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Modelling the Heat Demand of Buildings

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Contents

1 Introduction

A heating system functions optimally when it is correctly designed and dimensioned. It is then pleasantly warm during the winter and the system works energy-efficiently at the same time. Therefore, the heat load needs to be calculated to dimension the heating system of every building and to assess the heat transfer systems of every room.

This paper is about implementing the DIN EN 12831-1 standard for energetic evaluation, which calculates the building and individual room heat loads. It is a python implementation which is utilizing a JSON data structure for the building information as well as for the calculated results. The correctness and accuracy of the implementation is verified with 4 reference buildings and their calculations. Two Examples are verifications for the standard and the simplified calculation procedures and two are comparisons to the DIN V 18599 standard which has a similar calculation to the simplified calculation procedure of the DIN EN 12831-1 standard.

All calculations stem from the DIN 12831-1 standard, established software tools, and consultancies and the DIN V 18599 examples are from a quality association. The performance of the implementation is shown with a comparison to a competing manufacturer's product and by showing the profiling improvements, that could not be improved further.

Energy demand is steadily rising, while it is still largely generated by using fossil fuels. Energy prices steadily go up, as fossil fuels become scarce and renewable energy doesn't come cheap. The recent price explosion in fuel, gas and electricity prices shows how important it is to conserve energy and use it in the most efficient way possible.

The building heat load quantifies the amount of heat that a building loses because there is a temperature difference between it and its surroundings. The heat load corresponds to a heat loss which must be compensated for with the help of a heating system. It is the required heating power to reach the specified standard internal temperature under standard external conditions, with the internal temperature mostly around 20 ℃ and the external temperature being based on the coldest conditions in the local area.

These specified design conditions for the heat load calculation describe an extreme situation that is only achieved in the rarest of cases. As a result, the heating system that was dimensioned with the results of the heat load calculations is almost exclusively operated at partial load. The heat load is therefore not suitable for estimating the energy demand, but only for dimensioning heating systems.

After German law, heaters can only be operated for 30 years, and therefore they need to be replaced a minimum of two times in the lifespan of a building and therefore the heat load has to be reevaluated at least once. Starting in 2024, all heating systems that are installed have to be powered by at least 65% renewable energy. The rising fossil fuel costs also increase the demand to change heaters to renewable energies such as heat pumps. The heat load and the temperature delta can influence which heating types can be utilized, for example, an air heat pump cannot be used for a too-high heat load.

It is important to have an accurate model of the heat load which does not overestimate since a heater works most efficiently when it is properly dimensioned. If the heat load is overestimated the high cycle behaviour increases wear on the burner components and if it is underestimated there can be an undersupply of heat in the building. To prevent this, there is a standardized calculation of the heat load in DIN 12831-1 [2].

The standard heat load can be determined either for the dimensioning of the building heater or of the individual heating surfaces in each room. The boilers and heating surfaces are often oversized in existing buildings. In addition, even small changes to the building envelope affect the heat load. Even replacing the windows can have a significant impact. This makes it all the more important to determine the heat load in the course of a heating system modernization and renovation. For a new building, the heat load has to be determined in any case.

The external volume and the net area are also calculated. They are necessary to calculate the heat load by square meter and by volume. Therefore, the heat loss can be easily compared to other buildings and the rooms can be compared to each other. This is why the feasibility of a heating renovation can be assessed easier, depending on the heat load by square meter or the heat load per building component.

1.1 Related Works

Calculating the heat load is standardized according to the German DIN EN 12831-1 [2] Norm. The heat load calculation is obligatory according to German law and must be completed prior to each installation of a heat generator or a heat transfer system in any building.

Other standards like DIN V 18599 [3] calculate the maximum heat load on the design day with similar but different equations. The DIN V calculation is primarily meant for calculating the energy demand of a building. An example application of the DIN V 18599 standard was published by the 18599 Gütegemeinschaft which can issue the 18599 seal of approval.

The heat load calculation of the DIN EN 12831-1 [2] standard does not include drinking water heating in its heat load, which different standards from other countries might do for example. That is why the heat load might vary depending on which standard it is calculated by.

Creating a software solution for calculating the heat load is not a new idea. In Table 13, different established companies can be seen that offer various calculation services for the heat load that are calculated according to DIN EN 12831-1.

The company WBS offers a calculation service that has a base price per building and an additional price per room as can be seen in their work order [9]. There is a standardized calculation form by DIN in [4] which is similar to the work order used by WBS [9]. WBS takes up to 24 hours to complete the order. The other companies, that calculate the heat load according to DIN EN 12831 offer software products that are expensive for private use. The software EVEBI by the company ENVISYS (see Table 24) for example currently costs 860€ for the base version [5].

Instead of calculating the heat load, Kalogirou et al. [6] take the approach of training a neural network to predict the required heat load of buildings. Compared to the DIN approximations, this approach has the advantage of the simplicity of the input data and more accurate predictions with a lot of training data. However, compared to the DIN standard this has the downsides of a higher computational burden and of over fitting or of over generalisation. Neural networks also do not give consistent answers, as they inherently approximate. Consistent results are important to dimension a heater, especially when dealing with government regulations and considering that neural networks cannot guarantee their accuracy since they are a black box. Therefore, the approximations and averages by the DIN standard are preferred to a neural network.

Mohan, N. et al. [7] proposes a 3D building scan to avoid measuring everything manually and to calculate the heat load automatically. They create a point cloud out of a laser scan, which is then converted into a 3D building. But this method relies on very demanding post-processing works and the high costs associated with the scanning. That is why it would only be viable for professionals who deal with it regularly. In addition to that, the design measurements are enough to properly calculate the heat load, with only the heat transfer properties of the building needing to be determined or approximated.

1.2 Contribiution

The goal of this work is to discuss my implementation of a Model for the heat load of buildings according to the DIN EN 12831-1 [2] standard.

The correctness of the implementation is proven by the means of two example buildings from two competing software products. By comparing the calculation of the results of the implementation to the ones of the competing products, not only the implementation is proven correct, but it also shows that these calculations and therefore their products are correct as well.

By using the implementation, the heat load of buildings can be determined accurately, and therefore it can not only be used by heating installers but also by private individuals. Someone may want to calculate the heat load themselves because of the cost or because they are installing the heater by themselves, or to verify the calculation done by a heating installer.

The implementation is compared to the performance of another software, which is considerably slower and therefore the implementation has an advantage.

The encountered problems and the approach to implementing the standard is presented and the data structure is compared to the solutions of other implementations.

1.3 Outline

At the beginning of Section 2 the language is defined, which is required to understand the explanation of calculations as well as the validation of the implementation. After that, the different calculation procedures of the heat load from the DIN EN 12831-1 [2] standard are explained. The standard calculation method for every building type and predominantly new buildings is stated in Section 2.3. The calculation procedure for already built residential buildings is presented in Section 2.9. The implementation of the standard and the simple calculation are verified by comparing them to two examples from the companies Dendrit and WBS. After, there is a comparison to the DIN V 18599 [3] standard, which has a similar calculation to the simple calculation type of this standard. This is followed by a performance comparison with a competitor's program and it is shown what speed improvements could be achieved through profiling. In the end, the specifics of the implementation, as well as interesting topics and encountered problems, are presented.

2 Modelling the Heat Demand of Buildings

In this section, the calculation procedures to determine the heat load are explained according to the 2017 DIN/TS 12831-1 [2] standard and its corrections in 2020 [4]. In the following section, the definitions are explained, which are required to fully understand the language that will be used in the explanation of the standard.

2.1 Definitions

(Building) Component The building component is the internal or external component of the building structure and/or thermal envelope, with identical thermal conditions on each side of the component [2]. A wall between two rooms would be an example for such a component.

Component Borders The component borders the area, which is adjacent to the side of the component facing away from the considered room.

Component Abbreviations

Abbr.	Description
e	Outside air
g	Soil
a	Scheduled heated room of the same utility unit
ae	Unheated room/area or other building according to the building plan
abe	Other usage unit in the same building (e.g. neighbouring apartment)

Abbr.	Description
AW	Exterior wall
AF	Exterior window
AT	Exterior door
IW	Interior wall
IF	Interior window
IT	Interior door
DE	Ceiling
FB	Floor
DA	Roof
DF	Roof window
GÖ	Large opening

Table 1: On the left are abbreviations for the area, which the components border. The right Table shows abbreviations for components.

Heat Transfer Coefficient U (U-value) This value indicates how much heat escapes over one square meter of the building envelope at a temperature difference of one degree. The insulation properties of a building component can therefore be easily seen from this U-value $[W/m^2 \cdot K]$.

Air Exchange Rate n The air exchange rate $[h^{-1}]$ shows how often the room air volume is exchanged by natural or mechanical ventilation.

Standard Heat Load Φ_{build} The heat load $[W]$ is the heating power required to reach the specified standard indoor temperature under standard outdoor conditions [2].

Standard Temperatures $\theta_e, \theta_{int,i}$ The DIN standard specifies inside and outside temperatures [°C], which can be seen in Section 2.5.1, 2.5.2. The standard inside temperature has to be reached with a heating system under the standard outside temperature.

Standard Heat Loss The standard heat loss $[W]$ is the heat loss leaving the building to the external environment under specified standard conditions [2].

Standard Transmission Heat Loss $\Phi_{T,build}$ The transmission heat loss $[W]$ is the heat loss to the outside and between heated and other heated or unheated rooms in a building, due to heat conduction through the enclosing surfaces [2].

Standard Ventilation Heat Loss $\Phi_{V,build}$ The ventilation heat loss $[W]$ is the heat loss to the outside that is due to ventilation, infiltration through the building envelope and the heat transferred by ventilation from one heated to another heated or unheated room [2].

Building Abbreviations

Abbreviation	Description
EFH	single family home
MFH	multi-family house

Table 2: These are the abbreviations used in the building examples.

Zone (ventilation zone) A zone is a group of rooms which, according to their design, have a direct or indirect (through other intermediate rooms) air connection [2]. E.g. a house or a floor of an apartment building.

2.2 Description of the Calculation Procedures

All the calculation procedures described in the following adhere to the 2017 DIN/TS 12831-1 [2] standard and its corrections in 2020 [4]. There is one standard procedure and two simplified procedures that are defined in the standard. The simplified procedures are limited to specific applications and boundary conditions, while the standard procedure is a general method [2]. In Table 3 the applications and limitations of each calculation procedure is described.

The calculation type has to be specified for each building, as shown in Table 1 since you cannot tell the calculation type apart based on the JSON data structure alone. The calculation types are sorted from the most generally appliable and accurate to the least appliable and accurate. The less accurate the types are, the less input information they need. In addition to that, they also enable estimating unknown inputs, which may be hard or inconvenient to get or find.

#	Procedures	Application	Limitations regarding the Application

2	Standard procedure	- generally applicable approach for any heat load considerations
		- typical for assessment of heating systems in case of:
		  - new buildings
		  - extensive reconstruction measures
			-

1	Standard procedure with a more simplified ventilation heat loss	- applicable in impermeable buildings, neither with fan-assisted ventilation nor external wall air vents.	- low air exchange rate at a pressure difference of 50 Pa - no air flow through outdoor wall vents - no supply/exhaust airflow, technical air volume flow, air volume flow through large openings, etc.

0	Simplified procedure	- applicable before measures relating to heat generation, e.g.:
		  - replacement of the heat generator
		- applicable before measures related to the heat transfer system in individual rooms, e.g.:
		  - replacement of the heat dissipation system (e.g. radiators)
		  - hydraulic balancing
			only applicable in:
			- residential buildings or buildings with comparable use
			- existing buildings
			- buildings with free ventilation, which means no air vents

Table 3: These are all the different calculation methods, based on [2, Sec. 5, p. 19].

2.3 Standard Calculation: Buildings and Rooms

It is a general approach, which can be applied to every consideration of heat load. It is typically used when the building is new or when there are extensive reconstruction measures. The standard heat load for a building is calculated from the total transmission heat loss to the outside (direct and indirect), the total ventilation heat loss of the building and, if necessary, the additional total heating power. The heat load is calculated with equation (1) [2, Eq. (1)] using $\Phi_{gain} = 0$, which is specified in [4]:

$$\Phi_{HL,build} = \sum_{i} \langle \Phi_{T,ie} + \Phi_{T,iae} + \Phi_{T,ig} \rangle + \Phi_{V,build} + \sum_{i} \langle \Phi_{hu,i} \rangle \tag{1}$$

where:

$\Phi_{HL,build}$	is the design heat load of the building,	W
$\sum_{i} \langle \Phi_{T,ie} + \Phi_{T,iae} + \Phi_{T,ig} \rangle$	is the sum of the direct or indirect transmission heat losses to the outside for all contained heated rooms (i),	W
$\Phi_{V,build}$	is the ventilation heat loss of the entire building,	W
$\sum_{i} \langle \Phi_{hu,i} \rangle$	is the sum of the heat-up powers that occur simultaneously under standard outdoor conditions; This is optional,	W

2.4 Transmission Heat Loss of a Room $\Phi_{T,i}$

In the standard method (Table 3), the transmission heat loss is generally calculated based on transmission heat transfer coefficients and the temperature differences that causes the heat loss. The standard heat loss coefficients are temperature-adjusted by multiplying with the difference between the standard internal temperature and the standard external temperature, as shown in equation (2) for a room i. The room transmission heat loss is calculated with equation (2) [2, Eq. (4)] and the partial transmission heat loss with equation (3) [2, Eq. (5)]:

$$\Phi_{T,i} = (H_{T,ie} + H_{T,ia} + H_{T,iae} + H_{T,iaBE} + H_{T,ig}) \cdot (\theta_{int,i} - \theta_e) \tag{2}$$

$$\Phi_{T,ix} = H_{T,ix}(\theta_{int,i} - \theta_e) \tag{3}$$

where:

x	adjacent area (e, a, ae, aBE, g)	-
$H_{T,ix}$	is the transmission heat transfer coefficient of the heated space (e, a, ae, aBE, g) $\rightarrow H_{T,i(e,a,ae,aBE,g)}$,	W/K
$\theta_{int,i}$	is the standard internal temperature, see in Table 4,	℃
θ_e	is the standard outdoor temperature, see Section 2.5.1,	℃

2.4.1 Heat Transfer Coefficients H

The heat transfer coefficient describes the ability of a gas or liquid to dissipate energy from or to the surface of a substance. The heat transfer coefficient to the outside (e) is calculated with equation (4) [2, Eq. (6)]:

$$H_{T,ie} = \sum_k \langle A_k \cdot (U_k + \Delta U_{TB}) \cdot f_{U,k} \cdot f_{ie,k} \rangle \tag{4}$$

The heat transfer coefficient to adjacent rooms (a, ae, abe) is calculated with equation (5) [2, Eq. (7)]:

$$H_{T,ia}(\dots) = \sum_k \langle A_k \cdot U_k \cdot f_{ia,k} \rangle \tag{5}$$

The heat transfer coefficient to the ground (g) is calculated with equation (6) [2, Eq. (8)]:

$$H_{T,ig} = f_{\theta ann} \cdot \sum_k \langle A_k \cdot U_{\text{equiv},\,k} \cdot f_{ig,k} \cdot f_{GW,k} \rangle \tag{6}$$

where:

A_k	is the area of the component (k),	m^2
U	is the heat transfer coefficient of the component (k),	$W/(m^2 \cdot K)$
ΔU_{TB}	is the flat-rate additional heat output for thermal bridges,	$W/(m^2 \cdot K)$
f	is the temperature adjustment factor,	$-$

2.5 Standard Temperatures

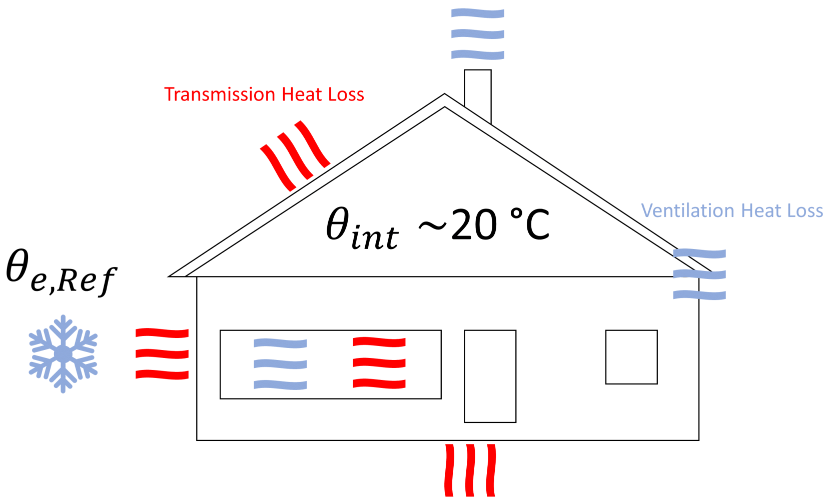

Figure 1: This is the simplified representation of the heat load calculation.

The heat load is the required heating power to reach the standard internal temperature under standard external conditions, which is illustrated by Figure 1. The heat load corresponds to a heat loss which must be compensated for with the help of a heating system. The building heat loss is then divided into the heat loss due to heat conduction (transmission), due to ventilation & infiltration of air (ventilation) and into the additional heat-up power.

2.5.1 Standard Outside Temperature θ_e

The standard outside temperature θ_e is the sum of the standard outdoor temperature of the building location $\theta_{e,0}$ and the temperature correction $\Delta\theta_{e,\tau}$ to account for the time constant of the building. The standard outdoor temperature for the intended reference location is the lowest temperature of a cold period, which must have been maintained for at least two consecutive days 10 times within 20 years. The standard outside temperature is calculated with equation (7) [2, Eq. (45), (46), (47)]:

$$\theta_e = \theta_{e,0} + \Delta\theta_{e,\tau} = \theta_{e,Ref} + G_{\theta,Ref} \cdot (h_{build} - h_{Ref}) + max\langle min\langle 0,016 \cdot \tau - 0,8; 4\rangle; 0\rangle \quad (7)$$

where:

h_{Build}	is the mean height of the building under consideration above sea level,	m
h_{Ref}	is the average height of the considered building location above sea level,	m
$\theta_{e,Ref}$	is the standard outdoor temperature for the intended reference location,	°C
$G_{\theta,Ref}$	is the temperature gradient for the intended reference location,	K/m
τ	is the building time constant, see Section 2.8.1,	h
h_{Ref} and $\theta_{e,Ref}$	can either be entered directly or looked up automatically from the climate data of Germany if a postcode is given,	m

2.5.2 Standard Indoor Temperatures $\theta^*_{int,(i,k)}, \theta_{int,i}$

The average indoor air temperature $\theta^*_{int,i}$ of the considered room (i) is calculated with equation (8) [2, Eq. (49)]:

$$\theta^*_{int,i} = \theta_{int,i} + G_{\theta,air,i} \cdot (\frac{h_i}{2} - 1) - \Delta\theta_{rad} \quad (8)$$

The average temperature $\theta^*_{int,k}$ of the inner surface of a component (k) is calculated with equation (9) [2, Eq. (48)]:

$$\theta^*_{int,k} = \theta_{int,i} + G_{\theta,air,i} \cdot (h_k - 1) + \Delta\theta_{surf,k} \quad (9)$$

where:

$\theta_{int,i}$ is the standard internal temperature of the space (i) (see Table 4) ℃

h_i is the mean room height of the considered room (i), m

h_k is the average height of the considered component (k) above the floor, m

Parameters of the heat transfer system (see Table 5):

$G_{\theta,air,i}$ is the air temperature gradient of the heat transfer system used in the room (i), K/m

$\Delta\theta_{surf,k}$ is the correction term to account for the difference between air and surface temperatures, K

$\Delta\theta_{rad}$ is the correction term to account for the difference between air and operating temperatures, K

<table>
<tr><th>Category</th><th colspan="2">Type of building/room</th><th>θ_{int} ℃</th></tr>
<tr><td>1</td><td colspan="2">Living rooms & bedrooms</td><td>20</td></tr>
<tr><td>2</td><td colspan="2">Office and meeting rooms, exhibition rooms, hallways and stairs within the utilization unit, counter halls</td><td>20</td></tr>
<tr><td>3</td><td colspan="2">Hotel room</td><td>20</td></tr>
<tr><td>4</td><td colspan="2">Salesrooms, retail stores</td><td>20</td></tr>
<tr><td>5</td><td colspan="2">Teaching rooms</td><td>20</td></tr>
<tr><td>6</td><td colspan="2">Theater and concert halls</td><td>20</td></tr>
<tr><td>7</td><td colspan="2">WC</td><td>20</td></tr>
<tr><td>8</td><td colspan="2">Bathrooms, showers, changing rooms (Rooms, which are used undressed)</td><td>24</td></tr>
<tr><td>9</td><td colspan="2">Heated ancillary rooms outside of utilization unit (e.g. hallways and stairs).</td><td>15</td></tr>
<tr><td>10</td><td rowspan="3">Commercial /industrial rooms with</td><td>heavy activity, mostly standing</td><td>15</td></tr>
<tr><td>11</td><td>moderate activity, mostly standing</td><td>17</td></tr>
<tr><td>12</td><td>with light activity, mostly sitting (office)</td><td>20</td></tr>
</table>

Table 4: The standard indoor temperature can be acquired by building/room type, based on [4, p. 58].

#	1	2	3	4
	Heat transfer system	Air-temperature gradient	Difference between air temperature and operative temperature	Correction term for the influence of the heat transfer system on surface temperatures
		$G_{\theta air,i}$ [K/m]	$\Delta\theta_{rad}$ [K]	$\Delta\theta_{surf}$[K]
1	Air heating without additional warm air recirculation(e.g. ceiling fans)/radiators	1	0	0
2	Air heating with additional warm air recirculation(e.g. ceiling fans)	0.35	0	0
3	Ceiling radiant panels	0.35	1.5	0
4	Dark/light radiator	0.2	1.5	0
5	Component-integrated surface heating	0.2	1.5	1.5

Table 5: The parameters of heat transfer systems in high rooms, based on [4, p. 22].

2.6 Simplified Ventilation Heat Loss $\Phi_{V,build}, \Phi_{V,z}, \Phi_{V,i}$

The following simplified approach to calculating ventilation heat losses was derived from the general calculation model explained in the next Section by restricting the input parameters:

- Low air exchange rate at a pressure difference of 50 Pa
- No air volume flow through outdoor wall diffusers
- No supply/exhaust air flow rate, technical air flow rate, air flow rate through large openings, etc.

Therefore, the simplified approach is only suitable for relatively air-impermeable buildings with neither fan-assisted nor outside wall air diffusers (e.g., residential buildings without fan-assisted ventilation). The building ventilation heat loss $\Phi_{V,build}$, the zone (z) ventilation heat loss $\Phi_{V,z}$ and the room ventilation heat loss $\Phi_{V,i}$ is calculated with equations (10), (11), (12) [2, Eq. (12), (13), (14)] respectively:

$$\Phi_{V,build} = \sum_{z} \langle \Phi_{V,z} \rangle \tag{10}$$

$$\Phi_{V,z} = \rho \cdot c_p \cdot \sum_{i} \langle f_{i-z} \cdot q_{v,min,i} \cdot (\theta_{int,i} - \theta_e) \rangle \tag{11}$$

$$\Phi_{V,i} = \rho \cdot c_p \cdot q_{v,min,i} \cdot (\theta_{int,i} - \theta_e) \tag{12}$$

where:

ρ	is the density of air at the standard internal temperature $\theta_{int,i}$,	kg/m^3
c_p	is the specific heat capacity of air at $\theta_{int,i}$,	$Wh/(kg \cdot K)$
f_{i-z}	is the ratio between the minimum value of the air flow rate of a single room (i),	$-$
$q_{v,min,i}$	is the minimum air flow rate of the room (i),	m^3/h

2.7 General Ventilation Heat Loss $\Phi_{V,build}, \Phi_{V,z}, \Phi_{V,i}$

The building ventilation heat loss $\Phi_{V,build}$, the zone ventilation heat loss $\Phi_{V,z}$ and the room ventilation heat loss $\Phi_{V,i}$ is calculated with equations (13), (14),(15) [2, Eq. (15), (16), (17)] respectively:

$$\Phi_{V,build} = \sum_z \langle \Phi_{V,z} \rangle \tag{13}$$

$$\Phi_{V,z} = \rho \cdot c_p \cdot \sum_i \left(\begin{array}{c} \max \langle q_{v,leak+ATD,i} + q_{v,open,i}; f_{i-z} \cdot q_{v,min,i} - q_{v,techn,i} \rangle \cdot \left(\theta^*_{int,i} - \theta_e\right) \\ +q_{v,sup,i} \cdot \left(\theta^*_{int,i} - \theta_{rec,z}\right) \\ +q_{v,tanseferij} \cdot \left(\theta^*_{int,i} - \theta_{transfer,ij}\right) \end{array} \right) \tag{14}$$

$$\Phi_{V,i} = \rho \cdot c_p \cdot \sum_i \left(\begin{array}{c} \max \langle q_{v,env,i} + q_{v,open,i}; q_{v,min,i} - q_{v,techn,i} \rangle \cdot \left(\theta^*_{int,i} - \theta_e\right) \\ +q_{v,sup,i} \cdot \left(\theta^*_{int,i} - \theta_{rec,z}\right) \\ +q_{v,tanseferij} \cdot \left(\theta^*_{int,i} - \theta_{transfer,ij}\right) \end{array} \right) \tag{15}$$

$$\Phi_{V,build} = \sum_i \Phi_{V,leak/min,i} + \sum_i \Phi_{V,sup,i} + \sum_i \Phi_{V,transfer,ij} \tag{16}$$

where:

ρ	is the density of air at the standard internal temperature $\theta_{int,i}$,	kg/m^3
c_p	is the specific heat capacity of air at the standard internal temperature $\theta_{int,i}$,	$Wh/(kg \cdot K)$
f_{i-z}	is the ratio between the minimum value of the airflow rate of a single room (i), and the resulting air flow rate of the zone (z),	$-$
$q_{v,leak+ATD,i}$	is the outdoor air flow rate into the room (i) through leakage and outdoor diffusers,	m^3/h
$q_{v,open,i}$	is the outdoor air volume flow through large openings in the building envelope for room (i),	m^3/h
$q_{v,min,i}$	is the minimum air flow rate of the room (i),	m^3/h
$q_{v,techn,i}$	is the technical air flow rate of the room (i),	m^3/h
$q_{v,sup,i}$	is the supply air flow rate of the room (i),	m^3/h
$q_{v,transfer,ij}$	is the overflow air volume flow into the room (i) from a neighbouring room (j),	m^3/h
$q_{v,env,i}$	is the outdoor air volume flow into the room (i) through the building envelope,	m^3/h
$\theta^*_{int,i}$	is the indoor air temperature of the considered space (i),	°C
θ_e	is the standard outdoor temperature,	°C
$\theta_{rec,z}$	is the temperature of the supply airflow into the zone (z) after passing through the heat recovery system and, if present, passive preheating; without active preheating,	°C
$\theta_{transfer,ij}$	is the temperature of the overflow air volume flow $q_{v,transfer,ij}$ from an adjacent space (j) into space (i),	°C

2.8 Additional Heat-up Power $\Phi_{hu,i}$

Rooms with intermittent heating may require additional heat-up power to reach the required standard indoor temperature within an acceptable heat-up period after a period of temperature drop.

The additional heating power is primarily to be taken into account when calculating the heat load for individual rooms (dimensioning of the heat transfer system). The extent to which this additional power is to be taken into account when dimensioning a (central) heat generator must be estimated. Additional heating power for the heat generation system is usually only required for heating systems in detached and semi-detached houses, single apartments/floors and similar configurations. The additional heat-up power is calculated with equation (17) [2, Eq. 39]:

$$\Phi_{hui} = A_i \cdot \phi_{hu,i} \tag{17}$$

where:

A_i	is the floor area of the room (i),	m^2
$\phi_{hu,i}$	is the specific heating power,	W/m^2

Two methods for determining the heat output for a single room are described below:

- based on non-use period Fig. 2;
- based on the temperature drop Fig. 3.

Duration of non-use $t_{du,i}$ **[h]**	**8** **Night reduction in residential buildings** **two-shift operation**				**14** **Night reduction in offices** **single-shift operation**				**62** **weekend reduction**			
Air exchange rate during lowering[a] $n_{sb,i}$ **[h^{-1}]**	**0.1**		**0.5**		**0.1**		**0.5**		**0.1**		**0.5**	
Heat storage capacity[b]	**g**	**h**	**g**	**h**	**g**	**h**	**g**	**h**	**g**	**h**	**g**	**h**
Heat-up time $t_{hu,i}$ [h]	**specific additional heating** $\Phi_{hu,i}$[W/m^2]											
0.5	63	16	74	26	88	38	91	56	92	> 100	92	> 100
1	34	10	43	16	50	29	50	43	55	100	55	> 100
2	14	3	21	8	28	18	28	29	32	86	32	> 100
3	5	0	10	2	17	12	18	21	23	73	22	94
4	0	0	3	0	11	7	12	15	17	64	17	84
6	0	0	0	0	3	1	5	5	10	52	10	70
12	0	0	0	0	0	0	0	0	2	31	2	45

Figure 2: This is the specific additional heating power for periods of non-use, based on [2, p. 93].

	1	2				3				4				5				6			
	Temperature drop $\Delta\theta_{sb,I}$ [K]	1				2				3				4				5			
	Air exchange during the temperature drop[a] $n_{sb,i}$ [h^{-1}]	0.1		0.5		0.1		0.5		0.1		0.5		0.1		0.5		0.1		0.5	
	Heat storage capacity[b] **heat-up time**	*g*	*m*	*g*	*m*	*g*	*m*	*g*	*m*	*g*	*m*	*g*	*m*	*g*	*m*	*g*	*m*	*g*	*m*	*g*	*m*
	$t_{hu,i}$ [h]	**specific additional heating** $\Phi_{hu,i}$ [W/m²]																			
1	0.5	12	12	14	18	27	28	29	35	39	44	44	53	50	60	58	69	–	–	–	–
2	1	8	8	10	14	18	21	21	28	26	34	32	43	33	48	41	56	–	–	–	–
3	2	5	5	7	11	10	15	13	22	15	25	21	33	20	35	28	43	43	85	47	94
4	3	3	3	5	10	7	12	10	19	9	20	15	27	14	29	21	37	33	75	37	84
5	4	2	2	4	9	5	10	8	17	7	18	13	25	10	26	17	34	28	72	31	76

[a] With closed windows and doors, an air exchange rate of n = 0.1 h^{-1} can be assumed within the scope of this approximation method.

[b] Categories are according to heat storage capacity Table (g ≙ low; m ≙ medium/high)

Figure 3: This is the specific additional heating power depending on the temperature drops, based on [4, p. 47].

If the drop in internal temperature is unknown, the heat-up capacity can be estimated on the following conditions:

- high standard of thermal insulation;
- low room height (average room height $\leq$ 3.5 m);

The temperature drop at the end of the cooling phase is calculated with equation (18) [4, Eq. (35)]:

$$\Delta\theta_{sb,i} = min\langle(\theta_{int,i} - \theta_{e,sb}) \cdot (1 - e^{-\frac{t_{sb,i}}{\tau}}; \theta_{int,i} - \theta_{support})\rangle \tag{18}$$

where:

$\theta_{int,i}$	is the standard indoor temperature, see Table 4,	℃
$\theta_{e,sb}$	is the standard outside temperature during the reduction period. If unknown it can be simplified to the standard outside temperature ($\theta_{e,sb} = \theta_e$),	℃
$t_{sb,i}$	is the lowering period,	h
$\theta_{support}$	is the support temperature, which is ensured by the control system,	℃
τ	is the time constant of the building,	h

2.8.1 Time Constant of the Building τ

The building time constant is the ratio of the heat storage capacity to the heat transfer coefficient, which means that it is the thermal inertia of a building. The time constant and the total heat storage capacity is calculated with equations (19), (20) [2, Eq. (40), (41)] respectively:

$$\tau = \frac{C_{eff}}{H} \tag{19}$$

$$C_{eff} = c_{eff} \cdot V_e \tag{20}$$

where:

τ	is the time constant of the building	h
C_{eff}	is the total heat storage capacity of the building	Wh/K
c_{eff}	is the effective volume-specific heat storage capacity, it is given or see Fig. 6	$Wh/(m^3 \cdot K)$
H	is the total heat transfer coefficient of the building	W/K
V_e	is the external volume of the building	m^3

Category	Description/Indications	c_{eff} $Wh/(m^3 \cdot K)$
small (g)	High interior to exterior volume ratio, high rooms, thin wall constructions; e.g.: - industrial halls - warehouses - sports halls - markets Predominantly lightweight construction, such as: - lightweight roofs - lightweight walls (timber frame construction, sandwich insulation panels on a steel skeleton, etc.) - suspended ceilings and/or raised floors	15
medium/high (m)	Small interior to exterior volume ratio, low room heights, thick walls/high proportion of walls in gross floor area; predominantly multi-storey construction Predominantly solid construction, such as: - concrete floors/roofs; - concrete/sandstone/brick walls.	50

Table 6: This is the volume-specific heat storage capacity, based on [4, p. 24].

2.8.2 Estimated Heat Transfer Coefficient H_{12}

The approximate transmission heat transfer coefficient without temperature adjustments is only for determining the time constant τ of the building. It is calculated with equation (21) [2, Eq. (42)]:

$$H_{12} = H_{T,12} + H_{V,12} \tag{21}$$

The transmission heat transfer coefficient between rooms (1) and (2) $H_{T,12}$ is calculated with equation (22) [4, Eq. (7)]:

$$H_{T,12} = \sum_k \langle A_k \cdot U_{eff,k} \cdot f_x \rangle \tag{22}$$

The ventilation heat transfer coefficient between rooms (1) and (2) $H_{V,12}$ is calculated with equation (23) [2, Eq. (44)]:

$$H_{V,12} = q_{V,12} \cdot \rho \cdot c_p \tag{23}$$

The air volume flow between rooms (1) and (2) is calculated with equation (24) [4, Eq. (8)]:

$$q_{V,12} = \sum_z \sum_i \langle max\langle q_{v,leak+ATD,i}; f_{i-z} \cdot q_{v,min,i} - q_{v,techn,i} \rangle + q_{v,sup,i} \rangle \tag{24}$$

where:

A_k	is the area of the component (k),	m^2
$U_{eff,k}$	is the effective heat transfer coefficient of the building component k,	$W/(m^2 \cdot K)$
f_x	is the temperature adjustment factor,	-
ρ	is the density of air at the standard internal temperature $\theta_{int,i}$,	kg/m^3
c_p	is the specific heat capacity of air at $\theta_{int,i}$,	$Wh/(kg \cdot K)$

For the definitions of the parameters of the air volume flow ($q_{V,12}$), see Section 2.7.

2.9 Simplified Calculation: Buildings

The simplified procedure can only be used if the building is an already built residential building or has comparable use and has free ventilation. In the simplified procedure, the additional heating capacity is not taken into account.
The standard heat loss of the building $\Phi_{HL,build}$ is calculated by the transmission heat losses, which are heat losses over components of the building envelope and ventilation heat losses, which are leaks and hygienic-related minimum air exchange. It is calculated with equation (25) [2, Eq. (54)]:

$$\Phi_{HL,build} = \Phi_{T,build} + \Phi_{V,build} \tag{25}$$

where:

$\Phi_{T,build}$	is the standard transmission heat loss of the building,	W
$\Phi_{V,build}$	is the standard ventilation heat loss of the building,	W

2.9.1 Transmission Heat Loss of the Building $\Phi_{T,build}$

Only the external surfaces of the thermal envelope of the building need to be considered in the simple calculation procedure.
Therefore, only components (k) adjacent to:

- outdoor air (e),
- unheated rooms (ae) and
- the soil (g)

must be considered. The transmission heat loss of the building is calculated with equation (26) [2, Eq. (55)]:

$$\Phi_{T,build} = \sum_k \Phi_{T,k} = \sum_k \langle A_k \cdot (U_k + \Delta U_{TB}) \cdot f_{x,k} \rangle \cdot (\theta_{int,build} - \theta_e) \tag{26}$$

where:

$\Phi_{T,k}$	is the transmission heat loss of the component (k),	W
A_k	is the area of the component (k),	m^2
U_k	is the heat transfer coefficient of the component (k),	$W/(m^2 \cdot K)$
ΔU_{TB}	is the thermal bridge surcharge,	$W/(m^2 \cdot K)$
$f_{x,k}$	is the temperature adjustment factor,	$-$
$\theta_{int,build}$	is the standard indoor temperature of the heated building, see Table 4,	℃
θ_e	is the standard outside temperature,	℃

2.9.2 Ventilation Heat Loss of a Building $\Phi_{V,build}$

The ventilation heat loss of the building is due to leakage, outdoor air diffusers and hygienically necessary minimum outdoor air exchange and is calculated with equation (27) [2, Eq. (56)]:

$$\Phi_{V,build} = V_{build} \cdot n_{build} \cdot \rho_L \cdot c_{p,L} \cdot (\theta_{int,build} - \theta_e) \tag{27}$$

where:

V_{Build}	is the internal air volume of the building,	m^3
n_{Build}	is the air exchange rate of the building,	h^{-1}
$\rho_L \cdot c_{p,L} = 0.34$	is the material constant of the air, simplified to 0.34,	$Wh/(m^3 \cdot K)$

2.10 Simplified Calculation: Rooms

the standard heat loss of a heated room (i) $\Phi_{HL,i}$ is calculated with equation (28) [2, Eq. (50)]:

$$\Phi_{HL,i} = \Phi_{T,i} + \Phi_{V,i} + \Phi_{hu,i} \tag{28}$$

where:

$\Phi_{T,i}$	is the standard transmission heat loss of the heated space (i),	W
$\Phi_{V,i}$	is the standard ventilation heat loss of the heated space (i),	W
$\Phi_{hu,i}$	is the additional heat-up power, see Section 2.8,	W

2.10.1 Transmission Heat Loss of a Heated Room $\Phi_{T,i}$

With this simplified approach, only the enveloping surfaces of the room (i) under consideration must be taken into account for which there is a temperature difference > 4 K between the room (i) and the adjacent area. The room transmission heat loss is calculated with equation (29) [2, Eq. (51)]:

$$\Phi_{T,i} = \sum_k \Phi_{T,k} = \sum_k \langle A_k \cdot (U_k + \Delta U_{TB}) \cdot f_{x,k} \rangle \cdot (\theta_{int,i} - \theta_e) \tag{29}$$

See building transmission heat loss (Sec. 2.9.1) for the definitions.

2.10.2 Ventilation Heat Loss of a Heated Room $\Phi_{V,i}$

The ventilation heat loss of a heated room is calculated with equation (30) [2, Eq. (53)]:

$$\Phi_{V,i} = V_i \cdot n_i \cdot p_L \cdot c_{p,L} \cdot (\theta_{int,i} - \theta_e) \tag{30}$$

where:

V_i	is the internal room volume	m^2
n_i	is the room exchange rate, if unknown $n_i = 0.5$	h^{-1}
$\rho_L \cdot c_{p,L} = 0.34$	is the material constant of the air, simplified to 0.34	$Wh/(m^3 \cdot K)$

2.11 Approximations and Inputs in the Simple Calculation

These Approximations can be made in the simple calculation type, if the accurate value of the inputs is unknown, or if it is less complicated and therefore practical.

2.11.1 Thermal Bridge Surcharge ΔU_{TB}

ΔU_{TB} can be simplified to $0.1W/(m^3 \cdot K)$ in the simple calculation type [2, Sec. B.3.2] otherwise, like in the standard method, the Table 7 can be applied by looking up the insulation characteristics of the building.

2.11.2 Standard Indoor Temperature $\theta_{int,(build,i)}$

The indoor building and room temperatures in all calculation types are selected by building/room type from Table 4.

#	**Selection criteria**	**Additional heat transfer coefficient** ΔU_{TB} $W/(m^2 \cdot K))$
1	New buildings; high degree of thermal insulation and minimization of thermal bridges, which exceeds the requirements of the generally accepted rules of technology	0.02
2	New buildings that meet the generally accepted technical rules regarding the minimization of thermal bridges	0.05
3	Buildings with mainly internal thermal insulation damaged by solid ceilings (e.g. reinforced concrete)	0.15
4	All other buildings	0.1

Table 7: The additional heat transfer coefficient can be acquired by building type, based on [2, Sec. B.2.1, p. 68].

2.11.3 Standard Outside Temperature θ_e

The standard outside temperature in the simple calculation type is simplified to the standard outdoor temperature for the intended reference location $\theta_{e,Ref}$, which can be entered or looked up automatically if a postcode is given. The calculation for the standard calculation type can be seen in Section 2.5.1.

2.11.4 Temperature Adjustment Factor $f_{x,k}$

The temperature adjustment factor can either be estimated by the adjacent area, see Table 8 or by the unheated adjacent area. f_1 from Figure 6.

Component is adjacent to	**Temperature adjustment factor** f_x	**Index**
Outside air (e)	1.0	e
Unheated room or other usage unit (u)	0.5	ae
Soil (g)	0.3	g
Heated room (j)	0.3	a

Table 8: The temperature adjustment factor f_x can be acquired by adjacent area [4, Sec. 5.4, p. 53].

2.11.5 Air exchange rate n_{Build}

Measure the exchange rate or approximate it by construction year or air tightness with Table 9.

Degree of airtightness		**Air exchange rate** n $[h^{-1}]$
Room heat load		0.5
$n_{50} \leq 3h^{-1}$	- Construction year $\geq$ 1995 - Buildings with airtight windows	0.25
$3h^{-1} < n_{50} \leq 6h^{-1}$	- Construction year 1977-1994 - Medium airtightness	0.5
$n_{50} > 6h^{-1}$	- Construction year < 1977 - Buildings with obvious leaks	1

Table 9: The air exchange rate can be acquired by construction year or air tightness, based on [4, p. 53].

2.11.6 Component Area A_k

In this standard, wall surfaces used to calculate transmission heat losses are based on external dimensions. If only the inner dimensions of the outer walls are known, the outer surfaces are to be determined according to equation (31) [2, Eq. (52)]:

$$A_k = f_{int-ext} \cdot A_{k,inner} \tag{31}$$

where:

A_k	is the area of the outer wall (k), external dimensions,	m^2
$f_{int-ext}$	is the ratio between interior and exterior surface,	$-$
$A_{k,inner}$	is the area of the outer wall (k), internal dimensions,	m^2

	Component	$f_{int-ext}$
1	Vertical Exterior Walls	1.25
2	Roofs	1
3	Top floor ceilings	1
4	Floors/ceilings against unheated areas (e.g. basement ceiling)	1
5	Floor against soil	1

Table 10: This is the ratio between exterior and interior surfaces depending on the component, based on [4, p. 48].

2.11.7 Heat Transfer Coefficient U_k

Measuring the U-value directly or knowing it from the manufacturer is the most accurate. The opaque components that can be seen in Table 11 can be estimated by temperature measurements. It is only valid for opaque components between a heated room and the outside air, where the difference between indoor and outdoor air temperature is $\geq$ 10 ℃ and the uncertainty of measurement is not exceeding $\pm$ 0.1 ℃.

Therefore, the U-value can be determined by equation (32) [4, Eq. (45)]:

$$U = \frac{1}{R_{si}} \cdot \frac{(\theta_{meas,int} - \theta_{meas,si})}{(\theta_{meas,int} - \theta_{meas,e})} \tag{32}$$

where:

$\theta_{meas,int}$	the measured value of the indoor air temperature,	℃
$\theta_{meas,si}$	the measured value of the indoor surface temperature,	℃
$\theta_{meas,e}$	the measured value of the outdoor air temperature,	℃

Component	**Internal heat transfer resistance** $R_{si}(m^2K)/W$
Vertical walls	0.13
Ceilings between heated rooms	0.17
Ceilings/floors to unheated rooms	0.11

Table 11: The heat transfer resistance can be acquired by the component type, based on [4, p.64].

Otherwise, there is a simplified determination of the U-value by component type in Figure 4/5.

If there was subsequent thermal insulation, Table 12 can be applied to the old U-value to find the current U-value.

	1	2	3	4	5	6	7	8	9
	U-value before insulation $W/(m^2 \cdot K)$	**U-value after insulation** $W/(m^2 \cdot K)$							
		Thickness of the subsequently applied thermal insulation cm							
		2	5	8	12	16	20	30	40
1	$U > 2.5$	1.20	0.63	0.53	0.30	0.23	0.19	0.13	0.10
2	$2.0 < U \leq 2.5$	1.11	0.61	0.42	0.29	0.23	0.19	0.13	0.10
3	$1.5 < U \leq 2.0$	1.00	0.57	0.40	0.29	0.22	0.18	0.13	0.10
4	$1.0 < U \leq 1.5$	0.86	0.52	0.38	0.27	0.21	0.18	0.12	0.09
5	$0.7 < U \leq 1.0$	0.67	0.44	0.33	0.25	0.20	0.17	0.12	0.09
6	$0.5 < U \leq 0.7$	0.52	0.37	0.29	0.23	0.18	0.16	0.11	0.09
7	$U \leq 0.5$	0.40	0.31	0.25	0.20	0.17	0.14	0.11	0.08

Table 12: These are the U-values after subsequent thermal insulation, based on [4, p. 62].

<table>
<tr><th rowspan="4"></th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th></tr>
<tr><th colspan="3" rowspan="3">Component</th><th colspan="8">u-Values
W/(m²· K)</th></tr>
<tr><th colspan="8">Year of construction (related to component)</th></tr>
<tr><th>≤ 1918</th><th>1919…48</th><th>1949…57</th><th>1958…68</th><th>1969…78</th><th>1979…83</th><th>1984…94</th><th>≥ 1995</th></tr>
<tr><td>1</td><td rowspan="5">windows, French doors</td><td rowspan="3">wooden frame</td><td>single glazing</td><td colspan="6">5.0</td><td>—</td><td>—</td></tr>
<tr><td>2</td><td>double glazing</td><td colspan="7">2.7</td><td>—</td></tr>
<tr><td>3</td><td>Insulated glazing</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>1.6</td></tr>
<tr><td>4</td><td colspan="2">Plastic frames, Insulated glazing</td><td>—</td><td>—</td><td>—</td><td colspan="4">3.0</td><td>1.9</td></tr>
<tr><td>5</td><td colspan="2">metal frame, Insulated glazing</td><td>—</td><td>—</td><td>—</td><td colspan="3">4.3</td><td>3.2</td><td>1.9</td></tr>
<tr><td>6</td><td rowspan="2">roller shutter boxes</td><td colspan="2">not thermally insulated</td><td colspan="8">3.0</td></tr>
<tr><td>7</td><td colspan="2">thermally insulated</td><td colspan="8">1.8</td></tr>
<tr><td>8</td><td rowspan="2">doors</td><td colspan="2">essentially metal</td><td colspan="8">4.0</td></tr>
<tr><td>9</td><td colspan="2">essentially made of wood, wood-based materials and plastic</td><td colspan="8">2.9</td></tr>
<tr><td>10</td><td rowspan="6">External wall as a solid construction (also walls to the ground, to unheated rooms, to basement rooms)</td><td colspan="2">Double-shell wall structures without an insulating layer</td><td colspan="3">1.3</td><td>1.4</td><td>1.0</td><td>0.8</td><td>0.6</td><td>0.5</td></tr>
<tr><td>11</td><td colspan="2">Solid wall made of solid bricks, little or non-porous natural stone, sand-lime brick, solid pumice concrete bricks or comparable materials up to 20 cm wall thickness (including plaster if necessary)</td><td colspan="3">2.8</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr>
<tr><td>12</td><td colspan="2">as above, but 20 cm to 30 cm wall thickness (possibly including plaster)</td><td colspan="3">1.8</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr>
<tr><td>13</td><td colspan="2">as above, but more than 30 cm wall thickness (possibly including plaster)</td><td colspan="3">1.5</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr>
<tr><td>14</td><td colspan="2">Solid wall made of perforated bricks, hollow pumice concrete blocks or comparable porous or heavily perforated materials</td><td colspan="4">1.4</td><td>1.0</td><td>0.8</td><td>0.6</td><td>0.5</td></tr>
<tr><td>15</td><td colspan="2">Other massive wall constructions up to 20 cm wall thickness over all layers</td><td colspan="3">3.0</td><td>1.4</td><td>1.0</td><td>0.8</td><td colspan="2">0.7</td></tr>
<tr><td>16</td><td rowspan="2">Exterior wall as a wooden structure (half-timbered, prefabricated house or similar)</td><td colspan="2">Solid wood wall (e.g. log house), wooden frame or wooden panel wall with insulating filling</td><td colspan="6">0.5</td><td colspan="2">0.4</td></tr>
<tr><td>17</td><td colspan="2">Half-timbered wall with clay/mud brick infill up to 25 cm wall thickness including plaster</td><td colspan="3">1.5</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr>
</table>

Figure 4: The U-value can be acquired by year of construction, based on [4, p.61].

<table>
<tr><th rowspan="4"></th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th></tr>
<tr><th colspan="3" rowspan="3">Component</th><th colspan="8">u-Values
$W/(m^2 \cdot K)$</th></tr>
<tr><th colspan="8">Year of construction (related to component)</th></tr>
<tr><th>≤ 1918</th><th>1919…48</th><th>1949…57</th><th>1958…68</th><th>1969…78</th><th>1979…83</th><th>1984…94</th><th>≥ 1995</th></tr>
<tr><td>18</td><td rowspan="2"></td><td colspan="2">Half-timbered wall with solid bricks or solid natural stone infill up to 25 cm wall thickness including plaster</td><td colspan="3">2.0</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td></tr>
<tr><td>19</td><td colspan="2">other wooden construction</td><td colspan="2">2.0</td><td>1.5</td><td>1.4</td><td>0.6</td><td>0.5</td><td colspan="2">0.4</td></tr>
<tr><td>20</td><td rowspan="6">Floors against the ground or ceilings to unheated rooms or basements</td><td colspan="2">Solid reinforced concrete basement ceiling</td><td colspan="2">1.6</td><td>2.3</td><td colspan="2">1.0</td><td>0.8</td><td colspan="2">0.6</td></tr>
<tr><td>21</td><td colspan="2">Basement ceiling as a wooden beam ceiling</td><td colspan="3">1.0</td><td>0.8</td><td colspan="2">0.6</td><td colspan="2">0.4</td></tr>
<tr><td>22</td><td colspan="2">Cellar ceiling as brick or hollow stone construction</td><td colspan="2">1.2</td><td>1.5</td><td colspan="2">1.0</td><td>0.8</td><td colspan="2">0.6</td></tr>
<tr><td>23</td><td colspan="2">Floor to earth, solid reinforced concrete</td><td colspan="2">1.6</td><td>2.3</td><td colspan="2">1.2</td><td>0.8</td><td colspan="2">0.6</td></tr>
<tr><td>24</td><td colspan="2">Ground against ground as a brick or hollow block construction</td><td colspan="2">1.2</td><td>1.5</td><td colspan="2">1.0</td><td>0.8</td><td colspan="2">0.6</td></tr>
<tr><td>25</td><td colspan="2">Ground against ground/cavity as a wooden construction</td><td colspan="2">1.8</td><td>1.0</td><td>0.8</td><td colspan="2">0.6</td><td colspan="2">0.4</td></tr>
<tr><td>26</td><td rowspan="2">Roofs, walls between heated and unheated attics/lofts</td><td colspan="2">solid construction</td><td colspan="3">2.1</td><td colspan="2">1.3</td><td>0.6</td><td>0.4</td><td>0.3</td></tr>
<tr><td>27</td><td colspan="2">wooden construction</td><td>2.6</td><td colspan="3">1.4</td><td>0.8</td><td>0.7</td><td>0.5</td><td>0.3</td></tr>
<tr><td>28</td><td rowspan="2">Top storey ceilings, floors/ceiling exposed to outside air (e.g. above passageways)</td><td colspan="2">solid construction</td><td colspan="4">2.1</td><td colspan="2">0.6</td><td colspan="2">0.3</td></tr>
<tr><td>29</td><td colspan="2">wooden beam construction</td><td colspan="2">1.0</td><td>0.8</td><td>0.7</td><td>0.6</td><td>0.4</td><td colspan="2">0.3</td></tr>
</table>

Figure 5: The U-value can be acquired by year of construction 2, based on [4, p.62].

	Unheated adjacent area				f_1
1	general rooms (except those listed below), front buildings/attachments, floor corridors	without an outer wall			0.10
2		with an outside wall	without doors/windows to the outside		0.40
3			with doors/windows to the outside		0.50
4		with two outer walls	without doors/windows to the outside		0.50
5			with doors/windows to the outside		0.60
6		with three or more outer walls			0.80
7	Heating installation rooms (boiler room, technical/utility room with heat generator or similar)				0.20
8	Staircases (connected over several floors)	mostly internal in relation to the heat inputs via adjacent rooms i very low transmission heat losses to the outside, $\frac{\sum H_{T,ie}}{\sum H_{T,iae}} \geq 3$	Building height ≤ 20m	basement, ground floor	0.45
9				1st floor	0.30
10				≥ 2nd floor	0.25
11			Building height > 20 m	basement, ground floor	0.65
12				1st floor	0.45
13				2nd Floor	0.35
14				3rd to 7th floor	0.30
15				≥ 8th floor	0.25
16		external			0.80
17	Basement rooms[a]	without doors/windows to the outside			0.4
18		with doors/windows to the outside			0.5
19	attics, abodes	open or heavily ventilated roofs, cold roofs			1.0
		closed roofs	**Heat transfer coefficient of the separating components** *U* [W/(m²c)]		
			between unheated area and outside air (e.g. roof cladding) U_{ie}	between heated space and unheated space (e.g. top floor ceiling) U_{iae}	
20		leaking (n ≈ 2.5 h⁻¹)	5	1.25	0.85
21				0.60	0.90
22			2.5	1.25	0.80
23				0.60	0.90
24		dense (n ≈ 0.5 h⁻¹)	5	1.25	0.85
25				0.60	0.90
26			2.5	1.25	0.75
27				0.60	0.85
28			1.0	1.25	0.55
29				0.60	0.70
30			0.5	1.25	0.50
31				0.60	0.65
32			0.25	1.25	0.40
33				0.60	0.60
34	Elevated floor over crawl space				0.8

[a] A room can be considered a basement room if more than 70% of the external wall surface of the floor containing it is exposed to the ground.

Figure 6: The Temperature adjustment term f_1 can be acquired by the adjacent area, based on [4, p. 18].

2.12 Competing Products

Two Example buildings were taken from the companies Dendrit and WBS for verification purposes, as corresponding sample calculations are available from their website. The heat load of the example buildings is calculated with the software trial of EVEBI as well to gain further results for verification. In Table 13, all the different programs that were looked at in the course of the implementation are shown.

Company	**Type of product**	**Trial**
Dendrit	Software	× only for companies
ENVISYS	Software	✓
SOLAR-COMPUTER	Software	× only for companies
WBS	Calculation service	–
ZUB Systems	Software	✓
ZVPLAN	Software	✓

Table 13: These are the companies that offer heat load calculation services according to DIN 12831.

3 Validation of Implementation

The two following examples are from the software manufacturer Dendrit which has the same example as the DIN standard and the calculation service/consulting WBS and were obtained from their sample forms. Since these examples are for verifying the correctness and legitimacy of their performance before the purchase, they are most likely correct. Dendrit uses the same example building as the DIN standard for its example calculations and therefore the ventilation heat loss, as well as 4 rooms, are unquestionably correct and the rest are even more trustworthy. Therefore, if the implementation produces the same results as the reference calculations within tolerance, the implementation and the reference data will be deemed correct. In Table 14 the abbreviations used in the graphs are explained.

Four calculations are performed for each reference building. The two standard procedures and the simple procedure are performed and the simple procedure is calculated again with every U-value and f_x estimated by the construction year and component type (Simple approx.), as shown in Table 14. The standard procedure and the simple procedure will therefore be verified by the reference data and there will be a comparison of the simple calculation with estimated values (Simple approx.). Since all standard example buildings have supply flow rates, the simple calculation procedure as well as restricted standard procedure is not allowed to be applied. For these calculation procedures, the limitations will be assumed and this is why they are going to be compared to each other and not to the reference and the standard calculation procedure.

Calculation procedure abbreviation	Description
Reference	Result from reference data, which was calculated by the Standard calculation type
Standard	Using the standard calculation method
Restricted Standard	Standard calculation but no wall vents assumed, to compare to the simple type (only influences ventilation)
Simple	Uses the simple calculation procedure
Simple approx.	Simple calculation procedure but all U-values and f_x are estimated by construction year/component type (only influences transmission)

Table 14: These are the calculation procedure abbreviations.

3.1 DIN/Dendrit Example

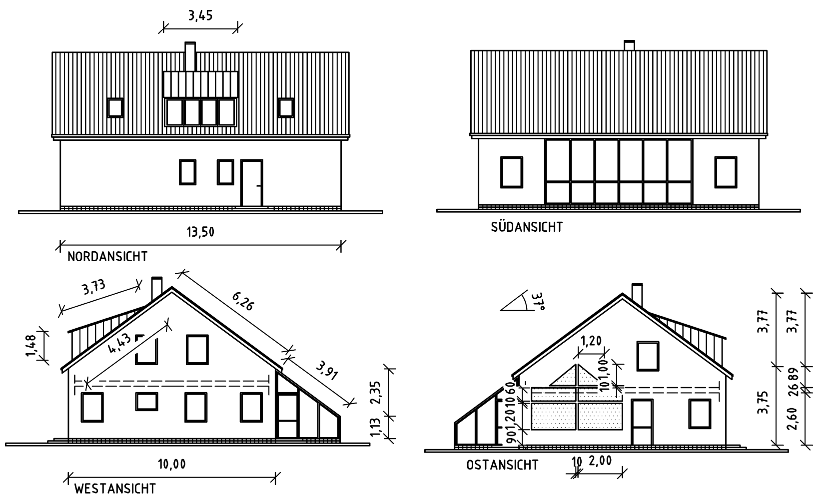

Figure 7: These are all views of the building from [4, p. 112].

3.1.1 Comparison between Calculation Methods

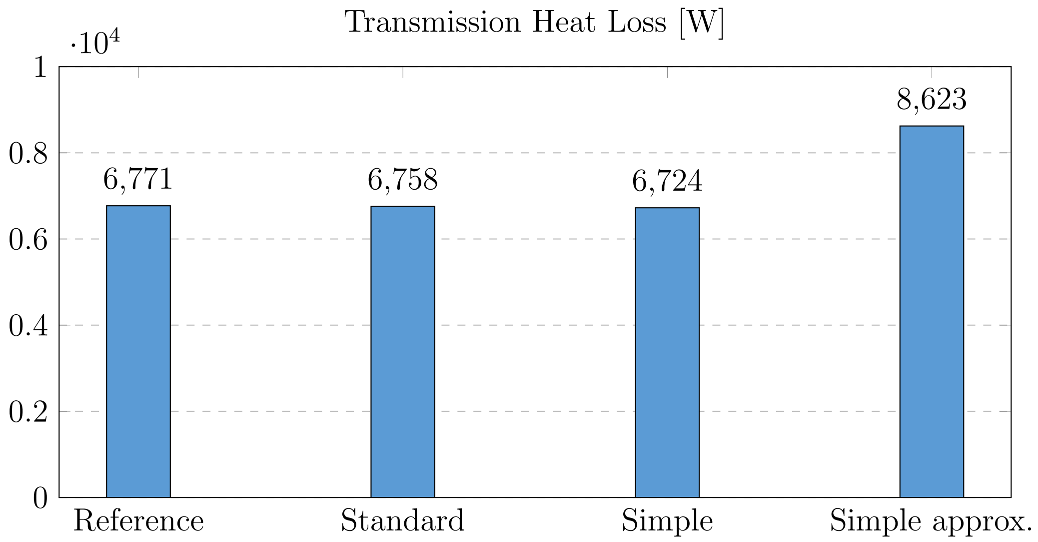

Figure 8: A transmission heat loss comparison is made between all the calculation methods, where the reference is from [1].

As can be seen in Figure 8 the transmission heat loss is the same within tolerance for every calculation type. But for the estimated input data (Simple approx.) the transmission heat loss is about 1kW higher than the reference transmission heat loss, which is not considered a similar result.

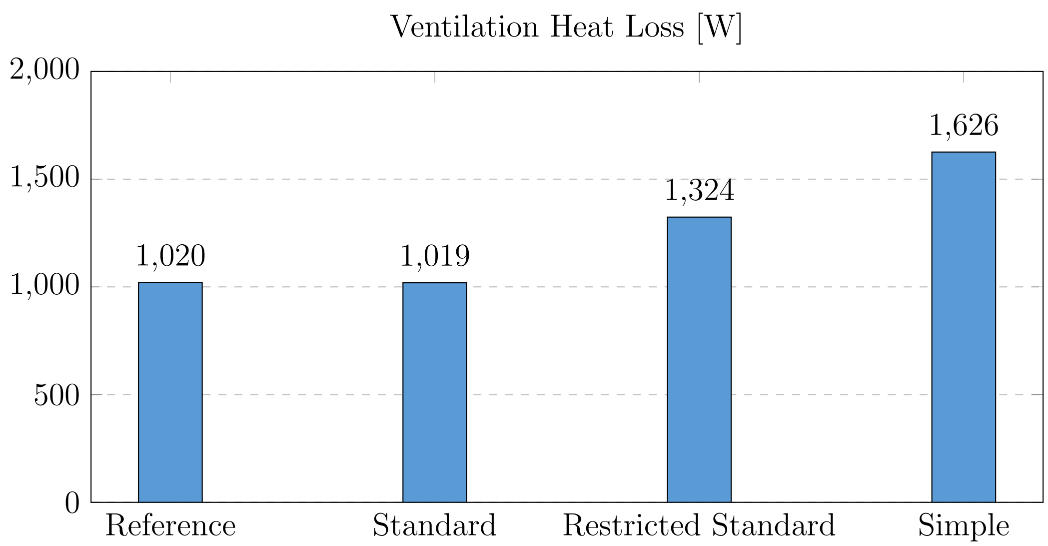

Figure 9: A ventilation heat loss comparison is made between all the calculation methods, where the reference is from [1].

For the ventilation heat loss, the restricted standard calculation method is slightly above the reference ventilation heat loss(∼300W), which would still be an acceptable result, but the simple calculation type is about 600 watts above the reference. This is a too big difference, which is due to this example not having free ventilation.

3.1.2 Verification with Standard Reference Results

Type of calculation	**Reference by Dendrit** [1]	**Calculated**	**Relative Deviation**	**Deviation per Component/-Room**	**Standard Deviation**
Transmission heat loss	6771 W	6758 W	0.192%	0.0856W	4.2W
Ventilation heat loss	1020 W	1019 W	0.098%	0.05W	0.211W
Time constant τ	103 h	103 h	0%	-	-

Table 15: These are the results calculated by the standard calculation method.

3.1.3 Transmission Heat Loss

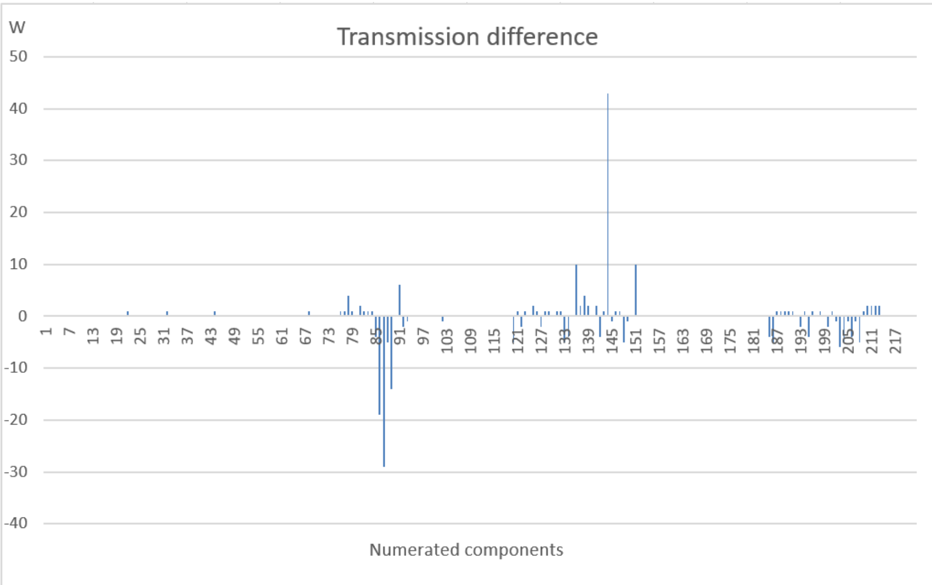

Figure 10: The difference between the reference [1] and the calculated transmission heat loss of each component is shown in the graph.

As shown in the graph in Fig. 10, there are 3 areas of outliers in the individual component transmission heat loss differences. The outliers lie in the rooms “stairs”, the “first child’s bedroom” and in the “gallery”. These outliers all have in common that they lie in rooms, which have a ceiling height above 4 m. In these rooms the heat transfer system needs to be considered, which is not given in the reference data and therefore the results vary. I chose the heat transfer system or variable values, shown in

Table 5, which fit the room ventilation heat loss best, and therefore the transmission heat loss varies more.

On the other hand, it also shows that the calculation is accurate if these outliers are excluded. This is underlined by the average difference between the reference and calculated heat loss per component, which is only 0.086 watts. The calculated transmission heat loss for the building is only 13 watts less than in the reference values, which is about 0.2% relatively to the total transmission heat loss. The standard deviation of the difference is 4.2 watts, which also shows these outliers.

3.1.4 Ventilation Heat Loss

The calculated ventilation heat loss for the building is 1.2 watts less compared to the reference data, which is a relative deviation of about 0.2%. The average difference between the reference and calculated heat loss per room is 0.05 watts. The standard deviation of the difference is only 0.211 watts, which shows that there is a very low deviation from the reference data and that it has no outliers. It follows that this calculation is accurate.

3.1.5 Time Constant of the Building τ

In this standard, it is calculated independently of the regular heat transfer coefficients. That is why it has to be compared separately. The calculated time constant of the building is identical to the reference data, which is 103 hours. Therefore, the calculation of the estimated heat transfer coefficients and the time constant of the building is correct and accurate.

3.2 Wbs EFH Example

3.2.1 Comparison Between Calculation Methods

As can be seen in Fig. 11 all different calculation types nearly equal the reference transmission heat loss. However, the estimated input data in the simple calculation type nearly doubles the transmission heat loss. Estimating in this example is less accurate than normal since this is a relatively new building (after 1995) and the estimating is more accurate for older buildings.

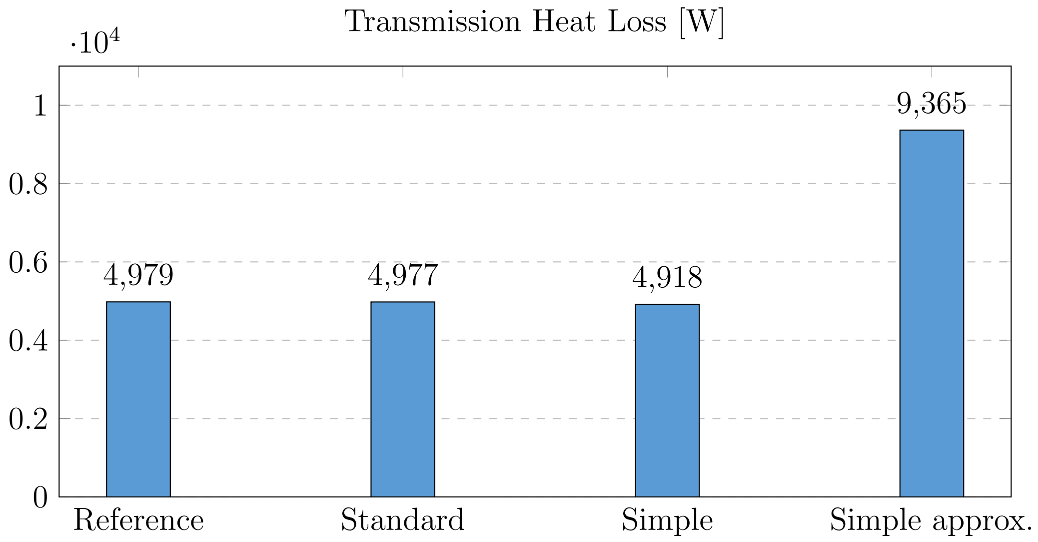

Figure 11: A transmission heat loss comparison is made between all the calculation methods, where the reference is from WBS [10].

In the calculation of the ventilation heat loss, the restricted standard and the simple method perform similarly and get nearly double the heat loss of the standard calculation. This is because the simple and restricted standard procedures can only apply to buildings with free ventilation, which is not the case in this example.

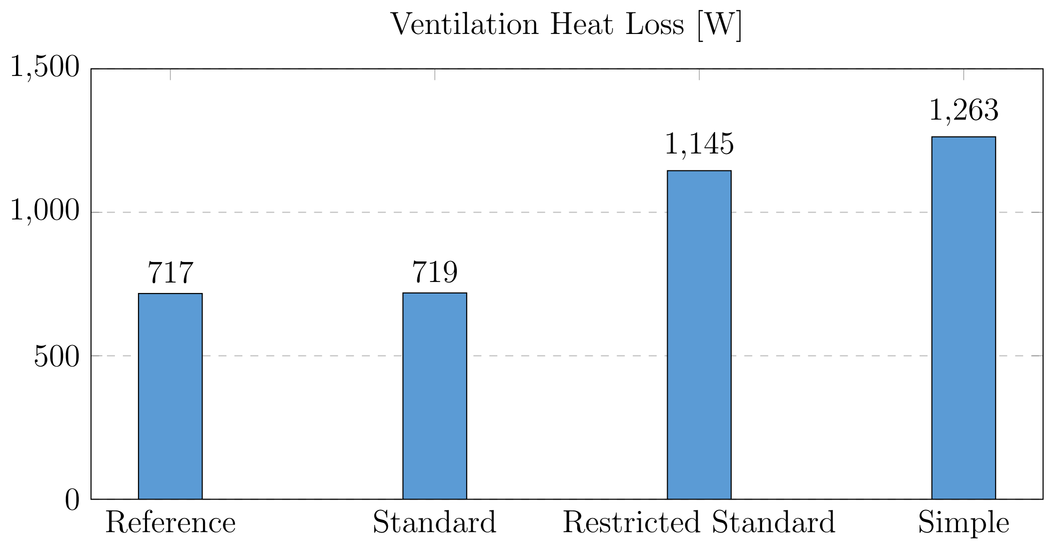

Figure 12: A ventilation heat loss comparison is made between all the calculation methods, where the reference is from WBS [10].

3.3 Verification with Standard Reference Results

Type of calculation	**Reference by WBS** [10]	**Calculated**	**Relative Deviation**	**Deviation per Component/-Room**	**Standard Deviation**
Transmission heat loss	4979 W	4977,4 W	0.0321%	0.0156W	0.333W
Ventilation heat loss	717 W	718,6 W	0.223%	0W	0W
Time constant τ	-	-	-	-	-

Table 16: These are the results calculated by the standard calculation method.

3.3.1 Transmission

All the individual transmission heat losses of each component are correct, except for 7 components, which deviate by 1 watt, which is small compared to the about 5kW heat load of the hole building. The actual building heat loss deviation is smaller than 7 watts since the transmission difference is rounded. It is rounded because the reference values are rounded to a full number. The building transmission heat loss is only 1.57 watts less than the reference values, which is about 0.03% less relatively, as can be seen in Table 16. The average difference between reference and calculated heat loss per component is 0.016 watts and the standard deviation of the difference is 0.33 watts. This shows that there are nearly no outliers in the individual calculated components, and the average deviation per component is next to none, which means that the calculation is accurate and correct.

3.3.2 Ventilation

The calculated ventilation heat loss for the building is 1.58 watts more than in the reference data, which is approximately 0.2% more. All of the room ventilation heat losses are identical to the reference room heat losses since they are rounded to the full number. Therefore, the standard deviation is 0 and this deems the ventilation calculation accurate.

3.3.3 Time Constant of the Building τ

Since the effective heat storage capacity c_{eff} nor the time constant of the building τ is given, τ cannot be calculated and subsequently, the external temperature cannot be corrected.

3.4 Verification of the Simple Calculation Result

Type of calculation	**Calculated by EVEBI [5]**	**Calculated**	**Relative Deviation**
Transmission heat loss	4918 W	4917.7W	0.0061%
Ventilation heat loss	1263 W	1262.7W	0.02375%
Heat load	6180 W	6180.4W	0.00647%

Table 17: These are the results calculated by the simple calculation method.

As shown in Table 17, all the heat loads calculated by EVEBI [5] are identical to the Heat loads calculated by this implementation, which shows that the implementation of the simple calculation procedure is accurate as well.

4 Conclusion of the Calculation Results

The calculation could not be compared in rooms that are higher than 4 m, because there was no reference data to compare it to. Therefore, the calculation in high rooms cannot be deemed correct definitely, but the calculation still resulted in a similar range that is still accurate enough to dimension the heat transfer systems.

Excluding high rooms, I conclude that the deviation from the reference data in the standard method is due to rounding errors since the reference transmission and ventilation heat loads are all rounded and every input parameter is rounded as well. Therefore, I conclude that the deviations are from small rounding differences and that the calculation is precise and correct.

As floating point numbers are used in the calculation, some very small rounding deviations occur naturally from the programming language, due to the floating point arithmetic, but they are negligible for the end result.

For the simple calculation procedure, the heat load calculation is identical to the one calculated by the EVEBI [5] software tool as shown before. Additionally, all the transmission heat losses are nearly identical to the standard results, which shows its accuracy, and its very good approximations to the standard method. The ventilation heat loss in the simple method is the same as the one calculated by EVEBI [5] and it consistently performs very close to the restricted standard ventilation heat loss, which shows its accuracy. Furthermore, the simplicity of the ventilation calculation does not leave any room for mistakes as seen in Section 2.9.2. Therefore, the simple calculation procedure is deemed precise and correct as well.

5 EFH/MFH Comparison to the DIN V 18599 Standard

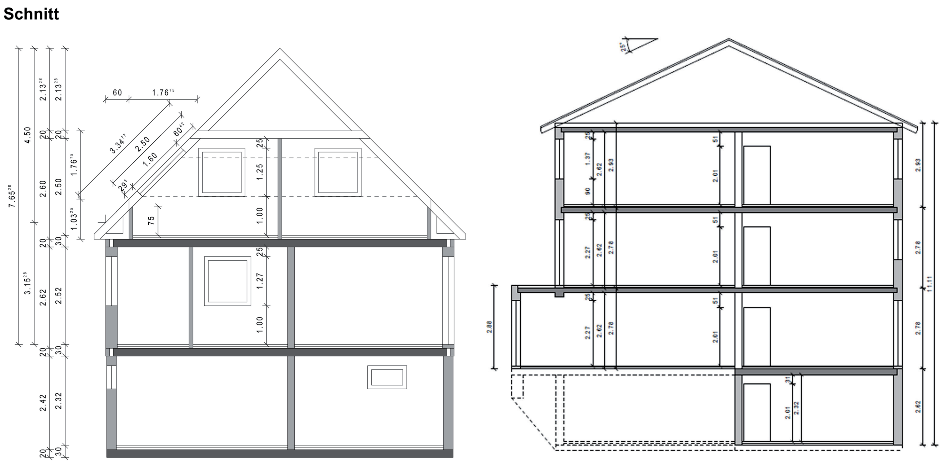

Figure 13: These are the buildings EFH/MFH from [8, p.7, p.165].

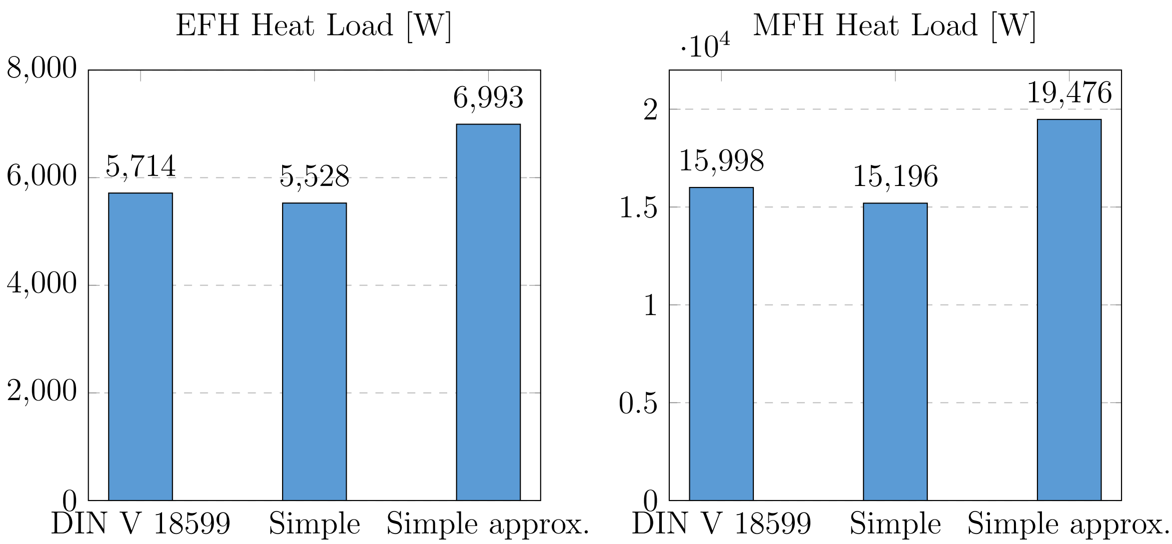

Figure 14: The calculation procedures are compared to each other, where the reference values for DIN V 18599 are from [8].

Since the given example is calculated with the standard DIN V 18599 [8], the heat loads will be similar to the simple calculation type of this standard, but not identical. Hence, this will be a comparison between the DIN standards.

As shown in the EFH comparison in Fig. 14, the simple calculation method results in an about 200 W lower heat load compared to the reference. This is a tolerable difference since it won't result in a different heater. Estimating the input data, as can be seen on the Simple approx. bar, results in a 1.4kW higher heat load, which is substantially higher and is not tolerable.

With MFH on the other hand the simple calculation results in an approximately 700W lower heat load compared to the DIN V 18599 standard [3]. This difference could already result in a different heater. The estimated input data, gives a 4kW higher heat load which makes a huge real-world difference, but since these 2 examples are in a relatively new building (after 1995) the estimation is especially rough.

5.1 Conclusion of the Comparison

The heat load calculated in the DIN V 18599 standard is slightly higher compared to the one calculated by the simple calculation procedure in the given examples. But as the simple calculation type is already a rougher approximation than the standard calculation method, as can be seen in Section 2.9, it cannot replace the calculation of the simple calculation type, since the calculations are equally uncomplicated. Although the ventilation heat loss of the simple calculation procedure is a rougher estimate compared to the standard calculation procedure.

6 Performance

The runtime of the implementation is measured 1000 times and the results are averaged. In the Table 18 the runtimes in and excluding the loading of the JSON data structure from storage can be seen. The times for the program EVEBI by ENVISYS [5] include the loading of the project file. The measured time for running EVEBI is averaged over 10 calculations that are timed manually, without taking into account the approximately 5 seconds that the program needs to start because the comparison would otherwise be unfair. Every example is run on an AMD Ryzen 5 5600X system. All the run times of the implementation are timed with the timeit python library[1]. It minimizes the impact that the other tasks, that run on the operating system, have on the implementation runtime. Therefore, a more accurate average execution time can be obtained.

Example	**Times(ms)**		
	EVEBI	Implementation with load of file	Implementation without load of file
Dendrit	784	2.1	0.82
WBS	570	0.89	0.29
EFH	636	0.31	0.03
MFH	650	0.26	0.019

Table 18: This is a performance comparison between EVEBI and the Implementation.

[1] timeit, URL https://docs.python.org/3/library/timeit.html

As shown in Table 18, the calculation time of EVEBI is about 400 times slower compared to my implementation, although the performance of EVEBI is measured roughly it is still considerably slower. The individual runtimes of EVEBI can be seen in the Table 23 in the appendix. The loading of the JSON file takes about a third of the calculation time in the standard Dendrit/WBS examples and nearly the entire calculation time in the simple EFH/MFH examples in the implementation, as can be seen in the Table 18. The runtime of the implementation for the DIN building is 2.1 milliseconds while the runtime without loading the input data is 0.8 milliseconds. This shows that the implementation is very performant since it can calculate in the single-digit millisecond range.

6.1 Profiling

The testing method is that each test case is run 1000 times which is averaged. The run times have been profiled with cProfile[2] and are visualized by SnakeViz[3]. Loading or saving the JSON input data from storage will not be timed here, since it will make the comparison less accurate because the time for reading the JSON from storage can vary vastly.

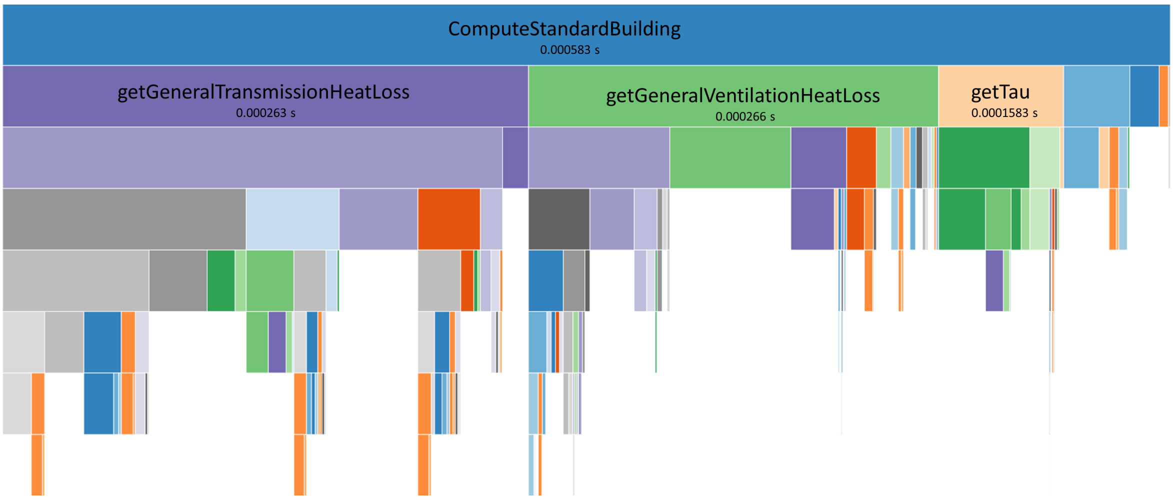

Figure 15: This is the SnakeViz[3] visualization of the profiling of the WBS standard calculation.

The major calculation time can be divided into the three main computations of the transmission heat loss, the ventilation heat loss and the building time constant τ which can be seen in the SnakeViz profiling for WBS in Figure 15. Since calculating the enveloping surface of the building has only a minor impact on the calculation time and also has low improvement capability, it is not considered in the profiling. Therefore, only the total run time and the runtime of the transmission heat loss, ventilation heat

[2]cProfile, URL `https://docs.python.org/3/library/profile.html`
[3]SnakeViz, URL `https://jiffyclub.github.io/snakeviz/`

loss and tau, are taken into account. The improvements shown in Table 19 are the average improvements between the DIN and WBS examples and between the EFH and MFH examples by the quality association. Each runtime is the average of 1000 timed runs.

	Method	Total	Transmission	Ventilation	τ
Time Improvement	Standard	-14.82%	-29.34%	-7.13%	-24.34%
	Simple	-16%	-	-	-

Table 19: These are the total improvements after utilizing profiling.

The total runtime calculating a big project like Dendrit is 0.82 ms on average and the about three times smaller project WBS takes 0.292 ms on average. Dendrit's example has many more individual components, which require a longer time to compute. This explains why the processing time is not roughly three times higher. The improvements made after the profiling, amount to a roughly 16% total faster calculation time on average. As many calculation results are cached as possible and some are precalculated. Every cached value by the implementation is an intermediate calculation step result, which is also relevant or interesting in the calculation results. For the transmission heat loss, the speed up is nearly 30% and the calculation of tau is sped up close to 25%. The ventilation heat loss calculation improved the lowest amount with about a 7% lower time. There is not as much improvement potential because the ventilation heat load calculations are pretty linear.

6.1.1 Individual Profiling

For the bigger project Dendrit, the total speed improvement is only about 10% faster. The ventilation calculation, on the other hand, stayed roughly the same with an approximately 7% speed improvement and the transmission heat loss, was sped up by about 15%. The calculation of tau was massively sped up by nearly 35% as shown in Table 20.

For WBS, which has a lower amount of components per room as well as only 13 rooms instead of 17 rooms when compared to Dendrit, the total speed improvement is about 20% which is nearly double the speed improvement when compared to Dendrit. The transmission heat loss calculation got a huge speed improvement of about 44% and the calculation of tau got a smaller speed up of 14.1% compared to the speed improvement of Dendrit, which is mostly because of the lower amount of components. The ventilation heat loss calculation speed stayed roughly the same, with about 7% time improvement, as shown in Table 20.

For the simple calculation type, EFH is sped up by 11.5% compared to the 20.5% for MFH, as shown in Table 22. MFH has more components, and since the major speed up is achieved in calculating the individual components, the impact is bigger for the MFH.

	Total		Transmission		Ventilation		τ	
	before	after	before	after	before	after	before	after
Time (ms)	0.909	0.8196	0.572	0.4875	0.206	0.192	0.217	0.14
Improvement	-9.83%		-14.77%		-7.29%		-34.58%	

Table 20: These are the standard calculation times of the DIN/Dendrit building before and after profiling.

	Total		Transmission		Ventilation		τ	
	before	after	before	after	before	after	before	after
Time (ms)	0.351	0.292	0.230	0.129	0.115	0.107	0.0910	0.0782
Improvement	-19.8%		-43.9%		-6.96%		-14.1%	

EFH	Total	
	before	after
Time (ms)	0.0356	0.0319
Improvement	-11.5%	

MFH	Total	
	before	after
Time (ms)	0.0235	0.0187
Improvement	-20.5%	

Table 21: These are the standard calculation times of the WBS building before and after profiling.

Table 22: These are the simple calculation times of the EFH/MFH buildings by the Gütegemeinschaft before and after profiling.

7 Implementation

Python has many inbuilt libraries like cProfile. The code has to be maintained by others therefore the widely known easily readable programming language Python was chosen. Python is also supported by all platforms and is very versatile and therefore modifying the codebase and adding features is done easily.

The compute heat load function is given a building as a dictionary (Python data type) as input and returns the dictionary with the computed results added.

The implementation has a linear time complexity. Multiple iterations over the data structure are necessary because for example, if there is a comfort surcharge, each heat loss has to be calculated a second time with increased room temperatures which is not specific to the implementation, but required by the DIN standard.

The calculation is performed in place, which means that the input dictionary of the function is overwritten by the output dictionary. Copying the input data before the calculation would result in a big performance hit. Creating a copy of the input might not be necessary since the output of the function contains all the input parameters with the addition of the output parameters. It makes sense to perform the calculation in place since the input parameters are still required for the output. If the uncomputed input data is still necessary, simply copy the input before calculating the function.

The building data structure, seen in Listing 1, is in a JSON format. All parameters contained in the data structure are a property of a building. There is a list of zones that represents the ventilation zones, which contains a list of all rooms in the zone. Each room has a list with all of its components. There is also a list of components as a property of the building since the components are properties of buildings as well as rooms in the simple calculation procedure.

```
"building": {
  "calculationType": 2,
  ...,
  "zones": [
    {
      ...,
      "rooms": [
        {
          ...,
          "components": [{...}]
        }
      ]
    }
  ],
  "components": [{...}]
}
```

Listing 1: This is the general datastructure of the building input.

An alternative data structure, which was also considered during the implementation, is one similar to the data structure used by EVEBI, which has zones, rooms and components in three separate arrays, which can be referenced by their IDs. But this data structure is less optimal since more data accesses are necessary. This data structure does not need to rely on IDs or array positions because everything is calculated separately in the DIN standard, e.g. the heat load of one room does not influence another.

It should be highlighted that with the data structure of the implementation, it is possible to have a consistent data structure between all calculation procedures. Some parameters are therefore unused in the simple calculation type. The list of components in the building is the only parameter unused in the standard calculation procedure.

Depending on the parameter “calculationType”, the standard or the simple calculation is performed. The ID of each procedure for the calculation type is defined in Table 3. The consistent data structure makes it possible to switch between the standard calculation type to the simple calculation type but not the other way around since additional information is required and would need to be entered. The calculation type can be switched from the top to the bottom according to the order shown in Table 3.

The implementation contains the climate data of every postcode in Germany as it was included in the CD by DIN [4]. Should the building location be outside of Germany, instead of the postcode the standard location temperature, the average location temperature and the average height of the location must be entered.

7.1 Encountered Problems

Instead of entering the adjacent room temperature of a component, the ID of the adjacent room can be entered. Iterating through the entire zone list for each component slows the processing down. That is why, I precompute all the room temperatures and map them to their room IDs as seen in Listing 2.

```
building['roomIds'] = {}
for zone in building['zones']:
    for room in zone['rooms']:
        building['roomIds'][room['id']] = getIndoorTempRoom(room,
    False, building['DeltaThetaComf'])
```

Listing 2: This is how the room temperature map is created.

8 Conclusion

The implemented calculation of the DIN EN 12831-1 standard has been compared to established calculation results by known software manufacturers and consultancies. This was done using two different example buildings one coming from a software manufacturer and one from a consultancy. With these examples, it was shown that the implementation of the calculation had less than half a percent of deviation from the results of the companies. The only test case that was inconclusive was the heat load in rooms with a ceiling height above 4 meters. In this case, the heat transfer system, which is not given in the reference data, plays a role. Overall, the accuracy of the implementation has been shown and the deviation, excluding high rooms, was concluded to be the result of the rounded reference data.

The implementation proved to be about 400 times faster than a competitor's program. To reach a calculation time in the one millisecond range the code was profiled and a performance improvement of about 15% was reached which shaves off 0.1 milliseconds on average in the biggest project. The very high performance of the implementation has therefore been proven.

By using this tool, the user can accurately determine the heating requirements of a building and dimension the heat transfer systems of its rooms. This helps to make more informed decisions about the different types of heaters. It also helps with designing the building and making a sensible decision about whether to renovate it or to add additional insulation.

8.1 Future Work

Since this is an implementation of the 2020 DIN 12831-1 [4] standard it has to be updated according to new standards or corrections of it in order to remain up-to-date, accurate and relevant. Input validation could be added to prevent unwanted edge cases like inputs which may result in null division errors or similar issues. For rooms with a ceiling height above 4 meters, the implementation should be compared to multiple other implementations to ensure the complete correctness of the implementation.

There should be an application to easily input all the building information and to visualise the output data sensibly. All the information should be displayed in the app similar to the DIN form and there should certainly be a way to download the information in the form of a Word/Excel file or as PDF. The implementation already includes a way to automatically generate an Excel report file in the format of the forms given by the DIN standard. Converting to Word rather than to Excel has the advantage of easily adding further information and exporting better-formatted PDFs. The building information could be imported from a CAD drawing as new buildings may already have had one done by an architect, which would make everything more convenient.

The application can be realized as a mobile app or a website, or in the best case both. With all the user-inputted building data, there could be a calculated average heat load per square meter depending on the house type and depending on age. Based on this data the application could tell the user if their heat load per square meter is above or below average in the building's age category.

References

[1] Dendrit. Heizlastreport Beispieldokument Dendrit STUDIO, 2022. URL https://qr.dendrit.net/documents/HeizlastReport.pdf.

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A Figures

Number	Time (s)			
	Dendrit	WBS	EFH	MFH
1	0.92	0.68	0.58	0.65
2	0.90	0.64	0.5	0.57
3	0.84	0.54	0.56	0.62
4	0.87	0.58	0.73	0.71
5	0.74	0.62	0.63	0.62
6	0.84	0.59	0.69	0.76
7	0.72	0.75	0.81	0.63
8	0.70	0.62	0.55	0.6
9	0.69	0.62	0.66	0.57
10	0.62	0.68	0.65	0.77
	Average (s)			
	0.784	0.57	0.636	0.65

Table 23: These are the times of EVEBI calculations.

Software manufacturer	**Trial**	**API?**	**Webpage**
Dendrit	× only for companies	×	`https://www.dendrit.de`
WBS	× only consulting	×	`https://www.heizlast.de`
ZVPLAN	✓	×	`https://www.zvplan.de/Testen/Testversion.aspx`
ZUB Systems	✓	?	`https://www.zub-systems.de/de/produkte/helena/heizlast`
SOLAR-COMPUTER	× only for companies	×	`https://www.solar-computer.de/index.php?seite=produkte&sub=heizung`
ENVISYS	✓	✓	`https://www.envisys.de/energieberatersoftware-evebi/`
EVA leuchter	× didn't work	×	https://www.leuchter.de/eva-downloads

Table 24: Manufacturers webpages

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