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Energetische Bilanzierung von Gebäuden
Energetic Evaluation of Buildings

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1. Introduction

1.1. Motivation

In times of global warming, the energy efficiency of buildings has become more and more important. Modern concepts allow to reduce the required amount of energy to heat up a building and to minimize all kinds of losses. The aim of having energy efficient buildings is not only to reduce CO_2-emissions but also to save money which does not have to be spent on gas or oil. The energetic balancing of a building however depends on many of a building's features such as heating, cooling, ventilating, moistening, tap water, lighting and the building's geographic location, as well as its components such as windows and doors. Many components of a building affect each other. For example the incoming thermal energy through insolation and the outgoing thermal energy by ventilation have an influence on a heating system's workload. Taking account of all these different factors comes along with a noticeable computational effort, especially as there are different environmental conditions during different seasons. While the required physical know-how is well-known and documented, its extend leads to wish for a lucid and uncomplicated possibility to automatically calculate the energetic balancing of a building. Therefore, the aim of this work is to implement a program which takes all required information of a building as input and calculates the energy balance according to the DIN V 18599 standard [1]. The goal is to provide the possibility to calculate a building's energy balance to everyone, therefore the implemented program is planned to be part of a web app that everyone may use.

1.2. Related work

As the standard to be used to calculate energy balances is defined by law, several software manufacturers have already developed their own program for evaluating energetic balances according to DIN V 18599. A list of the software manufacturers and the calculations they provide is shown in Table 1. Each of the tools are accurate and have the seal of quality established by the '18599 Gütegemeinschaft' [2], therefore these tools fulfill all requirements for calculating the energy balance of buildings.

Apart from the DIN V 18599 standard's application in software tools, it has as well been used for various researches. For example, it was used in [25] for a model which forecasts the energy demand for heating of a whole district. A similar idea has been approached in [23] for calculating the energy demand of a city by using a 3D-model of the considered areas. In other studies, the influence of specific modifications on a building has been analyzed. For instance, [24] describes the influence of photovoltaic systems on the primary energy demand. In [2], the final energy of a historic building has been calculated before and after refurbishing the building's windows and potential energy savings have been analyzed. The possible costs and savings which may come

[1] DIN V 18599: https://www.din.de/de/mitwirken/normenausschuesse/nabau/auslegungendinv18599-68632

[2] 18599 Gütegemeinschaft: http://www.18599guetegemeinschaft.de/index.html

along one day when supplying buildings with hydrogen are evaluated in [17]. While most works consider the energy demand for heating, in [20] an approach is described and evaluated to reduce the energy demand for cooling by opening windows at night. The effects of for what purpose a building is used and what components it consists of are studied in [1] based on concrete examples. In [18] a model is presented which allows to estimate the available exergy in low-temperature district heating systems. Several works propose adaptations in the DIN V 18599 standard. For example a simplified but reliable process for capturing and managing the surfaces of the building shell for improving calculation run times is shown in [22]. In [21] it is described how the air change of a building is affected by leaks in the building shell and suggestions for alternative calculations are made. Another alternative calculation model for non-residential buildings is presented in [19] with the aim to simplify the calculation process. In [26], a further project is presented where the energy balance of a building has been calculated and eventually the DIN V 18599 standard itself and the results it provides have been evaluated.

Service	DIN-standard	Developer							
		IBP: 18599 [3]	Leuchter [4]	ZUB-Systems (Helena) [5]	Solar-Computer [6]	Hottgenroth [7]	BKI [8]	ENVISYS [9]	Rowa-Soft [10]
Energy balance for residential buidings DIN V 18599	DIN V 18599	✓	✓	✓	✓	✓	✓	✓	✓
Energy balance for non-residential buidings DIN V 18599	DIN V 18599	✓	✓	✓	✓	✓	✓	✓	✓
Energy pass	/	✓	✓	✓	✓	✓	✓	✓	✓
Renovation strategy	/		✓	✓	✓	✓	✓	✓	✓
Thermal bridges	DIN 4108		✓	✓	✓	✓	✓	✓	✓
Hydraulic balance	DIN 4108		✓	✓	✓	✓		✓	
Heat protection	DIN 18599		✓	✓	✓	✓	✓	✓	✓
Heating load	DIN EN 12831		✓	✓	✓	✓	✓	✓	
Ventilation and air conditioning systems	DIN 1946		✓	✓	✓	✓	✓	✓	
Photovoltaic	DIN 15316		✓			✓	✓	✓	
Soundproofing	DIN 4108 DIN 4109		✓			✓			✓
Test version available	/		✓	✓	✓	✓		✓	✓

Table 1: Established software tools and calculation methods they provide.

[3]https://www.ibp.fraunhofer.de/de/projekte-referenzen/ibp-18599-produktfamilie.html
[4]https://www.leuchter.de
[5]https://www.zub-systems.de/de/produkte/helena
[6]https://www.solar-computer.de/index.php?seite=produkte&sub=produktansicht
[7]https://www.hottgenroth.de/M/SOFTWARE/EnergieNachweise/Energieberater-18599-3D/Seite.html,73274,80422
[8]https://bki.de/energieplaner.html
[9]https://www.envisys.de/index.php?id=1451
[10]https://rowa-soft.shop/c/rowa-soft-waerme-und-dampf

1.3. Contribution

Some of the shown tools may provide a free test version, however, in order to have full access to each of the tools, a license must be purchased. Additionally, each of the tools has to be installed, which requires storage capacity and which only works on the most popular operating systems. In this work, an algorithm will be implemented which allows to calculated the energy balance of residential buildings according to the DIN V 18599 standard. However, the tool to be implemented is planned to be part of a web app which does not depend on any operating system. The main aim of this work is to develop a reliable software tool which correctly applies the DIN V 18599 standard in order to get reliable results but also to have decent run times for calculation processes. The presented implementation has therefore been tested by comparing the results of its calculation and its run times to those of the professional software tools. As the established tools are not meant to be used by laymen, an additional goal of this work is to offer the possibility for normal users to calculated the energy balance of their own houses by using simplified input. A challenge coming along with this feature is that several inputs values have to be reasonably estimated. Fortunately, the DIN V 18599, as well as other standards, provide many standard values which can be used for this purpose. Whenever possible, the newest version of the DIN V 18599 standard has been applied for this work's implementation. However, in order to be able to compare the results of this work with verified results, an implementation according to the DIN V 18599 standard of the year 2011 had to be made, where a few calculations are done with different equations.

1.4. Outline

This thesis is structured as follows: Section 2 provides an overview of the calculation steps for the balancing and the required input data for processing them. The calculation steps are summarized in the following sections. In Section 3, the calculation of heat sinks and heat sources in the building shell, such as transmission and different ventilation methods, are explained. Section 4 states the equations for the first approximate balancing. Then Section 5 summarizes the remaining heat sources within a building. The corresponding equations are presented in Section 6, which covers heating systems, and Section 7, which covers tap water systems. The calculation steps for considering solar systems which support heat generation are presented in Section 8. Then the calculations for determining the final energy demand are shown in Section 9, followed by the calculations for the primary energy demand in Section 10. Section 11 shows and discusses the results of the implemented program, while in Section 12 a conclusion is stated.

2. Calculation model

This thesis describes how to calculate the energetic balancing of buildings according to the DIN V 18599 standard. The aim of this work is to implement a program in Python, which does the necessary calculations and generates a JSON-file containing the required results from other JSON-files, which serve as the program's input. To provide an idea of the problem, Figure 1 shows a sketch of a building with many conditioning systems which affect the energy balancing.

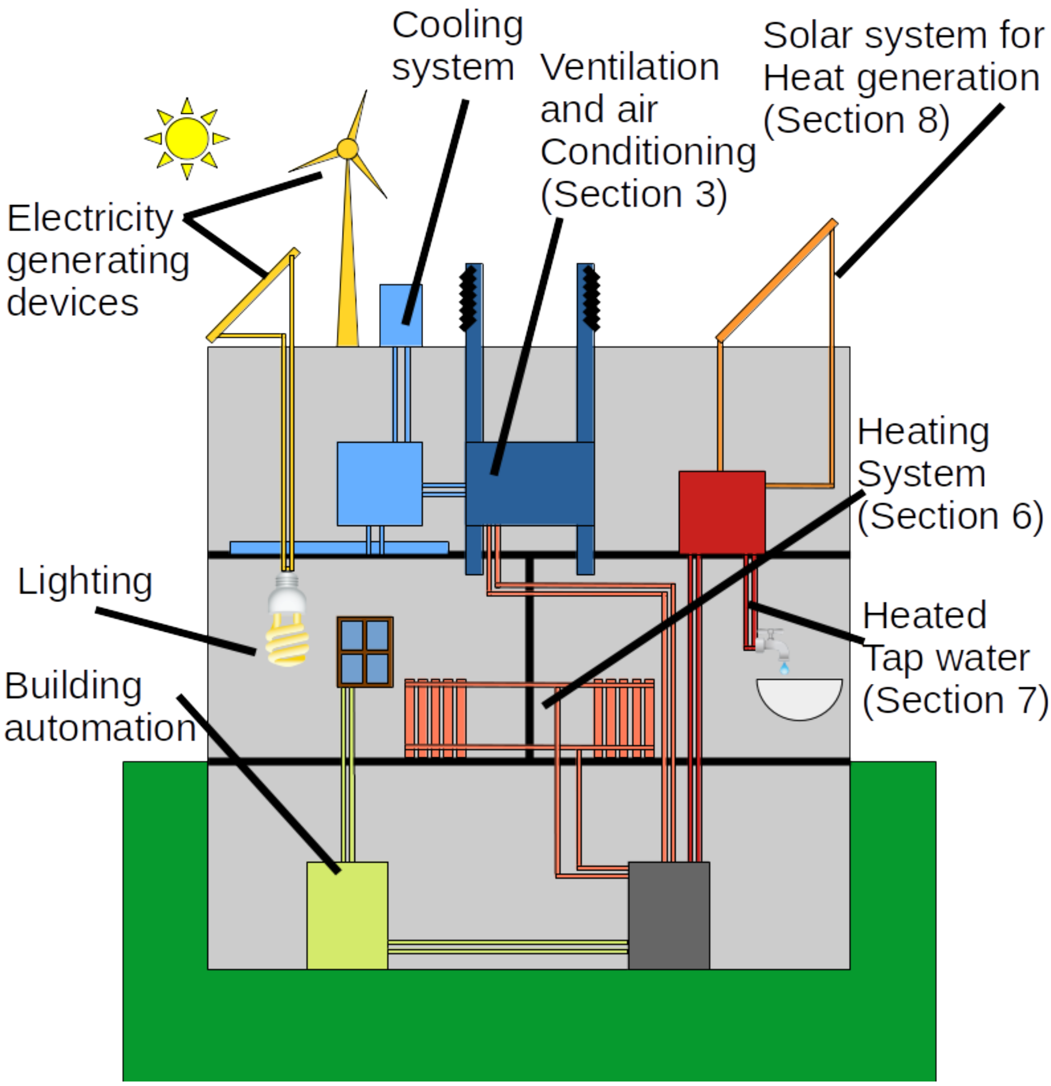

Figure 1: An illustration of the different systems a building may have, inspired by [6].

While many buildings are probably not equipped with all of these systems, the final program should ideally be able to handle an input with any of the most established systems. Therefore the equations in this work are based on these in the individual parts of the DIN V 18599 standard, which state the required physical Equations. Apart from the conditioning systems, many other factors affect a building's energy balance. For instance:

- the zones of the building, if they are heated or not and how they are conditioned,
- the exterior walls and walls and ceilings between heated and unheated zones,
- if the exterior walls border to the outer air or to the ground,
- the thermal transmission properties of walls, base plates, windows, doors and roofs and
- the tilt of roofs and roof windows.

Within the context of this work, a zone describes a part of the building with similar conditions. Additionally, the results of the balancing depend on the location of the building and the climatic conditions, as well as specific parameters which the people in charge desire, such as the internal temperatures and if the heating activity should be reduced during nights, for example. These and many other factors are considered in this work.

2.1. Steps of calculation

The following sections present the required equations and parameters for the steps of calculations of the balancing process:

1. Determining the boundary conditions for the set of a building's zones according to [7].
2. Summarizing the required related data for each zone, such as geometric data and characteristic physical values as well as parameters of build-in systems (such as the heating system) according to [9] and [7].
3. Calculating the net energy demand and the final energy demand for lighting according to [10].
4. Calculating heat sinks and heat sources through mechanical ventilation according to [13].
5. Calculating heat sinks and heat sources of the building shell [8].
6. First approximate calculation of the building's net energy demand for heating and cooling according to [8].
7. Allocating of the building net energy demand according to [9], [11], [12] and [13] depending on the available systems.

8. Calculating heat sources through the heating system in each zone according to [11].
9. Calculating heat sinks and heat sources through the cooling system in each zone according to [13].
10. Calculating heat sources through the preparation of the tap water in each zone according to [11].
11. Calculating the net energy demand for heating and cooling for each zone of the building according to [8]. The steps 7 to 11 have to be repeated until the received results for the net energy demand for heating and cooling do not diverge by more than 0.1 % in comparison to the previous iteration. However, the mentioned steps must be repeated at most 10 times.
12. Calculating the net energy demand for air conditioning and, if necessary, the net energy demand for cooling according to [9].
13. Final allocation of the net energy demand to the care systems according to [9], [11], [12] and [13] depending on the available systems.
14. Calculating the energy losses through transfer, distribution and storage through the heating system according to [11].
15. Calculating the energy losses through transfer and distribution through the ventilation system according to [12] and [13].
16. Calculating the energy losses through transfer, distribution and storage through the air conditioning system according to [13].
17. Calculating the energy losses through transfer, distribution and storage through the cooling system according to [13].
18. Calculating the energy losses through transfer, distribution and storage for conditioning tap water according to [13].
19. Allocating the required energy dissipation for heating of every energy generator to the available generating systems according to [11].
20. Allocating the required energy dissipation for heating of every energy generator to the available generating systems according to [13].
21. Calculating the energy losses for generating coldness according to [13].
22. Calculating the energy losses for generating steam according to [13].
23. Calculating the energy losses for generating heat according to [11], [12], [13], [14] and [15] depending on the available systems.

24. Assembling the auxiliary energy amounts according to [9] and [12].

25. Assembling the final energy for each energy source according to [6].

26. Calculating the primary energy according to [6].

The steps 3, 9, 12. 16, 17, 20. 21 and 22 are only required for calculating the energy balance of non-residential buildings according to [6]. The program to be implemented will only cover residential buildings and will be tested with the test cases provided in [16]. For visualization purposes, the work schedule of for processing the calculation steps is shown in Figure 2.

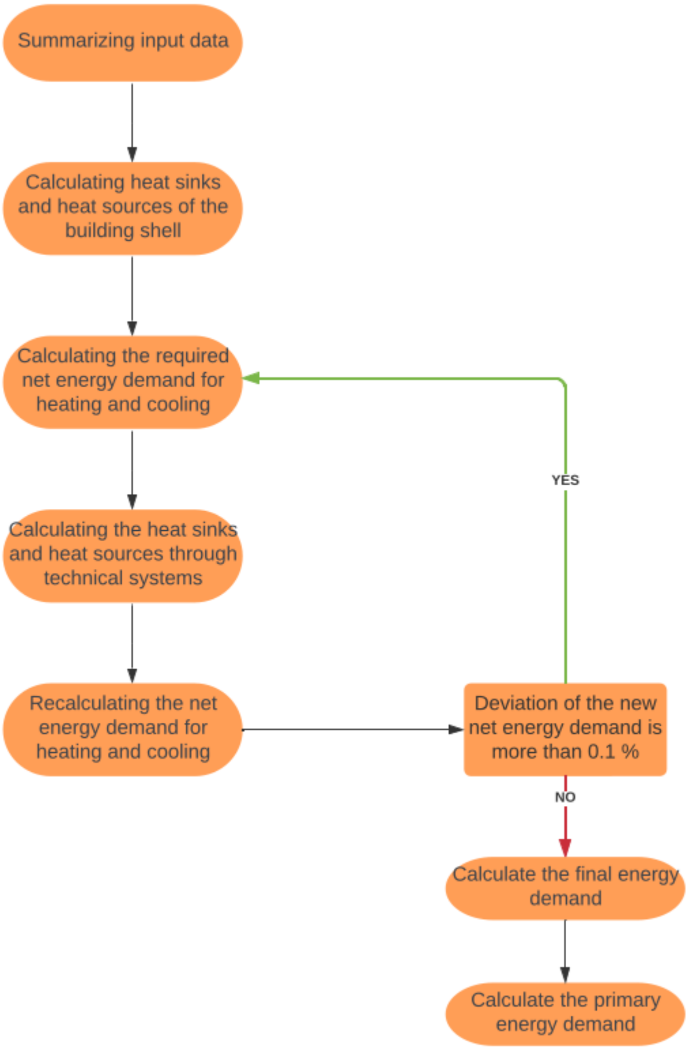

Figure 2: A work schedule of the program presented in this work.

2.2. Boundary conditions

The boundary conditions for all kinds of buildings are presented in [7]. The conditions for residential buildings do not differ considerably among each other and the most important standard values are given in Table 2. The boundary conditions are part of the input for the presented project and they are given as JSON-files, which allows to easily adapt them. For non-residential buildings, other values are provided for specific parameters as they are not the same for schools, sports halls and supermarkets for example. Additionally, other parameters have to be taken into account, such as the utilization time. To ensure consistent results many values which are defined in the boundary conditions are even prescribed by law.

Parameter	**Standard value**
Desired internal temperature	For heating: $\theta_{\mathrm{i,soll}} = 20\,°\mathrm{C}$ For cooling: $\theta_{\mathrm{i,soll}} = 25\,°\mathrm{C}$
Temperature difference for reduced heating activity	$\Delta\theta_{\mathrm{i,NA}} = 4\,\mathrm{K}$
Minimal temperature while heating	$\theta_{\mathrm{i,h,min}} = 20\,°\mathrm{C}$
Maximal temperature while cooling	$\theta_{\mathrm{i,c,max}} = 26\,°\mathrm{C}$
Internal heat sources	Single family house: $q_{\mathrm{I}} = 45\,\mathrm{Wh/m^2d}$ Apartment house: $q_{\mathrm{I}} = 90\,\mathrm{Wh/m^2d}$
Operating times	Ventilation system: 24 h Heating system: 17 h Ventilation system: 24 h per day Ventilation system: 24 h per day Operating days: $d_{\mathrm{nutz,a}} = 365$ days per year Ventilation system mode: heating period
net energy demand demand for tap water	$Q_{\mathrm{w,b}} = \max\left[16.5 \cdot \left(A_{\mathrm{NGF,WE,m}} \cdot 0.05\right), 8.5\right]\,\mathrm{kWh/m^2{\cdot}a}$
Usage related minimal air change from outside	not demand-based: $n_{\mathrm{nutz}} = 0.5\,\mathrm{h}^{-1}$ demand-based: $n_{\mathrm{nutz}} = 0.45\,\mathrm{h}^{-1}$
Electricity demand	$q_{\mathrm{el,b}} = 63\,\mathrm{Wh/m^2d}$
Factor for reduction through dirtiness	$F_{\mathrm{v}} = 1$
Addend for considering building automation	$\Delta\theta_{\mathrm{EMS}} \in \{-1, -0.5, 0\}$
Factor for considering adaptive temperature control	$\Delta f_{\mathrm{adapt}} \in \{1, 1.35\}$

Table 2: Boundary conditions for residential buildings according to Table 5 in [3].

2.3. Building related data

Of course the building's metes and the specifications of the components it is made of have to be available for the calculations. Table 3 shows the required input parameters of the building's shell.

Description	**Symbol**	**Unit**
Net volume of the building	V	m^3
Use area	A_{N}	m^2
Net area	A_{NGF}	m^2
Thermal bridge supplement	$\Delta U_{\mathrm{T,WB}}$	$^{\mathrm{kW}}/_{\mathrm{m^2K}}$
Storey height	h_{G}	m
Amount of storeys	n_{G}	
Characteristic length	L_{char}	m
Characteristic width	B_{char}	m

Table 3: A list of the required building related data for the input including their symbols which are used in this thesis and their units.

Analogously to Table 3, in this work, lengths, areas and volumes are considered to be in m, m^2 or m^3 respectively, if not further specified. Additionally, temperatures are considered to be in °C and energy amounts are considered to be in kWh. t described the time period of a calculation step, which generally is one month for the calculations in this work.

Additionally, information about the building components must be part of the input. These components include windows, doors, walls, baseplates, ceilings and the roof. For each part, the parameters shown in Table 4

Description	**Symbol**	**Unit**
Area	A	m^2
Pitch	/	deg
Heat transfer coefficient	U	$^{\mathrm{kW}}/_{\mathrm{m^2K}}$
Correction factor	F_{x}	/
Energy transmittance	g	/

Table 4: A list of the required component related data for the input including their symbols which are used in this thesis and their units. The pitch of a component does not occur in any of the equations. The insolation from different angles is taken into account instead.

If the heat transfer coefficient and the temperature correction factor are not given in the input, they can be estimated according to section 6.1.4 in [8]. The possible values for F_{x} are shown in Tables 30 and 31. The type of use allows to determine whether a component delimits the zone to outside, to an unheated zone or to the earth, which affects the calculations. For the components which delimit the zone to outside, their orientation to which it's faced must be included for considering insolation. Tilted components, such as roofs and roof windows also require their angle as part of their input. For windows and other transparent components, their total energy transmittance g can be stated. However, the values for g can also be estimated by Tables 33, 34 and 35, as well as values for U_{g} and τ_{e}. The different glass types and the corresponding number are shown in Table 32. In order to reasonably estimate values if no measurements or plans are available, the year of manufacture can be considered. The final input file also contains information about all available conditioning systems of a building.

2.4. Climate data

For the energetic balancing of a building, specific climate-related data is required. These data of course depend on the location of a building and are given in [7] for different climate zones in Germany. The data include the monthly average temperature and the average insolation from different angles and directions.

2.5. Calculation of missing parameters

There are many input values which are required for calculating the energy balance of a building and for getting precise results, the input values should be as accurate as possible, of course. For new buildings, especially if building plans are still available, this does usually not cause a problem. However, especially for older buildings, plans might not be available and some required parameters might be difficult to measure. Some input values can then be estimated as described in this section.

The net floor area A_{NGF} can generally be calculated by Equation (27) in [6]:

$$A_{\mathrm{NGF}} = 1.1 \cdot A_{\mathrm{Wohn}}, \tag{1}$$

For a single-family house with a heated basement it is given by Equation (28) in [6]:

$$A_{\mathrm{NGF}} = \frac{1.1}{1.35} \cdot A_{\mathrm{N}}, \tag{2}$$

For single-family house without a heated basement and multi-family houses it is given by Equation (29) in [6]:

$$A_{\mathrm{NGF}} = \frac{1.1}{1.2} \cdot A_{\mathrm{N}}, \tag{3}$$

where:

- A_{Wohn} is the living area and
- A_{N} is usable area.

A_N can be calculated by Equation (30) in [6]:

$$A_\mathrm{N} = 0.32\frac{1}{\mathrm{m}} \cdot V_e, \tag{4}$$

where V_e is the building's volume (external dimension).

If the storey height $h_G < 2.5\,\mathrm{m}$ or $h_G > 3\,\mathrm{m}$, A_N can be calculated by Equation (31) in [6]:

$$A_\mathrm{N} = \left(\frac{1}{h_\mathrm{G}} - 0.04\frac{1}{\mathrm{m}}\right) \cdot V_\mathrm{e}, \tag{5}$$

For an apartment, the median net floor area ANGF,WE,m can be calculated by Equation (32) in [6]:

$$A_\mathrm{NGF,WE,m} = \frac{A_\mathrm{NGF}}{n_\mathrm{WE}}, \tag{6}$$

where n_WE is the amount of apartment units in the building.

If no measuring of a building's internal metes are available the net volume V can be calculated by Equation (33) in [6]:

$$V = 0.76 \cdot V_\mathrm{e}.$$

If the buildings consists of 4 or more entire floors, it is given by Equation (34) in [6]:

$$V = 0.8 \cdot V_\mathrm{e}.$$

The characteristic length L_{char} and height B_{char} can be calculated with Equations (38) and (39) in [6] respectively:

$$L_\mathrm{char} = \sqrt{\frac{A_\mathrm{NGF}}{n_\mathrm{G} \cdot f_\mathrm{geo}}} \tag{7}$$

and

$$B_\mathrm{char} = L_\mathrm{char} \cdot f_\mathrm{B/L}, \tag{8}$$

where f_geo and $f_\mathrm{B/L}$ are constant factors given in Table 5. The building groups are shown in Table 6.

Network type	**Building group**	$f_\mathrm{B/L}$	f_geo
Heating system	1	0.31	0.392
	2	0.27	0.325
	3	0.37	0.407
	4	0.41	0.439
	5	0.24	0.275
Tap water	1	0.22	0.277
	2	0.33	0.391
	3	0.43	0.484
	4	0.22	0.235

Table 5: Values for $f_\mathrm{B/L}$ and f_geo according to Table 9 in [6].

Building group	**Application**
1	Residential buildings, offices, surgeries, hotels, hostels, seminar buildings, dormitories, kindergardens, foster homes
2	Schools, convention halls, concourses, laboratories, libraries, museums, theaters, auditoriums, data centers
3	Sales buildings, kitchens, restaurants, canteens, butcher's shops, bakeries, hair dressers
4	Natatoriums, sports halls, dressing rooms
5	Factory halls, workshops, production facilities

Table 6: Building groups according to Table 9 in [6].

3. Determining heat losses and heat sources in the building shell

In order to detect how much energy is required to heat up a building to a specific temperature, it is necessary to calculate the heat gains and losses of the building shell itself without considering any heat generation devices such as heating systems. These energy amounts depend on the building's environment and therefore take different values for every month of the year.

The considered energy amounts for this calculation step cover heat gains and losses through heat transmission across the building shell, ventilation and insolation. The required equations are given in [8]. Figure 3 shows an illustration of the different heat losses and gains which may occur.

The total energy amount of the heat losses is combined as described in Equation (11) in [8]:

$$Q_{\mathrm{sink}} = Q_{\mathrm{T}} + Q_{\mathrm{V}} + Q_{\mathrm{S}} + Q_{\mathrm{I,sink}} + \Delta Q_{\mathrm{C,sink}}, \tag{9}$$

and the total energy amount of the heat sources is combined as described in Equation (16) in [8]:

$$Q_{\mathrm{source}} = Q_{\mathrm{T}} + Q_{\mathrm{V}} + Q_{\mathrm{S}} + Q_{\mathrm{I,source}}, \tag{10}$$

where:

- Q_{T} is the transmission heat sink or heat source,
- Q_{V} is the ventilation heat sink or heat source,
- Q_{S} is the irradiation heat sink or heat source and
- $Q_{\mathrm{I,sink}}$ or $Q_{\mathrm{I,source}}$ is the heat sink or heat source through internal factors and
- $\Delta Q_{\mathrm{C,sink}}$ is the heat stored on normal days which the components of a building give off during reduced heating periods.

Q_{T}, Q_{V} and Q_{S} may represent either a heat sink or a heat source.

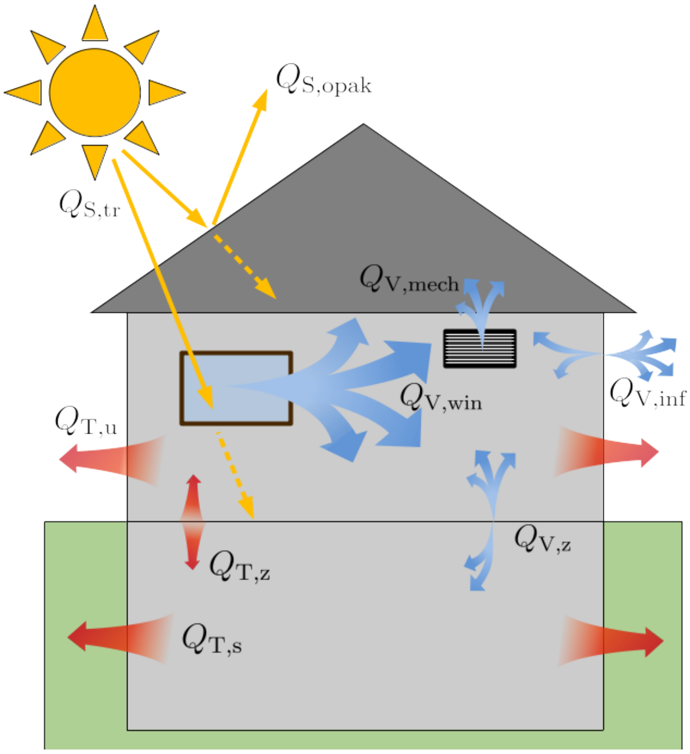

Figure 3: Visualization of the different heat losses and gains which may occur. In red: Transmission heat loss though the building shell and between different zones. In yellow: Heat gains through insolation through windows and opaque components. In green: Ventilation through windows, mechanical ventilation and infiltration.

3.1. Transmission

Heat transmission is an unavoidable process which must be considered for the energy balancing. As the building's shell takes down available thermal energy from its inside and loses the energy to its environment or vice-versa, transmission always occurs if the outside temperature differs from the building's inside temperature. Heat may be transferred from heated or unheated zones to outside or to the earth and between different building zones and must be considered for the balancing, too, if their temperature difference is more than 4 K.

3.1.1. Heat transmission from heated and cooled zones to the outside

Heat sinks and heat sources of a whole zone through transmission to the outside can generally be calculated by Equations (45) and (46) in [8] respectively:

$$Q_{\mathrm{T,e}} = (H_{\mathrm{T,D}} + H_{\mathrm{T,WB}})\,|\theta_i - \theta_e|\,t, \tag{11}$$

where:

- $H_{\mathrm{T,D}}$ is the heat transfer coefficient between the considered zone and the outside,
- $H_{\mathrm{T,WB}}$ is the heat transfer coefficient for two dimensional heat bridges,
- θ_i is the reference internal temperature,
- θ_e is the average outside temperature and
- t is the considered period for the calculation step.

θ_i depends on several factors and has to be calculated for each month. Its calculation is described in subsection 3.8.

3.1.2. Heat transmission through unheated and uncooled zones to the outside

Heat sinks and sources through transmission through unheated and uncooled zones to the outside can be evaluated as heat sinks and sources through transmission to the outside if the component's heat transfer coefficient already consider these rooms. If not, Equations (48) and (49) in [8] can be applied for heat sinks and heat sources respectively:

$$Q_{\mathrm{T,u}} = H_{\mathrm{T,iu}}\,|\theta_i - \theta_u|\,t, \tag{12}$$

where:

- $H_{\mathrm{T,iu}}$ is the heat transfer coefficient between the considered zone and the outside and
- θ_u is the median temperature of the adjacent area.

3.1.3. Heat transmission between heated and cooled zones

Heat sinks and heat sources to heated or refrigerated zones only have to be considered if the temperature difference between the zones is more than 4 K. They are given by Equations (52) and (53) in [8] respectively:

$$Q_{\mathrm{T,z}} = H_{\mathrm{T,iz}}\,|\theta_i - \theta_z|\,t, \tag{13}$$

where:

- $H_{\mathrm{T},iz}$ is the heat transfer coefficient between the considered zone and the adjacent area and
- θ_z is the median temperature of the adjacent area.

3.1.4. Heat transmission to the earth

If a zone is connected to the heating system but no other conditioning system, then its heat sinks and heat sources are considered as in subsection 3.1.1. If not, heat sinks and heat sources to the earth can be calculated by Equations (55) and (56) in [8] respectively:

$$Q_{\mathrm{T,s}} = H_{\mathrm{T,s}} \left|\theta_i - \theta_e\right| t, \tag{14}$$

where:

- $H_{\mathrm{T,s}}$ is the heat transfer coefficient to the earth and and
- θ_e is the average outside temperature.

3.1.5. Heat transfer coefficient for two dimensional heat bridges

$H_{\mathrm{T,WB}}$ is given by Equation (58) in [8]:

$$H_{\mathrm{T,WB}} = \Delta U_{\mathrm{T,WB}} \sum A_j, \tag{15}$$

where $\Delta U_{\mathrm{T,WB}}$ is the thermal bridge surcharge, which may take one of several values:

- $\Delta U_{\mathrm{T,WB}} = 0.1$ if no verification is available or
- $\Delta U_{\mathrm{T,WB}} = 0.15$ if external components have an internal insulation layer.

However, $\Delta U_{\mathrm{T,WB}}$ can alternatively be specified according to DIN 4108, as stated in [8].

3.2. Ventilation

There are several types of ventilation which have to be considered. These include infiltration, ventilation through windows, mechanical ventilation and ventilation between unheated and uncooled zones.

3.2.1. Infiltration

Especially in older buildings joints may not be completely sealed, which results in an air flow between outside and inside. Heat sinks or heat sources through infiltration can be calculated by Equations (61) and (62) in [8] respectively:

$$Q_{\mathrm{V,inf}} = H_{\mathrm{V,inf}} \left|\theta_i - \theta_e\right| \cdot t, \tag{16}$$

where:

- $H_{\mathrm{V,inf}}$ is the ventilation heat transfer coefficient for ventilation from the outside, from another zone or through a ventilation system and
- θ_e is the average monthly outside temperature.

3.2.2. Windows

Heat sinks or heat sources through windows can be calculated by Equations (71) and (72) in [8] respectively:

$$Q_{\mathrm{V,win}} = H_{\mathrm{V,win}} \left| \theta_i - \theta_e \right| \cdot t, \tag{17}$$

where $H_{\mathrm{V,win}}$ is the heat transfer coefficient for ventilation through windows. For residential building without mechanical ventilation, different monthly values for the heat transfer coefficient $H_{\mathrm{V,win},mth}$ can be calculated.

3.2.3. Mechanical ventilation

Heat sinks or heat sources through mechanical ventilation can be calculated by Equations (90) and (91) in [8] respectively:

$$Q_{\mathrm{V,mech}} = H_{\mathrm{V,mech}} \left| \theta_i - \theta_{\mathrm{V,mech}} \right| \cdot t, \tag{18}$$

where:

- $H_{\mathrm{V,mech}}$ is the heat transfer coefficient for mechanical ventilation and
- $\theta_{\mathrm{V,mech}}$ is the median temperature of the supply air.

3.2.4. Ventilation between zones

Heat sinks or heat sources through ventilation among two zones can be calculated by Equations (104) and (105) in [8] respectively:

$$Q_{\mathrm{V,z}} = H_{\mathrm{V,z}} \left| \theta_i - \theta_{\mathrm{V,z}} \right| \cdot t, \tag{19}$$

where:

- $H_{\mathrm{V,z}}$ is the heat transfer coefficient for ventilation among two zones and
- $\theta_{\mathrm{V,z}}$ is the reference internal temperature of the considered adjacent zone.

3.3. Emitted radiation and insolation

Transparent components, such as windows, allow solar energy to heat up the building's interior. Therefore this always represents a heat source. In contrast, depending on an opaque component's structure, its emitted radiation of heat may exceed the ingoing insolation energy. Then heat losses may occur.

Heat gains and losses through insolation and emitted radiation Q_{S} are given by Equation (17) in [8]:

$$Q_{\mathrm{S}} = \sum Q_{\mathrm{S,tr}} + \sum Q_{\mathrm{S,opak}}, \tag{20}$$

where:

- $Q_{\mathrm{S,tr}}$ is the sum of all heat sources through transparent components and
- $Q_{\mathrm{S,opak}}$ is the sum of all heat sources through opaque components.

3.3.1. Insolation through transparent components

$Q_{\mathrm{S,tr}}$ can only represent a heat source and is given by Equation (112) in [8]:

$$Q_{\mathrm{S,tr}} = F_{\mathrm{F}} A g_{\mathrm{eff}} I_{\mathrm{S}} t, \tag{21}$$

where:

- F_{F} is the reduction factor of the frame share which corresponds to the amount of transparent surface in contrast to the whole component,
- A is the total surface area of the component,
- g_{eff} is the total energy transmittance,
- I_{S} the median monthly insolation and
- t is the period of the calculation step.

F_{F} can be set to its standard values $F_{\mathrm{F}} = 0.7$ or $F_{\mathrm{F}} = 0.9$ for roof light windows and winter gardens. g_{eff} is given by Equations (113), (114) or (115) in [8] respectively:

$$g_{\mathrm{eff}} = F_{\mathrm{S}} F_{\mathrm{W}} F_{\mathrm{V}} g, \tag{22}$$

$$g_{\mathrm{eff}} = F_{\mathrm{S}} F_{\mathrm{W}} F_{\mathrm{V}} g_{\mathrm{tot}} \tag{23}$$

or

$$g_{\mathrm{eff}} = F_{\mathrm{W}} F_{\mathrm{V}} \min\left\{a g_{\mathrm{tot}} + (1-a) g, F_{\mathrm{S}} g\right\} \tag{24}$$

respectively, where:

- F_{S} is the reduction factor for possible shadows from objects around, such as other buildings, mountains or overhanging components,
- F_{W} is the reduction factor for considering non perpendicular entry of insolation,
- F_{V} is the reduction factor for dirt,
- g is the total energy transmittance,
- g_{tot} is the total energy transmittance including the sun protection device and
- a is a numerical parameter for the activation of adjustable sun protection devices.

These equations apply if there is:

- no sun protection device (Equation 28),
- a fixed sun protection device (Equation 29) or
- an adjustable sun protection device (Equation 30).

F_W can be set to its standard value $F_W = 0.9$. $F_V = 1$ for residential buildings and $F_V = 0.9$ for non-residential buildings according to the boundary conditions presented in [7]. g and g_{tot} can be determined by Table (8) in [8] shown in Table 33, 34 and 35. F_S can be set to $F_S = 0.9$ as a default value. However, it can be determined by Equation (116) in [8]:

$$F_S = \min\left(F_h, F_o, F_f\right), \tag{25}$$

where:

- F_h is the reduction factor for horizon shading,
- F_o is the reduction factor for considering overhangs and
- F_f is the reduction factor for considering lateral component protrusion.

3.3.2. Emitted or taken radiation

$Q_{S,opak}$ can be a heat source or a heat sink and is given by Equations (117) and (118) in [8] respectively:

$$Q_{S,opak} = R_{se} U A \left|\alpha I_S - F_f h_r \Delta\theta_{er}\right| t, \tag{26}$$

where:

- R_{se} is the outer heat transfer resistance,
- U is the heat transmission coefficient of the component,
- A is the surface area of a component in a specific direction,
- F_f is the radiation-effective form factor between element and sky, or partial shading correction factor for fins,
- h_r is the external radiative heat transfer coefficient,
- $\Delta\theta_{er}$ is the difference between the external air temperature and sky temperature,
- α is the solar absorption coefficient of a component and
- I_S is the average monthly solar irradiance.

α can be determined by Table 7 shown in Figure (8). F_f can be set to $F_f = 1$ if the component has a slope of 45 ° or less, in other cases $F_f = 0.5$ according to [8]. $\Delta\theta_{er}$ can be assumed to be $\Delta\theta_{er} = 10\,\mathrm{K}$ according to [8]. h_r can be calculated by Equation (119) in [8]:

$$h_r = 5\epsilon, \tag{27}$$

where:

- ϵ is the emissivity for heat radiation of the outer surface.

ϵ can eb assumed to be $\epsilon = 0.9$ according to [8].

Heat sources through transparent thermal insulation can be calculated by Equation (120) in [8]:

$$Q_{\mathrm{S,opak,TI}} = R_{\mathrm{e}} U A F_{\mathrm{F}} F_{\mathrm{S}} F_{\mathrm{W}} g_{\mathrm{TI}} \alpha I_{\mathrm{S}} t \tag{28}$$

- R_{e} is the outer heat transfer resistance and
- g_{TI} is the total energy transmittance of the component.

g_{TI} can be set to $g_{\mathrm{TI}} = 0.35$ if no measurement is available according to [8].

3.4. Heat sources through irradiation and insolation in unheated and uncooled sun porches

Heat sources through irradiation and insolation in unheated and uncooled sun porches are calculated as in Equation (29) but an additional energy amount has to be added which is given by Equation (121) in [8]:

$$Q_{\mathrm{S,tr}} = F_{\mathrm{F,iu}} A_{\mathrm{iu}} g_{\mathrm{eff,iu}} F_{\mathrm{F,ue}} \tau_{\mathrm{e,ue}} I_{\mathrm{S}} t, \tag{29}$$

where:

- $F_{\mathrm{F,iu}}$ is the reduction factor depending on the ratio of the window fringe in comparison to the transparent part of the inner glass,
- A_{iu} is the surface area of the component,
- $F_{\mathrm{F,ue}}$ is the reduction factor depending on the ratio of the window fringe in comparison to the transparent part of the outer glass and
- $\tau_{\mathrm{e,ue}}$ is the transmission degree of the outer glass.

	Surface type	α
Walls	Bright paint	0.4
	Muted paint	0.6
	Dark paint	0.8
	Clinker brick masonry	0.8
	Fairfaced brickwork	0.6
Roofs	Brick red	0.6
	Dark	0.8
	Metal	0.2
	Tarred roofing felt	0.6

Table 7: Values for α according to Table 9 in [8].

3.5. Internal factors

There are some more types of heat transfer which have to be considered for the energy balancing. These include heat losses of devices and machines, people and animals inside, hot or cold materials and lightning.

3.5.1. Heat sinks through internal factors

The total heat loss through internal factors $Q_{\mathrm{I,sink}}$ is given by Equation (15) in [8]:

$$Q_{\mathrm{I,sink}} = Q_{\mathrm{I,sink,c}} + Q_{\mathrm{I,sink,fac}} + Q_{\mathrm{I,sink,goods}}, \tag{30}$$

where:

- $Q_{\mathrm{I,sink,c}}$ is the heat sink through refrigerating systems,
- $Q_{\mathrm{I,sink,fac}}$ is the heat sink through devices and machines and
- $Q_{\mathrm{I,sink,goods}}$ is the heat sink through brought in materials which a colder than the inside temperature.

Note that $Q_{\mathrm{I,sink,c}} = 0$ for the approximate balancing (calculation step 6) and their calculation will be added later.

3.5.2. Heat sources through internal factors

The total heat gain through internal factors $Q_{\mathrm{I,source}}$ is given by Equation (20) in [8]:

$$Q_{\mathrm{I,source}} = Q_{\mathrm{I,source,p}} + Q_{\mathrm{I,source,l}} + Q_{\mathrm{I,source,fac}} + Q_{\mathrm{I,source,goods}} + Q_{\mathrm{I,source,h}}, \tag{31}$$

where:

- $Q_{\mathrm{I,source,p}}$ is the heat source through people,
- $Q_{\mathrm{I,source,l}}$ is the heat source through lighting,
- $Q_{\mathrm{I,source,fac}}$ is the heat source through devices and machines,
- $Q_{\mathrm{I,source,goods}}$ is the heat source through brought in materials which are colder than the inside temperature and
- $Q_{\mathrm{I,source,h}}$ is the heat source through cooling systems.

Also $Q_{\mathrm{I,source,h}} = 0$ for the approximate balancing (calculation step 6) and their calculation will be added later. For residential buildings a standard value q_{I} allows to calculate the heat sinks through people, devices, machines and lightning with Equation (124) in [8]:

$$Q_{\mathrm{I,\ source,\ WG}} = q_{\mathrm{I}} A_{\mathrm{NGF}} \tag{32}$$

$q_{\mathrm{I}} = 45\,{}^{\mathrm{Wh}}/_{\mathrm{d \cdot m^2}}$ for single family houses and $q_{\mathrm{I}} = 90\,{}^{\mathrm{Wh}}/_{\mathrm{d \cdot m^2}}$ for apartments according to the boundary conditions for residential buildings in [7].

3.5.3. Devices and machines

$Q_{\text{I,sink,fac}}$ and $Q_{\text{I,source,fac}}$ can be calculated by Equations (126) and (127) in [8] respectively:

$$Q_{\text{l,source,fac}} = q_{\text{I,fac}} A_{\text{NGF}} \tag{33}$$

and

$$Q_{\text{l,source,fac}} = q_{\text{I,sink,fac}} A_{\text{NGF}}, \tag{34}$$

where:

- $q_{\text{I,fac}}$ is the heat source through devices and machines and
- $q_{\text{I,sink,fac}}$ is the heat source through lighting.

3.5.4. Materials

$Q_{\text{I,sink,goods}}$ and $Q_{\text{I,source,goods}}$ can be calculated by Equations (126) and (127) in [8] respectively:

$$Q_{\text{l,source,goods}} = c\dot{m}(\theta_{\text{out}} - \theta_{\text{in}})t, \tag{35}$$

and

$$Q_{\text{l,source,goods}} = c\dot{m}(\theta_{\text{in}} - \theta_{\text{out}})t \tag{36}$$

where:

- c is the specific heat capacity of the material,
- $\dot{m}$ is the daily mass flow,
- θ_{out} is the material's temperature when it leaves the zone and
- θ_{in} is the material's temperature when it enters the zone.

3.5.5. People

$Q_{\text{l,source,p}}$ can be calculated by Equation (125) in [8]:

$$Q_{\text{l,source,p}} = q_{\text{I,p}} A_{\text{NGF}}, \tag{37}$$

where $q_{\text{I,p}}$ is the average heat emission of a human. $q_{\text{I,p}}$ is given in Table 2.

As the energy for lightning is not considered for residential building, $Q_{\text{I,source,l}}$ will not be covered here.

3.6. Energy difference between normal and reduced usage

The calculation of $\Delta Q_{\mathrm{C,sink}}$ is only required for periods during which heating is necessary. It is given by Equation (134) in [8]:

$$\Delta Q_{\mathrm{C,sink}} = \Delta Q_{\mathrm{C,sink,nutz}} = \frac{\Delta Q_{\mathrm{C,b,we}} \cdot d_{\mathrm{we}}}{d_{\mathrm{nutz}}} \tag{38}$$

where:

- $\Delta Q_{\mathrm{C,sink,nutz}}$ is the heat which gets stored on usage days,
- d_{we} is the amount of days per month without or with restricted usage,
- d_{nutz} is the amount of days per month with normal usage and
- $Q_{\mathrm{C,b,we}}$ is the stored heat which is available on days without or with restricted usage.

$Q_{\mathrm{C,b,we}}$ is given by Equation (133) in [8]:

$$Q_{\mathrm{C,b,we}} = \min\left(\frac{2 \cdot C_{\mathrm{wirk}}(\theta_{\mathrm{i,h,soll}} - \theta_{\mathrm{i,h}})}{a_{we}}, \frac{C_{\mathrm{wirk}} \Delta\theta_{\mathrm{i,NA}}}{a_{\mathrm{we}}}, Q_{\mathrm{sink}} - \eta Q_{\mathrm{source}}\right) \quad \text{if} \quad \theta_{\mathrm{i,h,soll}} < \theta_{\mathrm{i,h}} \tag{39}$$

where:

- C_{wirk} is the effective heat capacity of a building zone,
- $\theta_{\mathrm{i,h,soll}}$ is the internal set-point temperature for heating during periods of use (usage periods),
- $\theta_{\mathrm{i,h}}$ is the reference internal temperature for restricted activity,
- a_{we} is the average amount of non-use days per week,
- $\Delta\theta_{\mathrm{i,NA}}$ is the permissible lowering of the internal temperature for reduced usage,
- Q_{sink} represents the heat sinks,
- Q_{source} represents the heat sources and
- η is the monthly performance ratio, efficiency, utilization factor of the heat sources for periods with restricted usage.

If $\theta_{\mathrm{i,h,soll}} \geq \theta_{\mathrm{i,h}}$, then $Q_{\mathrm{C,b,we}} = 0$

3.7. Heat transfer coefficients

3.7.1. Transmission

The heat transfer coefficients for transmission to outside, unheated zones and heated zones can all be calculated by Equations (47), (50) and (54) in [8] respectively:

$$H_{\mathrm{T,D}} = \sum (U_j A_j), \tag{40}$$

$$H_{\mathrm{T,iu}} = \sum (U_j A_j) \tag{41}$$

and

$$H_{\mathrm{T,iz}} = \sum (U_j A_j) \tag{42}$$

where:

- U_j is the heat transfer coefficient of component j and
- A_j is the surface area of component j.

A_j must be specified for each component in the input of the program. U_j can be calculated as described in other DIN standards or it can be part of the input as well.

3.7.2. Ventilation

Infiltration $H_{\mathrm{V,k}}$ is given by Equation (63) in [8]:

$$H_{\mathrm{V,inf}} = n_{\mathrm{inf}} V c_{\mathrm{p,a}} \rho_{\mathrm{a}}, \tag{43}$$

where:

- n_{inf} is the daily median infiltration air change,
- V is the net volume,
- $c_{\mathrm{p,a}}$ is the specific heat capacity of the air and
- ρ_{a} is the density of the air.

$c_{\mathrm{p,a}} \rho_{\mathrm{a}}$ can be set to $0.34\,{}^{\mathrm{Wh}}/_{\mathrm{m^3K}}$ according to [8].

n_{inf} is given by Equation (64) in [8] if no mechanical ventilation system is available:

$$n_{\mathrm{inf}} = n_{50} e f_{\mathrm{ATF}}, \tag{44}$$

where:

- n_{50} is the air change at a pressure difference of 50 Pa,
- e is the air flow coefficient and
- f_{ATF} is a factor for considering the outside air passage.

If a mechanical ventilation system is available, n_{inf} is given by Equation (65) in [8]

$$n_{\mathrm{inf}} = n_{50} e f_{\mathrm{ATF}} (1 + (f_e - 1) \frac{t_{\mathrm{V,mech}}}{24\,\mathrm{h}}), \tag{45}$$

where:

- t is the daily operating time of the ventilation system and
- f_{e} is a factor for determining the system's influence on infiltration.

f_{ATF} is given by Equation (67) or (66) in [8] respectively, depending on whether an outside air passage is available or not:

$$f_{\mathrm{ATF}} = \min(16, \frac{n_{50} + 1.5\mathrm{h}^{-1}}{n_{50}}) \tag{46}$$

or

$$f_{\mathrm{ATF}} = 1. \tag{47}$$

The information if an outside air passage is available has to be part of the input. For e, the standard value 0.07 will be assumed. The values of n_{50} are shown in Table 8. Values for n_{50} are chosen directly from the table if the net volume V of the building is less or equal to $1500\,\mathrm{m}^{\mathbf{3}}$. If the volume exceeds $1500\,\mathrm{m}^{\mathbf{3}}$ the air permeability q_{50} is determined. q_{50} depends on the enveloping surface A_E. Then n_{50} can be calculated with Equation (68) in [8]:

$$n_{50} = \frac{q_{50} A_{\mathrm{E}}}{V}. \tag{48}$$

f_e can generally be calculated by Equation (70) in [8]:

$$f_{\mathrm{e}} = \frac{1}{1 + \frac{f}{e} (\frac{n_{\mathrm{ETA}} - n_{\mathrm{SUP}}}{n_{50} f_{\mathrm{ATF}}})^2} \tag{49}$$

where:

- e is the volume flow coefficient,
- f is the win exposure coefficient,
- n_{ETA} is the sum of all supply air exchanges and
- n_{SUP} is the sum of all exhaust air exchanges.

For now, e can be set to the standard value $e = 0.07$ and f can be set to the standard value $f = 15$.

Windows $H_{\mathrm{V,win}}$ and $H_{\mathrm{V,win},mth}$ are given by Equations (73) and (74) in [8]:

$$H_{\mathrm{V,win}} = n_{\mathrm{win}} V c_{\mathrm{p,a}} \rho_{\mathrm{a}} \tag{50}$$

or:

$$H_{\mathrm{V,win},mth} = n_{\mathrm{win,mth}} V c_{\mathrm{p,a}} \rho_{\mathrm{a}}, \tag{51}$$

where:

- n_{win} is the median daily air change through windows and
- $n_{\mathrm{win,mth}}$ is the median daily air change through windows with an adaptation depending on a specific month.

$n_{\mathrm{win,mth}}$ is given by Equation (75) in [8]:

$$n_{\mathrm{win,mth}} = n_{\mathrm{win}} f_{\mathrm{win,seasonal}} \tag{52}$$

where:

- $f_{\mathrm{win,seasonal}}$ is the the factor for adapting the air flow to a specific season.

$f_{\mathrm{win,seasonal}}$ is given by Equation (76) in [8]:

$$f_{\mathrm{win,seasonal}} = 0.04\theta_e + 0.8 \tag{53}$$

where:

- θ_e is the average monthly outside temperature.

n_{win} is given by Equations (78), (81) or (82), depending on different conditions:

- If no mechanical ventilation system is available, or if it is disabled:

$$n_{\mathrm{win}} = n_{\mathrm{win,min}} + \Delta n_{\mathrm{win}} \frac{t_{\mathrm{nutz}}}{24\,\mathrm{h}}, \tag{54}$$

- if a mechanical ventilation system is available and the use time does not exceed the system's operating time ($t_{\mathrm{V,mech}} = t_{\mathrm{nutz}}$):

$$n_{\mathrm{win}} = n_{\mathrm{win,min}} + \Delta n_{\mathrm{win,mech}} \frac{t_{\mathrm{V,mech}}}{24\,\mathrm{h}}, \tag{55}$$

- if a mechanical ventilation system is available and the use time exceeds the system's operating time ($t_{\mathrm{V,mech}} < t_{\mathrm{nutz}}$):

$$n_{\mathrm{win}} = n_{\mathrm{win,min}} + \Delta n_{\mathrm{win}} \frac{t_{\mathrm{nutz}} - t_{\mathrm{V,mech}}}{24\,\mathrm{h}} + \Delta n_{\mathrm{win,mech}} \frac{t_{\mathrm{V,mech}}}{24\,\mathrm{h}}, \tag{56}$$

where:

- $n_{\text{win,min}}$ is the minimal air change through windows,
- Δn_{win} is the additional air change through windows without operating a mechanical ventilation system,
- $\Delta n_{\text{win,mech}}$ is the additional air change through windows while operating a mechanical ventilation system,
- t_{nutz} is the daily use time in hours and
- $t_{\text{V,mech}}$ is the daily operating time of the mechanical ventilation system in hours.

If not specified in the input data, $n_{\text{win,min}}$ can be set to its minimal value $n_{\text{win,min}} = 0.1$. For zones without a passage to outside, $n_{\text{win,min}}$ can be neglected. t_{nutz} and $t_{\text{V,mech}}$ are part of the input data. Δn_{win} can be calculated by Equations (79) or (80) in [8] respectively:

$$\Delta n_{\text{win}} = max(0, \frac{(n_{\text{nutz}} - (n_{\text{nutz}} - 0.2\text{h}^{-1}))}{\text{h}^{-1}} \cdot n_{\text{inf}} - 0.1\,\text{h}^{-1}) \quad \text{if} \quad n_{\text{nutz}} < 1.2\text{h}^{-1} \tag{57}$$

or

$$\Delta n_{\text{win}} = max(0.n_{\text{nutz}} - n_{\text{inf}} - 0.1\,\text{h}^{-1}) \quad \text{if} \quad n_{\text{nutz}} \geq 1.2\text{h}^{-1} \tag{58}$$

where n_{nutz} is the usage dependent minimal air change. For now, it is considered as input, as in the test cases.

Mechanical Ventilation $H_{\text{V,mech}}$ is given by Equation (92) in [8]:

$$H_{\text{V,mech}} = n_{\text{mech}} V c_{\text{p,a}} \rho_{\text{a}}, \tag{59}$$

where n_{mech} is the median daily air change by mechanical ventilation.

Category for estimating the building tightness	**Buildings with a net volume** $\leq 1500\,\text{m}^3$ n_{50}	**Buildings with a net volume** $> 1500\,\text{m}^3$ q_{50}
I	a) 2; b) 1	a) 3; b) 2
II	4	6
III	6	9
IV	10	15

Table 8: Values for n_{50} and q_{50} according to Table in [8]. a) indicates the value for buildings without mechanical ventilation and b) indicates the value for buildings with mechanical ventilation.

Ventilation among zones

$$H_{\mathrm{V,z}} = V_{\mathrm{V,z}} c_{\mathrm{p,a}} \rho_{\mathrm{a}}, \tag{60}$$

where $V_{\mathrm{V,z}}$ is the median daily air volume coming from the considered adjacent zone. $V_{\mathrm{V,z}}$ is given by Equation (107) in [8]:

$$\dot{V}_{\mathrm{z,d}} = \dot{V}_{\mathrm{z}} \frac{t_{\mathrm{V,mech}}}{24\ \mathrm{h}}, \tag{61}$$

where:

- $\dot{V}$ is the median daily air volume coming from the considered adjacent zone during the operating time of the ventilation system and
- $t_{\mathrm{V,mech}}$ is the daily operating time of the ventilation system.

3.8. Reference internal temperature

For calculating the required energy amounts of a zone, its reference internal temperature $\theta_{\mathrm{i,h}}$ must be determined. If a building is heated permanently, Equation (27) in [8] can be applied:

$$\theta_{\mathrm{i,h}} = \theta_{\mathrm{i,h,soll}}, \tag{62}$$

where $\theta_{\mathrm{i,h,soll}}$ is the desired temperature while heating. It is part of the boundary conditions.

However, it must be considered that heating systems might be disabled during scheduled periods for saving energy. Instead of shutting down the heating system, its activity could also be reduced. These aspects and the duration of the decreased heating activity affect the monthly reference internal temperature.

3.8.1. Reduced heating activity during nights

If the heating activity is reduced during nights, Equation (28) in [8] has to be applied:

$$\theta_{\mathrm{i,h}} = \max\left(\theta_{\mathrm{i,h,soll}} + \Delta\theta_{\mathrm{EMS}} - f_{\mathrm{NA}}\left(\theta_{\mathrm{i,h,soll}} - \theta_{\mathrm{e}}\right), \theta_{\mathrm{i,h,soll}} - \Delta\theta_{\mathrm{i,NA}} \frac{t_{\mathrm{NA}}}{24\,\mathrm{h}}\right), \tag{63}$$

where:

- $\Delta\theta_{\mathrm{EMS}}$ is the addend for considering building automation,
- f_{NA} is the correction factor for the reduced heating activity during nights,
- $\Delta\theta_{\mathrm{i,NA}}$ is the acceptable setback of the temperature and
- t_{NA} is the daily duration of the reduced activity.

$\Delta\theta_{\mathrm{EMS}}$ depends on the degree of automation and is given by Table 9. $\Delta\theta_{\mathrm{i,NA}}$ is given in the boundary conditions. t_{NA} can be calculated by using the heating system's daily operating time $t_{\mathrm{h,op,d}}$:

$$t_{\mathrm{NA}} = 24\,\mathrm{h} - t_{\mathrm{h,op,d}} \tag{64}$$

f_{NA} is given by Equation (29) in [8] if the heating system's activity is reduced during nights or by Equation (30) in [8] if the heating system is shut down during nights:

$$f_{\mathrm{NA}} = 0.13 \frac{t_{\mathrm{NA}}}{24\,\mathrm{h}} \exp\left(-\frac{\tau}{250\,\mathrm{h}}\right) f_{\mathrm{adapt}}, \quad \text{if reduced} \tag{65}$$

or

$$f_{\mathrm{NA}} = 0.26 \frac{t_{\mathrm{NA}}}{24\,\mathrm{h}} \exp\left(-\frac{\tau}{250\,\mathrm{h}}\right) f_{\mathrm{adapt}}, \quad \text{if disabled} \tag{66}$$

where:

- τ is the considered zone's thermal time constant and
- f_{adapt} the factor for adaptive temperature control.

f_{adapt} is given by Table 9. The required calculations for τ are presented in section 3.10

$\Delta\theta_{\mathrm{EMS}}$	**D**	**C**	**B**	**A**
	0	0	-0.5	-1
f_{adapt}	**D**	**C**	**B**	**A**
	1	1	1.35	1.35

Table 9: Values for $\Delta\theta_{\mathrm{EMS}}$ and f_{adapt} according to Table 4 in [7]. A, B, C and D indicate the building's level of automation.

3.8.2. Reduced heating activity during weekends or holidays

If the heating activity is reduced during weekend or holidays, Equation (31) in [8] has to be applied:

$$\theta_{\mathrm{i,h}} = \max\left(\theta_{\mathrm{i,h,soll}} - f_{\mathrm{we}}\left(\theta_{\mathrm{i,h,soll}} - \theta_{\mathrm{e}}\right), \theta_{\mathrm{i,h,soll}} - \Delta\theta_{\mathrm{i,NA}}\right), \tag{67}$$

where f_{we} is the correction factor for the reduced heating activity during several days. f_{we} is given by Equation (32) in [8] if the heating system's activity is reduced or by Equation (33) in [8] if the heating system is shut down:

$$f_{\mathrm{we}} = 0.2 \cdot \left(1 - 0.4 \cdot \frac{\tau}{250\,\mathrm{h}}\right), \quad \text{if reduced} \tag{68}$$

or

$$f_{\mathrm{we}} = 0.3 \cdot \left(1 - 0.2 \cdot \frac{\tau}{250\,\mathrm{h}}\right), \quad \text{if disabled} \tag{69}$$

3.8.3. Spatially restricted heating activity

For buildings without cooling systems which can be balanced within a single zone, $\theta_{\mathrm{i,h}}$ can be calculated by Equation (34) in [8]:

$$\theta_{\mathrm{i,h}} = \theta_{\mathrm{i,h,soll}} - f_{\mathrm{tb}} \left(\theta_{\mathrm{i,h,soll}} - \theta_e \right), \tag{70}$$

where f_{tb} is the correction factor for the spatially reduced heating activity. It is given by Equation (35) in [8]:

$$f_{\mathrm{tb}} = 0.8 \left(1 - \exp \left(- \frac{\Phi_{\mathrm{h,max}}}{A_{\mathrm{NGF}} \cdot 35 \mathrm{W/m^2}} \right) \right) a_{\mathrm{tb}}^2. \tag{71}$$

where:

- $\Phi_{\mathrm{h,max}}$ is the maximum heating load of the considered zone and
- a_{tb} is the ratio of the co-heated surface area.

The required calculations for $\Phi_{\mathrm{h,max}}$ are presented in section 3.9. a_{tb} may be given in the input data. If not, it can be calculated by Equation (36) in [8]:

$$a_{\mathrm{tb}} = \frac{A_{\mathrm{NGF,mitbeheizt}}}{A_{\mathrm{NGF}}}, \tag{72}$$

where $A_{\mathrm{NGF,mitbeheizt}}$ is the co-heated surface area, which corresponds to the total area which is cooler than $\theta_{\mathrm{i,h,soll}}$. Alternatively, a_{tb}^2 can be estimated by Equation (37) in [8]:

$$a_{\mathrm{tb}} = 0.25 + 0.2 \arctan \left(\frac{A_{\mathrm{NGF,WE,m}} - 100}{50} \right), \tag{73}$$

where $A_{\mathrm{NGF,WE,m}}$ is the median net area of an apartment.

3.8.4. Combination of spatially and temporarily restricted heating activity

Buildings which can be balanced within a single zone and which have spatially and temporarily restricted heating activity, $\theta_{\mathrm{i,h}}$ can be calculated by Equation (38) in [8]:

$$\theta_{\mathrm{i,h}} = \theta_{\mathrm{i,NA}} - f_{\mathrm{tb}} \left(\theta_{\mathrm{i,NA}} - \theta_e \right), \tag{74}$$

where $\theta_{\mathrm{i,NA}}$ is the reference internal temperature according to Equation (82).

3.8.5. Unheated and uncooled glass porches

In unheated or uncooled glass porches, $\theta_{\mathrm{i,h}}$ can be calculated by Equation (41) in [8]:

$$\theta_{\mathrm{u}} = \frac{\Phi_{\mathrm{u}} + \theta_{\mathrm{i}} \left(H_{\mathrm{T,iu}} + H_{\mathrm{V,u}} \right) + \theta_{\mathrm{e}} \left(H_{\mathrm{T,ue}} + H_{\mathrm{V,ue}} \right)}{H_{\mathrm{T,iu}} + H_{\mathrm{V,iu}} + H_{\mathrm{T,ue}} + H_{\mathrm{V,ue}}}, \tag{75}$$

where:

- Φ_{u} is incoming the heat flow,
- $H_{\mathrm{T,ue}}$ is the heat transfer coefficient of the components which delimit the sun porch to outside,
- $H_{\mathrm{V,iu}}$ is the heat transfer coefficient for ventilation among the heated zone and the sun porch and
- $H_{\mathrm{V,ue}}$ is the heat transfer coefficient for ventilation among the sun porch and the outside.

$H_{\mathrm{T,ue}}$ corresponds to $H_{\mathrm{T,D}}$ or $H_{\mathrm{T,s}}$. Φ_{u} is given by Equation (41) in [8]

$$\Phi_{\mathrm{u}} = \sum \Phi_{\mathrm{S,u}} - \frac{\sum Q_{\mathrm{S,tr}}}{t} + \sum \Phi_{\mathrm{I,u}}, \tag{76}$$

where:

- $\Phi_{\mathrm{S,u}}$ is the insolation into the son porch through transparent components,
- $Q_{\mathrm{S,tr}}$ is the insolation into the heated or cooled zone through the sun porch's transparent components and
- $\Phi_{\mathrm{I,u}}$ is the internal heat source of the sun porch.

$\Phi_{\mathrm{S,u}}$ is given by Equation (123) in [8]

$$\Phi_{\mathrm{S,u}} = F_{\mathrm{F,ue}} A_{\mathrm{ue}} g_{\mathrm{eff,ue}} I_{\mathrm{S}}, \tag{77}$$

where A_{ue} is the surface area of all components which delimit the sun porch to the outside.

3.9. Maximal heating load

The maximal heating load indicates how much power would be required to heat up a zone of a building at the most unfavourable conditions. Therefore it is calculated regarding the lowest occurring external temperature while all heat generation systems are ignored. It is calculated by Equation (B.1) in [8]:

$$\Phi_{\mathrm{h,max}} = \dot{Q}_{\mathrm{T,max}} + \dot{Q}_{\mathrm{V,max}} \tag{78}$$

where:

- $\dot{Q}_{\mathrm{T,max}}$ is the maximal heat loss through transmission and
- $\dot{Q}_{\mathrm{V,max}}$ is the maximal heat loss through ventilation .

$\dot{Q}_{\text{T,max}}$ is given by Equation (B.2) in [8]:

$$\dot{Q}_{\text{T,max}} = \sum_{j} H_{\text{T},j} \left(\theta_{\text{i,h,min}} - \theta_{\text{j,h,min}}\right) F_x \tag{79}$$

where:

- $H_{\text{T},j}$ is the heat transfer coefficient for transmission to zone j.
- $\theta_{\text{i,h,min}}$ is the desired internal temperature.
- $\theta_{\text{j,h,min}}$ is the minimal temperature of the considered adjacent zone or the outer temperature and
- F_x is the temperature correction factor.

$\dot{Q}_{\text{V,max}}$ is given by Equation (B.3) in [8]:

$$\dot{Q}_{\text{V,max}} = 0.5 \sum_{j} H_{\text{V},j} \left(\theta_{\text{i,h,min}} - \theta_{\text{k,h,min}}\right) \tag{80}$$

where:

- $H_{\text{V},j}$ is the heat transfer coefficient for the ventilation type j. These are presented in Section 3.2.
- $\theta_{\text{k,h,min}}$ is the temperature of the ventilation air flow.

3.10. Thermal time constant

The thermal time constant indicates how fast a building zone heats up or cools down. It is given by Equation (138) in [8]:

$$\tau = \frac{C_{\text{wirk}}}{\sum_j H_{\text{T},j} \cdot F_x + \sum_k H_{\text{V},k} + H_{\text{V,mech},\theta}}, \tag{81}$$

where:

- $\sum_j H_{\text{T},j}$ is the sum of each component's heat transfer coefficient for transmission,
- C_{wirk} is the effective heat capacity,
- F_x is the temperature correction factor,
- $\sum_k H_{\text{V},k}$ is the sum of all heat transfer coefficient for ventilation and
- $H_{\text{V,mech},\theta}$ is the temperature related heat transfer coefficient for the mechanical ventilation

For light zones, C_{wirk} is given by Equation (135) in [8]:

$$C_{\text{wirk}} = 50\,{}^{\text{Wh}}\!/\!_{\text{m}^2\text{K}} \cdot A_{\text{NGF}} \tag{82}$$

For moderately heavy zones, C_{wirk} is given by Equation (136) in [8]:

$$C_{\text{wirk}} = 90\,{}^{\text{Wh}}\!/\!_{\text{m}^2\text{K}} \cdot A_{\text{NGF}} \tag{83}$$

For heavy zones, C_{wirk} is given by Equation (137) in [8]:

$$C_{\text{wirk}} = 130\,{}^{\text{Wh}}\!/\!_{\text{m}^2\text{K}} \cdot A_{\text{NGF}} \tag{84}$$

Zones are moderately heavy if:

- their ceiling is made of reinforced concrete,
- they have massive inner and outer components with a bulk density of $600\,{}^{\text{kg}}\!/\!_{\text{m}^3}$ or more,
- there are no drop ceilings or thermally covered ceilings,
- there are no inlying thermal isolation on the outer components and
- there are no rooms higher than 4.5 m

Zones are heavy if additionally:

- they have massive inner and outer components with a bulk density of $1600\,{}^{\text{kg}}\!/\!_{\text{m}^3}$ or more and
- a hall building containing furnishings with high thermal storage capacity is considered, such as logistics halls.

If a ventilation and air-conditioning system with a cooling feature is available, $H_{\text{V,mech},\theta}$ is given by Equation (139) in [8]:

$$H_{\text{V,mech},\theta} = H_{\text{V,mech}} \frac{\theta_{i,soll} - \theta_{V,mech}}{6\,\text{K}}, \tag{85}$$

where:

- $H_{\text{V,mech}}$ is heat transfer coefficient for mechanical ventilation and
- $\theta_{V,mech}$ is the minimal temperature of the supply air.

If no cooling feature is available Equation (140) in [8] applies:

$$H_{\text{V,mech},\theta} = H_{\text{V,mech}} \tag{86}$$

If $\theta_{i,soll} < \theta_{V,mech}$ or if no ventilation system is available Equation (141) applies:

$$H_{\text{V,mech},\theta} = 0 \tag{87}$$

4. First approximate balancing of the net energy demand

With the parameters which have been calculated to this point, the monthly net energy demand demand for heating $Q_{\mathrm{h,b}}$ and for cooling $Q_{\mathrm{c,b}}$ can now be determined. $Q_{\mathrm{h,b}}$ is given by Equation (1) in [8]:

$$Q_{\mathrm{h,b}} = Q_{\mathrm{sink}} - \eta \cdot Q_{\mathrm{source}} - \Delta Q_{\mathrm{c,b}}, \tag{88}$$

where:

- η is the degree of utilization for heat sources and
- $\Delta Q_{\mathrm{c,b}}$ is the emitted heat energy while reduced heating activity which has been stored in the building's components (such as walls) during normal heating activity.

$Q_{\mathrm{c,b}}$ is given by Equation (2) in [8]:

$$Q_{\mathrm{c,b}} = (1 - \eta) \cdot Q_{\mathrm{source}}, \tag{89}$$

η is given by Equation (24) or (25) respectively:

$$\eta = \frac{1 - \gamma^{a}}{1 - \gamma^{a+1}}, \quad \text{if} \quad \gamma \neq 1, \tag{90}$$

or:

$$\eta = \frac{a}{a+1}, \quad \text{if} \quad \gamma = 1, \tag{91}$$

where:

- γ is the ratio between Q_{source} and Q_{sink} and
- a is a parameter for considering the thermal time constant.

γ is given by Equation (145) in [8]:

$$\gamma = \frac{Q_{\mathrm{source}}}{Q_{\mathrm{sink}}}, \tag{92}$$

a is given by Equation (26) in [8]:

$$a = a_0 + \frac{\tau}{\tau_0}, \tag{93}$$

where a_0 and τ_0 are constants, namely $a_0 = 1$ and $\tau_0 = 16$ according to [8].

If $Q_{\mathrm{sink}} = 0$, then $\eta = 0$ according to [8].

For this calculation step, additional conditions may apply:

- If $1 - (\eta\gamma) < 0.01$, then $\eta = \frac{1}{\gamma}$ for the calculation of $Q_{\mathrm{h,b}}$ according to Equation (146) in [8],
- if $(1 - \eta)\,\gamma < 0.01$, then $\eta = 1$ for the calculation of $Q_{\mathrm{h,c}}$ according to Equation (147) in [8] and
- if a high basic air change applies for the ventilation system, namely $V_{\mathrm{mech}} \geq \frac{\dot{Q}_{\mathrm{C,max}}}{c_{\mathrm{p,a}}\rho_{\mathrm{a}}(\theta_i - \theta_{\mathrm{mech}})}$, then $\eta = 1$ according to Equation (148) in [8].

In the first step, the net energy demands for heating and cooling do not consider heating or tap water systems. However they strongly depend one heat losses of these systems, as well as these system's workloads depend on the net energy demands. Therefore the heating and tap water systems' heat losses have to be calculated and the approximation procedure presented in this section is repeated, as the heat losses of the heating and tap water system change the total heat sources and heat sinks. This happens up to 10 times or until the results two consecutive repetitions do not deviate by more than 0.1 %.

5. Remaining heat sources and heat sinks

As stated in section 3, the heat source through the heating system $Q_{\mathrm{I,source,h}}$ is not considered for the approximate balancing. It partially depends on the net energy demand, therefore all of the related energy amounts have to be adapted to each other. This is done by calculating $Q_{\mathrm{I,source,h}}$ and $Q_{\mathrm{I,sink,h}}$ and adding them to the total heat sources and heat sinks, as in Equations 9 and 10. Then the net energy demand can be recalculated with the updated values for the total heat sources and heat sinks. This again may change the required net energy for heating and cooling and the calculations have to be repeated again. These calculation steps are repeated up to 10 times, unless the net energy demand does not vary by more than 0.1 % in two consecutive repetitions.

5.1. Heat sources through heat generation systems

$Q_{\mathrm{I,source,h}}$ is given by Equation (131) in [8]:

$$Q_{\mathrm{I,source,h}} = Q_{\mathrm{I,h}} + Q_{\mathrm{I,w}} + Q_{\mathrm{I,vh}} + Q_{\mathrm{I,ch}}, \tag{94}$$

where:

- $Q_{\mathrm{I,h}}$ is the unregulated heat source through the heating system,
- $Q_{\mathrm{I,w}}$ is the unregulated heat source through the tap water system,
- $Q_{\mathrm{I,vh}}$ is the unregulated heat source through mechanical ventilation,
- $Q_{\mathrm{I,ch}}$ is the unregulated heat source through the cooling system.

5.1.1. Unregulated heat losses through heating systems

There are several processes which affect a heating system's heat losses. Heat must first be generated by a heat generator, such as a boiler. Depending on the type of the heat generator, a reservoir for already heated heating medium may be available. Then the heating medium has to be distributed among a building's rooms. Finally the heating medium arrives in radiators or other heat transfer devices, such as floor heating systems, where it also flows back again from. At each point, a specific energy amount is emitted to the building's interior, which contributes to the total energy balance. As these energy losses may contribute to heating the building, they are also called recoverable. However, if the losses occur in a non-heated zone of the building, they are not recovered, as only heated zones are considered for the energy balance. Figure 4 shows a simple Illustration of these aspects.

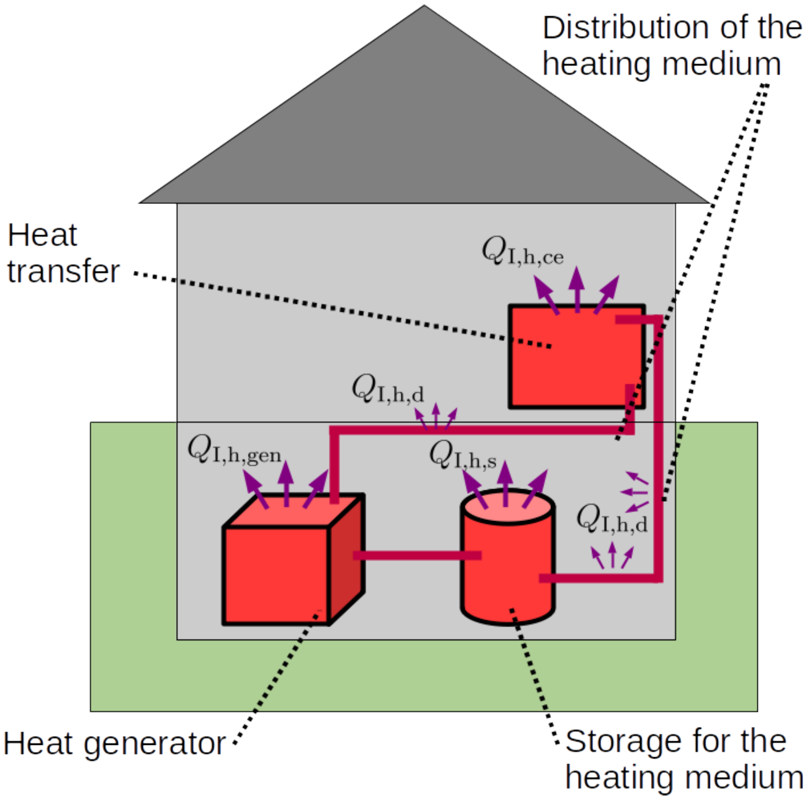

Figure 4: Illustration of a tap water system in a building and the different aspects which affect the tap water system's heat loss. The arrows indicate the heat loss.

The sum of the recoverable energy losses of the heating system $Q_{\mathrm{I,h}}$ is given by Equation (7) in [11]:

$$Q_{\mathrm{I,h}} = Q_{\mathrm{I,h,ce}} + Q_{\mathrm{I,h,d}} + Q_{\mathrm{I,h,s}} + Q_{\mathrm{I,h,gen}}, \tag{95}$$

where:

- $Q_{\mathrm{I,h,ce}}$ is the unregulated heat source through transfer,
- $Q_{\mathrm{I,h,d}}$ is the unregulated heat source through distribution,
- $Q_{\mathrm{I,h,s}}$ is the unregulated heat source through storing and
- $Q_{\mathrm{I,h,gen}}$ is the unregulated heat source through heat generation.

$Q_{\mathrm{I,h,ce}}$ is only considered for non-residential buildings. The equations for required addends are presented in Section 6.

5.1.2. Unregulated heat sources through tap water systems

Similar to the heating system, there are several aspects which affect the tap water system's heat losses as well. Again, heat must be generated first. Usually, this is done by the same heat generation device as for the heating system. The hot tap water can also be stored and must then be distributed. At each point, heat is emitted and may be recovered. Figure 5 shows an illustration of a tap water system inside a building.

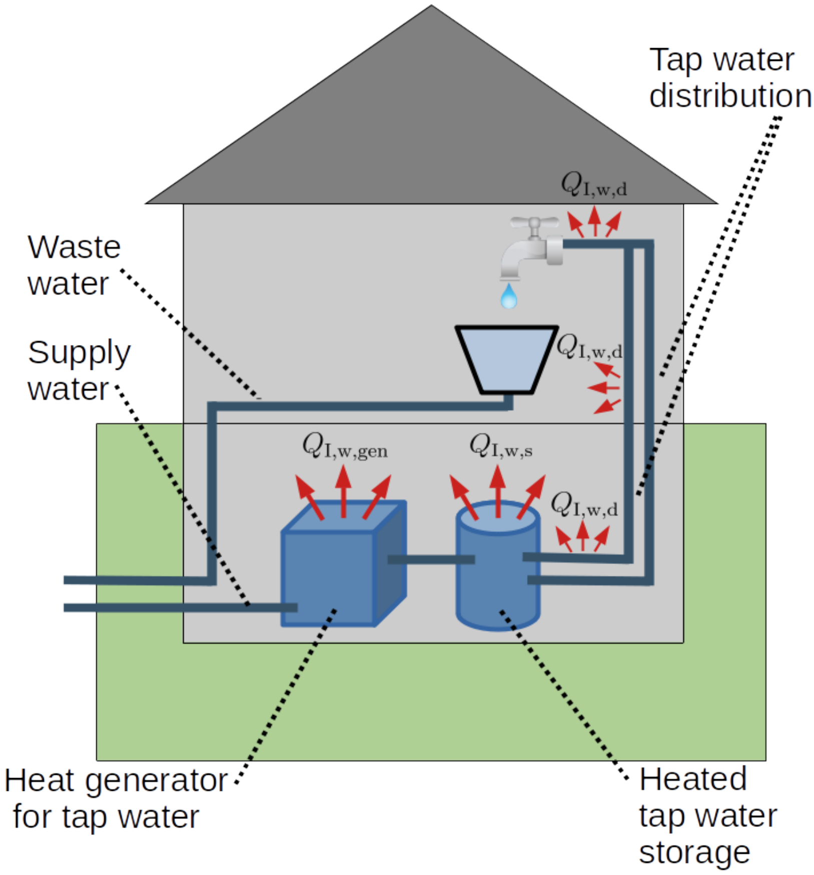

Figure 5: Illustration of a tap water system in a building and the different aspects which affect the tap water system's heat loss. The arrows indicate the heat loss.

The sum of the recoverable energy losses of the tap water system is given by Equation (7) in [14]

$$Q_{\mathrm{I,w}} = Q_{\mathrm{I,w,d}} + Q_{\mathrm{I,w,s}} + Q_{\mathrm{I,w,gen}}, \tag{96}$$

where:

- $Q_{\mathrm{I,w,d}}$ is the unregulated heat source through distribution,
- $Q_{\mathrm{I,d,s}}$ is the unregulated heat source through storing and
- $Q_{\mathrm{I,s,gen}}$ is the unregulated heat source through heat generation.

The required addends are presented in Section 7.

6. Heat sources of the heating system

The internal heat sinks and heat sources through heating and cooling systems have not been considered in the approximate balancing because they depend on the net energy demand demand for cooling and heating. As these have been determined in the last step, the remaining he internal heat sinks and heat sources can be calculated. Heat losses over the heating system cover the heat sources through heat transfer, heat distribution and heat storage.

The energy emitted by the heat generator $Q_{\mathrm{h,outg}}$ can then be calculated by Equation (1) in [11]:

$$Q_{\mathrm{h,outg}} = Q_{\mathrm{h,b}} + Q_{\mathrm{h,ce}} + Q_{\mathrm{h,d}} + Q_{\mathrm{h,s}}, \tag{97}$$

where:

- $Q_{\mathrm{h,b}}$ is the net energy demand demand,
- $Q_{\mathrm{h,ce}}$ is the heat loss of the heating system through heat transfer,
- $Q_{\mathrm{h,d}}$ is the heat loss of the heating system through distribution and
- $Q_{\mathrm{h,s}}$ is the heat loss of the heating system through storage.

6.1. Heat losses through heat transfer

The heat loss through heat transfer $Q_{\mathrm{h,ce}}$ is given by Equation (34) in [11]:

$$Q_{\mathrm{h,ce}} = Q_{\mathrm{h,b}} \cdot \frac{\Delta\theta_{\mathrm{ce}}}{\theta_{\mathrm{i,h}} - \theta_{\mathrm{e}}}, \tag{98}$$

where $\Delta\theta_{\mathrm{ce}}$ is the sum of all temperature variations given in Equation (35) in [11]:

$$\Delta\theta_{\mathrm{ce}} = \Delta\theta_{\mathrm{str}} + \Delta\theta_{\mathrm{ctr}} + \Delta\theta_{\mathrm{emb}} + \Delta\theta_{\mathrm{rad}} + \Delta\theta_{\mathrm{im}} + \Delta\theta_{\mathrm{hydr}} + \Delta\theta_{\mathrm{roomaut}}, \tag{99}$$

where:

- $\Delta\theta_{\mathrm{str}}$ is the temperature variation caused by stratification,
- $\Delta\theta_{\mathrm{ctr}}$ is the temperature variation caused by the usual temperature variation,
- $\Delta\theta_{\mathrm{emb}}$ is the temperature variation caused by the additional heat loss through radiators which are inside the enveloping components of the zone,
- $\Delta\theta_{\mathrm{rad}}$ is the temperature variation caused by the radiation depending on the heating method,
- $\Delta\theta_{\mathrm{im}}$ is the temperature variation caused by intermittent heating activity,
- $\Delta\theta_{\mathrm{hydr}}$ is the temperature variation caused by the stay out of a hydraulic adjustment and

- $\Delta\theta_{\mathrm{roomaut}}$ is the temperature variation caused by automation.

$\Delta\theta_{\mathrm{hydr}}$ depends on the setup of the heating system and the number of storeys in the building. It is given by 36.

For $\Delta\theta_{\mathrm{im}}$ it is:

$$\Delta\theta_{\mathrm{im}} = \Delta\theta_{\mathrm{im;emt}} + \Delta\theta_{\mathrm{im;ctr}}, \tag{100}$$

where:

- $\Delta\theta_{\mathrm{im;emt}}$ is the temperature variation caused by the regulation during the reduced heating activity and

- $\Delta\theta_{\mathrm{im;ctr}}$ is the temperature variation caused by the heat transfer system during the reduced heating activity.

The temperature variations depend on several different factors, such as the height of the considered zone and the heating method. However, for zones with a height of more than 4 m, some exceptions apply:

$\Delta\theta_{\mathrm{str}}$ is given by Equation (39) in [11]:

$$\Delta\theta_{\mathrm{str}} = 10 \cdot \frac{\Delta\theta_{\mathrm{str}}}{a} \cdot \left(0.5 \cdot h_{\mathrm{R}} - b\right), \tag{101}$$

where:

- $\Delta\theta_{\mathrm{str}}$

- h_{R} is the height of the zone,

- a is a constant, $a = 16$ and

- b is a constant, $b = 1.1$.

$\Delta\theta_{\mathrm{rad}}$ is given by Equation (40) in [11]:

$$\Delta\theta_{\mathrm{rad}} = 10 \cdot \left[\frac{0.36}{RF + 0.2} + 0.354 \cdot \left(\frac{70}{p_{\mathrm{h}}}\right)^{0.12} \cdot \left(\frac{10}{h_{\mathrm{R}}}\right)^{0.15} - 0.9\right], \tag{102}$$

where:

- RF is the radiation factor given in Table 18 in [11] and

- p_{h} is the heating system's specific performance.

6.1.1. Free heating surface

In zones which have a height of 4 m or less and common radiators, representing a free heating surface, the values for $\Delta\theta_{\mathrm{str}}$, $\Delta\theta_{\mathrm{ctr}}$ and $\Delta\theta_{\mathrm{emb}}$ are shown in Table 37.

$\Delta\theta_{\mathrm{str}}$ is then given by Equation (42) in [11]:

$$\Delta\theta_{\mathrm{str}} = \frac{\Delta\theta_{\mathrm{str;1}} + \Delta\theta_{\mathrm{str;2}}}{2}, \tag{103}$$

If certified products are used, then $\Delta\theta_{\mathrm{ctr}}$ is set to $\Delta\theta_{\mathrm{ctr;2}}$. If no information is available, then it is set to $\Delta\theta_{\mathrm{ctr;1}}$.

If the heating activity is temporarily reduced, then:

$$\Delta\theta_{\mathrm{im;ctr}} = 0\,\mathrm{K} \tag{104}$$

and

$$\Delta\theta_{\mathrm{im;emt}} = -0.3\,\mathrm{K}. \tag{105}$$

apply.

For $\Delta\theta_{\mathrm{rad}}$ it is:

$$\Delta\theta_{\mathrm{rad}} = 0\,\mathrm{K}. \tag{106}$$

With automation systems for heating, then:

- for autonomous systems:
  $\Delta\theta_{\mathrm{roomaut}} = -0.5\,\mathrm{K}$,
- for autonomous systems with an independent start-stop-mechanism:
  $\Delta\theta_{\mathrm{roomaut}} = -1\,\mathrm{K}$,
- Networking with autonomous adjustments and interaction:
  $\Delta\theta_{\mathrm{roomaut}} = -1.2\,\mathrm{K}$.

6.1.2. Embedded radiators

In zones which have a height of 4 m or less and embedded radiators, the values for $\Delta\theta_{\mathrm{str}}$, $\Delta\theta_{\mathrm{ctr}}$ and $\Delta\theta_{\mathrm{emb}}$ are shown in Table 38.

$\Delta\theta_{\mathrm{emb}}$ is then given by Equation (43) in [11]:

$$\Delta\theta_{\mathrm{emb}} = \frac{\Delta\theta_{\mathrm{emb;1}} + \Delta\theta_{\mathrm{emb;2}}}{2}, \tag{107}$$

If the heating activity is temporarily reduced, then

$$\Delta\theta_{\mathrm{im;emt}} = -0.3\,\mathrm{K} \tag{108}$$

applies. The other parameters take the same value as in 6.1.1.

6.1.3. Unregulated heat losses

In residential buildings, the unregulated heat losses through heat transfer are not considered:

$$Q_{\mathrm{I,h,ce}} = 0. \tag{109}$$

6.1.4. Auxiliary power

The auxiliary energy for the heat transfer is given by Equation (44) in [11]:

$$W_{\mathrm{h,ce}} = W_{\mathrm{C}} + W_{\mathrm{fan,Pu}}, \tag{110}$$

where:

- W_{C} is the auxiliary energy for the control system and
- $W_{\mathrm{fan,Pu}}$ is the auxiliary energy for ventilators, blowers and pumps.

W_{C} is given by Equation (45) in [11]:

$$W_{\mathrm{C}} = \frac{P_{\mathrm{C,aux}} \cdot d_{\mathrm{mth}} \cdot 24}{1000}, \tag{111}$$

where $P_{\mathrm{C,aux}}$ is the nominal power for the control system. It depends on the available actuators according to Table (20) in [11]:

- $P_{\mathrm{C,aux}} = 0.1\,\mathrm{W}$ for each electromotive actuators,
- $P_{\mathrm{C,aux}} = 1\,\mathrm{W}$ for each electrothermal actuators and
- $P_{\mathrm{C,aux}} = 15\,\mathrm{W}$ for each actuators with an expansion valve.

$W_{\mathrm{fan,Pu}}$ is given by Equation (46) in [11]:

$$W_{\mathrm{fan,Pu}} = \frac{(P_{\mathrm{fan,aux}} \cdot n_{\mathrm{fan}} + P_{\mathrm{Pu,aux}} \cdot n_{\mathrm{Pu}}) \cdot t_{\mathrm{h,rL}}}{1000}, \tag{112}$$

where:

- $P_{\mathrm{fan,aux}}$ is the nominal power of ventilators and blowers,
- n_{fan} is the amount of ventilators and blowers,
- $P_{\mathrm{Pu,aux}}$ is the nominal power of pumps and
- n_{Pu} is the amount of pumps.

According to Table (21) in [11], the values for $P_{\mathrm{fan,aux}}$ are:

- $P_{\mathrm{fan,aux}} = 10\,\mathrm{W}$ for convectors electromotive actuators and
- $P_{\mathrm{fan,aux}} = 12\,\mathrm{W}$ for thermal storage heating.

$P_{\mathrm{Pu,aux}}$ is given by Equation (47) in [11]:

$$P_{\mathrm{Pu,aux}} = 50 \cdot [P_{\mathrm{LH,aux}}]^{0.08}, \tag{113}$$

where $P_{\mathrm{LH,aux}}$ is the nominal power of the air heater.

6.2. Heat losses through heat distribution

The heat losses through heat distribution $Q_{\mathrm{h,d}}$ are calculated separately for different parts of the pipes and then added up. The different pipe sections include horizontal pipes, vertical pipes and the connections to the radiators, if available. $Q_{\mathrm{h,d}}$ is given by Equation (52) in [11]:

$$Q_{\mathrm{h,d}} = \sum_i Q_{\mathrm{h,d,i}}, \tag{114}$$

where $Q_{\mathrm{h,d,i}}$ heat loss through heat distribution at the heating pipe section i, which is given by Equation (53) in [11]:

$$Q_{\mathrm{h,d,\,i}} = \frac{1}{1000} \cdot U_i \cdot (\theta_{\mathrm{HK,av}} - \theta_{\mathrm{I}}) \cdot L \cdot t_{\mathrm{h,rL}}, \tag{115}$$

where:

- U_i is the length related heat transfer coefficient,
- $\theta_{\mathrm{HK,av}}$ the median temperature of the heating medium,
- θ_{I} is the reference internal temperature, previously noted as $\theta_{\mathrm{i,h}}$,
- L is the length of the heating pipe section and
- $t_{\mathrm{h,rL}}$ is the monthly mathematical operating time of the heating system.

U_i depends on the heating system's pipes' insulation, their age and and the zone's net area. It can be determined by Table 40. L can be determined by Table 39.

The equations for calculating $\theta_{\mathrm{HK,av}}$ and $t_{\mathrm{h,rL}}$ are given in 6.5 and 6.6 respectively.

6.2.1. Unregulated heat losses

The unregulated heat losses through heat distribution is only considered in hall building. For any other building type including residential buildings Equation (54) in [11] applies:

$$Q_{\mathrm{I,h,d,i}} = Q_{\mathrm{h,d,i}}. \tag{116}$$

6.2.2. Auxiliary power

The auxiliary energy for heat distribution is given by Equation (55) in [11]:

$$W_{\mathrm{h,d}} = W_{\mathrm{h,d,hydr}} \cdot e_{\mathrm{h,d,aux}}, \tag{117}$$

where:

- $W_{\mathrm{h,d,hydr}}$ is the required energy for hydraulics and
- $e_{\mathrm{h,d,aux}}$ is the effort of the heating pump.

$W_{\mathrm{h,d,hydr}}$ is given by Equation (56) in [11]:

$$W_{\mathrm{h,d,hydr}} = \frac{P_{\mathrm{hydr}}}{1000} \cdot \beta_{\mathrm{h,d}} \cdot (t_{\mathrm{h}} \cdot f_{\mathrm{d,PM}}) \cdot f_{\mathrm{Sch}}, \tag{118}$$

where:

- P_{hydr} is the hydraulic power of the pump,
- $\beta_{\mathrm{h,d}}$ is the median workload for distribution given in 6.5,
- $f_{\mathrm{d,PM}}$ is the correction factor for heat generators with internal pump management and
- f_{Sch} is the correction factor for a hydraulic switching.

$f_{\mathrm{d,PM}}$ can take one of the following values:

- $f_{\mathrm{d,PM}} = 1$ without internal pump management,
- $f_{\mathrm{d,PM}} = 0.75$ with internal pump management and the boiler temperature is adjusted with respect to the outer temperatures or
- $f_{\mathrm{d,PM}} = 0.45$ with internal pump management and the boiler temperature is adjusted with respect to the inner temperatures.

According to [11], for two-pipe-systems:

$$f_{\mathrm{Sch}} = 1 \tag{119}$$

for single-pipe-systems and:

$$f_{\mathrm{Sch}} = 8.6 \cdot \gamma + 0.7, \tag{120}$$

where γ is the mass flow through the radiators. If not specified, $\gamma = 0.35$.

P_{hydr} is given by Equation (57) in [11]:

$$P_{\mathrm{hydr}} = 0.2778 \cdot \Delta p \cdot \dot{V}, \tag{121}$$

where:

- Δp is the pressure difference at the design point and
- $\dot{V}$ is the volume flow at the design point.

Equation (58) in [11]:

$$\dot{V} = \frac{\Phi_{\mathrm{h,max}}}{1.15 \cdot \Delta\theta_{HK}}, \tag{122}$$

where $\Delta\theta_{\mathrm{HK}}$ is the temperature difference at the design point.

Δp is given by Equation (59) in [11]:

$$\Delta p = 0.13 \cdot L_{\mathrm{max}} + 2 + \Delta p_{\mathrm{FBH}} + \Delta p_{\mathrm{gen}} + \Delta p_{\mathrm{WMZ}} + \Delta p_{\mathrm{Stranga}}, \tag{123}$$

where:

- $L_{\max}$ is the maximal pipe length,
- Δp_{FBH} is the pressure difference of the flow heating system,
- Δp_{gen} is the pressure difference of the heat generator,
- Δp_{WMZ} is the pressure difference of the heat meter and
- $\Delta p_{\text{Stranga}}$ is the pressure difference of the line fittings.

$L_{\max}$ is given by Equation (60) in [11]:

$$L_{\max} = 2 \cdot \left(L_{\text{char}} + \frac{B_{\text{char}}}{2} + n_{\text{G}} \cdot h_{\text{G}} + l_{\text{d}} \right), \tag{124}$$

where l_{d} is the supplement for the connection of two-pipe-systems. It is $l_{\text{d}} = 10$

$e_{\text{h,d,aux}}$ is given by Equation (61) in [11]:

$$e_{\text{h,d,aux}} = f_{\text{e}} \cdot \left(C_{\text{P1}} + C_{\text{P2}} \cdot {\beta_{\text{h,d}}}^{-1} \right) \cdot \frac{EEI}{0.25}, \tag{125}$$

where:

- f_{e} is the efficiency factor,
- C_{P1} and C_{P2} are constants and
- EEI energy efficiency index after act (EG) Nr. 641/2009.

If not specified, $EEI = 0.25$.

If the pump is not known, f_{e} is given by Equation (62) in [11]:

$$f_{\text{e}} = \left(1.25 + \left(\frac{200}{P_{\text{hydr}}} \right)^{0.5} \right) \cdot b. \tag{126}$$

where b is the over sizing factor which is 1 for pumps which are dimensioned for the demand or $b = 2$ for any other pump.

If the pump is not known, but no value for EEI is given, then Equation (63) in [11] applies:

$$f_{\text{e}} = \frac{P_{\text{Pu}}}{P_{\text{hydr}}}. \tag{127}$$

If the pump is known, and a value for EEI is given, then Equation (63) in [11] applies:

$$f_{\text{e}} = \frac{P_{\text{ref}}}{P_{\text{hydr}}}, \tag{128}$$

where P_{ref} is the electrical reference power after act (EG) Nr. 641/2009. It is given by Equation (65) in [11]:

$$P_{\text{ref}} = 1.7 \cdot P_{\text{hydr}} + 17 \cdot \left(1 - e^{-0.3 \cdot P_{\text{hydr}}} \right), \tag{129}$$

The values for C_{P1} and C_{P2} are given in Table 10.

Pump control system	C_{p1}	C_{p2}
uncontrolled	0.25	0.75
$\Delta p_{\mathbf{const}}$	0.75	0.25
$\Delta p_{\mathbf{variabel}}$	0.90	0.10

Table 10: Values for C_{P1} and C_{P2} according to Table 28 in [11].

6.3. Heat losses through heat storage

The heat loss through heat storage $Q_{\mathrm{h,s}}$ is given by Equation (68) in [11]:

$$Q_{\mathrm{h,s}} = f_{\mathrm{con}} \cdot \frac{\theta_{\mathrm{h,s}} - \theta_{\mathrm{i,h}}}{45} \cdot d_{\mathrm{op,mth}} \cdot Q_{\mathrm{PO,s,day}}, \tag{130}$$

where:

- f_{con} is a factor for considering the setup of the heat generator and the heat storage,
- $\theta_{\mathrm{h,s}}$ the median temperature of the heat storage,
- $d_{\mathrm{op,mth}}$ is the monthly operating time in days and
- $Q_{\mathrm{P0.s,day}}$ is the daily heat loss during standby mode.

f_{con} can be set to $f_{\mathrm{con}} = 1.2$ if the heat generator and the heat storage are in the same room. If not, heat losses through distribution have to be considered, as in 6.2.

$Q_{\mathrm{P0.s,day}}$ is given by Equation (70) in [11]:

$$Q_{\mathrm{P0.s,day}} = 0.4 + 0.14 \cdot V_{\mathrm{S}}^{0.5}, \tag{131}$$

where V_{S} is the storage's nominal volume. The equations for calculating $\theta_{\mathrm{h,s}}$ and $d_{\mathrm{op,mth}}$ are given in Section 6.5 and 6.6 respectively.

6.3.1. Unregulated heat losses

If the storage is within a zone which is considered for the energy balancing, Equation (69) in [11] applies for the unregulated heat losses through distribution:

$$Q_{\mathrm{I,h,s}} = Q_{\mathrm{h,s}}. \tag{132}$$

6.3.2. Auxiliary energy

If a buffer tank is available, the auxiliary energy for heat distribution is given by Equation (71) in [11]:

$$W_{\mathrm{h,s}} = \frac{P_{\mathrm{Pu}} \cdot t_{\mathrm{Pu}}}{1000}, \tag{133}$$

where:

- P_{Pu} is the nominal power required by the pump and
- t_{Pu} is the operating time of the circulation pump

P_{Pu} is given by Equation (72) in [11]:

$$P_{\mathrm{Pu}} = 40 + 0.03 \cdot A_{\mathrm{NGF}}. \tag{134}$$

According to [11], t_{Pu} is given by:

$$t_{\mathrm{Pu}} = \beta_{\mathrm{h,s}} \cdot 24 \cdot d_{\mathrm{h,mth}}, \tag{135}$$

where $\beta_{\mathrm{h,s}}$ is the workload for storage.

6.4. Heat sources through heat generation

The heat sources through heat generation are given by Equation (178) in [11]:

$$Q_{\mathrm{h,gen}} = \sum \left(Q_{\mathrm{h,gen,ls,\ day\ ,i}} \cdot d_{\mathrm{h,rB}} \right), \tag{136}$$

where $Q_{\mathrm{h,gen,ls,\ day\ ,i}}$ is the daily heat loss of the boiler.

$Q_{\mathrm{h,gen,ls,\ day\ ,i}}$ is given by Equation (179) in [11]:

$$Q_{\mathrm{h,gen,ls,day,i}} = \left(\frac{\beta_{\mathrm{h,\ gen,\ i}}}{\beta_{\mathrm{h,gen,Pint}}} \cdot \left(P_{\mathrm{gen,Pint}} - P_{\mathrm{gen,\ P0}} \right) + P_{\mathrm{gen,\ P0}} \right) \cdot \left(t_{\mathrm{h,rL,day}} - t_{\mathrm{w,Pn,day}} \right), \tag{137}$$

if $0 < \beta_{\mathrm{h,\ gen,\ i}} < \beta_{\mathrm{h,gen,Pint}}$.

If $\beta_{\mathrm{h,gen,Pint}} < \beta_{\mathrm{h,\ gen,\ i}} < 1$, it is given by Equation (180) in [11]:

$$Q_{\mathrm{h,\ gen,ls,day,i}} = \left(\frac{\beta_{\mathrm{h,\ gen,i}} - \beta_{\mathrm{h,gen,\ Pint}}}{1 - \beta_{\mathrm{h,\ gen,Pint}}} \cdot \left(P_{\mathrm{gen,Pn}} - P_{\mathrm{gen,Pint}} \right) + P_{\mathrm{gen,Pint}} \right) \cdot \left(t_{\mathrm{h,rL,\ day}} - t_{\mathrm{w,Pn,\ day}} \right), \tag{138}$$

where:

- $\beta_{\text{h, gen, i}}$ is the workload of the boiler,
- $\beta_{\text{h,gen,Pint}}$ is the workload of the boiler at part load,
- $P_{\text{gen,Pn}}$ is the dissipation power at nominal power,
- $P_{\text{gen,Pint}}$ is the dissipation power at part load and
- $P_{\text{gen, P0}}$ is the dissipation power at downtime.

The equations for $\beta_{\text{h, gen, i}}$ and $\beta_{\text{h,gen,Pint}}$ are given in Section 6.7. $P_{\text{gen,Pn}}$ is given by Equation (183) in [11]

$$P_{\text{gen,P0}} = q_{\text{P0.}\theta} \cdot \frac{P_{\text{n}}}{\eta_{\text{k,Pn}}} \cdot f_{\frac{\text{Hs}}{\text{Hi}}}, \tag{139}$$

$P_{\text{gen,Pint}}$ is given by Equation (187) in [11]:

$$P_{\text{gen,Pint}} = \frac{f_{\frac{\text{Hs}}{\text{Hi}}} - \eta_{\text{gen,Pint}}}{\eta_{\text{gen,Pint}}} \cdot \beta_{\text{h, gen,Pint}} \cdot P_{\text{n}} \tag{140}$$

and $P_{\text{gen, P0}}$ is given by Equation (188) in [11]:

$$P_{\text{gen,Pn}} = \frac{f_{\frac{\text{Hs}}{\text{Hi}}} - \eta_{\text{gen,Pn}}}{\eta_{\text{gen,Pn}}} \cdot P_{\text{n}}, \tag{141}$$

where:

- $q_{\text{P0.}\theta}$ is the standby loss at median boiler temperature,
- $\eta_{\text{k,Pn}}$ is the boiler's level of efficiency,
- $f_{\frac{\text{Hs}}{\text{Hi}}}$ is the ratio of fuel and calorific value,
- $\eta_{\text{gen,Pint}}$ is the boiler's level of efficiency at part load and
- $\eta_{\text{gen,Pint}}$ is the boiler's level of efficiency at part load.

Values for $f_{\frac{\text{Hs}}{\text{Hi}}}$ are shown in Table 41. $q_{\text{P0.}\theta}$ is given by Equation (184) in [11]:

$$q_{\text{P0.}\theta} = q_{\text{P0.70}} \cdot \frac{\theta_{\text{HK,av}} - \theta_{\text{i,h}}}{70 - 20}, \tag{142}$$

where:

- $\theta_{\text{HK,av}}$ is the median temperature of the boiler and
- $q_{\text{P0.70}}$ is the standby loss at median boiler temperature of 70 °C.

If no measurements are available, as for new builds, $q_{\mathrm{P0.70}}$ is given by Equation (219) in [11]:

$$q_{\mathrm{P0.70}} = \left(E \cdot (P_{\mathrm{n}})^F\right)/100. \tag{143}$$

where the factors E and F are given in Table 44.

$\eta_{\mathrm{gen,Pn}}$ is given by Equation (185) in [11]:

$$\eta_{\mathrm{gen,Pn}} = \eta_{\mathrm{k,Pn}} + K \cdot (\theta_{\mathrm{gen,Test,Pn}} - \theta_{\mathrm{HK,av}}) \tag{144}$$

and $\eta_{\mathrm{gen,Pint}}$ is given by Equation (186) in [11]:

$$\eta_{\mathrm{gen,Pint}} = \eta_{\mathrm{k,\ Pint}} + L \cdot (\theta_{\mathrm{gen,Test,Pint}} - \theta_{\mathrm{HK,av}}), \tag{145}$$

where:

- $\theta_{\mathrm{gen,Test,Pn}}$ is the test temperature of the boiler at nominal power,
- $\theta_{\mathrm{gen,Test,Pint}}$ is the test temperature of the boiler at part load,
- K and L are factors given in Table 45.

$\eta_{\mathrm{k,Pn}}$ is given by Equation (217) in [11]:

$$\eta_{\mathrm{k,Pn}} = (A + B \cdot \log_{10}(P_{\mathrm{n}}))/100 \tag{146}$$

and $\eta_{\mathrm{k,Pint}}$ is given by Equation (217) in [11]:

$$\eta_{\mathrm{k,\ Pint}} = (C + D \cdot \log_{10}(P_{\mathrm{n}}))/100. \tag{147}$$

where A, B, C and D are factors shown in Table 42 and Table 43.

6.4.1. Unregulated heat losses

The internal heat sources through heat generation are given by Equation (191) in [11]:

$$Q_{\mathrm{I,h,gen}} = q_{\mathrm{s},\theta} \cdot \frac{P_{\mathrm{n}}}{\eta_{\mathrm{k,Pn}}} \cdot (t_{\mathrm{h,rL,\ day}} - t_{\mathrm{w,Pn,day}}) \cdot d_{\mathrm{h,rB}}, \tag{148}$$

where $q_{\mathrm{s},\theta}$ is the unregulated heat loss through the boiler's outer shell. For special gas boilers it is given by Equation (189) in [11]:

$$q_{\mathrm{s},\theta} = 0.5 \cdot q_{\mathrm{P0.}\theta}. \tag{149}$$

For other all other boiler types it is given by Equation (190) in [11]:

$$q_{\mathrm{s},\theta} = 0.75 \cdot q_{\mathrm{P0.}\theta}. \tag{150}$$

6.4.2. Auxiliary power

The required auxiliary energy for heat generation is given by Equation (192) in [11]:

$$W_{\mathrm{h,gen}} = \sum P_{\mathrm{h,\ gen,aux,i}} \cdot (t_{\mathrm{h,rL}} - t_{\mathrm{w,Pn,day}} \cdot d_{\mathrm{mth}} \cdot d_{\mathrm{op,a}}/365) + P_{\mathrm{aux,P0}} \cdot (24 \cdot d_{\mathrm{mth}} - t_{\mathrm{h,rL}}), \tag{151}$$

where:

- $P_{\mathrm{h,\ gen,aux,i}}$ is the electrical power consumption while the boiler is operating and
- $P_{\mathrm{aux,P0}}$ is the electrical power consumption in standby mode

$P_{\mathrm{h,\ gen,aux,i}}$ is given by Equation (193) in [11]:

$$P_{\mathrm{h,\ gen,aux,i}} = (\beta_{\mathrm{h,\ gen,i}} / \beta_{\mathrm{h,\ gen,Pint}}) \cdot (P_{\mathrm{aux,Pint,i}} - P_{\mathrm{aux,P0}}) + P_{\mathrm{aux,P0}} \tag{152}$$

if $0 < \beta_{\mathrm{h,\ gen,\ i}} < \beta_{\mathrm{h,gen,Pint}}$.
If $\beta_{\mathrm{h,gen,Pint}} < \beta_{\mathrm{h,\ gen,\ i}} < 1$, it is given by Equation (194) in [11]:

$$P_{\mathrm{h,\ gen,aux\ ,i}} = (\beta_{\mathrm{h,\ gen\ ,i}} - \beta_{\mathrm{h,\ gen,Pint}}) / (1 - \beta_{\mathrm{h,\ gen,Pint}}) \cdot (P_{\mathrm{aux,Pn}} - P_{\mathrm{aux,\ Pint}}) + P_{\mathrm{aux,\ Pint}} \tag{153}$$

Values for $P_{\mathrm{aux,\ Pint}}$, $P_{\mathrm{aux,P0}}$ and $P_{\mathrm{aux,Pn}}$ are given by Equation (220) in [11]:

$$P_{\mathrm{aux,x}} = (G + H \cdot (P_{\mathrm{n}})^{\mathrm{n}}) / 1000. \tag{154}$$

where G, H and n are factor given in Table 46.

6.5. Temperatures

The temperature of the heating medium $\theta_{\mathrm{HK,av}}$ is given by Equation (12) in [11]:

$$\theta_{\mathrm{HK,av}}(\beta_{\mathrm{h},i}) = 0.5 \cdot (\theta_{\mathrm{VL,av}}(\beta_{\mathrm{h},i}) + \theta_{\mathrm{RL,av}}(\beta_{\mathrm{h},i})), \tag{155}$$

where:

- $\beta_{\mathrm{h},i}$ is the median workload of the process i,
- $\theta_{\mathrm{VL,av}}$ is the median supply temperature and
- $\theta_{\mathrm{RL,av}}$ is the median return temperature.

$\beta_{\mathrm{h},i}$ can be calculated individually for heat transfer, distribution, storing and generating.

$\theta_{\mathrm{VL,av}}$ is given by Equation (14) in [11]:

$$\theta_{\mathrm{VL,av}}\left(\beta_{\mathrm{h},i}\right) = \left(\theta_{\mathrm{VA}} - \theta_{\mathrm{i,h,soll}}\right) \cdot \beta_{\mathrm{h},i}^{\frac{1}{n}} + \theta_{\mathrm{i,h,soll}}, \tag{156}$$

where:

- θ_{VA} is the supply temperature for the heating medium and
- n is the heating surface exponent, which can be set to $n = 1.3$ for radiators and $n = 1.1$ for floor heating systems.

For distributions systems with two pipes, $\theta_{\mathrm{RL,av}}$ is given by Equation (16) in [11]:

$$\theta_{\mathrm{VL,av}}\left(\beta_{\mathrm{h},i}\right) = \left(\theta_{\mathrm{RA}} - \theta_{\mathrm{i,h,soll}}\right) \cdot \beta_{\mathrm{h},i}^{\frac{1}{n}} + \theta_{\mathrm{i,h,soll}}, \tag{157}$$

where θ_{RA} is the return temperature of the heating medium.

For distributions systems with one pipe, $\theta_{\mathrm{RL,av}}$ is given by Equation (15) in [11]:

$$\theta_{\mathrm{VL,av}}\left(\beta_{\mathrm{h},i}\right) = \left[\left(\theta_{\mathrm{RA}} - \theta_{\mathrm{i,h,soll}}\right) \cdot \beta_{\mathrm{h},i}^{\frac{1}{n}} + \theta_{\mathrm{i,h,soll}}\right] \cdot \gamma + \theta_{\mathrm{VL,av}}\left(\beta_{\mathrm{h},i}\right) \cdot (1-\gamma)\,, \tag{158}$$

where γ is the ratio of the radiators in comparison to the whole heating circle volume.

6.6. Operating times

The monthly mathematical operating time $t_{\mathrm{h,rL}}$ is given by Equation (30) in [11]:

$$t_{\mathrm{h,rL}} = t_{\mathrm{h,rL,day}} \cdot d_{\mathrm{h,rB}}, \tag{159}$$

where:

- $t_{\mathrm{h,rL,day}}$ is the daily mathematical operating time and
- $d_{\mathrm{h,rB}}$ is the number of active days of the heating system per month.

$d_{\mathrm{h,rB}}$ is given by Equation (28) in [11]:

$$d_{\mathrm{h,rB}} = d_{\mathrm{mth}} \cdot \frac{365 - f_{\mathrm{I,we}} \cdot (365 - d_{\mathrm{op,a}})}{365} \cdot \frac{t_{\mathrm{h}}}{d_{\mathrm{mth}} \cdot 24}, \tag{160}$$

where:

- d_{mth} is the number of days per month,
- $f_{\mathrm{I,we}}$ the factor for considering reduced heating activity at weekends or during holidays,
- $d_{\mathrm{op,a}}$ is the number of days per year with active heating system,which is part of the input and
- t_{h} the monthly heating time.

$f_{\mathrm{I,we}}$ is given by Equation (29) in [11]:

$$f_{\mathrm{I,we}} = 0 \quad \text{if the heating activity stays the same during nights,} \tag{161}$$

$$f_{\mathrm{I,we}} = 1 \quad \text{if the heating systems is shut down during nights or} \tag{162}$$

$$f_{\mathrm{I,we}} = 1 - \frac{\theta_{\mathrm{we,Grenz}} - \theta_{\mathrm{e}}}{\theta_{\mathrm{we,Grenz}} - \theta_{\mathrm{e,min}}} \quad \text{if the heating activity is reduced during nights.} \tag{163}$$

where:

- $\theta_{\mathrm{we,Grenz}}$ is minimal temperature during reduced heating activity at weekends or during holidays,
- θ_{e} the average outside temperature and
- $\theta_{\mathrm{e,min}}$ is the number of days per year with active heating system, which is part of the input.

For heating periods $\theta_{\mathrm{e,min}} = -12°\mathrm{C}$ according to Table 9 [7]. According to [11], $\theta_{\mathrm{we,Grenz}} = 15\,°\mathrm{C}$.

t_{h} is given by Equation (D.1) in [8]:

$$t_{\mathrm{h}} = t_{\mathrm{h,nutz}} + t_{\mathrm{h,we}} \tag{164}$$

where:

- $t_{\mathrm{h,nutz}}$ is the heating time with normal usage and
- $t_{\mathrm{h,we}}$ is the heating time with restricted usage.

$t_{\mathrm{h,nutz}}$ and $t_{\mathrm{h,we}}$ are given by Equation (D.2) in [8]:

$$t_{\mathrm{h},i} = \begin{cases} t_{\mathrm{mth},i} \cdot \frac{\beta_{\mathrm{h},i}}{\beta_{\mathrm{h,grenz}}} & \text{if} \quad \beta_{\mathrm{h},i} \leq \beta_{\mathrm{h,grenz}} \\ t_{\mathrm{mth},i} & \text{if} \quad \beta_{\mathrm{h},i} > \beta_{\mathrm{h,grenz}} \end{cases} \tag{165}$$

where:

- $t_{\mathrm{mth},i}$ represents the heating time for normal usage $t_{\mathrm{mth,nutz}}$ or the heating time for restricted usage $t_{\mathrm{mth,we}}$,
- $\beta_{\mathrm{h},i}$ is the median monthly workload during normal usage $\beta_{\mathrm{h,nutz}}$ or restricted usage $\beta_{\mathrm{h,we}}$ and
- $\beta_{\mathrm{h,grenz}}$ is the minimal workload of the heating system, which is $\beta_{\mathrm{h,grenz}} = 0.05$

$t_{\mathrm{mth},i}$ is given by Equation (D.3) in [8]:

$$t_{\mathrm{mth},i} = d_i \cdot 24\,\mathrm{h}, \tag{166}$$

where d_i is the number of days with normal usage d_{nutz} or the number of days with restricted usage d_{we}.

$\beta_{\mathrm{h},i}$ is given by Equation (D.2) in [8]:

$$\beta_{\mathrm{h},i} = \frac{Q_{\mathrm{h,b},i}}{\Phi_{\mathrm{h,max,res}} \cdot 24\,\mathrm{h}} \tag{167}$$

where:

- $Q_{\mathrm{h,b},i}$ represents the net energy demand demand for normal usage $Q_{\mathrm{h,b,nutz}}$ or for restricted usage $Q_{\mathrm{h,b,we}}$

$t_{\mathrm{h,rL,day}}$ is given by Equation (24) in [11]:

$$t_{\mathrm{h,rL,day}} = 24 - f_{\mathrm{I,NA}} \cdot (24 - t_{\mathrm{h,op,day}}) \tag{168}$$

where:

- $f_{\mathrm{I,NA}}$ is the factor for considering reduced heating activity during nights and
- $t_{\mathrm{h,op,day}}$ is the daily mathematical operating time which is part of the input.

$f_{\mathrm{I,NA}}$ is given by Equation (25), (26) or (27) in [11] respectively:

$$f_{\mathrm{I,NA}} = 0 \quad \text{if the heating activity stays the same during nights,} \tag{169}$$

$$f_{\mathrm{I,NA}} = 1 \quad \text{if the heating systems is shut down during nights,} \tag{170}$$

$$f_{\mathrm{I,NA}} = 1 - \frac{\theta_{\mathrm{NA,Grenz}} - \theta_{\mathrm{e}}}{\theta_{\mathrm{NA,Grenz}} - \theta_{\mathrm{e,min}}} \quad \text{if the heating activity is reduced during nights,} \tag{171}$$

where $\theta_{\mathrm{NA,Grenz}}$ is minimal temperature during reduced heating activity during nights. According to [11], $\theta_{\mathrm{NA,Grenz}} = 10\,^{\circ}\mathrm{C}$.

6.7. Workloads

The median workload for heat transfer is given by Equation (8) in [11]:

$$\beta_{\mathrm{h,ce}} = \frac{Q_{\mathrm{h,b}}}{\Phi_{\mathrm{h,max}} \cdot t_{\mathrm{h}}}, \tag{172}$$

where t_{h} is the monthly heating time.

The median workload for heat distribution is given by Equation (9) in [11]:

$$\beta_{\mathrm{h,d}} = \frac{Q_{\mathrm{h,b}} + Q_{\mathrm{h,ce}}}{\Phi_{\mathrm{h,max}} \cdot t_{\mathrm{h}}} \cdot f_{\mathrm{hydr}}, \tag{173}$$

where f_{hydr} is the factor for the hydraulic balance.

The median workload for heat storage is given by Equation (10) in [11]:

$$\beta_{\mathrm{h,s}} = \frac{(Q_{\mathrm{h,b}} + Q_{\mathrm{h,ce}}) \cdot f_{\mathrm{hydr}} + Q_{\mathrm{h,d}}}{\Phi_{\mathrm{h,max}} \cdot t_{\mathrm{h}}}. \tag{174}$$

The median workload for heat generation is given by Equation (11) in [11]:

$$\beta_{\mathrm{h,gen}} = \frac{(Q_{\mathrm{h,b}} + Q_{\mathrm{h,ce}}) \cdot f_{\mathrm{hydr}} + Q_{\mathrm{h,d}} + Q_{\mathrm{h,s}}}{\Phi_{\mathrm{h,max}} \cdot t_{\mathrm{h}}}. \tag{175}$$

f_{hydr} may take different values according to 11.

Condition	f_{hydr}
No hydraulic balance	1.06
Single pipe systems with flow regulator or only static adjusted systems and for two-pipe systems with more than 8 radiators per automatic controller for differential pressure	1.02
Single pipe systems with flow regulator or only static adjusted systems and for two-pipe systems with more than 8 radiators per automatic controller for differential pressure	1

Table 11: Values for f_{hydr} depending on specific conditions according to [11].

7. Heat sources through tap water

Similar to the heating system, the pipes for the tap water affect a building's energy balance. For this step of calculation, the heat losses of the tap water by distribution, storing and heating is considered.

The heat losses of the tap water $Q_{\mathrm{w,outg}}$ are given by Equation (3) in [11]:

$$Q_{\mathrm{w,outg}} = Q_{\mathrm{w,b}} + Q_{\mathrm{w,ce}} + Q_{\mathrm{w,d}} + Q_{\mathrm{w,s}}, \tag{176}$$

where:

- $Q_{\mathrm{w,b}}$ is the net energy demand demand for the tap water,
- $Q_{\mathrm{w,ce}}$ is the loss through heat transfer of the tap water,
- $Q_{\mathrm{w,d}}$ is the heat loss through distribution of the tap water and
- $Q_{\mathrm{w,s}}$ is the heat loss of storing tap water.

7.1. Net energy demand

For residential buildings, the net energy demand demand for tap water is given in the boundary conditions in [3]:

$$Q_{\mathrm{w,b}} = \max\left[16.5 - (0.05 \cdot A_{\mathrm{NGF,WE,m}}); 8.5\right] \mathrm{kWh}/\mathrm{m^2 a}, \tag{177}$$

where $A_{\mathrm{NGF,WE,m}}$ is the median net area of the building or of an apartment respectively.

If the required water volume of a building is known, Equation (10) in [14] may be applied:

$$Q_{\mathrm{w,b}} = 0.001 \cdot \rho \cdot c \cdot V_{\mathrm{W}} \cdot (\theta_{\mathrm{w,av}} - \theta_{\mathrm{K}}), \tag{178}$$

where:

- ρ is the density of water in $\mathrm{kg}/\mathrm{m^3}$,
- c is the specific heat capacity of water, which is $1.163 \cdot 10^{-3}\,\mathrm{kWh}/\mathrm{kg \cdot K}$,
- V_{W} is the average monthly required water volume,
- $\theta_{\mathrm{w,av}}$ is the median temperature of the pipe section and
- θ_{K} is the median temperature of the cold water supply, given in Table 48.

7.2. Transfer

According to [14], the heat loss through the transfer of tap water $Q_{\mathrm{w,ce}}$ is already included in the net energy demand demand $Q_{\mathrm{w,b}}$, therefore $Q_{\mathrm{w,ce}} = 0$. However, $Q_{\mathrm{w,b}}$ may have to be adapted with using the factor f_{Zapf} if:

- the temperature of the tapped water can automatically be controlled ($f_{\mathrm{Zapf}} = 0.98$) or
- hydraulic controlled flow heater is available ($f_{\mathrm{Zapf}} = 1.05$).

Then $Q^*_{\mathrm{w,b}}$ is given by equation (12) in [14]:

$$Q^*_{\mathrm{w,b}} = f_{\mathrm{Zapf}} \cdot Q_{\mathrm{w,b}}. \tag{179}$$

7.2.1. Unregulated heat losses

The heat losses through transfer are already included in $Q_{\mathrm{w,b}}$, therefore:

$$Q_{\mathrm{i,w,ce}} = 0, \tag{180}$$

according to [14].

7.2.2. Auxiliary power

For the same reason, the auxiliary power is given by:

$$W_{\mathrm{w,ce}} = 0. \tag{181}$$

7.3. Distribution

The heat losses through heat distribution $Q_{\mathrm{w,d}}$ consist of the heat losses of the different pipe section, similar to the heating system. $Q_{\mathrm{w,d}}$ is given by Equation (12) in [14]:

$$Q_{\mathrm{w,d}} = \sum_i Q_{\mathrm{w,d,i}}, \tag{182}$$

where $Q_{\mathrm{w,d,i}}$ heat loss through heat distribution at the tap water pipe section i, which is given by Equation (13) in [14]:

$$Q_{\mathrm{w,d,i}} = \frac{1}{1000} \cdot U_i \cdot L_i \cdot (\theta_{\mathrm{w,av}} - \theta_{\mathrm{I}}) \cdot t_{\mathrm{op,day}}, \tag{183}$$

where:

- U_i is the length related heat transfer coefficient,
- L is the length of the heating pipe section,
- θ_I is the reference internal temperature and
- $t_\mathrm{op,day}$ is the daily operating time.

U_i depends on the tap water pipes' insulation, their age and and the zone's net area. It can be determined by Table 40, analogously to the U_i-values for the heating system.

L can be determined by Table 47

If the required temperature values can not be specified, they can be estimated according to 48. If the tap water circulation is not available or shut down, then Equation (8) in [14] applies:

$$\theta_\mathrm{w,av} = 25 \cdot U^{-0.2}. \tag{184}$$

If additionally, decentralized systems such as flow heater are utilized, then Equation (9) in [14] applies:

$$\theta_\mathrm{w,av} = 20 \cdot U^{-0.2}. \tag{185}$$

7.3.1. Unregulated heat losses

For the unregulated heat source through distribution, Equation (15) in [14] applies:

$$Q_{\mathrm{I,w,d},i} = Q_{\mathrm{w,d},i}. \tag{186}$$

7.3.2. Auxiliary power

The auxiliary energy for the distribution of tap water is given by Equation (16) in [14]:

$$W_\mathrm{w,d} = W_\mathrm{w,d,hydr} \cdot e_\mathrm{W,d,aux}, \tag{187}$$

where:

- $W_\mathrm{w,d,hydr}$ is the required energy for hydraulic systems and
- $e_\mathrm{W,d,aux}$ is the effort of the circulation pump.

$W_\mathrm{w,d,hydr}$ is given by Equation (17) in [14]:

$$W_\mathrm{w,d,hydr} = \frac{P_\mathrm{hydr}}{1000} \cdot d_\mathrm{op,mth} \cdot z, \tag{188}$$

where:

- P_hydr is the hydraulic power of the pump at the design point and
- z is the daily operating time of the circulation pump.

z is given by Equation (18) in [14]:

$$z = 10 + \frac{1}{0.07 + \frac{50}{A_{\mathrm{NGF}}}}. \tag{189}$$

P_{hydr} is given by Equation (19) in [14]:

$$P_{\mathrm{hydr}} = 0.2778 \cdot \Delta p \cdot \dot{V}, \tag{190}$$

where:

- Δp is the pressure difference at the design point and
- $\dot{V}$ is the volume flow at the design point.

$\dot{V}$ is given by Equation (20) in [14]:

$$\dot{V} = \frac{P_{\mathrm{W,d,A}}}{1.15 \cdot \Delta\theta_{\mathrm{Z,A}} \cdot 1000}, \tag{191}$$

where:

- $P_{\mathrm{W,d,A}}$ is the power dissipation at the design point and
- $\Delta\theta_{\mathrm{Z,A}}$ is the temperature difference in the circulation circuit at the design point.

$P_{\mathrm{W,d,A}}$ is given by Equation (21) in [14]:

$$P_{\mathrm{w,d,A}} = \sum U_{\mathrm{w,d},i} \cdot L_i \cdot \left(57.5 - \theta_{\mathrm{I,h,soll}}\right). \tag{192}$$

Δp is given by Equation (22) in [14]:

$$\Delta p = 0.1 \cdot L_{\max} + \Delta p_{\mathrm{RV,TH}} + \Delta p_{\mathrm{App}}, \tag{193}$$

where:

- $L_{\max}$ is the maximal pipe length,
- $\Delta p_{\mathrm{RV,TH}}$ is the pressure difference of the non return valve and
- Δp_{App} is the pressure difference in the tap water.

$\Delta p_{\mathrm{RV,TH}}$ can be set to $\Delta p_{\mathrm{RV,TH}} = 12\,\mathrm{kPa}$. If no values are available for Δp_{App}, it is $\Delta p_{\mathrm{App}} = 1\,\mathrm{kPa}$ for a storage and $\Delta p_{\mathrm{App}} = 15\,\mathrm{kPa}$.

$e_{\mathrm{W,d,aux}}$ is given by Equation (24) in [14]:

$$e_{\mathrm{w,d,aux}} = f_e \cdot \left(C_{\mathrm{p1}} + C_{\mathrm{p2}}\right), \tag{194}$$

where:

- C_{p1} and C_{p2} are constants given in Table 12 and
- f_e is the efficiency factor.

For an unknown pump, f_e is given by:

$$f_{\text{e}} = \left(1.25 + \left(\frac{200}{P_{\text{hydr}}}\right)^{0.5}\right) \tag{195}$$

or by:

$$f_{\text{e}} = \frac{P_{\text{Pu}}}{P_{\text{hydr}}} \tag{196}$$

for known pumps.

Pump control system	C_{p1}	C_{p2}
unregulated	0.25	0.94
regulated	0.50	0.63

Table 12: Values for C_{p1} and C_{p2} according to Table 11 in [14].

7.4. Storage

The heat loss through an indirectly heated heat storage $Q_{\text{w,s}}$ is given by Equation (25) in [14]:

$$Q_{\text{w,s}} = f_{\text{con}} \cdot \frac{\theta_{\text{s,av}} - \theta_{\text{I}}}{45} \cdot d_{\text{op,mth}} \cdot Q_{\text{PO,s,day}}, \tag{197}$$

where $\theta_{\text{s,av}}$ is the median temperature of the storage in °C

$Q_{\text{s,P0.day}}$ is generally given by Equation (26) and (27) in [14] respectively:

$$Q_{\text{PO,s,day}} = 0.8 + 0.02 \cdot V_{\text{S}}^{0.77} \quad \text{if } V_{\text{S}} \leq 1000. \tag{198}$$

or

$$Q_{\text{s,P0.day}} = 0.5 + 0.39 + V_{\text{S}}^{0.35} \quad \text{if } V_{\text{S}} > 1000. \tag{199}$$

However, for older system other equations apply: If the system was applied before 1978, Equation (28) in [14] applies:

$$Q_{\text{s,P0.day}} = 0.4 + 0.27 + V_{\text{S}}^{0.5}. \tag{200}$$

If the system was applied between 1978 and 1986, Equation (29) in [14] applies:

$$Q_{\text{s,P0.day}} = 0.4 + 0.08 + V_{\text{S}}^{0.6}. \tag{201}$$

If the system was applied between 1987 and 1994, Equation (30) in [14] applies:

$$Q_{\text{s,P0.day}} = 0.4 + 0.1 + V_{\text{S}}^{0.6}. \tag{202}$$

If the storage's volume is not known, it can be estimated by Equation (31) in [14]:

$$V_\mathrm{S} = \frac{Q_\mathrm{w,b,day} \cdot f_\mathrm{N} \cdot 860}{(\theta_\mathrm{s,av} - \theta_\mathrm{K}) \cdot \eta_\mathrm{S}}, \tag{203}$$

where:

- $Q_\mathrm{w,b,day}$ is the daily net energy demand demand for tap water,
- f_N is the usage factor and
- η_S is the efficiency of the storage.

$Q_\mathrm{w,b,day}$ can be calculated through the yearly or monthly net energy demand demand for tap water. f_N is given by Equation (32) in [14]:

$$f_\mathrm{N} = 1.85 \cdot N_\mathrm{Wohnung}^{-0.42}, \tag{204}$$

where N_Wohnung is the number of apartments in a building. If N_Wohnung is not known or for single family houses, it can be estimated by:

$$N_\mathrm{Wohnung} = \frac{A_\mathrm{NGF}}{80}. \tag{205}$$

For non-residential buildings, it is given by Equation (33) in [14]:

$$f_\mathrm{N} = \frac{1}{t_\mathrm{op,day} \cdot n_\mathrm{Sp}}, \tag{206}$$

where n_Sp is the number of daily peak tapping.

7.4.1. Other storage types

Tap water reservoirs which are heated electronically or by gas can also be considered. In these cases, Equation (39) in [14] applies:

$$Q_\mathrm{w,s} = \frac{(\theta_\mathrm{s,av} + 5 - \theta_\mathrm{I})}{45} \cdot d_\mathrm{op,mth} \cdot Q_\mathrm{s,PO,day}. \tag{207}$$

Additionally, $Q_\mathrm{s,P0.day}$ and V_S are calculated differently.

7.4.2. Unregulated heat losses

If the tap water storage is placed within a heated zone, $Q_\mathrm{I,w,s}$ is given by:

$$Q_\mathrm{I,w,s} = Q_\mathrm{W,s}, \tag{208}$$

if not, it is:

$$Q_\mathrm{I,w,s} = 0 \tag{209}$$

according to [14].

7.4.3. Auxiliary power

The required auxiliary energy for tap water storage is given by Equation (36) in [14]:

$$W_{\mathrm{w,s}} = 0.001 \cdot P_{\mathrm{Pu}} \cdot t_{\mathrm{Pu}}, \tag{210}$$

where:

- P_{Pu} is the nominal power of the pump and
- t_{Pu} is the operating time of the pump.

t_{Pu} is given by Equation (37) in [14]:

$$t_{\mathrm{Pu}} = \frac{Q_{\mathrm{w,\ outg}} \cdot 1.1}{P_{\mathrm{n}}} \tag{211}$$

and P_{Pu} is given by Equation (38) in [14]:

$$P_{\mathrm{Pu}} = 44 + 0.005 \cdot V_{\mathrm{s}}^{1.43}. \tag{212}$$

7.5. Generation

The heat source through heat generation for tap water is given by Equation (102) in [14]:

$$Q_{\mathrm{w,gen}} = Q_{\mathrm{w,\ gen,Pn,day}} \cdot t_{\mathrm{w,Pn,day}} \cdot d_{\mathrm{op,mth}} + Q_{\mathrm{w,gen,P0.day}} \cdot \left(d_{\mathrm{op,mth}} - d_{\mathrm{h,rB}}\right), \tag{213}$$

where:

- $Q_{\mathrm{w,\ gen,Pn,day}}$ is the daily dissipation power at nominal power,
- $Q_{\mathrm{w,gen,P0.day}}$ is the daily dissipation power in standby mode and
- $t_{\mathrm{w,Pn,day}}$ is the daily operating time of the boiler for the heating of tap water.

$Q_{\mathrm{w,\ gen,Pn,day}}$ is given by Equation (103) in [14]:

$$Q_{\mathrm{W,gen,Pn,day}} = \frac{f_{\frac{\mathrm{Hs}}{\mathrm{Hi}}} - \eta_{\mathrm{k,Pn,w}}}{\eta_{\mathrm{k,Pn,w}}} \cdot \frac{Q_{\mathrm{W,outg}}}{24 \cdot d_{\mathrm{op,mth}}}, \tag{214}$$

where:

- $f_{\frac{\mathrm{Hs}}{\mathrm{Hi}}}$ is the ratio of the fuel value and the heat value and
- $\eta_{\mathrm{k,Pn,w}}$ is the efficiency factor of the boiler for the heating of tap water.

$Q_{\mathrm{w,gen,P0.day}}$ is given by Equation (104) in [14]

$$Q_{\mathrm{w,gen,P0.day}} = q_{P0.\theta} \cdot \frac{P_{\mathrm{n}}}{\eta_{\mathrm{k,Pn,w}}} \cdot \left(t_{\mathrm{op,day}} - t_{\mathrm{w,Pn\cdot\ day}}\right) \cdot f_{\frac{\mathrm{HS}}{\mathrm{Hi}}}, \tag{215}$$

where $q_{P0.\theta}$ is the heat loss during standby mode.

$t_{\mathrm{w,Pn,day}}$ is given by Equation (107) in [14]:

$$t_{\mathrm{w,Pn,day}} = \frac{Q_{\mathrm{w,outg}}}{(P_n \cdot d_{\mathrm{op,mth}})}. \tag{216}$$

$\eta_{\mathrm{k,Pn,w}}$ is given by Equation (105) in [14]:

$$\eta_{\mathrm{k,Pn,w}} = \eta_{\mathrm{k,Pn}} + K \cdot \left(50 - \theta_{\mathrm{s,av}}\right), \tag{217}$$

where K is a correction factor whose values are shown in Table 13.

$q_{\mathrm{P0.\theta}}$ is given by Equation (106) in [14]:

$$q_{\mathrm{P0.\theta}} = q_{\mathrm{P0.70}} \cdot \frac{(\theta_{\mathrm{gen,av}} - \theta_{\mathrm{i,h}})}{(70 - 20)}, \tag{218}$$

where:

- $q_{\mathrm{P0.70}}$ is the heat loss in standby mode at a median boiler temperature of 70 °C and
- $\theta_{\mathrm{gen,av}}$ is the average temperature of the boiler.

Boiler type	**Factor K**
Standard boiler (fossil and biogenic fuel)	0
Low-temperature boiler	0.0004
Condensing boiler, gaseous fuels	0.002
Condensing boiler, liquid fuels	0.0004

Table 13: Values for K according to Table 27 in [14].

7.5.1. Unregulated heat losses

The unregulated heat losses through heating of tap water is given by Equation (110) in [14]:

$$Q_{\mathrm{I,w,gen}} = \frac{q_{\mathrm{s},\theta} \cdot P_n}{\eta_{\mathrm{k,Pn}}} \cdot \left((t_{\mathrm{op,day}} - t_{\mathrm{w,Pn,day}}) \cdot (d_{\mathrm{op,mth}} - d_{\mathrm{h,rB}}) + t_{\mathrm{w,Pn,day}} \cdot d_{\mathrm{op,mth}}\right), \tag{219}$$

where $q_{\mathrm{s},\theta}$ is the unregulated heat loss through the boiler's outer shell. If the heat generator is placed inside a heated zone, $q_{\mathrm{s},\theta}$ is given by Equation (108) in [14]:

$$q_{\mathrm{s},\theta} = 0.5 \cdot q_{\mathrm{P0.\theta}}. \tag{220}$$

If not, it is given by Equation (109) in [14]:

$$q_{\mathrm{s},\theta} = 0.75 \cdot q_{\mathrm{P0.\theta}}. \tag{221}$$

7.5.2. Auxiliary power

The auxiliary energy for the heating of tap water is given by Equation (11) in [14]:

$$W_{\mathrm{w,gen}} = P_{\mathrm{aux,Pn}} \cdot t_{\mathrm{w,Pn,day}} \cdot d_{\mathrm{op,m}th} + P_{\mathrm{aux,P0}} \cdot (24 - t_{\mathrm{w,Pn,day}}) \cdot (d_{\mathrm{op,mth}} - d_{\mathrm{h,rB}})\,. \quad (222)$$

8. Energy coverage of solar systems for supporting heat generation

If a solar system for supporting heat generation is available, the heat generation system load is lightened. The solar system can either support the tap water system only or the tap water and the heating system together. The total heat losses of the heating system $Q_{\mathrm{h,outg}}$ and the final energy demand of the tap water system $Q_{\mathrm{w,outg}}$ can then be lowered according to Equations (68) in [4] and (49) in [5] respectively:

$$Q^*_{\mathrm{h,outg}} = Q_{\mathrm{h,outg}} - Q_{\mathrm{h,sol}} - Q^*_{\mathrm{rv,h,outg}} \tag{223}$$

and

$$Q^*_{\mathrm{w,outg}} = Q_{\mathrm{w,outg}} - Q_{\mathrm{w,sol}} - Q^*_{\mathrm{rv,w,outg}}, \tag{224}$$

where:

- $Q_{\mathrm{h,sol}}$ is the heat gain of the heat loss for the heating system,
- $Q^*_{\mathrm{rv,h,outg}}$ is the total outgoing thermal energy of the ventilation system which is recovered by the heating system,
- $Q_{\mathrm{w,sol}}$ is the heat gain of the heat loss for the tap water system and
- $Q^*_{\mathrm{rv,w,outg}}$ is the total outgoing thermal energy of the ventilation system which is recovered by the tap water system.

In this section the calculations for the monthly values of $Q_{\mathrm{h,sol}}$ and $Q_{\mathrm{w,sol}}$ are presented.

$Q_{\mathrm{h,sol}}$ is given by Equation (77) in [4]:

$$Q_{\mathrm{h,sol}} = \min\left(f_{\mathrm{part,h,mth}} \cdot Q_{\mathrm{h,sol,a}}; Q_{\mathrm{h,outg}}\right), \tag{225}$$

where:

- $f_{\mathrm{part,h,mth}}$ is a factor considering the monthly amount of incoming solar energy and
- $Q_{\mathrm{h,sol,a}}$ is the available annual solar energy for the heating system.

$Q_{\mathrm{w,sol}}$ can be calculated analogously with Equation (51) in [5]:

$$Q_{\mathrm{w,sol}} = \min\left(f_{\mathrm{part,w,mth}} \cdot Q_{\mathrm{w,sol,a}}; Q_{\mathrm{w,outg}}\right), \tag{226}$$

where:

- $f_{\mathrm{part,w,mth}}$ is a factor considering the monthly amount of incoming solar energy and
- $Q_{\mathrm{w,sol,a}}$ is the available annual solar energy for the tap water system.

$f_{\text{part},j,\text{mth}}$ for heating and tap water systems takes another value for each month and is given by Equation (78) in [4] or Equation (52) in [14]:

$$f_{\text{part},j,\text{mth}} = \frac{I_{\text{S}}}{I_{\text{S,Ref}}} \cdot f_{\text{part},j,\text{mth,Ref}}, \tag{227}$$

where:

- I_{S} is the average monthly insolation given in the climate data,
- $I_{\text{S,Ref}}$ is the average monthly insolation of the reference climate region (region 4 [7]) and
- $f_{\text{part},j,\text{mth,Ref}}$ are constants which depend on the month.

The monthly values for $f_{\text{part,h,mth,Ref}}$ are shown in Tables 14 and 15 respectively.

Jul	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**
$f_{\text{part,h,mth,Ref}}$ **in %**	5.7	5.5	11.7	13.4	10.9	8.1

Table 14: Values for $f_{\text{part,h,mth}}$ according to Table 25 in [4].

Month	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
$f_{\text{part,h,mth,Ref}}$ **in %**	8.7	7.3	9.8	9.7	6.9	2.3

Table 15: Values for $f_{\text{part,h,mth}}$ according to Table 25 in [4].

The monthly values for $f_{\text{part,w,mth,Ref}}$ are given in Table 16 and 17 respectively.

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**
$f_{\text{part,w,mth,Ref}}$ **in %**	2.7	3.2	6.9	13.7	12.3	13.4

Table 16: Values for $f_{\text{part,h,mth}}$ according to Table 13 in [5].

Moth	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
$f_{\text{part,w,mth,Ref}}$ **in %**	14.2	11.8	10.7	7.0	3.3	0.8

Table 17: Values for $f_{\text{part,h,mth}}$ according to Table 13 in [5].

$Q_{\text{h,sol,a}}$ is given by Equation (70) in [4]

$$Q_{\text{h,sol,a}} = \max\left(Q_{\text{K,sol,a}} - Q_{\text{w,sol,a}}; 0\right), \tag{228}$$

where $Q_{\text{K,sol,a}}$ is the available annual solar energy collected by the solar collector which is given by Equation (79) in [4]

$$Q_{\text{K,sol,a}} = Q_{\text{sys,a}} \cdot f_{\text{NGA}} \cdot f_{\text{slr}} \cdot f_{\text{s,ls}} \cdot f_{\text{h,HKT,A}} + Q_{\text{w,s,a}}, \tag{229}$$

where:

- $Q_{\text{sys,a}}$ is the yearly energy yield of the reference solar system,
- f_{NGA} is the correction factor for considering the solar panel's orientation and pitch,
- f_{slr} is the solar system's load factor,
- $f_{\text{s,ls}}$ is the correction factor for considering the heat loss of the storage and
- $f_{\text{h,HKT,A}}$ is the correction factor for considering the temperature level of the heating system at the design point.

$Q_{\text{w,sol,a}}$ is given by Equation (50) in [5]:

$$Q_{\text{w,sol,a}} = Q_{\text{sys,a}} \cdot f_{\text{NGA}} \cdot f_{\text{slr,w}} \cdot f_{\text{s,Vaux}} \cdot f_{\text{s,ls}} + Q_{\text{w,s,a}}, \tag{230}$$

where:

- $f_{\text{slr,w}}$ is the solar system's load factor which is different from f_{slr} and
- $f_{\text{s,Vaux}}$ is the correction factor for considering the storage's volume for standby mode.

$Q_{\text{sys,a}}$ is given by Equation (80) in [4]:

$$Q_{\text{sys,a}} = (271 \cdot \eta_0 - 18.8 \cdot k_1 - 653 \cdot k_2 + 172 \cdot \text{IAM}\,(50°) - 0.792 \cdot c - 20.7) \cdot A_{\text{C}}, \tag{231}$$

where:

- η_0 is the conversion factor,
- k_1 and k_2 are both heat loss coefficients,
- IAM (50°) is the correction factor for considering the angle of incidence,
- c is the effective heat capacity and
- A_{C} is the surface area of the solar collector in m.

η_0, k_1, k_2, IAM (50°) and c are constants depending on the collector type and its age. They are given by Table 18.

Symbol	**Unit**	**Flat-plate collectors**			**Tube collector**		
		After 1998	**1990 to 1998**	**Before 1990**	**After 1998**	**1990 to 1998**	**Before 1990**
η_0		0.77	0.75	0.72	0.71	0.70	0.65
k_1	$^{\text{W}}/_{\text{m}^2\text{K}}$	3.50	4.00	4.50	1.00	1.20	1.50
k_2	$^{\text{W}}/_{\text{m}^2\text{K}}$	0.02	0.02	0.02	0.01	0.01	0.01
IAM (50°)		0.90	0.90	0.90	0.99	0.99	0.99
c	$^{\text{kJ}}/_{\text{m}^2\text{K}}$	6.40	6.40	6.40	11.00	11.00	11.00

Table 18: Values for η_0, k_1, k_2, IAM (50°) and c according to Table 15 in [5].

A_{C} depends on the the collector type as well. Additionally, it is twice as large for solar systems which support the heating system and the tap water system as for the systems which only support the tap water system. A_{C} is given by the equations shown in Table 15 in [5]. For solar systems which support the tap water system it is:

$$A_{\mathrm{C}} = 0.095 \cdot (A_{\mathrm{NGF}})^{0.8} \quad \text{for flat-plate collectors and} \tag{232}$$

$$A_{\mathrm{C}} = 0.07 \cdot (A_{\mathrm{NGF}})^{0.8} \quad \text{for tube collectors.} \tag{233}$$

If the heating system is supported as well it is:

$$A_{\mathrm{C}} = 0.19 \cdot (A_{\mathrm{NGF}})^{0.8} \quad \text{for flat-plate collectors and} \tag{234}$$

$$A_{\mathrm{C}} = 0.14 \cdot (A_{\mathrm{NGF}})^{0.8} \quad \text{for tube collectors.} \tag{235}$$

f_{NGA} depends on the solar collector's pitch and orientation and is given by Table 26 in [4] for heating systems supporting solar systems and by Table 14 in [5] for solar system which only support the heating of tap water. However, the values in the tables have been adapted in [16] and are shown in 55 and 56.

$f_{\mathrm{slr,w}}$ is given by Equation (55) in [5]:

$$f_{\mathrm{slr,w}} = 0.000697 \cdot \frac{\ln\left(slr_{\mathrm{w}}\right)}{slr_{\mathrm{w}}} + \frac{0.00629}{slr_{\mathrm{w}}}, \tag{236}$$

where slr_w is solar system's load factor for tap water. It is given By Equation (54) in [5]:

$$slr_{\mathrm{w}} = \frac{A_{\mathrm{C}}}{Q_{\mathrm{w,outg,a}}}, \tag{237}$$

where $Q_{\mathrm{w,outg,a}}$ is the total annual heat losses of the tap water system.

In contrast, if the solar system also supports the heating system, f_{slr} is given by Table 57. In this case, slr is given by Equation (71) in [4]:

$$slr = \frac{A_C}{Q_{\mathrm{ges,outg},a}}, \tag{238}$$

where $Q_{\mathrm{ges,outg},a}$ is the sum of the heating system's and tap water system's heat losses which is given in [4]:

$$Q_{\mathrm{ges,outg},a} = Q_{\mathrm{h,outg},a} + Q_{\mathrm{w,outg},a}, \tag{239}$$

where $Q_{\mathrm{h,outg},a}$ is the annually heat loss of the heating system.

f_{slr} is also depending on $f_{\mathrm{K,w,a}}$ which is given by Equation (76) in [4]:

$$f_{\mathrm{K,w,a}} = \frac{Q_{\mathrm{w,outg,a}}}{Q_{\mathrm{ges,outg,a}}}. \tag{240}$$

If the solar system only supports the tap water system $f_{\mathrm{s,Is}}$ is given by Equation (57) in [5]:

$$f_{s,Is} = 1.22 - 0.464 \cdot \sqrt{Q_{\mathrm{w,outg,a}}} \cdot \frac{Q_{\mathrm{s,P0.\ day}}}{V_{\mathrm{s,aux}}}, \tag{241}$$

where $V_{\mathrm{s,aux}}$ is the volume of the standby storage which can be calculated analogously to V_{S} in Equation 203 according to Table 15 in [4].

If the solar system supports the heating system as well, $f_{\mathrm{s,Is}}$ is given by Equation (82) in [4]:

$$f_{\mathrm{s,ls}} = 1.07 - 0.07 \cdot R_{\mathrm{s,ls}}, \tag{242}$$

where $R_{s,\mathrm{ls}}$ is the specific heat loss rate of the solar system. It is given by Equation (81) in [4]:

$$R_{s,\mathrm{ls}} = \frac{(UA)_s^*}{\frac{0.0447 \cdot \sqrt{Q_{\mathrm{w,outg},a}} + 0.14\sqrt{V_{\mathrm{sol,ref}}}}{0.10187 \cdot Q_{\mathrm{w,outg},a} + V_{\mathrm{sol,ref}}}}, \tag{243}$$

where:

- $(UA)_s^*$ is the total specific heat loss rate of the storage and
- $V_{\mathrm{sol,ref}}$ is the volume of the reference solar system's buffer storage.

$V_{\mathrm{sol,ref}}$ is given by Equation 75 in [4]:

$$V_{s,\ \mathrm{sol,ref}} = A_{\mathrm{C}} \cdot 70. \tag{244}$$

$(UA)_s^*$ depends on the storage type of the heating system. If the is a combined storage for tap water and heating Equation (74) in [4] applies:

$$(UA)_{\mathrm{s}}^* = \frac{(UA)_{\mathrm{s}}}{V_{\mathrm{s}}}, \tag{245}$$

where $(UA)_{\mathrm{S}}$ is the heat loss rate of the storage. It is given by Equation (72) in [4]:

$$(UA)_s = Q_{\mathrm{P0.s,day}} \cdot \frac{1000}{45 \cdot 24} \tag{246}$$

If the tap water storage is separate from the heating system's storage $(UA)_s^*$ is given by Equation (73) in [4]:

$$(UA)_{\mathrm{s}}^* = \frac{(UA)_{\mathrm{w,s}} + (UA)_{\mathrm{s,sol}}}{V_{\mathrm{w,s}} + V_{\mathrm{s,sol}}}, \tag{247}$$

where:

- $(UA)_{\mathrm{w,s}}$ is the heat loss rate of the tap water storage,
- $(UA)_{\mathrm{s,sol}}$ is the heat loss rate of the solar system's buffer storage,
- $V_{\mathrm{w,s}}$ is the volume of the tap water storage and
- $V_{\mathrm{s,sol}}$ is the volume of the solar system's buffer storage.

$f_{\mathrm{h,HKT,A}}$ depends on slr and the average temperature of the heating system θ_{h}. The values for $f_{\mathrm{h,HKT,A}}$ are shown in Table 58.

$f_{\mathrm{s,Vaux}}$ is given by Equation (56) in [5]:

$$f_{\mathrm{s,\ Vaux}} = 1.12 - 2.36 \cdot \frac{V_{\mathrm{s,aux}}}{Q_{\mathrm{w,\ outg\ ,a}}} \tag{248}$$

If intermediate values are available for determining the values with Tables 55, 56, 57 and 58, the actual values can be estimated by interpolating them linearly according to [4] and [5].

9. Calculation of the final energy demand

With the calculated net energy amounts, the final energy amounts can now be determined. This is again done for each available conditioning system.

9.1. Heating system

The final energy for heating is given by Equation (4) in [11]:

$$Q_{\mathrm{h,f}} = (Q_{\mathrm{h,outg}} + Q_{\mathrm{h,gen}}) \cdot f_{\mathrm{gen,PM}}, \tag{249}$$

where $f_{\mathrm{gen,PM}}$ is the correction factor for considering a built-in pump management. It can take one of several values:

- $f_{\mathrm{gen,PM}} = 1$ for no built-in pump management,
- $f_{\mathrm{gen,PM}} = 1.03$ for built-in pump management and the boiler is controlled considering the outside temperature or
- $f_{\mathrm{gen,PM}} = 1.06$ for built-in pump management and the boiler is controlled considering the internal temperature.

$Q_{\mathrm{h,f}}$ is also composed of other energy amounts as Equation (5) in [11]:

$$Q_{\mathrm{h,f}} = Q_{\mathrm{h,f,\ in}} + Q_{\mathrm{h,f,prod}} - Q_{\mathrm{h,f,\ out}}\ , \tag{250}$$

where:

- $Q_{\mathrm{h,f,in}}$ is the energy amount provided from outside,
- $Q_{\mathrm{h,f,prod}}$ is the energy amount which has been generated or made available and
- $Q_{\mathrm{h,f,out}}$ is the final energy amount which has been dissipated to the outside.

The equations calculating $Q_{\mathrm{h,f,in}}$, $Q_{\mathrm{h,f,prod}}$ and $Q_{\mathrm{h,f,out}}$ depend on the technology which is used for heat generation. The equations are shown in Table 49.

The auxiliary energy for heating is given by Equation (6) in [11]:

$$W_{\mathrm{h}} = W_{\mathrm{h,ce}} + W_{\mathrm{h,d}} + W_{\mathrm{h,s}} + W_{\mathrm{h,gen}}. \tag{251}$$

9.2. Tap water system

The final energy for tap water is given by Equation (4) in [14]:

$$Q_{\mathrm{w,f}} = Q_{\mathrm{w,outg}} + Q_{\mathrm{w,gen}}. \tag{252}$$

$Q_{\mathrm{w,f}}$ is also composed of other energy amounts as in Equation (5) in [14]:

$$Q_{\mathrm{w,f}} = Q_{\mathrm{w,f,in}} + Q_{\mathrm{w,f,prod}} - Q_{\mathrm{w,f,out}}, \tag{253}$$

where:

- $Q_{\mathrm{w,f,in}}$ is the energy amount provided from outside,
- $Q_{\mathrm{w,f,prod}}$ is the energy amount which has been generated or made available and
- $Q_{\mathrm{w,f,out}}$ is the final energy amount which has been dissipated to the outside.

The equations calculating $Q_{\mathrm{w,f,in}}$, $Q_{\mathrm{w,f,prod}}$ and $Q_{\mathrm{w,f,out}}$ depend on the technology which is used for the heating of tap water. The equations are shown in Table 50.

The auxiliary energy for tap water is given by Equation (6) in [14]:

$$W_{\mathrm{w}} = W_{\mathrm{w,ce}} + W_{\mathrm{w,d}} + W_{\mathrm{w,s}} + W_{\mathrm{w,gen}}. \tag{254}$$

9.3. Ventilation system

The final energy for ventilation systems is given by Equation (6) in [12]:

$$Q_{\mathrm{rv,f}} = Q_{\mathrm{rv,\ outg}} + Q_{\mathrm{rv,g}} = \sum Q_{\mathrm{rv,f,\ in}} + \sum Q_{\mathrm{rv,f,prod}} - \sum Q_{\mathrm{rv,f,out}}, \tag{255}$$

where:

- $Q_{\mathrm{rv,f,in}}$ is the energy amount provided from outside,
- $Q_{\mathrm{rv,f,prod}}$ is the energy amount which has been generated or made available and
- $Q_{\mathrm{rv,f,out}}$ is the final energy amount which has been dissipated to the outside.

The equations calculating $Q_{\mathrm{rv,f,in}}$, $Q_{\mathrm{rv,f,prod}}$ and $Q_{\mathrm{rv,f,out}}$ depend on the technology which is used for mechanical ventilation. The equations are shown in Table 51.

The auxiliary energy for ventilation systems is given by Equation (7) in [12]:

$$W_{\mathrm{rv}} = W_{\mathrm{rv,ce}} + W_{\mathrm{rv,d}} + W_{\mathrm{rv,s}} + W_{\mathrm{rv,g}}. \tag{256}$$

9.4. Total final energy amounts

For an energy source j the total final energy amount which has been provided from outside is then given by Equation (19) in [6]:

$$\begin{aligned} Q_{\mathrm{f,in,j}} = (&Q_{\mathrm{h,f,in,j}} + Q_{\mathrm{h^*,f,in,j}} + Q_{\mathrm{c,f,in,j}} + Q_{\mathrm{c^*,f,in,j}} + Q_{\mathrm{st,f,i,j}} + Q_{\mathrm{rv,f,in,j}} \\ &+ Q_{\mathrm{rc,f,in,j}} + Q_{\mathrm{w,f,in,j}} + Q_{\mathrm{l,fin,j}} + W_{\mathrm{f,in,j}} + Q_{\mathrm{el,f,in,j}}) \cdot \alpha_{\mathrm{f,i,j}}, \end{aligned} \tag{257}$$

where:

- $W_{\mathrm{f,in,j}}$ is the sum of all final auxiliary energy amounts and
- $Q_{\mathrm{x,f,in,j}}$ represents the different final energy amounts which have to be supplied from the outside for each conditioning process in which the conditioning system j is involved.

$\alpha_{\mathrm{f,i,j}}$ represents the part of the total energy amounts for the fulfillment of demand which is supplied to the considered zones for the balancing. It depends on the conditioning systems and can take one of several values:

- $\alpha_{\mathrm{f,i,j}} = 1$ for fuels,
- $\alpha_{\mathrm{f,i,j}} = 1$ for district heating,
- $\alpha_{\mathrm{f,i,j}} = 0$ for energy amounts which have been supplied to and absorption cooling plant and
- $\alpha_{\mathrm{f,i,j}} = \alpha_{\mathrm{f,i,Strom}}$ for electricity. This is not considered for residential buildings.

Analogously, the total final energy amount which is required for processes outside of the considered zones is given by Equation (21) in [6]:

$$\begin{aligned} Q_{\mathrm{f,\ out\ ,j}} = {} & Q_{\mathrm{h,f,\ out\ ,j}} + Q_{\mathrm{h^*,f,\ out\ ,j}} + Q_{\mathrm{c,f,\ out\ ,j}} + Q_{\mathrm{c^*,f,\ out\ ,j}} + Q_{\mathrm{st,f,\ out\ ,j}} + Q_{\mathrm{rv,f,\ out\ ,j}} \\ & + Q_{\mathrm{rc,f,\ out\ ,j}} + Q_{\mathrm{w,f,\ out\ ,j}} + Q_{\mathrm{f,\ out,PV,j}} + Q_{\mathrm{f,\ out,WEA,j}} + Q_{\mathrm{f,\ out,CHP,j}}\ , \end{aligned} \tag{258}$$

where $Q_{\mathrm{x,f,out,j}}$ represents the different final energy amounts which have to be supplied from outside for each conditioning process in which the conditioning system j is involved.

The sum of all auxiliary energy amounts is given by Equation (16) in [6]:

$$W_{\mathrm{f,\ in}} = W_{\mathrm{h}} + W_{\mathrm{c}} + W_{\mathrm{v}} + W_{\mathrm{h^*}} + W_{\mathrm{c^*}} + W_{\mathrm{st}} + W_{\mathrm{rv}} + W_{\mathrm{rc}} + W_{\mathrm{w}} + W_{\mathrm{l}} + W_{\mathrm{aut}}, \tag{259}$$

The used abbreviations stand for:

- h: heating system,
- h*: heating of the ventilation and air conditioning system,
- c: cooling system,
- c*: cooling of the ventilation and air conditioning system,
- st: humidifying system,
- rv: ventilation system (in residential buildings),
- rc: cooling system (in residential buildings),
- w: tap water,
- l: lightning,
- el: electricity,
- PV: photovoltaic,

- WEA: wind power,
- CHP: thermal power station,
- v: air transport and
- aut: automation.

9.5. Determining the Energy efficiency class

For determining a residential building's energy efficiency class, the annual final energy demand relative to the building's usable area A_{N} has to be considered. With Equation (1) in [6] the yearly final energy can be calculated:

$$Q_{\mathrm{a}} = \sum_{j=1}^{12} Q_{\mathrm{mth},j}, \tag{260}$$

where:

- Q_{a} is an annual energy demand and
- $Q_{\mathrm{mth},j}$ is the corresponding monthly energy demand in month j.

For $Q_{\mathrm{f,a}}$ it is:

$$Q_{\mathrm{f,a}} = \sum_{j=1}^{12} Q_{\mathrm{f,mth},j}, \tag{261}$$

The final energy demand with respect to the building's usable area Q_{a}^{*} is then given by:

$$Q_{\mathrm{f,a}}^{*} = \frac{Q_{\mathrm{f,a}}}{A_{\mathrm{N}}}. \tag{262}$$

The energy efficiency classes are defined Appendix 10 of the corresponding law [11]. They are shown in Table 19.

[11] Gesetz zur Vereinheitlichung des Energieeinsparrechtsfur Gebäude und zur Anderung weiterer Gesetze, Vom August 2020

Energy efficiency class	$Q^*_{\mathrm{f,a}}$ **in** $^{\mathbf{kWh}}/_{\mathbf{a\ m^2}}$
A+	≤ 30
A	≤ 50
B	≤ 75
C	≤ 100
D	≤ 130
E	≤ 160
F	≤ 200
G	≤ 250
H	> 250

Table 19: Energy efficiency classes according to the corresponding law.

10. Calculation of the primary energy demand

With the calculated final energy amounts, the primary energy amounts can now be calculated. The primary energy with respect to the inferior heating value Q_{p} is given by Equation (25) in [6]:

$$Q_{\mathrm{p}} = Q_{\mathrm{p,in}} - Q_{\mathrm{p,out}}. \tag{263}$$

It can also be calculated with respect to the superior heating value as $Q_{\mathrm{p,Hs}}$ by Equation (26) in [6]:

$$Q_{\mathrm{p,Hs}} = Q_{\mathrm{p,in,Hs}} - Q_{\mathrm{p,out}}, \tag{264}$$

where:

- $Q_{\mathrm{p,in}}$ is the primary energy regarding the inferior heating value,
- $Q_{\mathrm{p,in,Hs}}$ is the primary energy regarding the superior heating value and
- $Q_{\mathrm{p,out}}$ is the primary energy required for processes outside of the considered zones.

$Q_{\mathrm{p,in}}$ is given by Equation (22) in [6]:

$$Q_{\mathrm{p,in}} = \sum_{j} \left(Q_{\mathrm{f,in,j}} \cdot \frac{f_{\mathrm{p,in,j}}}{f_{\mathrm{Hs/Hi,j}}} \right), \tag{265}$$

$Q_{\mathrm{p,in,Hs}}$ is given by Equation (23) in [6]:

$$Q_{\mathrm{p,in,Hs}} = \sum_{\mathrm{j}} \left(Q_{\mathrm{f,in,j}} \cdot f_{\mathrm{p,in,j}} \right) \tag{266}$$

and $Q_{\mathrm{p,out}}$ is given by Equation (24) in [6]:

$$Q_{\mathrm{p,out}} = \sum_{\mathrm{j}} \left(Q_{\mathrm{f,out,j}} \cdot f_{\mathrm{p,out,j}} \right), \tag{267}$$

where:

- $Q_{\mathrm{f,in,j}}$ is the supplied final energy with respect to the superior energy value of energy source j,
- $Q_{\mathrm{f,out,j}}$ is the supplied final energy required for processes outside of the considered zones for energy source j and
- $f_{\mathrm{p,j}}$ is the primary energy factor of energy source j.

$f_{\mathrm{p,j}}$ depends on the building's energy sources. Possible values are shown in Table , 53 and 54 respectively as well as the corresponding CO_2-equivalents $\chi_{\mathrm{CO_2}}$. These can be used in the presented equations instead of $f_{\mathrm{p,j}}$ for calculating the total mass of emitted CO_2.

11. Results

In order to evaluate the accuracy of this work's implementation, the final results have been compared to those of the most established software tools which have been mentioned in Table 1. This has been done for each exemplary building setups presented in [16], except those with a heat pump as heat generation system. For each test case, the final energy amounts of all technical systems within the building have been calculated by each tool and have been summed up and compared to each other in the tables in Section 3 in [16]. Analogously, the results and relative deviations of this work's implementation regarding the reference result in [16] are listed in Tables 22, 23, 24 and 25 respectively. The input for each of the considered test cases has precisely been described in [16] and had to be used for the calculations by the other tools in order to earn the seal of quality of the '18599 Gütegemeinschaft' [12]. By using these inputs for this work's implementation, the obtained results can indeed be used for a meaningful comparison of the results' precision.

Apart from the results' accuracy, the program's average run time is another important quality criterion for software. Therefore the run time of this work's implementation has been tracked in order to compare it with those of the other tools. Before the actual run time comparison, the run time of this work's implementation has been profiled and improved. For this, the most time consuming program parts were took into accounts and their run time was lowered as much as possible. Similar to the comparison of the final results, comparing the run times is only meaningful if the same input is used for all of the tools whose run times should be compared. Unfortunately, [16] only provides the results of the different calculations by each tool but not the run times. Therefore it was necessary to download and install the available test versions of the considered software tools and track their run times. However, these some of test versions are only partially usable while others do not allow to accurately track their run time as it is not possible to distinguish the programs' loading times from their actual run times. The only software tool which allowed a relatively meaningful run time comparison is 'EVA 18599 Wohnbau' by Leuchter [13] because an input file can be loaded and then recalculated again, such that the program's run time can be measured. Additionally, the considered test cases in [16] are available within 'EVA 18599 Wohnbau' as example projects. By using these, the run time comparison is meaningful as well.

11.1. Discussion of results

The final results of the different software tools including this work's implementation have been compared to each other. For single family houses, the test cases 5, 6, 7, 8, 9, 10, 14 and 15 in [16] have been considered while for apartment buildings, the test cases 5, 6, 7, 8, 9, 10, 11, 14 and 15 were took into account. These test cases cover many of the most established technical systems which may be installed in residential buildings. The maximal deviation of this work's implementation is rounded up to about 0.1%.

[12] 18599 Gütegemeinschaft: http://www.18599guetegemeinschaft.de/index.html
[13] https://www.leuchter.de

This deviation can be considered as acceptable, as the allowed maximal deviation for sufficient accuracy is 1%, according to the 'DIN V 18599 Gütegemeinschaft' [14]. In most of the test cases, the results do not differ from the reference results in [16] regarding the given numerical precision. Although the implementation of this work does not yet cover all of the test cases, it calculates most of them with little to no deviations with respect to the reference results and, if at all, the deviations are about as considerable as those of the established tools. Overall, this work's implementation is an accurately calculating tool and the tested features even fulfill some of the requirements for earning the seal of quality of the '18599 Gütegemeinschaft'. For actually earning the quality seal, the remaining test cases which cover heat pumps have to be tested successfully. Note that in Tables 22, 23, 24 and 25, several relative deviations of other software tools have been rounded down while a relative deviation of this work's implementation has been rounded up in each case.

11.1.1. Profiling

After the correct results have been obtained, the last step was to improve the implemented program's run time. For this, each test case has been run 1000 times before and after making the improvements to the source code. The program has been profiled with cProfile [15], which allow to track the different program parts' run times. The total run time and the run times of the 4 costliest functions have been taken into account. In order to lower these run times, the specific program part has been analyzed and any detected unnecessary operation have been removed. In most of the cases these operations were redundant loop runs or recalculating constant values which only differ for different building setups.

Overall, the average total run time could be lowered by about 22.13%, as shown in Tables 20 and 21, which also show the relative run time improvements of the 4 costliest functions, as well as the average run time before and after improvements had been made.

Note that several program parts may be sub programs to other program parts, for example the program part 'heat_generating' is part of 'heating_system'. Therefore the sum of the run times shown in Tables 20 and 21 exceed the total run time.

	Total		**net_energy**		**heating_system**	
	before	after	**before**	**after**	**before**	**after**
Run time (ms)	108	84.1	90.5	66.2	48.1	9.71
Improvement	-22.13 %		-26.85 %		-79.81 %	

Table 20: Run times of the most costly program parts in seconds and the relative run time improvements.

[14] 18599 Gütegemeinschaft: http://www.18599guetegemeinschaft.de/index.html
[15] https://docs.python.org/3.8/library/profile.html#module-cProfile

	heat_generating		tap_water	
	before	**after**	**before**	**after**
Run time (ms)	35.6	31	18.1	6.09
Improvement	-12.92 %		-66.35 %	

Table 21: Run times of the most costly program parts in seconds and the relative run time improvements, continued.

Analogously, the run times and relative improvements for each test case are shown in in Tables 26 and 27. In order to obtain reliable results, each test case has been recalculated 1000 times. However, the shown run times were divided by 1000 to obtain the average run time for a single run. In one case, one of the functions' run times (the one for heat generation) was slightly increased. However, the total run time of the same test case was still lowered and in each of the other cases, the run time of the considered function was lowered. Overall, the total run time for calculating the energy balance of one building amounts to about 4.95 ms.

The partitioning of the run times for 1000 runs before the improvements have been illustrated in 6 and 7. In comparison, 8, 9 and 10 show the run times after the improvements. The illustrations have been generated with SnakeViz [16].

11.1.2. Run time comparison

In order to compare the program's run time with the one of a commercial software tools, 'EVA 18599 Wohnbau' by Leuchter [17] has been used. Its test version is suitable for the comparison as it can be downloaded for free and all of the considered test cases are available in the tool as example projects. These example projects have been imported and the calculation has been repeated 5 times for each of the considered test cases. The software tool itself does not provide the possibility to track its run time, therefore a mobile device was used which allowed make a slow-motion shot of the monitor of the computer on which the test cases were run. Along with the software tool's window and the mouse's loading icon, a stop watch has been recorded which later allowed to determine the start and the end of a program sun with the precision of a hundredth second. After each test cases has been run 5 times, the differences of the corresponding start and end times have been calculated which result in the program's run time. The average run times for each of the test cases are shown in Table 28 for single family houses and in Table 29 for apartment buildings. Overall, the total average run time is about 2.88 s. In comparison to 'EVA 18599 Wohnbau', the run time of this project's implementation is about 581.8 times shorter.

[16] https://jiffyclub.github.io/snakeviz/
[17] https://www.leuchter.de

Building setup	System	Reference	BKI	ENVISYS	IBP	Hottgenroth	Kern	Leuchter	Rowa-Soft	Solar-Computer	Vision-World	ZUB	This Project
Condensing boiler (CB)	**Heating**	13065	13013	13061	13067	13067	13069	13064	13035	13065	13065	13067	13065
			-0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.2%	0.0%	0.0%	0.0%	0.0%
	Tap water	4129	4129	4134	4129	4129	4127	4129	4127	4129	4129	4129	4129
			0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CB with solar System for Tap water	**Heating**	13206	13153	13205	13208	13208	13206	13206	13155	13205	13206	13208	13206
			-0.40 %	0.0%	0.0%	0.0%	0.0%	0.0%	-0.4%	0.0%	0.0%	0.0%	0.0%
	Tap water	2011	2012	2012	2012	2012	2012	2012	2012	2012	2011	2012	2011
			0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CB with solar System for Tap water and exhaust air Ventilation	**Heating**	12381	12341	12381	12382	12382	12384	12381	12338	12380	12381	12382	12381
			-0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.3%	0.0%	0.0%	0.0%	0.0%
	Tap water	2067	2067	2068	2067	2067	2068	2068	2067	2068	2067	2067	2067
			0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
	Ventilation	102	102	102	102	102	102	102	102	102	102	102	102
			0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Reference building with pipe lengths according to DIN V 4701	**Heating**	11236	11237	11236	11237	11237	11238	11235	11221	11236	11236	11236	11236
			0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%
	Tap water	2294	2295	2282	295	2295	2289	2296	295	2.295	2294	2295	2294
			0.0%	-0.5%	0.0%	0.0%	-0.2%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
	Ventilation	89	89	89	89	89	89	89	89	89	89	89	89
			0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 22: Final energy of single family houses in kWh/a and deviations comparatively to similar tools.

Building setup	System	Reference	BKI	ENVISYS	IBP	Hottgenroth	Kern	Leuchter	Rowa-Soft	Solar-Computer	Vision-World	ZUB	This Project
CB with solar System for Tap water and Heating	**Heating**	11836	11822 -0.1%	11823 -0.1%	11822 -0.1%	11822 -0.1%	11823 -0.1%	11829 -0.1%	1182 -0.1%	11829 -0.1%	11836 0.0%	11822 -0.1%	11829 -0.1%
	Tap water	1710	1708 -0.1%	1710 0.0%	1708 -0.1%	1708 -0.1%	1709 0.0%	1710 0.0%	1708 -0.1%	1710 0.0%	1710 0.0%	1708 -0.1%	1710 0.0%
Condensing boiler with exhaust and supply Ventilation	**Heating**	10041	10070 0.3%	10040 0.0%	10044 0.0%	10042 0.0%	10043 0.0%	10044 0.0%	10008 -0.3%	10042 0.0%	10041 0.0%	10044 0.0%	10041 0.0%
	Tap water	4203	4200 -0.1%	4209 0.1%	4203 0.0%	4203 0.0%	4201 0.0%	4203 0.0%	4203 0.0%	4203 0.0%	4203 0.0%	4203 0.0%	4203 0.0%
	Ventilation	539	539 0.0%	539 0.0%	539 0.0%	539 0.0%	539 0.0%	539 0.0%	539 0.0%	539 0.0%	539 0.0%	539 0.0%	539 0.0%
Biomass boiler	**Heating**	14004	14000 0.0%	14014 0.1%	14000 0.0%	14000 0.0%	14005 0.0%	14013 0.1%	14000 0.0%	14001 0.0%	14004 0.0%	14000 0.0%	14004 0.0%
	Tap water	5519	5524 0.1%	5527 0.1%	5524 0.1%	5524 0.1%	5520 0.0%	5523 0.1%	5524 0.1%	5519 0.0%	5519 0.0%	5524 0.1%	5519 0.0%
District Heating	**Heating**	12356	12356 0.0%	12356 0.0%	12356 0.0%	12356 0.0%	12354 0.0%	12343 -0.1%	12356 0.0%	12356 0.0%	12356 0.0%	12356 0.0%	12356 0.0%
	Tap water	3732	3732 0.0%	3738 0.1%	3732 0.0%	3732 0.0%	3732 0.0%	3732 0.0%	3732 0.0%	3732 0.0%	3732 0.0%	3732 0.0%	3732 0.0%

Table 23: Final energy of single family houses in kWh/a and deviations comparatively to similar tools, continuation.

Building setup	System	Reference	BKI	ENVISYS	IBP	Hottgenroth	Kern	Leuchter	Rowa-Soft	Solar-Computer	Vision-World	ZUB	This Project
CB	**Heating**	38598	38598	38653	38598	38598	38605	38592	38598	38597	38598	38598	38598
			0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Tap water	15901	15901	15892	15901	15901	15901	15901	15901	15901	15901	15901	15901
			0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CB with solar System for Tap water	**Heating**	38610	38609	38665	38609	38609	38615	38604	38609	38609	38610	38609	38610
			0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.00%	0.0%	0.0%
	Tap water	10509	10507	10503	10507	10507	10512	10508	10507	10508	10509	10507	10509
			0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CB with solar System for Tap water and exhaust air Ventilation	**Heating**	35314	35313	35360	35313	35313	35311	35308	35314	35313	35314	35313	35314
			0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.00%	0.0%	0.0%
	Tap water	10649	10647	10643	10647	10647	10652	10648	10647	10648	10649	10647	10649
			0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Ventilation	384	384	384	384	384	384	384	384	384	384	384	384
			0.0%	0.0%	0.00%	0.00%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Reference building with pipe lengths according to DIN V 4701	**Heating**	29216	29218	29227	29218	29219	29218	29211	29218	29218	29216	29218	29216
			0.0%	0.00%	0.00%	0.0%	0.00%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Tap water	9050	9051	9063	9051	9051	9049	9052	9051	9051	9050	9051	9050
			0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Ventilation	302	302	302	302	302	302	302	302	302	302	302	302
			0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 24: Final energy of apartment buildings in kWh/a and deviations comparatively to similar tools.

Building setup	System	Reference	BKI	ENVISYS	IBP	Hottgenroth	Kern	Leuchter	Rowa-Soft	Solar-Computer	Vision-World	ZUB	This Project
CB with solar System for Tap water and Heating	**Heating**	34039	33937	34026	33937	33937	34012	34169	33937	34022	34039	33937	33809
			-0.3%	0.0%	-0.3%	-0.3%	-0.1%	0.4%	-0.3%	-0.1 %	0%	-0.1 %	-0.7%
	Tap water	9012	9010	8999	9010	9010	9017	9010	9010	9010	9012	9010	9012
			0.0%	-0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.00%	0.0%	0.0%	0.0%
CB with exhaust and supply Ventilation	**Heating**	27170	27166	27201	27166	27166	27184	27172	27166	27170	27170	27166	27170
			0.0%	0.1%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Tap water	16087	16088	16079	16088	16088	16087	16088	16088	16087	16087	16088	16087
			0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Ventilation	1885	1885	1885	1885	1885	1885	1885	1885	1885	1885	1885	1885
			0.00%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CB and flow heaters	**Heating**	40012	40011	40067	40011	40011	40035	40006	40011	39966	40012	40011	40012
			0.0%	0.1%	0.0%	0.0%	0.1%	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%
	Tap water	9265	9265	9265	9265	9265	9265	9265	9265	9265	9265	9265	9265
			0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Biomass boiler	**Heating**	50611	50612	50626	50612	50612	50619	50603	50612	50608	50611	50612	50612
			0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%
	Tap water	18536	18536	18523	18536	18536	18534	18535	18536	18536	18536	18536	18536
			0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.00%	0.0%	0.0%
District Heating	**Heating**	35867	35868	35821	35868	35868	35862	35842	35868	35867	35867	35868	35868
			0.0%	-0.1%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	-0.1%
	Tap water	15058	15058	15050	15058	15058	15058	15058	15058	15058	15058	15058	15058
			0.0%	-0.1%	0.00%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 25: Final energy of apartment buildings in $^{kWh}/_{a}$ and deviations comparatively to similar tools, continuation.

Setup		Total		net_energy		heating_system		heat_generating		tap_water	
		before	**after**	**before**	**after**	**before**	**after**	**before**	**after**	**before**	**after**
CB	**Run time**	6.99	5.68	6.01	4.65	3.41	0.517	2.62	2.26	1.05	0.284
	Improvement	-18.74 %		-22.63 %		-84.84 %		-13.74 %		-72.95 %	
CB with solar system for tap water	**Run time**	7.61	5.91	6.65	4.87	3.35	0.517	2.6	2.27	1.71	0.475
	Improvement	-22.34 %		-26.77 %		-84.57 %		-12.69 %		-72.22 %	
CB with solar system for tap water and exhaust air ventilation	**Run time**	6.62	5.5	5.63	4.4	2.86	0.527	2.22	2.04	1.44	0.481
	Improvement	-16.92 %		-21.85 %		-81.57 %		-8.11 %		-66.60 %	
Reference building with pipe lengths according to DIN V 4701	**Run time**	6.46	5.49	5.48	4.39	2.77	0.519	2.16	2.03	1.42	0.483
	Improvement	-15.02 %		-19.89 %		-81.26 %		-6.02 %		-65.99 %	
CB with solar system for tap water and heating	**Run time**	6.75	5.01	5.79	3.98	3.36	0.728	1.74	1.71	1.19	0.471
	Improvement	-25.78 %		-31.26 %		-78.33 %		-1.72 %		-60.42 %	
CB with exhaust and supply ventilation	**Run time**	6.670	6.35	5.66	5.13	3.22	0.565	2.46	2.51	0.992	0.476
	Improvement	-4.80 %		-9.36 %		-82.45 %		+2.03 %		-52.02 %	
Biomass boiler	**Run time**	6.18	5.78	5.25	4.68	3.12	0.641	2.17	1.99	0.856	0.297
	Improvement	-6.47 %		-10.86 %		-79.46 %		-8.29 %		-65.30 %	
District heating	**Run time**	3.79	3.53	2.9	2.54	1.56	0.459	1.24	1.17	0.383	0.194
	Improvement	-6.86 %		-12.41 %		-70.58 %		-5.65 %		-49.35 %	

Table 26: Run times in ms and relative improvements for each test case of the single family houses.

Setup		Total		net_energy		heating_system		heat_generating		tap_water	
		before	**after**	**before**	**after**	**before**	**after**	**before**	**after**	**before**	**after**
CB	**Run time**	4.97	4.43	4.03	3.42	2.24	0.496	1.76	1.66	0.625	0.251
	Improvement	-10.87 %		-15.14 %		-77.86 %		-5.68 %		-59.84 %	
CB with solar system for tap water	**Run time**	5.46	4.68	4.52	3.66	2.24	0.501	1.63	1.68	1.14	0.445
	Improvement	-14.29 %		-19.03 %		-77.63 %		3.07 %		-60.96 %	
CB with solar system for tap water and exhaust air ventilation	**Run time**	5.46	4.73	4.5	3.67	2.28	0.501	1.74	1.69	1.1	0.445
	Improvement	-13.37 %		-18.44 %		-78.03 %		-2.87 %		-59.55 %	
Reference building with pipe lengths according to DIN V 4701	**Run time**	6.23	5.14	5.27	4.08	2.65	0.481	2.1	1.93	1.33	0.448
	Improvement	-17.50 %		-22.58 %		-81.85 %		-8.10 %		-66.32 %	
CB with solar system for tap water and heating	**Run time**	5.62	4.38	4.67	3.36	2.66	0.714	1.53	1.42	0.899	0.444
	Improvement	-22.06 %		-28.05 %		-73.16 %		-7.19 %		-50.61 %	
CB with exhaust and supply ventilation	**Run time**	5.11	4.52	4.1	3.43	2.31	1.67	1.73	1.67	0.641	0.253
	Improvement	-11.55 %		-16.34 %		-27.71 %		-3.47 %		-60.53 %	
CB and decentralized the heating of tap water (flow heater)	**Run time**	4.8	4.35	3.86	3.31	2.17	0.506	1.69	1.58	0.453	0.295
	Improvement	-9.38 %		-14.25 %		-76.68 %		-6.51 %		-34.88 %	
Biomass boiler	**Run time**	4.57	4.3	3.59	3.27	2.04	0.619	1.43	1.34	0.547	0.258
	Improvement	-5.91 %		-8.91 %		-69.66 %		-6.29 %		-52.83 %	
District heating	**Run time**	3.84	3.42	2.93	2.46	1.47	0.437	1.15	1.02	0.474	0.29
	Improvement	-10.94 %		-16.04 %		-70.27 %		-11.30 %		-38.82 %	

Table 27: Run times in ms and relative improvements for each test case of the apartment buildings.

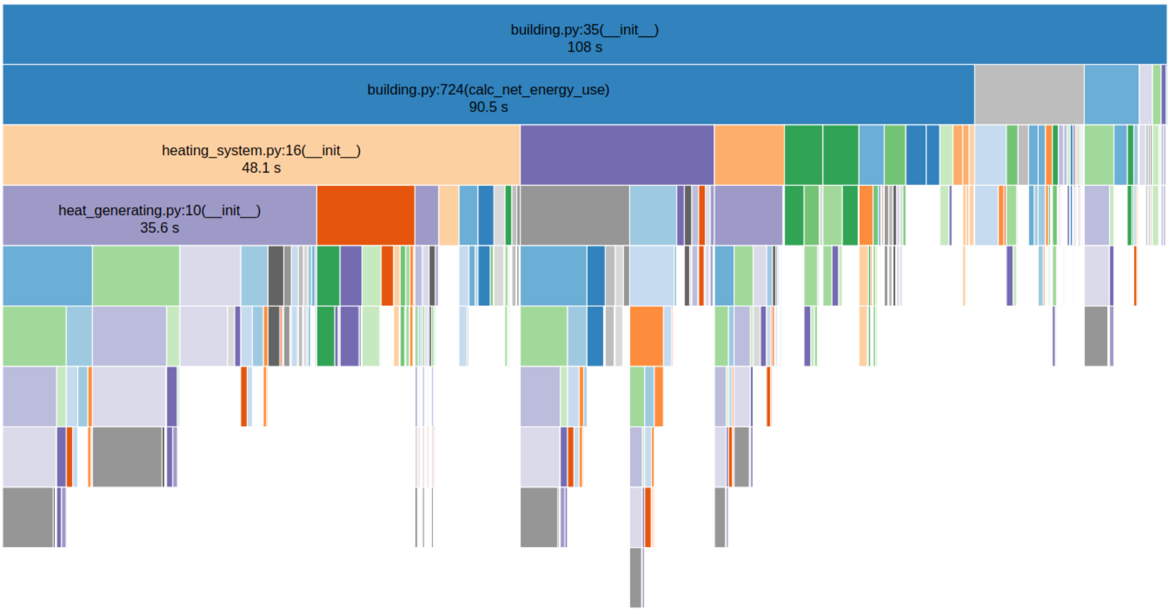

Figure 6: Visualization of the program parts' run times before profiling.

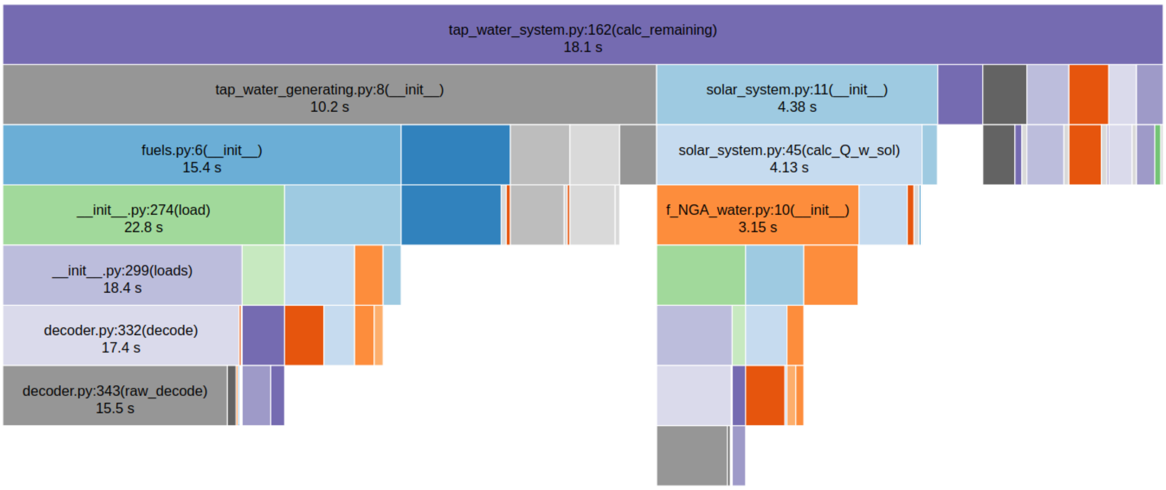

Figure 7: Visualization of the program parts' run times before profiling, continuation.

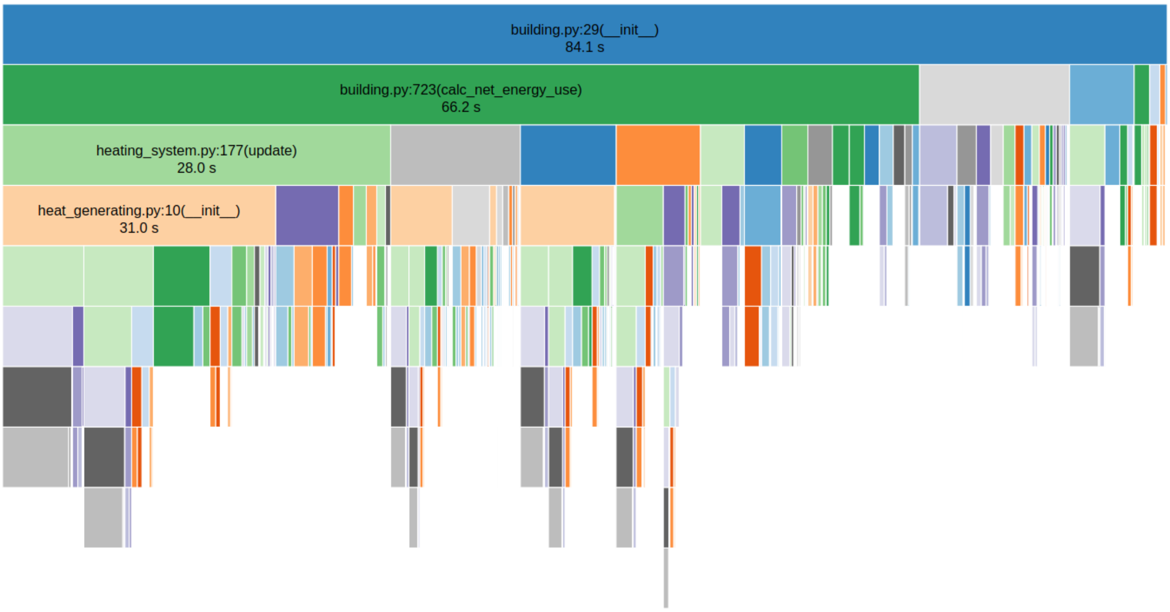

Figure 8: Visualization of the program parts' run times after profiling.

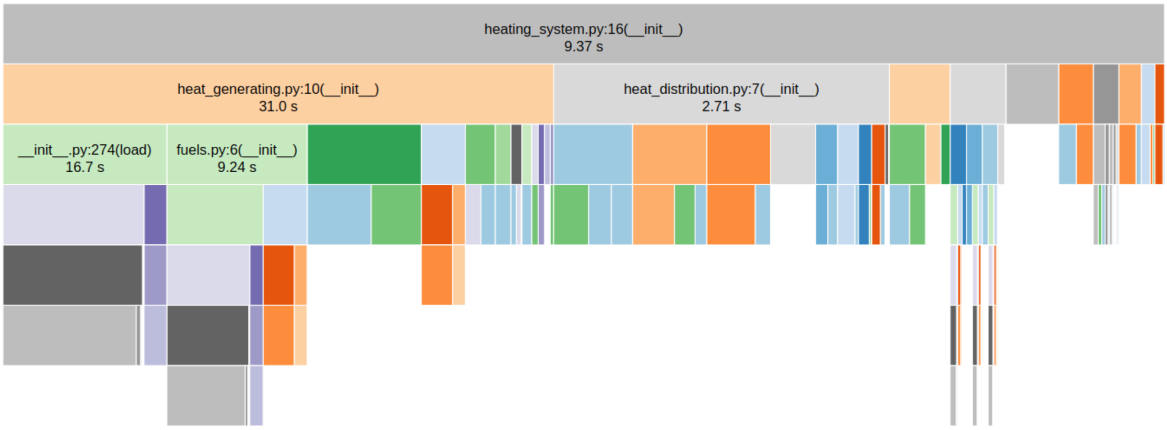

Figure 9: Visualization of the program parts' run times after profiling, continuation.

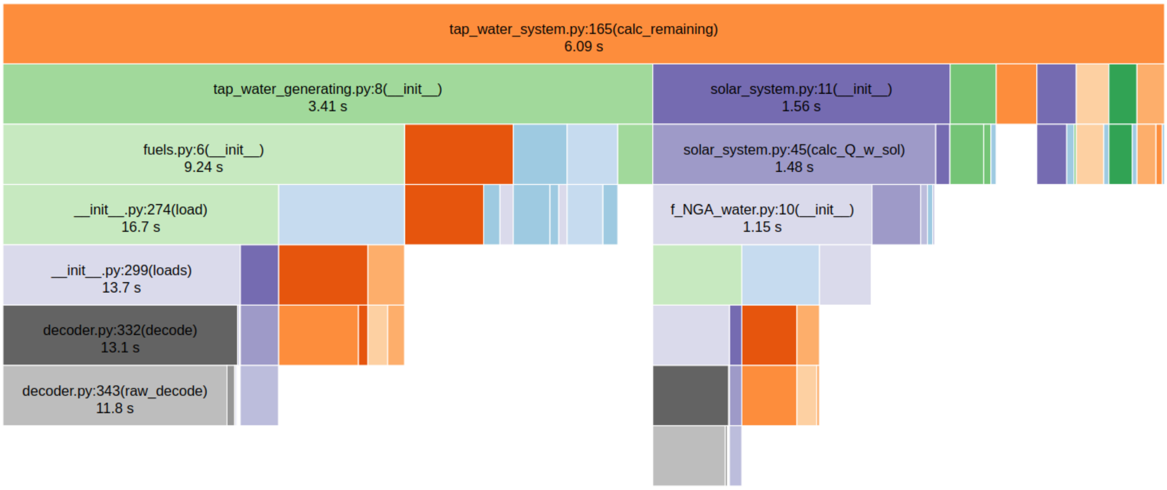

Figure 10: Visualization of the program parts' run times after profiling, another continuation.

Setup	**Run time (s)**
Condensing boiler (CB)	2.806
CB with solar system for tap water	2.906
CB with solar system for tap water and exhaust air ventilation	2.87
Reference building with pipe lengths according to DIN V 4701	2.91
CB with solar system for tap water and heating	2.864
CB with exhaust and supply ventilation	2.89
Biomass boiler	2.916
District heating	2.884

Table 28: Average run times of the software tool 'EVA 18599 Wohnbau' for calculating the considered test cases of the single family houses.

Setup	**Run time (s)**
CB	2.848
CB with solar system for tap water	2.896
CB with solar system for tap water and exhaust air ventilation	2.892
Reference building with pipe lengths according to DIN V 4701	2.88
CB with solar system for tap water and heating	2.918
CB with exhaust and supply ventilation	2.86
CB and decentralized the heating of tap water (flow heater)	2.796
Biomass boiler	2.922
District heating	2.89

Table 29: Average run times of the software tool 'EVA 18599 Wohnbau' for calculating the considered test cases of the apartment buildings.

12. Conclusion and outlook

Overall, the implemented software provides a broad basis for the final web app which users may use in future. The modular structure of the program code allows to effortlessly update or replace entire program parts if the corresponding standards have been changed. The results of this work fulfill the requirement of deviating less than 1% from the results of the 'DIN V 18599 Gütegemeinschaft' [18]. Hence, the software is accurate and can even keep up with established professional software tools. Additionally, with a run time of about 4.95 ms to calculate the energy balance of one building, the implemented program seems to be fast, at least in comparison to the test version of the software tool 'EVA 18599 Wohnbau' [19]. Unfortunately, this was the only free tool which allowed to reasonably retrace which calculations were made within a specific time. Regarding this work's application in a web app, the short run time allows to keep the loading times for users low.

As this work is based on the calculation of the DIN V 18599 standard which is continuously evolving with the years, the implementation has to be appropriately adapted and updated from time to time to ensure reliable results. Several program parts already have an updated version of their functions, while some others still remain outdated at this time. As the reference results provided by the 'DIN V 18599 Gütegemeinschaft' are outdated, the future aim is to compare the updated function's results to those of the established software tools with the same DIN V 18599 standard version. In addition, the remaining conditioning systems (heat pumps) are going to be implemented in order to reach the complete set of successfully tested test cases. As the current program version only calculates the energy balance of residential buildings, it is also going be extended to be able to calculate the energy balances of non-residential buildings too, as well as buildings consisting of residential and non-residential areas.

[18] 18599 Gütegemeinschaft: http://www.18599guetegemeinschaft.de/index.html
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A. Standard values

Symbol	Heat flow by	Value
F_e	Outer walls, windows, ceilings above outer air or underground garages	1.0
F_D	Roofs which delimit the considered zone	1.0
F_D	Ceilings to non thermal isolated attics	0.8
F_u	Dwarf walls	0.8
F_u	Walls and ceilings to unheated rooms (except basements)	0.5
F_nb	Walls and ceilings to unheated rooms with a temperature between 12 °C and 19 °C	0.35
F_u	Walls and windows to unheated sunporches with: Single-strength glass Double glazing Heat protection glass	 1.0 1.0 1.0

Table 30: Temperature correction factors F_x according to Table 5 in [8].

F_x																		
$B = A_\mathrm{G}/\,(0.5 \cdot P)$																		
Heat flow by			$< 5\,\mathrm{m}$				$5\,\mathrm{m}$ to $7.5\,\mathrm{m}$				$> 7.5\,\mathrm{m}$ to $10\,\mathrm{m}$				$> 10\,\mathrm{m}$			
With the heat transfer resistance R of the considered component																		
			$R \leq 0.3 \leq 1$	$0.3 < R \leq 1$	$1 < R \leq 3$	$3 \leq R$	$R \leq 0.3 \leq 1$	$0.3 < R \leq 1$	$1 < R \leq 3$	$3 \leq R$	$R \leq 0.3 \leq 1$	$0.3 < R \leq 1$	$1 < R \leq 3$	$3 \leq R$	$R \leq 0.3 \leq 1$	$0.3 < R \leq 1$	$1 < R \leq 3$	$3 \leq R$
	Components of heated basements																	
1	Floor	$f_\mathrm{f,b}$	0.2	0.45	55	0.7	0.2	0.4	0.5	0.65	0.15	0.35	0.45	0.6	0.15	0.3	0.4	0.55
2	Wall	$f_\mathrm{w,b}$	0.35	0.55	0.65	0.75	0.35	0.55	0.65	0.75	0.35	0.55	0.65	0.75	0.35	0.55	0.65	0.75
3	Floor on top of the earth without isolation	$f_\mathrm{f,b}$	0.3	0.55	0.7	0.8	0.25	0.5	0.6	0.75	0.2	0.4	0.55	0.65	0.15	0.35	0.45	0.6
	Floor on top of the earth with isolation																	
4	5m horizontally	$f_\mathrm{f,b}$	-	-	-	-	0.15	0.35	0.45	0.6	0.1	0.3	0.45	0.55	0.1	0.25	0.4	0.5
5	2m vertically	$f_\mathrm{f,b}$	0.2	0.4	0.5	0.65	0.15	0.35	0.5	0.6	0.15	0.35	0.45	0.6	0.1	0.3	0.4	0.55
	Ceiling and inner walls to unheated basement																	
6	with perimeter isolation	f_G	0.35	0.65	0.75	0.8	0.35	0.6	0.7	0.8	0.3	0.55	0.65	0.75	0.25	0.5	0.65	0.7
7	without	f_G	0.45	0.75	0.8	0.85	0.4	0.7	0.8	15	0.35	0.65	0.75	0.8	0.3	60	0.7	0.75
8	raised floor		0.9																

Table 31: Temperature correction factors F_x according to Table 6 in [8].

Glass type	**Description**
1	Single-strength glass
2	Double glazing, filled with air
3	Triple glazing, filled with air
4	Heat insulating glass, double, filled with argon, one covering
5	Heat insulating glass, triple, filled with argon, two coverings
6	Sun protection glass, double, filled with argon, one covering
7	Sun protection glass, double, filled with argon, two coverings
8	Heat insulating glass, double, filled with argon, one covering, switchable
9	Heat insulating glass, triple, filled with argon, two coverings, switchable

Table 32: Glass types.

Glas type	External sun protection									
	Sun blind (10 °)		**Sun blind (45 °)**		**Marquee**		**Shutter full**		**Shutter (3/4)**	
	white	**dark gray**	**white**	**dark gray**	**white**	**gray**	**white**	**dark gray**	**white**	**dark gray**
	g_{tot}	g_{tot}	g_{tot}	g_{tot}	g_{tot}	g_{tot}	g_{tot}	g_{tot}	g_{tot}	g_{tot}
1	0.12	0.2	0.18	0.21	0.28	0.23	0.23	0.25	0.39	0.4
2	0.1	0.15	0.15	0.16	0.25	0.19	0.2	0.19	0.35	0.34
3	0.08	0.12	0.13	0.13	0.23	0.16	0.18	0.16	0.31	0.3
4	0.08	0.11	0.13	0.12	0.23	0.15	0.18	0.16	0.32	0.3
	0.07	0.1	0.12	0.1	0.21	0.14	0.17	0.14	0.29	0.27
	0.07	0.08	0.11	0.09	0.2	0.13	0.16	0.13	0.28	0.25
	0.06	0.08	0.1	0.08	0.17	0.11	0.14	0.11	0.24	0.22
5	0.06	0.07	0.1	0.07	0.19	0.11	0.15	0.11	0.26	0.23
	0.05	0.06	0.09	0.06	0.17	0.1	0.13	0.1	0.23	0.2
6	0.06	0.09	0.1	0.1	0.17	0.12	0.14	0.12	0.22	0.21
	0.06	0.09	0.09	0.09	0.14	0.11	0.11	0.11	0.18	0.18
	0.05	0.08	0.08	0.09	0.12	0.09	0.09	0.1	0.13	0.14
	0.05	0.08	0.08	0.08	0.14	0.1	0.11	0.11	0.17	0.17
	0.05	0.08	0.07	0.08	0.12	0.09	0.09	0.1	0.14	0.14
7	0.04	0.06	0.07	0.06	0.12	0.08	0.1	0.08	0.16	0.15
	0.04	0.06	0.06	0.06	0.1	0.07	0.08	0.07	0.12	0.12
	0.03	0.06	0.05	0.06	0.08	0.06	0.06	0.07	0.09	0.09
8	0.2									
9	0.17									

Table 33: Value for g_{tot} according to Table 8 in [8].

Glass type	Internal sun protection						
	Sun blind (10 °)		**Sun blind (45 °)**		**Window shade**		**Foil**
	white	**dark gray**	**white**	**dark gray**	**white**	**dark gray**	**white**
	g_{tot}	g_{tot}	g_{tot}	g_{tot}	g_{tot}	g_{tot}	g_{tot}
1	0.43	0.64	0.45	0.65	0.42	0.46	0.38
2	0.44	0.63	0.46	0.64	0.42	0.47	0.4
3	0.43	0.59	0.45	0.6	0.41	0.46	0.4
4	0.44	0.61	0.46	0.62	0.42	0.47	0.4
	0.43	0.58	0.44	0.58	0.41	0.45	0.39
	0.42	0.56	0.44	0.56	0.4	0.44	0.39
	0.38	0.47	0.39	0.48	0.37	0.4	0.36
5	0.41	0.53	0.42	0.54	0.39	0.43	0.38
	0.38	0.48	0.39	0.48	0.37	0.4	0.36
6	0.35	0.43	0.36	0.43	0.34	0.37	0.34
	0.29	0.34	0.3	0.34	0.29	0.3	0.28
	0.21	0.23	0.22	0.23	0.21	0.22	0.21
	0.29	0.33	0.29	0.33	0.28	0.3	0.28
	0.23	0.25	0.23	0.25	0.23	0.23	0.22
7	0.28	0.32	0.28	0.32	0.27	0.28	0.27
	0.21	0.23	0.21	0.23	0.21	0.21	0.2
	0.15	0.15	0.15	0.15	0.14	0.15	0.14
8	0.2						
9	0.17						

Table 34: Value for g_{tot} according to Table 8 in [8].

Glass type	No sun protection		
	U_g	g	τ_e
1	5.8	0.87	0.85
2	2.9	0.78	0.73
3	2	0.7	0.63
4	1.7	0.72	0.6
	1.4	0.67	0.58
	1.1	0.64	0.58
	1	0.53	0.45
5	0.8	0.6	0.5
	0.7	0.53	0.46
6	1.3	0.48	0.44
	1.2	0.37	0.34
	1.2	0.25	0.21
	1.1	0.36	0.33
	1.1	0.27	0.24
7	0.7	0.34	0.29
	0.7	0.24	0.21
	0.7	0.16	0.13
8	1.1	0.41	0.36
9	0.7	0.36	0.31

Table 35: Value for U_g, g and τ_e according to Table 8 in [8].

<table>
<tr><th rowspan="2">Single-pipe-system</th><th rowspan="2">$\Delta\theta_{\mathrm{hydr}}$</th><th rowspan="2">Two-pipe-system</th><th>$n \leq 10$</th><th>$n > 10$</th></tr>
<tr><th>$\Delta\theta_{\mathrm{hydr}}$</th><th>$\Delta\theta_{\mathrm{hydr}}$</th></tr>
<tr><td>no hydraulic comparison</td><td>0.7</td><td>no hydraulic comparison</td><td colspan="2">0.6</td></tr>
<tr><td>Comparison per heating circuit</td><td>0.4</td><td>Comparison per radiator, no collective comparison</td><td>0.3</td><td>0.4</td></tr>
<tr><td>Dynamic comparison per heating circuit</td><td>0.3</td><td>Comparison per radiator and collective comparison, static</td><td>0.2</td><td>0.3</td></tr>
<tr><td>Dynamic comparison per heating circuit and dynamically controlled depending on its workload (temperature dependent)</td><td>0.2</td><td>Comparison per radiator and collective comparison, dynamic</td><td>0.1</td><td>0.2</td></tr>
<tr><td>Dynamic comparison per heating circuit and dynamically controlled depending on its workload</td><td>0.1</td><td>Dynamic comparison per radiator</td><td colspan="2">0</td></tr>
</table>

Table 36: Values for $\Delta\theta_{\mathrm{hydr}}$ according to Table 9 in [11].

Parameter		Variation				
		$\Delta\theta_{\mathrm{str}}$		$\Delta\theta_{\mathrm{ctr;1}}$	$\Delta\theta_{\mathrm{ctr;2}}$	$\Delta\theta_{\mathrm{emb}}$
Temperature controller	No controller, or central flow temperature control			2.5	2.5	
	Operation room or Single pipe heating system			2	1.8	
	electronic temperature control			1.8	1.6	
	P-Controller (before 1988)			1.4	1.4	
	P-Controller			1.2	0.7	
	PI-Controller			1.2	0.7	
	PI-Controller with optimization function			0.9	0.5	
Over temperature relative to $\theta_{\mathrm{I}} = 20\,^{\circ}\mathrm{C}$	Renewed single-pipe heating systems and two-pipe heating systems	$\Delta_{\mathrm{str.1}}$	$\Delta_{\mathrm{str.2}}$			
	60 K	1.2				
	42.5 K	0.7				
	30 K	0.5				
	20 K	0.4				
	Single-pipe heating system, not renewed					
	60 K	1.6				
	42.5 K	1.2				
	Heating systems combined with mechanical ventilation	0.2				
	Radiators with blowers	0				
Building shell	Radiator on interior wall		1.3			0
	Radiator on glass surface		1.7			0
	Radiator on glass surface with radiation shield		1.2			0
	Radiator on exterior wall		0.3			0

Table 37: Values for $\Delta\theta_{\mathrm{str}}$, $\Delta\theta_{\mathrm{ctr1}}$, $\Delta\theta_{\mathrm{ctr1}}$ and $\Delta\theta_{\mathrm{emb}}$ according to Table 10 in [11].

Parameter		Variation				
		$\Delta\theta_{str}$		$\Delta\theta_{ctr;1}$	$\Delta\theta_{ctr;2}$	$\Delta\theta_{emb}$
Temperature controller	No controller, or central flow temperature control			2.5	2.5	
	Operation room or Single pipe heating system			2	1.8	
	Electronic temperature control			1.8	1.6	
	P-Controller (before 1988)			1.4	1.4	
	P-Controller			1.2	0.7	
	PI-Controller			1.2	0.7	
	PI-Controller with optimization function			0.9	0.5	
System type	Floor heating system	$\Delta_{str.1}$	$\Delta_{str.2}$			
	Wet system	0				0
	Dry system	0.7				0
	Systems with low coverage	0.4				0
	Wall heating	0.2				0.4
	Overhead heating	0.7				0.7
	Heating systems combined with mechanical ventilation	0.7				0
Building shell	Without minimal insulation according to DIN EN 1264	1.4				
	With minimal insulation according to DIN EN 1264	0.5				
	With better insulation as in DIN EN 1264	0.1				

Table 38: Values for $\Delta\theta_{str}$, $\Delta\theta_{ctr1}$, $\Delta\theta_{ctr1}$ and $\Delta\theta_{emb}$ according to Table 11 in [11].

Distribution type	Building group	Horizontal distribution			Riser pipe			Connection	
		c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8
Type I		$L_\mathrm{V} = c_1 + c_2 \cdot A_\mathrm{NGF}^{c3}$			$L_\mathrm{S} = c_4 \cdot A_\mathrm{NGF}^{c_5} + c_6 \cdot A_\mathrm{NGF} \cdot h \cdot n_\mathrm{G}$			$L_\mathrm{A} = c_7 \cdot A_\mathrm{NGF}^{c_8}$	
	1	30	2.3	0.79	2.56	0.1	0.0006	0.06	1.13
					$L_\mathrm{S} = c_4 \cdot A_\mathrm{NGF} + c_5 \cdot (h \cdot n_\mathrm{G})^{c_6}$				
	2	30	1.5	0.79	0.005 0	1.5	1	0.05	1
	3	30	1	0.79	0.003 3	0.9	1.2	0.1	1
	4	30	0.8	0.8	0.000 3	1.75	0.9	7.1	0.42
	5	30	1	0.79	0.003 3	0.9	1.2	7.1	0.42
Type IIa		$L_\mathrm{V} = c_1 + c_2 \cdot \left(\frac{A_\mathrm{NGF}}{n_\mathrm{G}}\right)^{c_3}$			$L_\mathrm{S} = c_5 \cdot A_\mathrm{NGF}^{c_6}$			$L_\mathrm{A} = c_7 \cdot A_\mathrm{NGF}^{c_8}$	
	1	30	0.17	1.05		0.008	1.12	0.3	1.11
	2	30	0.45	0.84		0.003 5	1.23	0.17	1
	3.4	30	0.18	1.15		0.3	0.7	0.13	1.2
	5	30	0.45	0.84		0.0035	1.23	0.2	1.2
Type IIb		$L_\mathrm{V} = c_1 + c_2 \cdot \left(\frac{A_\mathrm{NGF}}{n_\mathrm{G}}\right)^{c_3}$			$L_\mathrm{S} = c_5 \cdot A_\mathrm{NGF}^{c_6}$			$L_\mathrm{A} = c_7 \cdot A_\mathrm{NGF}^{c_8}$	
	1	30	0.17	1.05		0.008	1.12	0	1
	2	30	0.45	0.84		0.003 5	1.23	0	1
	3.4	30	0.18	1.15		0.3	0.7	0	1
	5	30	0.45	0.84		0.003 5	1.23	0	1
Type III		$L_\mathrm{V} = c_1 + c_2 \cdot \left(\frac{A_\mathrm{NGF}}{n_\mathrm{G}}\right)^{c_3}$			$L_\mathrm{S} = c_5 \cdot A_\mathrm{NGF}^{c_6}$			$L_\mathrm{A} = c_7 \cdot A_\mathrm{NGF}^{c_8}$	
	1	30	2.6	0.72		0.008	1.39	0.25	1
		$L_\mathrm{V} = c_1 \cdot L_\mathrm{char} + c_2 \cdot \left(\frac{A_\mathrm{NGF}}{n_\mathrm{G}}\right)^{c_3} / L_\mathrm{char}$			$L_\mathrm{S} = c_5 \cdot A_\mathrm{NGF} \cdot h$				
	2	2	0.022	2		0.026		0.02	1.18
	3	2	0.02	2		0.042		0.23	1
	4, 5	2	0.02	2		0.009		2.5	0.65
Type IV		$L_\mathrm{V} = c_2 \cdot A_\mathrm{NGF}^{c_3}$			$L_\mathrm{S} = c_5 \cdot A_\mathrm{NGF} \cdot h$			$L_\mathrm{A} = c_7 \cdot A_\mathrm{NGF}^{c_8}$	
	1		0.35	0.9		0.000 7		0.1	1.13
	2 to 5		0.24	0.95		0.0004		1.12	0.56

Table 39: Values and equations for the pipe lengths according to Table 26 in [11].

Building class	**Distribution**	**Pipes outside of the thermal envelope**		**Pipes inside of the thermal envelope**	
	V	S	A	A	S
Isolated pipes					
After 1995	0.2	0.255	0.255	0.255	0.255
1980 to 1995	0.2	0.4	0.4	0.3	0.4
before 1980	0.4	0.4	0.4	0.4	0.4
Non-isolated pipes					
$A_{\mathrm{NGF}} \leq 200\,\mathrm{m}^2$	1	1	1	1	1
$200\,\mathrm{m}^2 < A_{\mathrm{NGF}} \leq 500\,\mathrm{m}^2$	2	2	2	2	2
$500\,\mathrm{m}^2 < A_{\mathrm{NGF}}$	3	3	3	3	3
Inside walls					
non-isolated		1.35/0.80			
isolated $U_{\mathrm{AW}} > 0.4\,{}^{\mathrm{W}}\!/\!{}_{\mathrm{m^2 \cdot K}}$		1.00/0.90			
isolated $U_{\mathrm{AW}} \leq 0.4\,{}^{\mathrm{W}}\!/\!{}_{\mathrm{m^2 \cdot K}}$		0.75/0.55			

Table 40: Values for U_{i} according to Table 27 in [11].

Energy source	$f_{\mathrm{Hs/Hi}}$	
Fuels	Fuel oil, bio oil	1.06
	Natural gas, bio gas	1.11
	Liquid gas	1.09
	Hard coal	1.04
	Brown coal	1.07
	Wood	1.08
Other energy sources	Electricity	1.00
	District heating	1.00
	Environmental energy	1.00
	Waste heat	1.00

Table 41: Values for $f_{\frac{\mathrm{Hs}}{\mathrm{Hi}}}$ according to Table (B.1) in [6].

Boiler type	**Year**	**A**	**B**	**C**	**D**
Dual-fuel boiler	before 1978	77.0	2.0	70.0	3.0
	1978 to 1987	79.0	2.0	74.0	3.0
Solid fuel boiler (fossil and biogenic fuel)	before 1978	78.0	2.0	72.0	3.0
	1978 to 1994	80.0	2.0	75.0	3.0
	after 1994	81.0	2.0	77.0	3.0
Gas special boiler	before 1978	79.5	2.0	76.0	3.0
	1978 to 1994	82.5	2.0	78.0	3.0
	after 1994	85.0	2.0	81.5	3.0
Forced draft boiler (fossil and biogenic fuel)	before 1978	80.0	2.0	75.0	3.0
	1978 to 1986	82.0	2.0	77.5	3.0
	1987 to 1994	84.0	2.0	80.0	3.0
	after 1994	85.0	2.0	81.5	3.0
Pellet boiler, System with buffer storage	after 1994	92.0	0.5	91.0	0.8
wood chips boiler, System with buffer storage	after 1994	91.5	0.5	90.0	0.8
Standard boiler, burner exchanged (only Forced draft boiler)	before 1978	82.5	2.0	78.0	3.0
	1978 to 1994	84.0	2.0	80.0	3.0

Table 42: Values for A, B, C and D according to Table (49) in [11].

Boiler type	**Year**	**A**	**B**	**C**	**D**
Gas special boiler	1978 to 1994	85.5	1.5	86.0	1.5
	after 1994	88.5	1.5	89.0	1.5
Flow water heater	before 1987	84.0	1.5	82.0	1.5
	1987 to 1992	86.0	1.5	82.0	1.5
Flow water heater	after 1994	86.0	1.5	82.0	1.5
Forced draft boiler	after 1994	86.0	1.5	82.0	1.5
Forced draft boiler	before 1987	84.0	1.5	82.0	1.5
	1987 to 1994	86.0	1.5	86.0	1.5
	after 1994	88.5	1.5	89.0	1.5
Low-temperature, Burner exchanged (only Forced draft boiler)	before 1987	86.0	1.5	85.0	1.5
	1987 to 1994	86.0	1.5	86.0	1.5
Condensing boiler	before 1987	89.0	1.0	95.0	1.0
	1987 to 1994	91.0	1.0	97.5	1.0
	after 1994	92.0	1.0	98.0	1.0
Condensing boiler, improved	ab 1999	94.0	1.0	103	1.0
Pellet-Condensing boiler, System with buffer storage	after 1994	100	1	98	1

Table 43: Values for A, B, C and D according to Table (49) in [11].

Boiler type	Year	E	F
Standard boiler			
Dual-fuel boiler	before 1987	12.5	−0.28
Solid fuel boiler (fossil and biogenic fuel)	before 1978	12.5	−0.28
	1978 to 1994	10.5	−0.28
	after 1994	8.0	−0.28
Gas special boiler	before 1978	8.0	−0.27
	1978 to 1994	7.0	−0.3
	after 1994	8.5	−0.4
Forced draft boiler (fossil and biogenic fuel)	before 1978	9.0	−0.28
	1978 to 1994	7.5	−0.31
	after 1994	8.5	−0.4
Solid fuel boiler (fuel: Pellet)	after 1994	3.0	−0.2
Solid fuel boiler (fuel: wood chips)	after 1994	4.0	−0.2
Low-temperature boiler			
Gas special boiler	to 1994	6.0	−0.32
	after 1994	4.5	−0.4
Flow water heater	to 1994	2.2	0.00
Combi boiler (small storage)	after 1994	2.2	0.00
Combi boiler (heat exchanger)	after 1994	1.2	0.00
Condensing boiler			
Forced draft boiler	to 1994	7.0	−0.37
	after 1994	4.25	−0.4
Condensing boiler	to 1994	7.0	−0.37
	after 1994	4.0	−0.4
Pellet-Condensing boiler, System with buffer storage	after 1994	3.0	−0.2

Table 44: Values for E and F according to Table (50) in [11].

Boiler type	K	L
Standard boiler (fossil and biologic fuel)	0	0.0004
Low-temperature boiler	0.0004	0.0004
Condensing boiler, gaseous fuels	0.002	0.002
Condensing boiler, liquid fuels	0.0004	0.001

Table 45: Values for L and K according to Table (37) in [11].

Boiler type	$P_{\mathbf{aux,i}}$	**G**	**H**	n
Boiler with forced-air burner	$P_{\text{aux,Pn}}$	0	45	0.48
	$P_{\text{aux,Pint}}$	0	15	0.48
	$P_{\text{aux,P0}}$	15	0	0
Boiler with atmospheric burner ($\leq 250\,\text{kW}$)	$P_{\text{aux,Pn}}$	40	0.35	1
	$P_{\text{aux,Pint}}$	20	0.1	1
	$P_{\text{aux,P0}}$	15	0	0
Boiler with atmospheric burner ($> 250\,\text{kW}$)	$P_{\text{aux,Pn}}$	80	0.7	1
	$P_{\text{aux,Pint}}$	40	0.2	1
	$P_{\text{aux,P0}}$	15	0	0
Pellet-boiler	$P_{\text{aux,Pn}}$	40	2	1
	$P_{\text{aux,Pint}}$	0	1.8	1
	$P_{\text{aux,P0}}$	5	0.2	1
Wood chips-boiler	$P_{\text{aux,Pn}}$	40	3	1
	$P_{\text{aux,Pint}}$	20	2	1
	$P_{\text{aux,P0}}$	15	0.1	1
Dual-fuel boiler	$P_{\text{aux,Pn}}$	0	45	0.48
	$P_{\text{aux,Pint}}$	0	15	0.48
	$P_{\text{aux,P0}}$	20	0	0
Solid fuel boiler	$P_{\text{aux,Pn}}$	15	0	0
	$P_{\text{aux,Pint}}$	15	0	0
	$P_{\text{aux,P0}}$	15	0	0
Gas special boiler	$P_{\text{aux,Pn}}$	40	0.35	1
	$P_{\text{aux,Pint}}$	20	0.1	1
	$P_{\text{aux,P0}}$	15	0	0
Gas special boiler	$P_{\text{aux,Pn}}$	80	0.7	1
	$P_{\text{aux,Pint}}$	40	0.2	1
	$P_{\text{aux,P0}}$	15	0	0
Flow water heater	$P_{\text{aux,Pn}}$	0	45	0.48
	$P_{\text{aux,Pint}}$	0	15	0.48
	$P_{\text{aux,P0}}$	15	0	0
Forced draft boiler	$P_{\text{aux,Pn}}$	0	45	0.48
	$P_{\text{aux,Pint}}$	0	15	0.48
	$P_{\text{aux,P0}}$	15	0	0
Condensation boiler, oil or gas	$P_{\text{aux,Pn}}$	0	45	0.48
	$P_{\text{aux,Pint}}$	0	15	0.48
	$P_{\text{aux,P0}}$	15	0	0
Condensation boiler, pellets with buffer storage	$P_{\text{aux,Pn}}$	40	2	1
	$P_{\text{aux,Pint}}$	0	1.8	1
	$P_{\text{aux,P0}}$	5	0.2	1

Table 46: Values for G, H and n according to Table 51 in [11].

Distribution type		Building group	Horizontal distribution			Riser pipes				Connection	
			c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9
Type I			$L_\mathrm{v} = c_2 \cdot \left(\frac{A_\mathrm{NGF}}{n_\mathrm{G}}\right)^{c_3}$			$L_\mathrm{S} = c_5 \cdot A_\mathrm{NGF}^{c_6}$				$L_\mathrm{A} = c_8 \cdot A_\mathrm{NGF}^{c_9}$	
	Single zone	1	0	0.11	1.24	0	0.005	1.38		0.09	1
		2	0	5.4	0.49	0	0.025	0.97		0.02	1
		3	0	5.4	0.49	0	0.025	0.97		2.39	0.43
		4	0	2.3	0.69	0	0.002	1.5		2.39	0.43
			$L_\mathrm{v} = c_2 \cdot \left(\frac{A_\mathrm{NGF}}{n_\mathrm{G}}\right)^{c_3}$			$L_\mathrm{S} = c_5 \cdot A_\mathrm{NGF} \cdot h_\mathrm{g}$				$L_\mathrm{A} = c_8 \cdot A_\mathrm{NGF}^{c_9}$	
	Several zones	1	0	2.7	0.97	0	0.05	0		0.5	1
		2	0	10.9	0.5	0	0.033	0		0.15	1
		3	0	10.9	0.5	0	0.033	0		1.36	0.69
		4	0	11.7	0.5	0	0.03	0		1.36	0.69
Type II			$L_\mathrm{v} = c_2 \cdot \left(\frac{A_\mathrm{NGF}}{n_\mathrm{G}}\right)^{c_3}$			$L_\mathrm{S} = c_5 \cdot A_\mathrm{NGF}^{c_6}$				$L_\mathrm{A} = c_8 \cdot A_\mathrm{NGF}^{c_9}$	
	Single zone	1	0	0.035	1.5	0	0.36	0.58		0.09	1
		2	0	1.7	0.67	0	0.72	0.44		0.02	1
		3	0	1.9	0.67	0	0.72	0.44		2.39	0.69
		4	0	32	0.19	0	2.9	0.1		2.39	0.69
			$L_\mathrm{v} = c_1 \cdot L_\mathrm{char} + c_2 \cdot A_\mathrm{NGF} \cdot h_\mathrm{G}$			$L_\mathrm{S} = c_4 \cdot A_\mathrm{NGF}^{c_5} + c_6 * (h_\mathrm{G} \cdot n_\mathrm{G})^{c_7}$				$L_\mathrm{A} = c_8 \cdot A_\mathrm{NGF}^{c_9}$	
	Several zones	1	5.6	0.2	0	0.006	1	1.6	1.09	0.5	1
		2	3.7	0.05	0	0.003	1	1.3	1.12	0.15	1
		3	3.7	0.05	0	0.003	1	1.3	1.12	1.36	0.69
		4	1.8	0.04	0	1.8	0.2	6	-1.17	1.36	0.69

Table 47: Values and equations for the pipe lengths according to [14].

Description	Symbol	Unit	Value
Median internal temperature in heated areas, if not calculated in 3.8	θ_{I}	°C	20
Median internal temperature in unheated areas, if not calculated in 3.8	θ_{I}	°C	13
Median temperature of the water grid, without circulation	$\theta_{\mathrm{w,av}}$	°C	25
Median temperature of the water grid, with circulation	$\theta_{\mathrm{w,av}}$	°C	57.5
Median temperature of the water storage	$\theta_{\mathrm{s,av}}$	°C	55
Temperature of the supplied cold water	θ_{K}	°C	10
Temperature spread in the circuit	Δ_{Z}	K	5

Table 48: Standard values for the tap water system related calculations according to Table 6 in [14].

Technology	$Q_{\mathbf{h,g}}$	$Q_{\mathbf{h,f,in}}$	$Q_{\mathbf{h,f,prod}}$	$Q_{\mathbf{h,f,out}}$
Solar collector system	0	0	$Q_{\mathrm{h,s,out}}$	0
Heat pump, electricity powered	0	$Q_{\mathrm{h,f.1}}$	$Q_{\mathrm{h,in}}$	0
Heat pump, heat powered	0	$Q_{\mathrm{h,f.1}}$	$Q_{\mathrm{h,in}}$	0
Boiler	$Q_{\mathrm{h,gen}}$	$Q_{\mathrm{h,out}} + Q_{\mathrm{h,gen}}$	0	0
Decentralized fuel heated systems	$Q_{\mathrm{h,f}} - Q_{\mathrm{h,b}}$	$Q_{\mathrm{h,f}}$	0	0
Decentralized heating systems for halls	$Q_{\mathrm{h,gen}}$	$Q_{\mathrm{h,out}} + Q_{\mathrm{h,gen}}$	0	0
Gas heat pump	$Q_{\mathrm{h,gen}}$	$Q_{\mathrm{h,f}}$	0	0
Electrically heated heat generation device	$Q_{\mathrm{h,f}} - Q_{\mathrm{h,out}}$	$Q_{\mathrm{h,f}}$	0	0
District heat supply	$Q_{\mathrm{h,gen}}$	$Q_{\mathrm{h,out}} + Q_{\mathrm{h,gen}}$	0	0

Table 49: Final energy amounts according to Table 5 in [11].

Technology	$Q_{\mathbf{w,g}}$	$Q_{\mathbf{w,f,in}}$	$Q_{\mathbf{w,f,prod}}$	$Q_{\mathbf{w,f,out}}$
Solar collector system	0	0	$Q_{\mathrm{w,s,out}}$	0
Heat pump, electricity powered	0	$Q_{\mathrm{w,f.1}}$	$Q_{\mathrm{w,in}}$	0
Heat pump, heat powered	0	$Q_{\mathrm{w,f.1}}$	$Q_{\mathrm{w,in}}$	0
Flow heaters, electric	$Q_{\mathrm{w,f}} - Q_{\mathrm{w,out}}$	$Q_{\mathrm{w,f}}$	0	0
Flow heaters, gas	$Q_{\mathrm{w,f}} - Q_{\mathrm{w,out}}$	$Q_{\mathrm{w,f}}$	0	0
Heat recovery through shower water	0	0	$Q_{\mathrm{w,DWHR}}$	0
Boiler	Eq (104) in [14]	$Q_{\mathrm{w,out}} + Q_{\mathrm{w,gen}}$	0	0
Gas heat pump	$Q_{\mathrm{w,f}} - Q_{\mathrm{w,out}}$	$Q_{\mathrm{w,f}}$	0	0
Electrically heated drinking water reservoirs	$Q_{\mathrm{w,f}} - Q_{\mathrm{w,out}}$	$Q_{\mathrm{w,f}}$	0	
Gas-fired drinking water reservoirs	Eq (130) in [14]	$Q_{\mathrm{w,out}} + Q_{\mathrm{w,gen}}$	0	0
District heat supply	Eq (133) in [14]	$Q_{\mathrm{w,out}} + Q_{\mathrm{w,gen}}$	0	0

Table 50: Final energy amounts according to Table 5 in [14].

Technology	$Q_{\mathbf{rv,g}}$	$Q_{\mathbf{rv,f,in}}$	$Q_{\mathbf{rv,f,prod}}$	$Q_{\mathbf{rv,f,out}}$
Heat pump, outgoing air and water	$Q_{\mathrm{rv,g,hp}}$	Eq (108) in [12]	Eq (149) in [12]	0
Heat pump, outgoing and supply air	$Q_{\mathrm{rv,g,hp}}$	Eq (108) in [12]	Eq (149) in [12]	0
Heat pump, outgoing and supply air and water	$Q_{\mathrm{rv,g,hp}}$	Eq (108) in [12]	Eq (149) in [12]	0
Heat transfer medium for outgoing and supply air	0	0	Eq (147) in [12]	0
Reheating radiators	$Q_{\mathrm{rv,g,re\text{-}h}}$	$Q_{\mathrm{rv,h,f,in,re\text{-}h}}$	0	0

Table 51: Final energy amounts according to Table 5 in [12].

Energy source		$f_{\mathbf{p,in}}$		$\chi_{\mathbf{CO_2}}$
		Total	**Non-sustainable part**	**Non-sustainable part**
Fossil fuels	Fuel oil	1.1	1.1	310
	Natural gas	1.1	1.1	240
	Liquid gas	1.1	1.1	270
	Black coal	1.1	1.1	400
	Brown coal	1.2	1.2	430
Biogen fuels	bio gas	1.4	0.4	120
	Bio-oil	1.4	0.4	190
	Wood	1.2	0.2	40
District heating	Cogeneration (fossil fuel)	0.7	0.7	*
	Cogeneration (sustainable fuel)	0.7	0	*
	Combined heat and power plant (CHP)	1.3	1.3	*
	General case	*	*	*
District cooling	General case	*	*	*
Electricity	General electricity mix	2.8	1.8	550

Table 52: Values for $f_{\mathrm{p,in}}$ and $\chi_{\mathrm{CO_2}}$ according to Table A.1 in [6]. A * indicates that standard value can not be specified. These values may be calculated individually.

Energy source		$f_{\mathrm{p,out}}$		$\chi_{\mathrm{CO_2}}$
		Total	**Non-sustainable part**	**Non-sustainable part**
Sustainable energy	Geothermal energy (heating)	1	0	0
	Geothermal energy (cooling)	1	0	0
	Photovoltaic (PV) and wind power (WP)	1	0	0
Dissipate waste heat	Several processes	1	0	40

Table 53: Values for $f_{\mathrm{p,prod}}$ and $\chi_{\mathrm{CO_2}}$ according to Table A.1 in [6].

Energy source		$f_{\mathrm{p,prod}}$		$\chi_{\mathrm{CO_2}}$
		Total	**Non-sustainable part**	**Non-sustainable part**
Electricity	Displacement electricity mix, CHP	2.8	2.8	860
	Displacement electricity mix, PV, WP	2.8	1.8	550
Thermal energy	Heat for other consumers	*	*	*
	Cold for other consumers	*	*	*
Dissipate waste heat	Several processes	1	0	40

Table 54: Values for $f_{\mathrm{p,out}}$ and $\chi_{\mathrm{CO_2}}$ according to Table A.1 in [6]. A * indicates that standard value cannot be specified. These values may be calculated individually.

Pitch in °	Deviation in °								
	-90	**-67.5**	**-45**	**-22.5**	**0**	**22.5**	**45**	**67.5**	**90**
0	0.66	0.66	0.66	0.66	0.660	0.660	0.66	0.66	0.66
15	0.66	0.713	0.753	0.786	8.1	0.798	0.773	0.733	0.68
25	0.653	0.736	0.806	0.858	0.89	0.876	0.834	0.771	0.693
30	0.65	0.748	0.833	0.894	0.930	0.915	0.865	0.79	0.7
40	0.643	0.761	0.863	0.939	0.977	0.955	0.902	0.81	0.7
45	0.64	0.768	0.878	0.961	1	0.975	0.92	0.82	0.7
50	0.633	0.763	0.879	0.968	1.007	0.984	0.923	0.818	0.693

Table 55: Values for f_{NGA} for solar system supporting tap water systems only, according to the corresponding Table in [16]. Deviation describes the deviation of the solar collector's orientation with respect to south.

Pitch in °	Deviation in °								
	-90	**-67.5**	**-45**	**-22.5**	**0**	**22.5**	**45**	**67.5**	**90**
0	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81
15	0.799	0.841	0.876	0.9	0.911	0.907	0.889	0.857	0.813
25	0.791	0.852	0.902	0.938	0.954	0.949	0,925	0.881	0.824
30	0.787	0.858	0.916	0.958	0.976	0.97	0,942	0.892	0.83
40	0.771	0.854	0.922	0.97	0.992	0.986	0.954	0.897	0.823
45	0.763	0.852	0.925	0.976	1	0.994	0.96	0.9	0.82
50	0.748	0.84	0.915	0.966	0.993	0.987	0.953	0.891	0.809

Table 56: Values for f_{NGA} for solar system supporting tap water systems only, according to the corresponding Table in [16]. Deviation describes the deviation of the solar collector's orientation with respect to south.

slr $^{\mathbf{m^2}}/_{\mathbf{kWh}}$	f_{slr}			
	$f_{\mathbf{K,w,a}} = 0.1$	$f_{\mathbf{K,w,a}} = 0.2$	$f_{\mathbf{K,w,a}} = 0.3$	$f_{\mathbf{K,w,a}} = 0.5$
0.00025	1.569	1.751	1.957	2.213
0.0005	1.312	1.466	1.634	1.852
0.00075	1.162	1.3	1.446	1.642
0.001	1.056	1.182	1.312	1.492
0.001 25	0.973	1.091	1.208	1.376
0.001 5	0.906	1.016	1.124	1.281
0.001 75	0.849	0.953	1.052	1.201
0.002	0.799	0.898	0.990	1.132
0.0025	0.717	0.807	0.886	1.016
0.003	0.649	0.732	0.801	0.921
0.0035	0.592	0.669	0.730	0.841
0.004	0.543	0.614	0.667	0.771
0.0045	0.499	0.566	0.613	0.710
0.005	0.460	0.522	0.564	0.655

Table 57: Values for f_{slr} according to Table (27) in [4].

$f_{\mathbf{h,HKT,A}}$						
$\theta_{\mathbf{h}}$	**slr**					
	0.00025	**0.00035**	**0.0006**	**0.001**	**0.004**	**0.006**
20	1.028	1.034	1.05	1.076	1.09	1.104
30	1.014	1.017	1.025	1.038	1.045	1.052
40	1	1	1	1	1	1
50	0.986	0.983	0.975	0.962	0.955	0.948
60	0.972	0.966	0.95	0.924	0.91	0.896
70	0.959	0.949	0.925	0.886	0.865	0.844
80	0.945	0.932	0.9	0.848	0.82	0.792

Table 58: Values for $f_{\mathrm{h,HKT,A}}$ according to Table 29 in [4]. θ_{h} represents the average temperature of the heating system.