stepless change of the rotational frequency of the impeller or rotor.

1.5.3. Variable pressure control $\Delta p - v$

In this control mode, the differential pressure reference value is changed linearly between Δp and $1/2\,\Delta p$. The differential pressure value becomes smaller with decreasing flow rate. The setpoint corresponds to the operating point, for which the required volume flow rate was calculated. (B3-B2''-B1'')

Demonstration board - Wilo Brain

To perform the following laboratory experiments, a small heating test system was installed on a small demonstration wall. The wall was built by the Wilo company under the denomination „Wilo-Brain-Board".

The Wilo-Brain-Board shows the key components of a hot water heating system which are necessary to explain the hydraulic process of such systems in a realistic way.

As the function of the heat source itself is of secondary importance in hydraulic processes, it has only been shown symbolically on this test wall and the water stays at room temperature.

To allow an easy understanding of the laboratory tests, the assembled components and their positioning on the wall is explained.

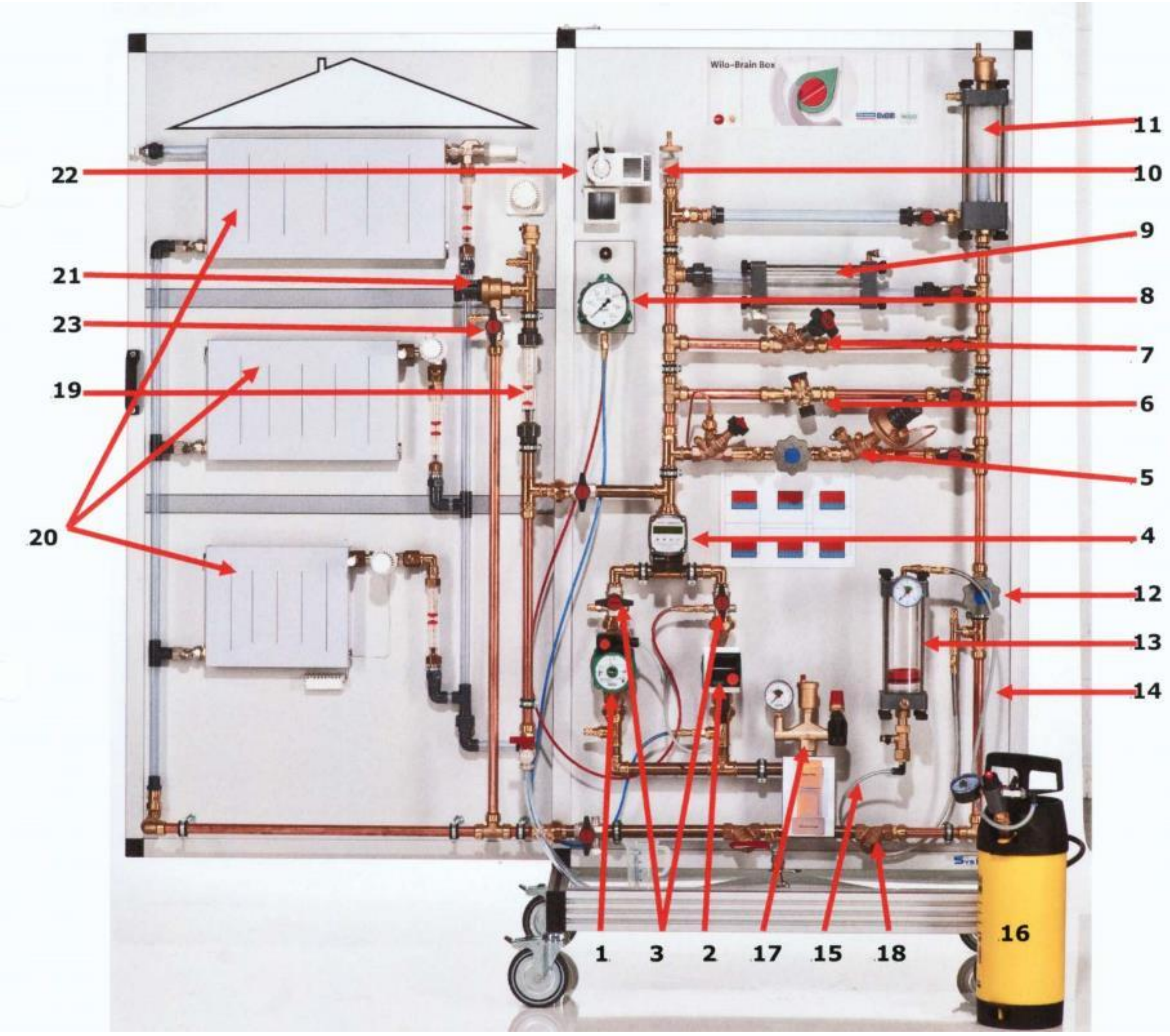


Fig. 5: Wilo Brain Box classic plus

Detailed parts list of the mounted components:

No.	Description	Technical feature
1	Uncontrolled heating circulation pump	Wilo, Type RS 25/6 (3-stage)
2	Controlled high efficiency pump	Wilo, Type Stratos PICO $U = 230\ V$; $P = 3 - 40W$ Control mode: Δp variable Energy Class A
3	Ball valves	To shut of the pumps and pipelines strands DN 20; PN 30
4	Flow transmitter	To measure the flow rates in the total pipeline route
5	Differential pressure regulator	½`; $\Delta p = 0{,}05 - 0{,}03\ bar$; $max. = 130°\ C$
6	Volume flow limiter	Adjustable from $90 - 450\ l/h$
7	Balancing valve	½`; $\Delta p = 0{,}15 - 0{,}4\ bar$
8	Differential pressure measurement device	PN 25, $\Delta p = 0 - 1{,}6\ bar$ with quick coupling
9	Air pot, horizontally	Transparent; 2 Air-screws; $D = 90mm$
10	Air vent	Transparent
11	Air pot, vertically	Transparent; 1 Air-screw; $D = 90mm$
12	Gear ball valve	1` ; DN 25
13	Membrane expansion vessel (MAG)	Transparent; perpendicular; $D = 90\ mm$; with 2 quickly off valves
14	Flexible tube	To regulate the admission pressure in the expansion vessel
15	Flexible connection tube	Makes the connection between the water reservoir of the expansion vessel and the piping system
16	Hand pump for filling	$V_{max.} = 5\ l$; $p_{e,zul.} = 3\ bar$
17	Security group of the heat generator	Consisting of a manometer, vent and security valve
18	Strainer	
19	Volume flow meter for the radiator circuit	$\dot{V} = 40 - 640\ l/h$
20	3 radiators	Each radiator possesses a thermostatic valve and a shut off lockshield
21	Overcurrent valve	Angular shape, ¾`; preset; $\Delta p = 100 - 500\ mbar$
22	Electrical power meter	$U = 230V$; $P_{max.} = 3000\ W$; Power consumption: $P = 1{,}5\ W$
23	Ball valves	To shut off the different tubing strings

Experiment 1.1

Pressure loss as a function of the volume flow

The experiment aims at determining the pressure loss of a partial section of a heating system at different flow rates through measuring and at determining pump characteristic curves as a function of pump pressure at a selected pump stage.

The relationship pressure drop versus flow rate will be represented graphically.

Important: Before starting the test, it must be ensured that the system has been properly filled and bled!

The ball valves on the wall have to be adjusted so that the water flows as shown by the **high-lighted green watercourse** in the following schematic diagram:

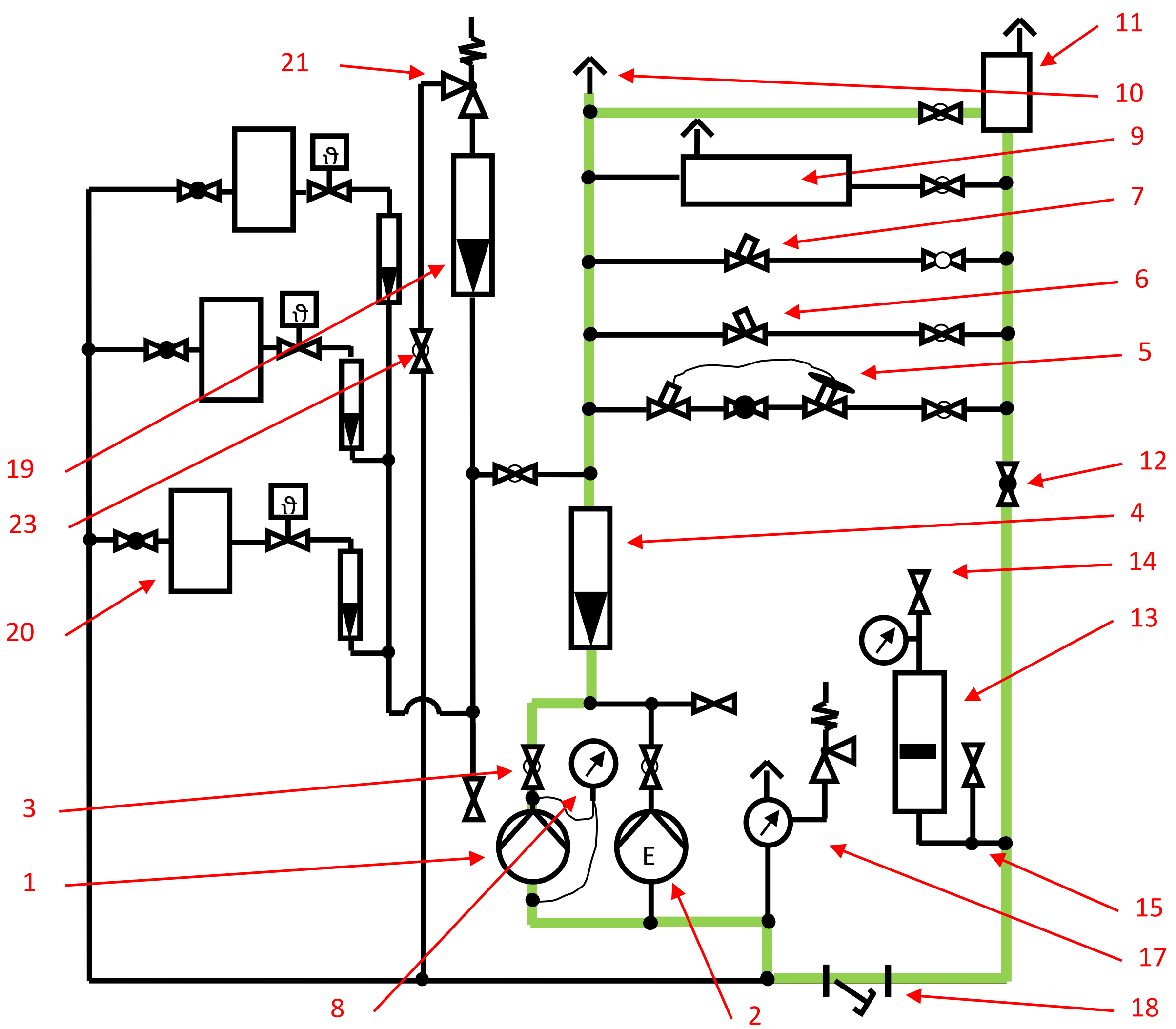


Fig. 6: Watercourse through the Wilo Brain Box classic plus

It should be noted that the gear ball valve (No. 12) has to be completely open!

- The red tube of the differential pressure gauge (No.8) has to be connected above and the blue one has to be connected below the circulating pump (No. 1).
- The pump differential pressure can be read on the differential pressure gauge (No. 8).
- The volume flow is indicated on the flow meter (No. 4).

1. The first test is carried out with the uncontrolled circulating pump (No. 1). Its speed is step-wise changeable from the smallest (level 1) to the highest level (level 3) by switching the tap changer on the housing of the pump.

Pump level	**Lowest (level 1)**	**Middle (level 2)**	**Highest (level 3)**
Volume flow $\dot{V}$ (l/h)	760	1140	1350
Pressure loss Δp (bar)	0,15	0,27	0,37
Electrical consumption (W)	48	55	68

Table 1: Evaluation of the experiment to determine the system characteristic

2. The next test is carried out to determine the pump characteristic for different power-levels with the same uncontrolled circulating pump (No. 1). Their speed is set on the highest level (level 3).

Close the gear ball valve (No. 12) so that you get the following values of the volume flow:

Volume flow $\dot{\mathbf{V}}$ $(\boldsymbol{l/h})$	**0**	**400**	**800**	**1200**
Pressure loss Δp (bar)	0,48	0,46	0,45	0,40
Electrical consumption (W)	59	63	67	72

Table 2: Evaluation of the experiment to determine the uncontrolled pump characteristic of level 3

3. The next test is carried out with the same uncontrolled circulating pump (No. 1). Their speed is set on the middle level (level 2).

Close the gear ball valve (No. 12) so that you get the following values of the volume flow:

Volume flow $\dot{V}$ $(\boldsymbol{l/h})$	**0**	**400**	**700**	**1000**
Pressure loss Δp (bar)	0,38	0,35	0,33	0,3
Electrical consumption (W)	45	49	51	54

Table 3: Evaluation of the experiment to determine the uncontrolled pump characteristic of level 2

- Now the red tube of the differential pressure gauge (No.8) has to be connected above and the blue one has to be connected below the controlled circulating pump (No. 2).

4. The next test is carried out with the controlled circulating pump (No. 2) with a **constant** differential pressure $\boldsymbol{\Delta p - c}$. The operating point should be the same as the operating point of the uncontrolled circulating pump. Their differential reference pressure is set on: $\Delta p = 0{,}27\, bar$.

Close the gear ball valve (No. 12) so that you reach the following values of the volume flow:

Volume flow $\dot{V}$ (l/h)	**0**	**400**	**700**	**1000**
Pressure loss Δp (bar)	0,.27	0,27	0,27	0,27
Electrical consumption (W)	13	14	16	17

Table 4: Evaluation of the experiment to determine the controlled pump characteristic $\Delta p - c$

5. The next test is carried out with the same controlled circulating pump (No. 2) with a **variable** differential pressure $\boldsymbol{\Delta p - v}$. Their differential reference pressure is not changed: $\Delta p = 0{,}27\, bar$.

Close the gear ball valve (No. 12) so that you get the following values of the volume flow:

Volume flow $\dot{V}$ (l/h)	**0**	**400**	**700**	**1000**
Pressure loss Δp (bar)	0,14	0,19	0,22	0,26
Electrical consumption (W)	9	11	14	17

Table 5: Evaluation of the experiment to determine the controlled pump characteristic $\Delta p - v$

All the measured values of volume flow and pressure loss should be presented graphically in the diagram 1.
The different pump levels should be annotated with the corresponding numbers in the graph.

Note that the operating point of the uncontrolled pump on level 3 intersect at:

$\boldsymbol{\Delta p = 0{,}37\, bar}$ and $\boldsymbol{\dot{V} = 1350\, l/h}$

Note that the operating point of the uncontrolled pump on level 2, the controlled circulating pump with $\Delta p - c$ and the controlled circulating pump with $\Delta p - v$ intersect at:

$\boldsymbol{\Delta p = 0{,}27\, bar}$ and $\boldsymbol{\dot{V} = 1150\, l/h}$

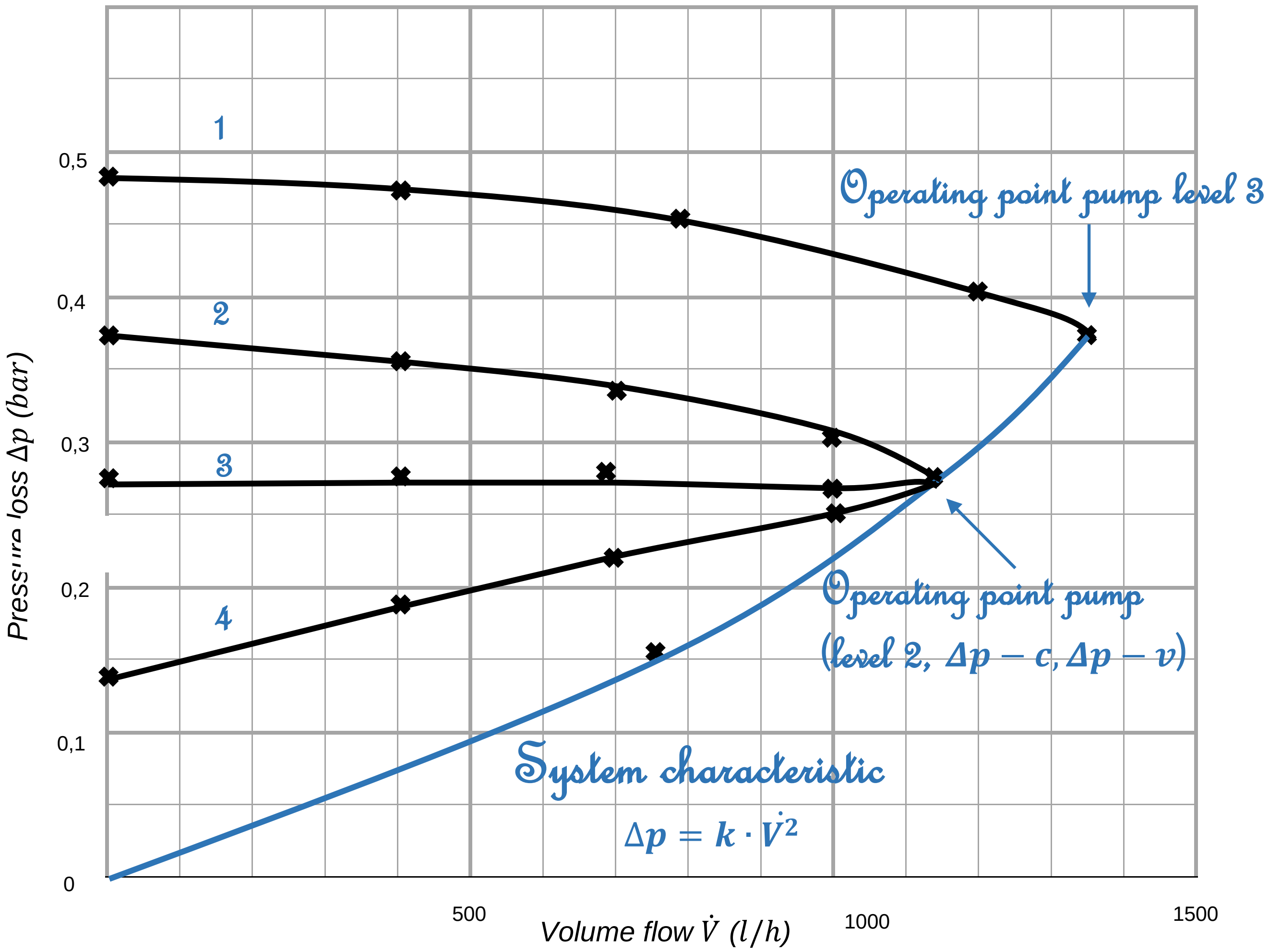
The electrical power of the different pumps can be used to calculate the efficiency of the pump.

Pump power of the uncontrolled pump at level 3:

$$P_1 = \dot{V} \cdot \Delta p = 1200 \frac{l}{3600s} \cdot 0,4 \cdot 10^5 \frac{N}{m^2} = 13,3\ W \qquad \eta = \frac{13,3\ W}{72\ W} = 0,18$$

Pump power of the controlled pump at level $\Delta p - v$:

$$P_2 = \dot{V} \cdot \Delta p = 1000 \frac{l}{3600} s \cdot 0,26 \cdot 10^5 \frac{N}{m^2} = 7,2\ W \qquad \eta = \frac{7,2\ W}{17\ W} = 0,4$$



1	2	3	4
Pump curve: uncontrolled pump highest level 3	Pump curve: uncontrolled pump middle level 2	Pump curve: controlled pump $\Delta p - c$	Pump curve: controlled pump $\Delta p - v$

Diagram 1

Experiment 1.2

Determination of pipe network characteristics of various sections

In each of the three sections of the highlighted green watercourse, the pressure losses leading to the radiators have to be measured at different flow rates (pump stages).

In the following step, the system characteristic of the green pipe work for the design case (all thermostat valves are fully open) should be determined. The values shall be drawn in a table and represented graphically.

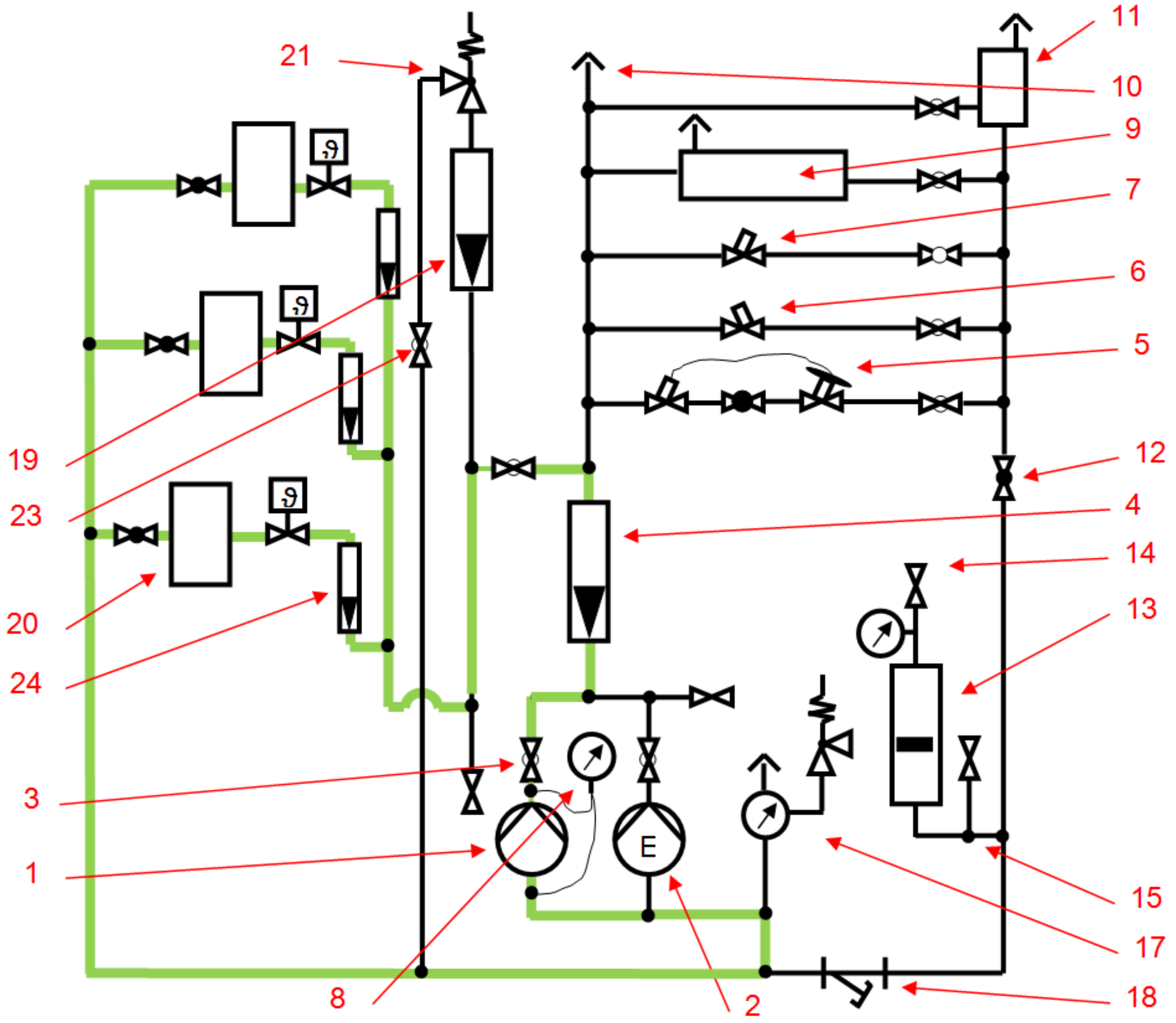


Fig. 7: Watercourse through the Wilo Brain Box classic plus

- The experiment is carried out with the uncontrolled circulating pump (No. 1). The speed of the pump is changed from the lowest level (1) to the highest level (3).
- The red tube of the differential pressure gauge (No. 8) has to be connected at the exit; the blue one has to be connected at the entrance of the uncontrolled circulator (No. 1).
- The pump differential pressure can be read on the differential pressure gauge (No. 8).
- The volume flow is indicated on the flow meter (No. 4).
- The ball valves on the wall are set so that hot water only flows through the radiator respectively required (No. 12 closed, No. 3 opened).
- To enable the determination of the pipe work characteristic of all three branches successively the thermostat valve of the measured section is opened to the maximum, while the thermostatic heads in the other (unmeasured) sections shall be completely closed.

All measured values should be entered in the measurement protocol.

The pressure drop as a function of the volume flow shall be represented graphically in the diagram 2.

These individual measurement points will define the pipework characteristic.

Measurement protocol

Pump level	**Lowest (level 1)**	**Middle (level 2)**	**Highest (level 3)**
Circuit of the upper radiator only			
Volume flow $\dot{V}$ (l/h)	59	87	95
Pressure loss Δp (bar)	0,24	0,38	0,48
Circuit of the middle radiator only			
Volume flow $\dot{V}$ (l/h)	205	270	300
Pressure loss Δp (bar)	0,22	0,36	0,47
Circuit of the lower radiator only			
Volume flow $\dot{V}$ (l/h)	291	387	445
Pressure loss Δp (bar)	0,2	0,33	0,45
All circuits opened to the maximum			
Volume flow $\dot{V}$ (l/h)	457	630	723
Pressure loss Δp (bar)	0,17	0,30	0,43

Table 6: Pressure losses leading to the radiators measured at different flow rates (pump stages)

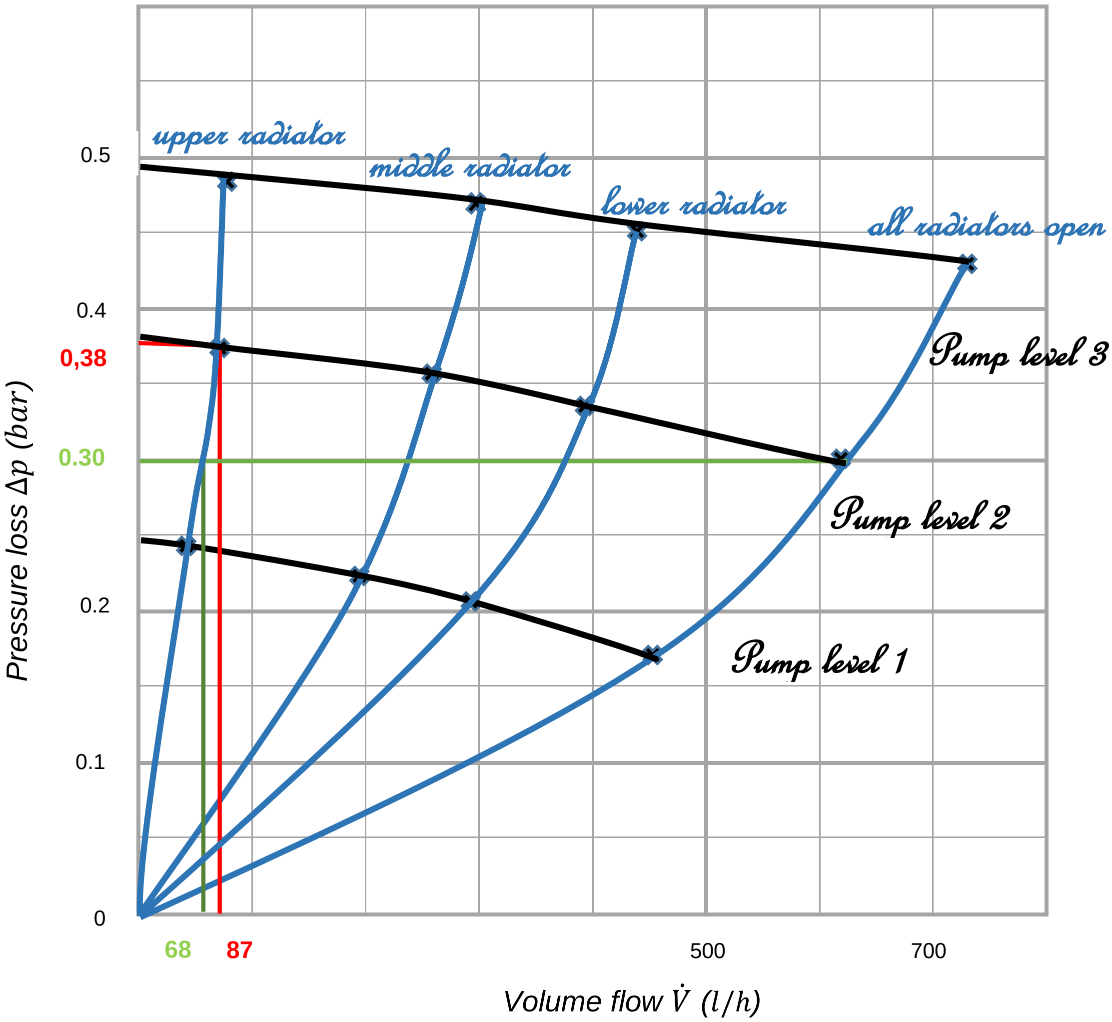


Diagram 2

1. In the diagram 2, all the measurement points of the respective pump levels can be connected to a pump characteristic curve. These lines show the pump characteristic without feed back control.

2. Note that the volume flow and the differential pressure at pump level 2 for the upper radiator, when the thermostatic valve of the measured partial circuit is opened to the maximum, while the thermostatic valves in the other (unmeasured) sections are completely closed are:

$\dot{V} = 87\, l/h$ and $\Delta p = 0{,}38\, bar$

3. Note that the volume flow and the differential pressure at pump level 2 for the upper radiator, when all the thermostatic valves are opened to the maximum water flow are:

only $\dot{V} = 68\, l/h$ and $\Delta p = 0{,}3\, bar$

Conclusion:

The volume flow through the upper radiator decreases when the water flows through all the radiators, because the differential pressure decreases due to the lowering of the system resistance.

If a volume flow of 68l/h is sufficient than we can accept level 2, otherwise we have to increase the level of the pump.

2. Hydraulic balancing

The hydraulic balancing is a process to optimize the distribution of water in a building's heating or cooling system. It is a procedure to save energy costs (because of the reduction of the feed and return temperature) while improving the well-being of the residents with minimal effort.

The heating water tends to follow the circuit with the lowest resistance. In an unbalanced system there will always be favoured circuits that receive more water than required. These favoured circuits "steal" flow of unfavoured circuits which will no longer receive the required flow. (See diagram 2)

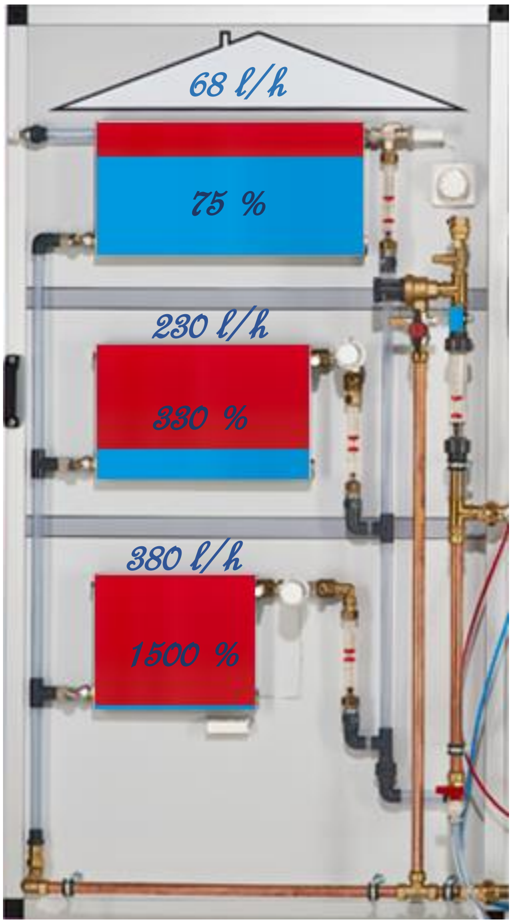


Fig. 7: Example of a non-balanced system leading to uncorrect heat distribution

Fig. 8: Example of a hydraulically balanced heating system

In new buildings, the hydraulic balance is becoming even more important because the generation and distribution losses are reduced by lower temperatures and lower electrical pump energy consumption. As a consequence of the static hydraulic balancing, the flow behavior of the heating water becomes better and each radiator gets only the required volume flow according to the design. This means that there is no hydraulic disfavoured radiator and the heat is distributed evenly. This also ensures that the temperatures of the heating water can be reduced and therefore more cooled. Especially the condensing boilers remain in practice, often under their technical capabilities because the efficiency depends mainly on the return temperature of the heating system. The lower the return temperature, the higher is the condensing effect in the boiler. If the return temperature is too high, the condensing effect in the boiler is scarce or completely absent thus resulting in poor efficiency. Consequently, not only the technology of the boiler, but the complete system must be adapted in order to exploit the efficiency of condensing technology. The same is even more important for heat pumps and their mean annual COP which is very sensitive to the temperature level.

Performing the classic hydraulic balancing

The classic hydraulic balancing is normally performed by presetting the thermostat valve using a special key. For example (depending on the manufacturer) if the valve is set to position 1, only a small volume of hot water flows into the radiator. By setting the thermostat valve to level 6, the maximum possible amount of water flows into the radiator. If no presetting of the valve is possible (older valves), it must be replaced in order to perform the hydraulic balance. This means that the hydraulic balancing is nothing else then finding the resistance for every radiator. These presetting throttle allows it to adjust the heat water to the designed demand of the room.

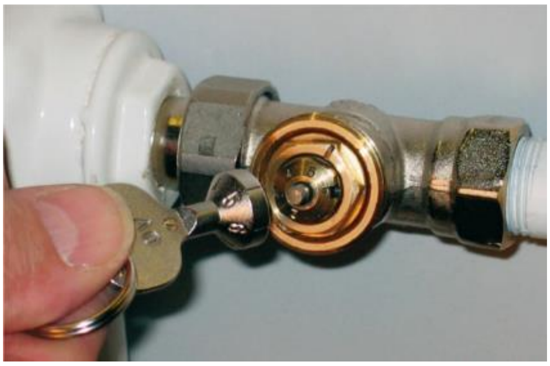


Fig. 9: Performing the hydraulic balance through presetting the K_v value of the valve

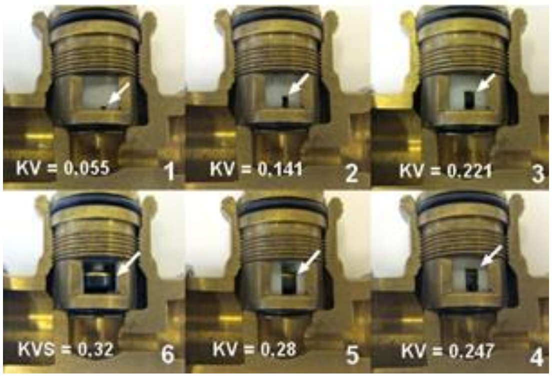


Fig. 10: Position 1 = low flow rate, position 6 = maximum flow rate

Experiment 2.1

Hydraulic balancing on a given heat system

In the following experiment, the building in Lausanne (calculated with Software Lesosai in TP1) is equipped with radiators in order to demonstrate the hydraulic balancing. To simplify the calculation, the house is divided in three sections equipped with 3 radiators.

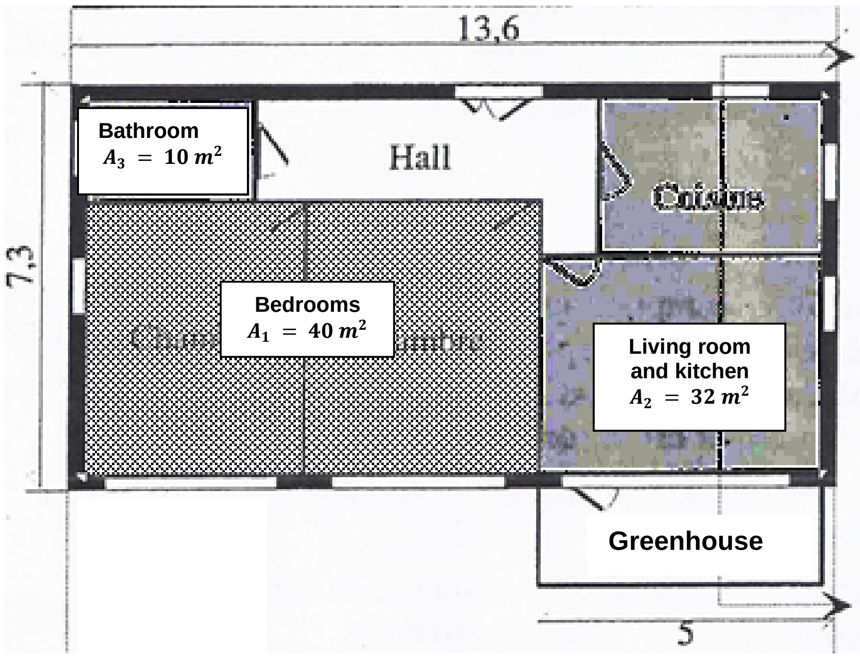


Fig.11: Sketch of a building project calculated with Lesosai (see TP1 Software Lesosai)

Step 1

The heat requirement for each room must be determined. When the heat requirement is not known, the possibility is given to estimate it for each room.

The unit for the specific heat demand $\dot{q}$ is Watt per square meter (W/m^2):

- $25 - 40\ W/m^2$ for low energy house
- $30 - 50\ W/m^2$ for buildings with thermal insulation regulation from EnEV 2002
- $40 - 60\ W/m^2$ for buildings with thermal insulation regulation from 1995
- $60 - 100\ W/m^2$ for buildings with thermal insulation regulation from 1982

The dimensioning of the heating leads to $\dot{q} = \dot{Q}/A = H \cdot \Delta T/A$, according to annexe L of EN 832 $H = 175\ W/K$, $\Delta T = 30\ °C$ (typically value) and $A = 100 m^2$.

$\dot{q} = 175 \cdot 30/100 = 52{,}5\ W/m^2$

Step 2

The specific heat demand $\dot{Q}_K$ for each room i must be determined. The heat demand is calculated by the heated areas of the room A_i and the specific heat demand $\dot{q}_i$:

$$\dot{Q}_K = A_i \cdot \dot{q}_i$$

We consider the house in Lausanne with an area of $100\ m^2$ living space.

The heat demand of the heated areas should be calculated. Then the heating system can be determined afterwards, the hydraulic balancing shall be done. This should be simulated at the Wilo demonstration board:

Bedrooms:	$40\ m^2$
Living room and kitchen	$32\ m^2$
Bathroom:	$10\ m^2$

The building has a thermal insulation regulation from 1995. The radiators should be dimensioned so that and the bedrooms request a specific heat demand $\dot{q}_1 = 50\ W/m^2$, the living room and the kitchen request a specific heat demand $\dot{q}_2 = 50\ W/m^2$ and the bathroom requests a specific heat demand $\dot{q}_3 = 60\ W/m^2$.

Calculate the heat demand for the 3 rooms:

Bedrooms:	$\dot{Q}_1 = A_1 \cdot \dot{q}_1$	$40\ m^2 \cdot 50\ W/m^2 = 2000\ W$
Living room and kitchen:	$\dot{Q}_2 = A_2 \cdot \dot{q}_2$	$32\ m^2 \cdot 50\ W/m^2 = 1600\ W$
Bathroom:	$\dot{Q}_3 = A_3 \cdot \dot{q}_3$	$10\ m^2 \cdot 60\ W/m^2 = 600\ W$

Step 3

The installed performance of the radiators shall be compared to the heat requirement of the room. Typical system temperatures for a warm water heating system are $60\ °C/40\ °C$ (feed and return temperatures). For a condensing boiler, the temperatures should be lower e.g. $50\ °C/30\ °C$.

To calculate the volume flow $\dot{V}$ of a radiator, the heat demand $\dot{Q}$, the density of water ρ, the specifical heat capacity of water c and the difference between the feed and return temperature $\Delta\vartheta$ must be known. The equation to calculate the volume flow is given by:

$$\dot{V} = \frac{\dot{Q}}{\rho \cdot c \cdot \Delta\vartheta}$$

- specific heat of water: $c = 4200 \frac{J}{kg \cdot K} = 1{,}16 \frac{Wh}{kg \cdot K}$
- density of water: $\rho = 1000 \frac{kg}{m^3} = 1 \frac{kg}{l}$
- temperature difference between the supply and return temperature

$$\Delta\vartheta = 60\,°C - 40\,°C = 20\,°C$$

The volume flow of every radiator can be calculated:

Bedrooms: $\dot{Q}_1 = 2000\,W$ $\quad \dot{V} = \frac{2000\,W}{1\frac{kg}{l} \cdot 1{,}16\frac{Wh}{kgK} \cdot 20\,K} \approx 86\,\frac{l}{h}$

Living room and kitchen : $\dot{Q}_2 = 1600\,W$ $\quad \dot{V} = \frac{1600\,W}{1\frac{kg}{l} \cdot 1{,}16\frac{Wh}{kgK} \cdot 20\,K} \approx 70\,\frac{l}{h}$

Bathroom: $\dot{Q}_3 = 600\,W$ $\quad \dot{V} = \frac{600\,W}{1\frac{kg}{l} \cdot 1{,}16\frac{Wh}{kgK} \cdot 20\,K} \approx 25\,\frac{l}{h}$

The total volume flow of the water is: $\approx 180\,\frac{l}{h}$

Hydraulic balance on the Wilo-Brain-Board

On the Wilo-Brain-Board, each radiator represents one part of the house (upper radiator for bedrooms, middle radiator for living room and kitchen, lower radiator for bathroom).

The previous measurements of the flow resistances in the different sections (Diagram 2) have shown that the partial section connected to the upper radiator establishes the largest pressure loss which determines the required pump differential pressure. If all valves are open, the upper radiator receives on level 2 only $68\,l/h$ which is insufficient for the bedroom. Level 3 has to be used while at the same time the two lower radiators receive far to much water ($230\,l/h$ instead of $70\,l/h$ and $380\,l/h$ instead of $25\,l/h$.

Implementation of the hydraulic balance

- To reduce the volume of through the middle and the lower radiator, the initial setting of the thermostatic valves must be reduced from 6 to a lower number. ➔ This is the hydraulic balancing of the system.
- To perform the presetting of the two lower radiator valves, the thermostat heads will be unscrewed.
- This operation is performed while the pump is working on level 2.
- The volume flows through the radiators are measured. The presetting of the K_v value of the valve must be chosen so that the design volume flow is reached.
- The results are recorded in the measurement protocol.

		Presetting the K_v value of the valve	Differential pressure at the pump Δp	Real flow
Design flow $\dot{V}$ (l/h) upper radiator	86	6	0,37	87
Design flow $\dot{V}$ (l/h) middle radiator	70	3	0,37	103
Design flow $\dot{V}$ (l/h) lower radiator	25	1	0,38	34
Total design flow $\dot{V}$ (l/h) all radiators open	180		0,35	217

Table 7: Measurement: Uncontrolled pump level 2

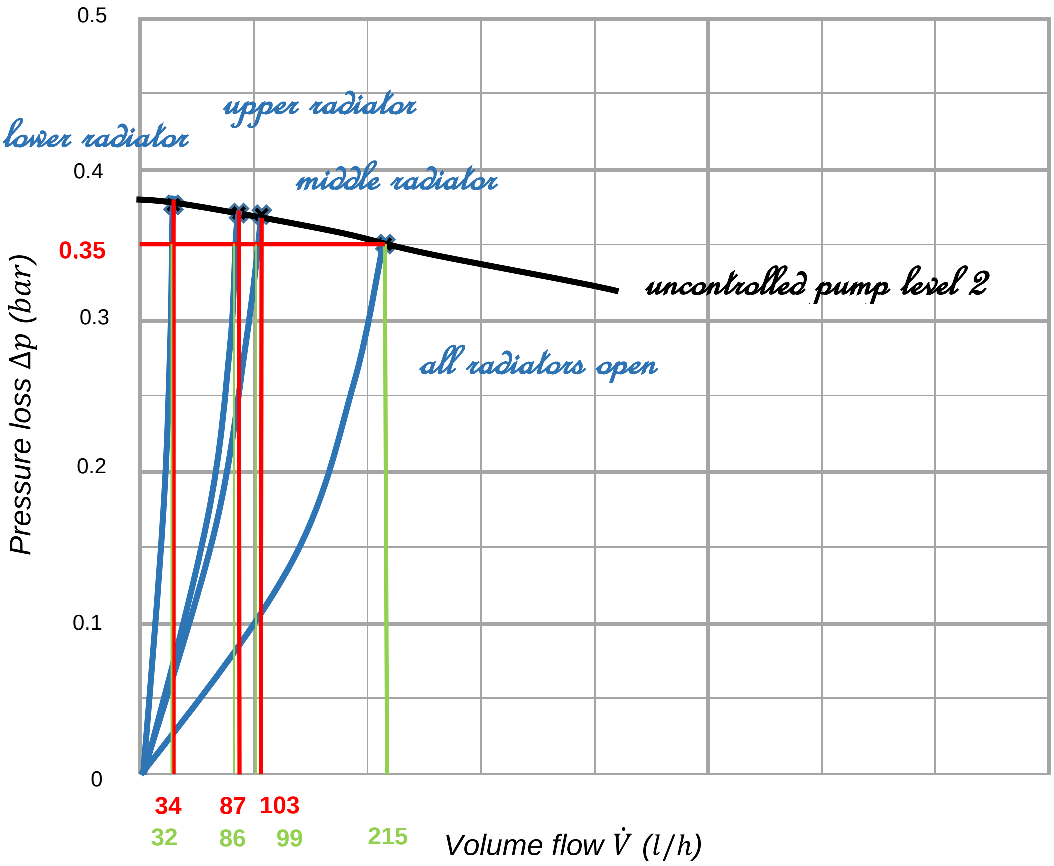


Diagram 4

By choosing the K_v value, it is possible to perform the hydraulic balancing of the system. When now all the thermostatic valves are open, the differential pressure only decreases a litte bit (from 0,38 to 0,35 bar). The volume flow stays nearly constant in the three radiators. The system characteristic changed completely from diagram 2 to diagram 4, because of the adjustment of the K_v values of the radiators.

3. Automatic hydraulic balancing (Vitoflow)

Viessmann has developed a software (Vitosoft 300) and the Vitoflow technology which can perform an automatic hydraulic balancing of a heating system.

In practice, during the process, the existing thermostatic heads of the valves in the building are removed and replaced by radio-controlled servomotors screwed on the thermostat valves. These servomotors are connected via radio antenna to a computer. The volume flow is measured by a volume flow meter, which can be temporarily installed by flexible tubes together with circulator, i.e. pump flow meter unit replaces for the measuring time the existing pump.

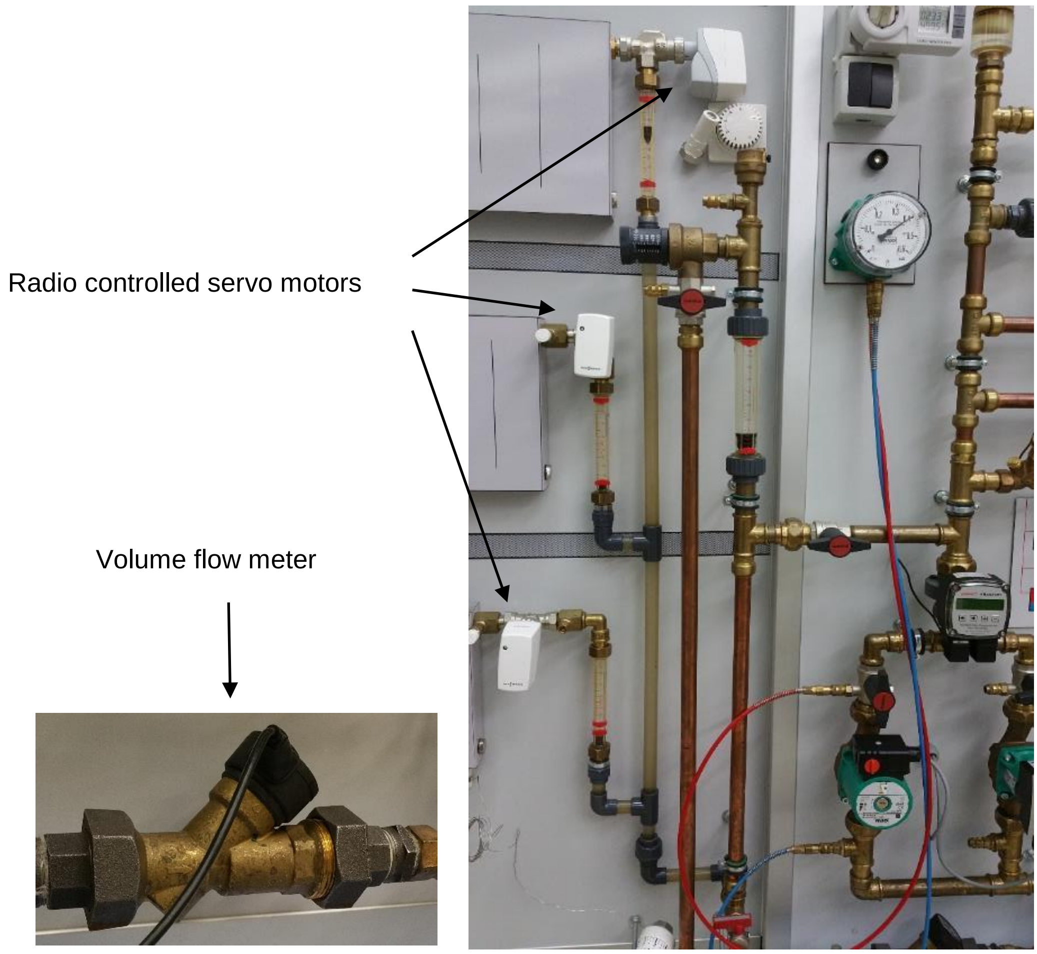


Fig.12: Volume flow meter and radio-controlled servomotors replacing the thermostat heads

This technology offers the advantage of avoiding complex and unprecise calculations of the pipework and its resistance of the heating systems. The Vitoflow technology measures any unknown flow resistances and can be operated in one hour, meaning that there are important savings in work time and costs compared to a classical balancing based on calculations.

Experiment 3.1

Hydraulic balancing with the automatic hydraulic balance system of Viessmann (Vitoflow)

It is performed in a few steps:

- The specific data such as the heating load and type of thermostat valves have to be entered in the Vitosoft 300 program running on a PC.
- After the definition of the heat load of any room, the other specific data such as the type of the pump and the different radiators including their thermostatic valves can be selected from a predefined list in the software.

Technische Angaben Heizkörper (bezogen auf eine Baulänge von 1000 mm)

Bauhöhe (mm)	300		400		500			
Typ	22	33	22	33	20	21	22	33
Wärmeleistung (Watt) bei Systemtemperatur 75/65/20 °C	1063	1521	1236	1723	880	1165	1497	2067
Wärmeleistung (Watt) bei Systemtemperatur 70/55/20 °C	844	1207	990	1379	706	934	1197	1653
Wärmeleistung (Watt) bei Systemtemperatur 55/45/20 °C	527	753	628	874	449	595	758	1047

Fig. 13: Heating load and type of thermostat valves entered in the Vitosoft 300 program

From valve data (for example the K_v values) the software can determine the hydraulic resistance of the open thermostatic valves. Therefore, it must be ensured that the valve settings of the radiators are reset to 6 (maximum open) before performing the automatic adjustment (see figures 9 & 10).

Now the individual radio-controlled servomotors will be mounted to each radiator and controlled by the software. It is important to ensure that the enumerated servomotors are attached on the enumerated radiators.

To perform the hydraulic adjustment, the software will run through a test program which will individually open the various servomotors to act on the particular thermostatic valve. The radiators receive a measured volume flow of water. The flow rate and the flow resistance for any radiator is measured with the flow meter.

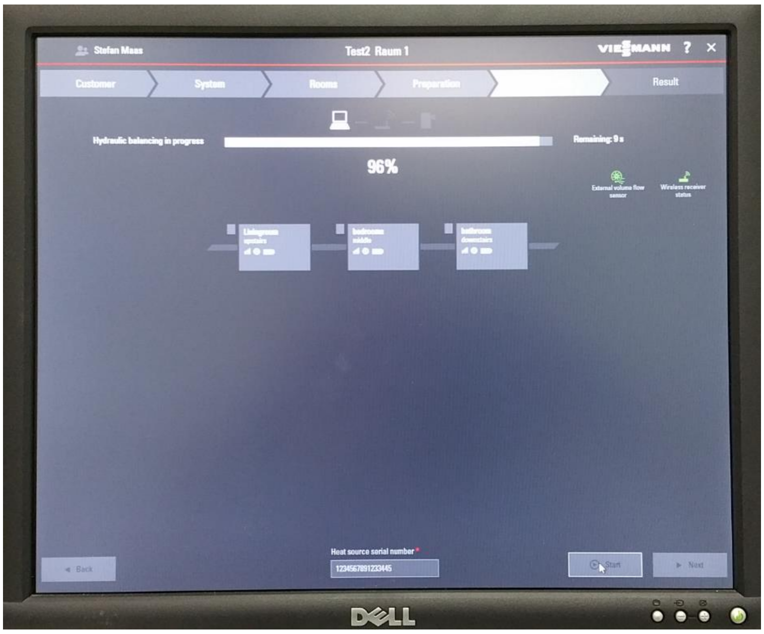


Fig. 14: Vitoflow Software to perform automatic hydraulic balance

After completion of the measurements, the servomotors can be removed and the K_v values (1-6) are calculated by the program and have to be adjusted by the operator. The consumer with the biggest pressure difference receives by default K_v setting for the thermostatic valve (no. 6). One tries to minimize Δp. The software displays the results from the measurements with the optimum set of adjustment for the thermostatic valves.

After performing this automatic adjustment we can control the precision on the Wilo-Brain-Board, as any radiator is equipped with a flow meter which is normally not the case.

4. Wilo-Geniax system

The pump manufacturer Wilo has developed a new concept under the branding of "Geniax system". This flexible decentralized heating valve system operates no longer with thermostatic valves and throttles on each radiator but uses high efficient miniaturized wet rotor pumps which are so quiet in operation that they may be fixed on all radiators.

These miniaturized pumps are linked to a central intelligence system (Geniax-Server) by a bus system. This central control system receives information about the reference and the actual temperature from any room. Control devices with integrated temperature sensor are installed in every room. They offer the advantage of individual room programming with individual reference temperature and heating time schedule.

Comparison to a conventional heating system

Thanks to a central pump the conventional heating system provides thermal energy, which is largely independent from the effective requirements in the various heated rooms. The flow temperature is determined by the outdoor temperature and a programmed heating curve, perhaps corrected by the internal temperature of a reference room. With this temperature, the heating feed water flows through the radiators, irrespective of solar thermal gains or additional thermal losses.

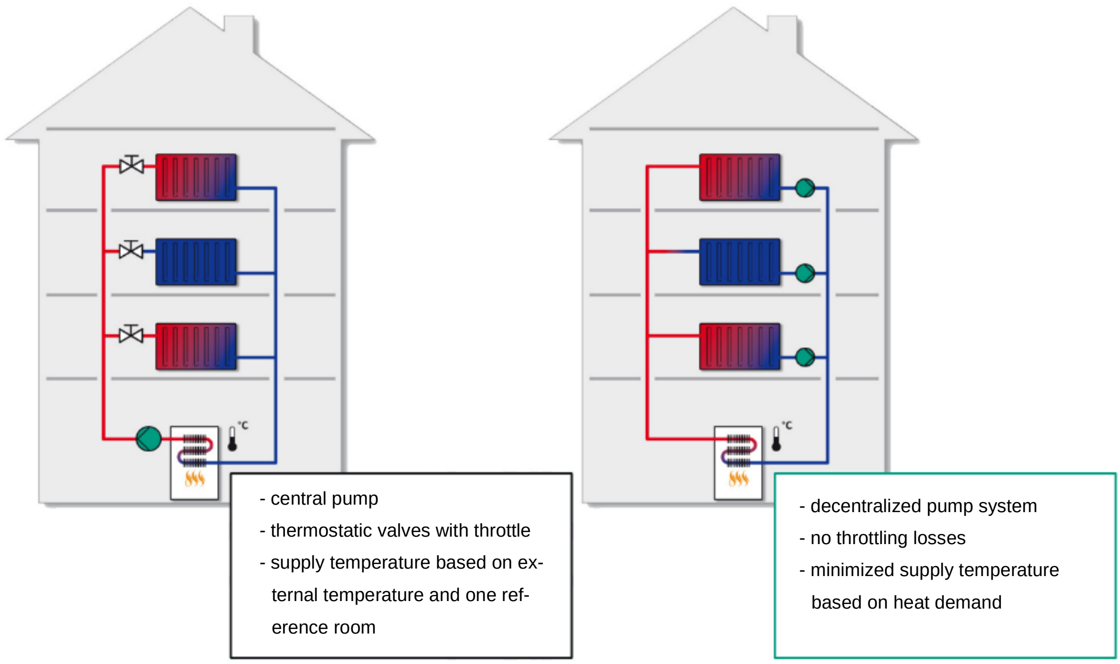


Fig. 15: Comparison of centralized and decentralized pump assembly

The conventional heating system allows time variations only for the complete system. Reductions for individual rooms for the maximum temperature are only possible through manual intervention on the thermostatic valves, i.e. by reduction of the set point. In conventional hydraulic systems, there are important throttling losses. Furthermore the feed temperature of the heated water reaches only a minimum when all radiators are fully working, i.e. in case of partial load there are reserves for minimization.
The decentralized pump system (Wilo-Geniax) allows a better “on demand” control of the flow temperature and the volume flow. This interaction between decentralized pumps, room control devices (for the detection and control of the temperature) and the central server, allows every room to be accurately supplied with the precisely exact heating energy, without hydraulic throttling losses.

The Geniax system considers solar gains and internal loads in any room. Also open windows can be signaled to the Geniax-Server by adding contacts to them. This allows the system to react in order to avoid unwanted heating losses. Should a room not require any heating energy, the pump on the radiator in this room will be switched off. This allows the system to disable individual subsections and to lower the feed temperatures for the remaining part minimizing distribution losses and optimizing production efficiency of condensing boilers and heat pumps. The backflow protectors are needed to avoid faulty flowing due to the interaction of the various pumps.

This general concept is advantageous for craftsmen and operators because the system automatically performs the hydraulic balancing of the heating system or precises that the hydraulic balancing is not necessary. In this manner the entire heating system works at any time in an energy-efficient and comfortable optimal way. All this results in a general lower feed temperature than in conventional external temperature controlled systems. Because the heating energy is distributed correctly, excessive return temperature can be avoided. This increases the efficiency of the heating appliances (condensing boilers) and increases the COP of heat pumps. The advantages of the decentralized pump system are therefore significant improvements not only in the hydraulics.
The disadvantage is that any radiator has to be connected electrically to run the pump. Furthermore the efficiency of multiple small micropumps is lower than the efficiency of one bigger central pump. Finally it is unclear what happens if the system is not perfectly vented and contains small amounts of air in the water. The question arises whether the micropumps are able to work robustly, e.g. in case of air in the system.

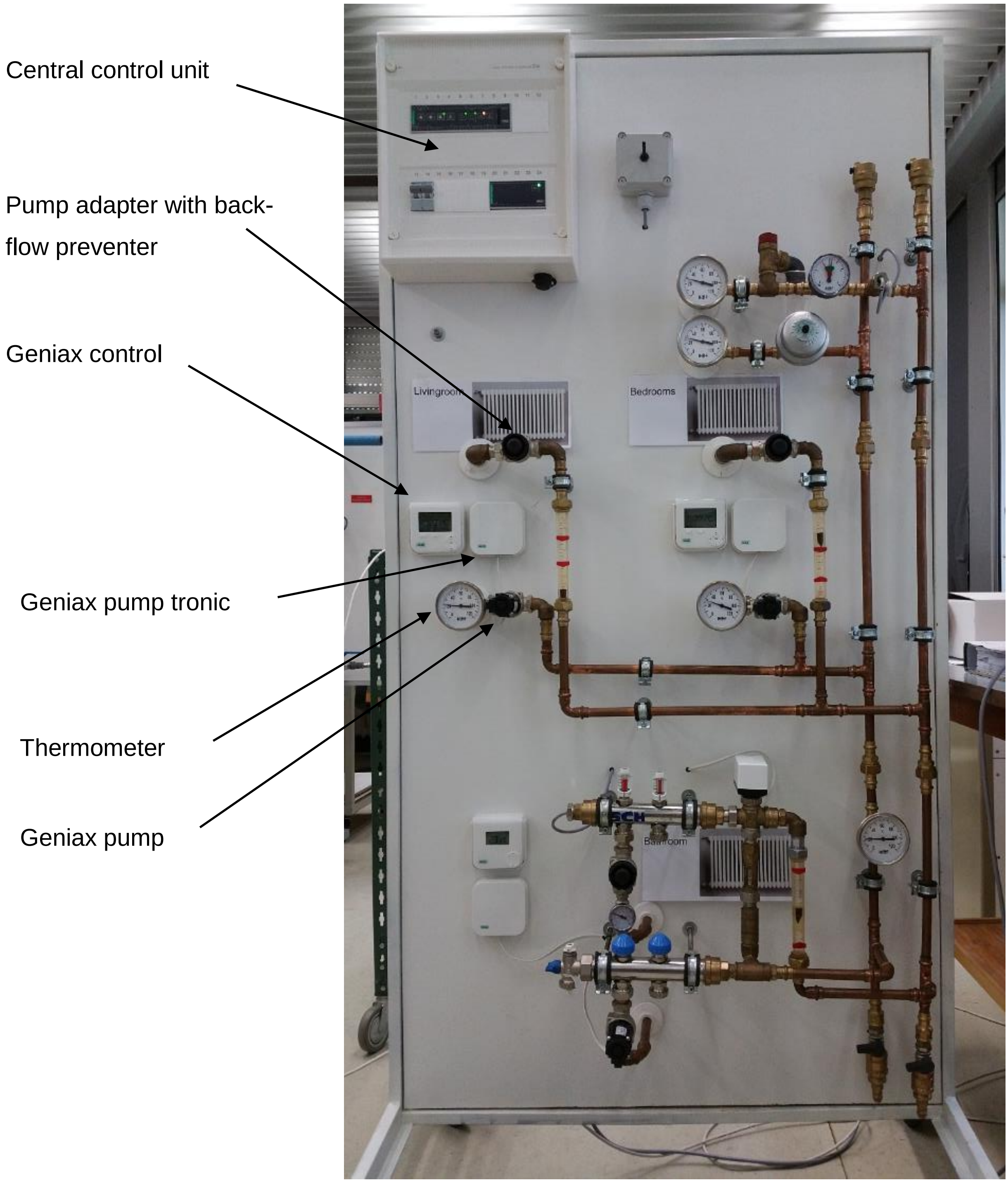


Fig. 16: Demonstration board: Wilo-Geniax

Essential elements of the Geniax system

	**<u>Pump adapter with pre-mounted bypass and backflow preventer:</u>** Through the bypass adapter the flow through the connected radiator can be controlled. The backflow preventer must be installed to prevent erroneous currents through the influence of the pumps which interact with each other.
	**<u>Geniax pump:</u>** These highly efficient circulating pumps have the same size as thermostatic valves. They can be used in all of the standard two-pipe systems. (Note: They cannot be used in one-pipe-systems, because the radiators are connected in series.) The Geniax pumps have a special connection cable, so they don't need to be wired. The pumps are used in conjunction with the corresponding pump electronics (Geniax pump tronic) and are directly mounted <u>in the return</u> of the heater or the heating circuit. It is always connected one pump to each radiator. For floor heating systems each strand needs its own miniature pump. Maximum power consumption: $P_{max} = 4\ W$
	**<u>Geniax pump tronic:</u>** The pump electronics serve for the electrical control and regulation of the pumps. They are connected via a bus line to the Geniax server. By control signals of the Geniax server, the pump speed and thus the mass flow and the heat output are regulated. The pump electronic is often flush-mounted and located in the immediate proximity to the Geniax pump. The distance to the Geniax pump shall not exceed 1,5 meters. Both are connected together by a dedicated connection cable so they don't need to be wired.
	**<u>Geniax control unit</u>** Room control unit to operate the system as well as to create individual time profiles and to display the system status. It contains an integrated sensor for room temperature detection.
	**<u>Central control unit (Geniax server)</u>** The central control unit processes the information of all the operating units and temperature sensors. This results in control signals for the pump, the heat source and if available for mixing valves. The installation is done in conventional electrical distribution boards.

Experiment 4.1

The advantages for the Wilo-Geniax system can be demonstrated in a simple way. Let us assume the maximum controlled flow rate of the pump is $100\ l/h$ in the given setting; the pump speed and thus the volume flow can be controlled by the server with a maximum of $100\ l/h$. The system temperatures for a warm water heating system are $60\ °C/40\ °C$ (feed and return temperatures) as in experiment 2.1.

The heat demand $\dot{Q}$ for the 3 rooms is also the same as before: bedrooms: $\dot{Q}_1 = 2000\ W$, living room and kitchen: $\dot{Q}_2 = 1600\ W$ and bathroom: $\dot{Q}_3 = 600\ W$. Wilo-Geniax first supplies the maximal volume flow before the temperature is increased. This will increase the COP of the heat pump or the efficiency of the condensing boiler.

The equation to calculate the temperature difference is:

$$\Delta\vartheta = \frac{\dot{Q}}{\rho \cdot c \cdot \dot{V}}$$

- specifically heat capacity of water: $c = 1{,}16\ \frac{Wh}{kg \cdot K}$
- density of water: $\rho = 1\frac{kg}{l}$
- nominal flow rate of the Geniax pump: $\dot{V} = 100\frac{l}{h}$

The temperature difference of each radiator must be calculated:

Bedrooms: $\dot{Q}_1 = 2000\ W$ $\quad \boldsymbol{\Delta\vartheta_1 = \frac{2000\ W}{1\frac{kg}{l} 1{,}16\frac{Wh}{kgK} \cdot 100\frac{l}{h}} = 17{,}2\ °C}$

Living room and kitchen: $\dot{Q}_2 = 1600\ W$ $\quad \boldsymbol{\Delta\vartheta_2 = \frac{1600\ W}{1\frac{kg}{l} 1{,}16\frac{Wh}{kgK} \cdot 100\frac{l}{h}} = 13{,}8\ °C}$

Bathroom: $\dot{Q}_3 = 600\ W$ $\quad \boldsymbol{\Delta\vartheta_3 = \frac{600\ W}{1\frac{kg}{l} 1{,}16\frac{Wh}{kgK} \cdot 100\frac{l}{h}} = 5{,}1\ °C}$

The largest temperature difference $\Delta\vartheta$ needed to provide every room with the necessary heat when the pumps are operating with the nominal flow is: $\mathbf{17{,}2\ °C}$.

The supply temperature of the whole system can be decreased from $60\ °C$ to

more or less $\mathbf{57{,}2\ °C = 40\ °C + 17{,}2\ °C}$, *depending on the power of the radiator.*

To reach the same return temperature for any radiator ($40\ °C$), the system can now reduce the pump speed of the other radiators and thus increase their volume flow:

$$\dot{V}_2 = \frac{1600\ W}{1\ \frac{kg}{l} \cdot 1,16\ \frac{Wh}{kgK} \cdot 17,2\ K} \approx 80\ \frac{l}{h}$$

$$\dot{V}_3 = \frac{600\ W}{1\ \frac{kg}{l} \cdot 1,16\ \frac{Wh}{kgK} \cdot 17,2\ K} \approx 30\ \frac{l}{h}$$

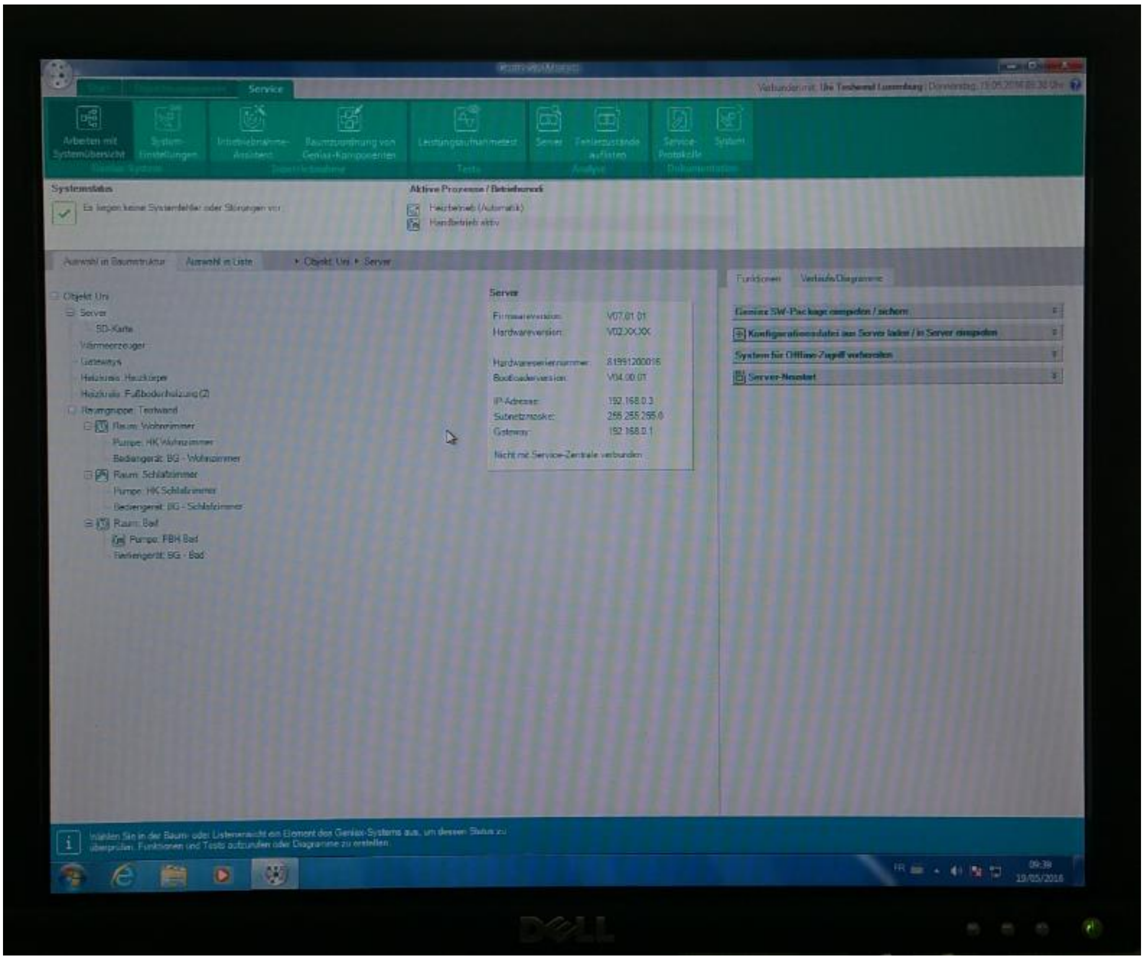


Fig. 17: Wilo-Geniax Software

Adjust the rotation speed of the pump in the software so that you get the volume flow for every radiator.

The volume flow can be read on the volume flow meter for any circuit.

Note the supply and feed temperature for every radiator.

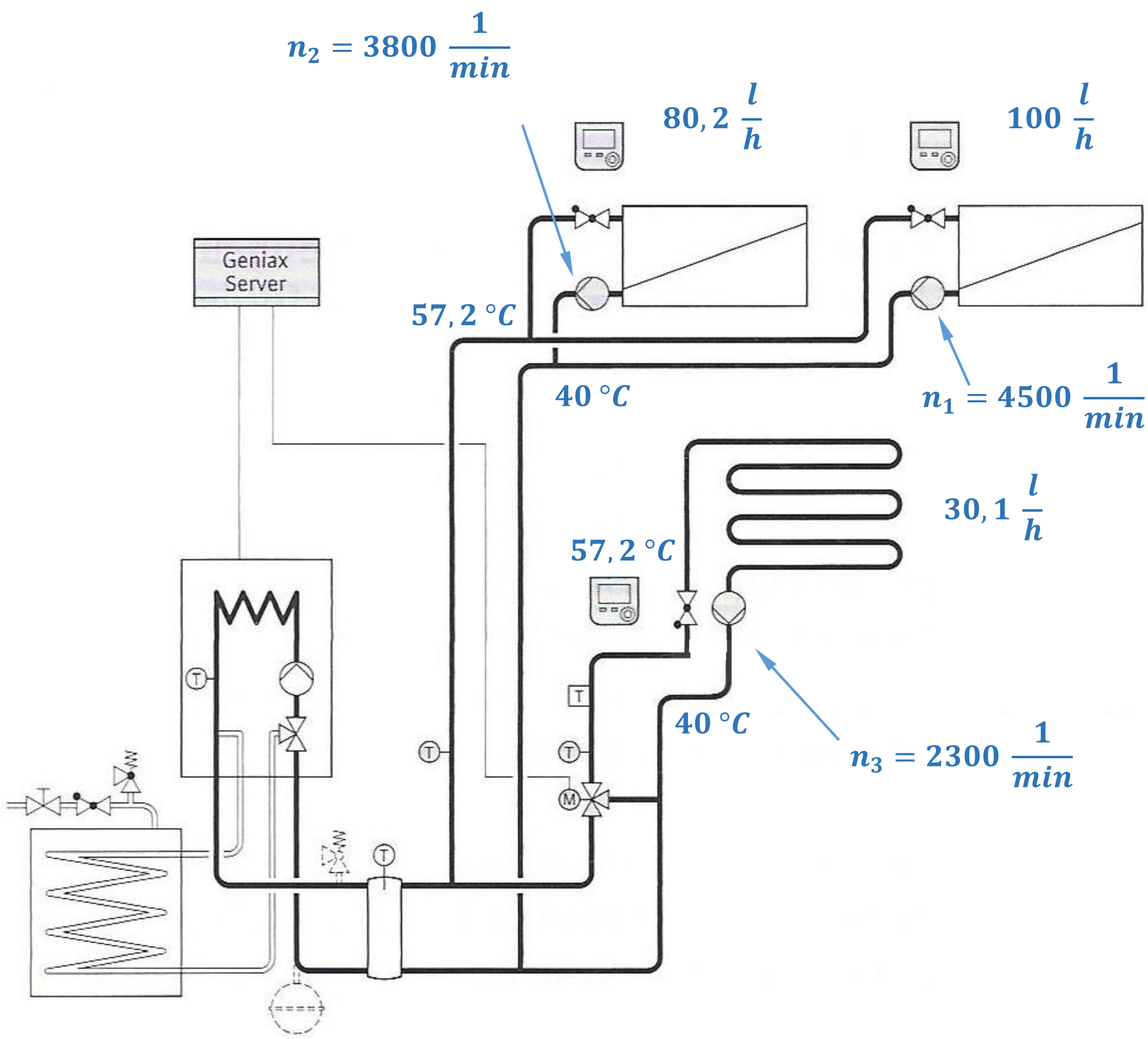


Diagram 5

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