International Center for Indoor Environment and Energy
Department of Civil Engineering
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Report to EURAY

Yearly energy performance of heating systems

Calculation of different heating systems efficiency and losses according to the Energy Performance of Building Directive

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Preface

This is the final report on task 3 of the EURAY-project. It includes energy performance calculations for three typical buildings (residential, office and industrial) for two type of heating systems (floor heating and radiators) in three climatic regions (Stockholm, Brussels, Venice).

The calculations are based on existing CEN- standards, which were developed in relation to the Energy Performance of Buildings Directive (EPBD). The conversion factors used for primary energy conversion and calculation of CO2 emissions are different from country to country. The values depend on the primary energy source for production of electricity and heat.

For the relevant standards used there are some future issues like:

- It is unacceptable to have two methods for emission losses, which will give different results.
- Control efficiencies of floor heating should be differentiated depending on the accuracy of the on-off control
- For high rise building it seems the stratification losses for ceiling panels are too small.

In general floor heating comes out as the best system in all cases even if the differences some times are small.

1 Introduction

1.1 Energy performance in buildings

One important function of a building is to provide a comfortable and healthy environment for its occupants, the attainment of which generally requires the use of energy for heating and/or cooling and for ventilation, domestic hot water and lighting. The use of energy for these purpose exploit natural energy resources in competition with other energy needs and also causes environmental impact.
In the sphere of global energy problems, lately there has been paid large attention to energy efficiency. The demand for saving energy in new and existing buildings create a necessity for developing new procedures and regulatory measures for increasing the energy efficiency. The Community is increasingly dependent on external energy sources which increase greenhouse gas emissions are on the increase. The Community can have little influence on the energy supply but can influence energy demand. One possible solution to both the above problems is to reduce energy consumption by improving energy efficiency. In that respect in 2003 the European commission issued a Directive 2002/91/EC on the energy performance of buildings (EPBD).
The directive forms part of the framework of Community initiatives on climate change, (commitments under the Kyoto Protocol). The reason of this measure is that the external dependence for energy of the European Union (EU) is constantly increasing. To day buildings account for 40% of the overall energy consumption in EU. [1]

From all indications, there is high cost-effective potential for energy savings in buildings. The Council Resolution of 7 December 1998 on energy efficiency (98/C 394/01) stated that meeting the indicative target of a 1 per cent improvement in energy intensity above the current trend would result in avoiding energy consumption of 55 Mtoe in buildings. This represents about 20 per cent of the Kyoto Protocol target. Most recent analysis is provided in the original proposal prepared by the EC on the Directive on the Energy Performance of Buildings. The global potential is about 22 per cent reduction of present consumption which can be realized by 2010. This consumption is for heating, hot water, air conditioning and lighting. [2]
By improving energy efficiency it is possible to reduce NOx emission and other gas originating from combustion as well. Mostly because of the environmentally implications a lot of money and time have been spent on researches and development, to reduce the fossil fuel usage.
In January 2006 a new building codes, regarding energy performance of buildings on a national level were implemented, contributed by the EPBD. This will reduce the use of energy in buildings across Europe, whilst at the same time perceptibly increasing comfort for users. The measures are a vital component of the EU´s strategy to meet its Kyoto Protocol commitments. Also the legislation concerns:

- A common methodology for calculating the energy performance of a building taking account of local climatic conditions;
- Minimum standards for energy performance to be determined by Member States, and applied both to new buildings and to major refurbishments of existing large buildings. Many were based on earlier- existing or planned European norms;
- A system of building certification will make energy consumption levels much more visible to owners, tenants and users;
- Boilers and air conditioning systems above minimum size will be inspected regularly to verify their energy efficiency and greenhouse gas emissions.

The Directive concerns the residential sector and the tertiary sector (offices, public buildings, etc). Certain buildings such as historic monuments, places of worship, temporary buildings, agricultural buildings and summer holiday homes may be exempted from the new energy performance standards

Since the beginning of 2006, each new European building must have an energy declaration based on the calculated energy performance of the building, including heating, ventilating cooling and lighting systems.

A mandate to the European Organization for standardization (CEN) from the Commission, M343-EN-2004 [2] was issued. This mandate asks CEN to elaborate and adopt standards for a methodology, calculating the integrated energy performance of buildings and estimating the environmental impact, in accordance with the directive. To coordinate the standardization related to the EPBD, CEN established an EPBD-Project Group including the following Technical Committees (TC's): TC 89 Thermal performance of buildings and building components; TC156 Ventilation for buildings; TC169 Light and Lighting; TC228 Heating systems in buildings; TC247 Building automation, controls and building management

The standards under the mandate shall constitute an integrated and interacting methodology for the calculation of the energy uses and losses for heating, cooling, ventilation, domestic hot water and lighting systems, taking into account natural lighting, passive solar systems, passive cooling, position and orientation, automation and controls, and auxiliary installations necessary for maintaining a comfortable indoor environment. The methodology shall integrate, where relevant, the positive influences of active solar systems and heat and electricity from renewable energy sources, as well as quality co-generation heating plants (CHP, including micro-CHP) and district heating and cooling systems. It should also facilitate an estimation of the environmental impact from this energy use and provide data requirements for carrying out standard economic evaluations for the use of different systems.

This series of standards (about 40) have or are being voted for as final standards. The objective is to establish common calculation methods in Europe for energy performance of buildings and HVAC systems. Unfortunately this did not happened because the standardization work started too late and several countries have adopted national calculation methods. Also some of the standards do include alternative methods, which mean the energy performance of the same system may be evaluated differently in different countries.

A basic standard for the calculation of the building energy demand (EN ISO 13790-2007) forms the central point of the calculation procedure. EN ISO 13790 covers the calculation of the building energy use for space heating and cooling. The calculation require an input data for indoor climate requirements, internal loads, building properties and climatic conditions of the building location.

1.2 Calculation process

The calculation of the energy performance is structured in three levels:

1. calculation of the building energy needs for heating and cooling (design heat load and thermal performance of the building and systems):

2. calculation of the building delivered energy for heating and cooling, ventilation, domestic hot water and lighting:

3. calculation of the overall energy performance indicators (primary energy, CO emissions, etc.).

The calculation sequence is [3]:

a) Calculate the building energy needs for heating and cooling, using several applicable standards. This part of the calculation considers only the building properties and not those of the heating/cooling system and results in the energy to be emitted by heat emitters, or energy to be extracted from the conditioned space, in order to maintain the intended internal temperature. EN ISO 13790 covers both heating and cooling.

To perform this calculation, data for indoor climate requirements, internal heat gains, building properties (EN 12831) and outdoor climatic conditions are needed. These data are to be found in several European standards listed in section 4 in Appendix A.
EN ISO 13790 includes guidance for partitioning a complex building into separate zones for the purposes of the calculation.

b) Take account of the characteristics of the space heating, cooling, ventilation, domestic hot water and lighting systems, inclosing controls and building automation, and calculate the delivered energy, using standards listed in Section 2 in Appendix A. Energy used for different purposes and by different fuels is recorded separately. The calculations take account of heat emission, distribution, storage and generation, and include the auxiliary energy needed for fans, pump etc.

c) Combine the results from b) for different purposes and from different fuels to obtain the overall energy use and associated performance indicators, using standards listed in Section 1 in Appendix 1.

There is a conflict between steps a) and b) because system losses that are recovered count as gains for the building in the calculation. When these gains cannot be predicted without knowing the heating and cooling needs, steps a) and b) may have to be iterated. In the first calculation the gains from systems are omitted in the calculation of the energy needs, in subsequent iterations they are included from the system calculations in the previous iteration.

Figure 1.1 illustrates the overall scheme [3]

1.2.1 Calculation of building net energy

The central point of the calculation procedure of the building net energy shall be a revised EN ISO 13790. This standard will be enlarged to include also cooling apart from the heating demand already existing in EN ISO 13790.

This standard do not consider the properties of the heating/cooling system, but only those of the building, and results in the net energy use. It assumes a 100 % effective heating system

To perform this calculation, input data for indoor climate requirements, building properties, internal loads and climatic conditions (weather data) are needed.

An energy balance is the basis for the calculation method within this standard, it takes into account internal and external temperature variations and through utilization factor the dynamic effect of the internal and solar gains. The energy balance in this approach is a seasonal calculation.

1.2.2 Calculation of building delivered energy

Calculation of building delivered energy comprises heat emission, distribution, storage and generation. The auxiliary energy, normally in the form of electrical energy, used for circulation pumps, fans, valves etc. is considered as well.
Energy used for different purposes (i.e electric energy, heat energy) and by different fuels (gas, oil, etc) is accounted separately**,** because for the calculation of primary energy there are different multiplicative coefficient.

Space heat emission

The energy required for heat emission and control of the indoor temperature in a building depends on various factors (EN15316 Part 2.1). The input of this calculation is the heat demand for space heating in according with EN ISO 13790 (building thermal properties and the indoor and outdoor climate). The emission losses are due to non-uniform internal temperature distribution in each thermal zone (stratification, difference between air temperature and mean radiant temperature). The efficiency of the control of the room temperature is another parameter, which are included into the calculation.

The auxiliary energy for the emission system is calculated separately from the thermal energy. Data will be calculated, the emission system heat loss, the auxiliary consumption and the recoverable heat losses.

Space heating distribution system

The calculation of the heating distribution system is done in order to take into account the additional energy requirements (thermal losses from piping, auxiliary consumption of pumps and controls) (EN15316 Part 2.3). In a distribution system energy is transported by a fluid from heat generation to the heat emissions. If the distribution system is not adiabatic, a part of energy conveyed is emitted to the surrounding environment. Energy is also required to distribute the heat carrier fluid within the distribution system, it is in most cases electrical energy required by the circulation pumps. This energy has to be summed to thermal energy demand. The thermal energy emitted by the distribution system and the electrical energy needed for the transport may be recovered as a heat source if the distribution system is placed inside the heated envelope of the building.

The standard provides three methods of calculation:

- The detailed method provides the basics and the physical background of the general calculation method. This method need to know all data of the project (such as length of pipes, the kind of insulation etc..).
- The simplified method need a minor number of data input, and some assumptions are made, this method can be used if only a few data are available. With this method the calculated energy demand is higher than the demand by the detailed method.

The tabulated method is possible with a minimum of input data, and is based on the simplified method. The most important influences are the input data for this method. The energy demand in the tables is higher than by the calculation with the simplified method.

Space heating generation

The energy requirements of the generation system (is the last part of the heating system) complete the method of calculation (EN15316- Part 4.x). The calculation method is based on the performance characteristics of the products presented in product standards as well as on other characteristics necessary to evaluate the performance of the system.

The follows factors influence the energy requirement:

- ⇒ type of the heat generator;
- ⇒ the location of the generator;
- ⇒ the part load ratio;
- ⇒ the running conditions
- ⇒ type of control (e.g. ON-OFF, multi-stage, modulating, cascading, etc)

The space heating generation systems considered in this report are:

- Boilers
- Heat pump systems

Boilers

In EN15316-4.1 three methods are described for calculation of boiler performance. They differ in the data used, in the running conditions taken into account and in the considered of calculation period.
For the first method, the considered period is the heating season. It is based on the boiler directive. The running conditions (climate, distribution system connected to the generator, etc) are considered according to the typology of the region taken into exam. If there is no appropriate annex with the adapted values, this method can not be used. In an annex of the standard default values are given for the calculation of this method, if these value are not given this method can not be used.
The second method is also based on the data related to the boiler directive, but this method need some complementary data in order to take into account the specific running conditions of each individual installation. The calculation period can be the heating season but also a shorter period (month, week etc.). The method is not limited and can be used with default value given in the annex of this standard. If there is not available default data this method can not be used.
The third method features in a more explicit way the losses of a generator during the boiler cycling. Some of these parameters can be measured on site, is possible to adapter this method for existing buildings.

Heat pump systems

The method covers heat pumps for heating, heat pump water heaters and heat pumps with combined heating and domestic hot water production, where the same heat pump delivers the heating and hot water heat requirement (EN15316-4.2). The procedure applies to electrically-driven heat pumps, gas motor-driven heat pumps and absorption heat pumps. Since heat performance depends on the operating conditions, i.e. the source and the sink temperature, thus calculation periods are oriented on the frequency of the ambient dry bulb temperature and not at the time scale (i.e. monthly value).

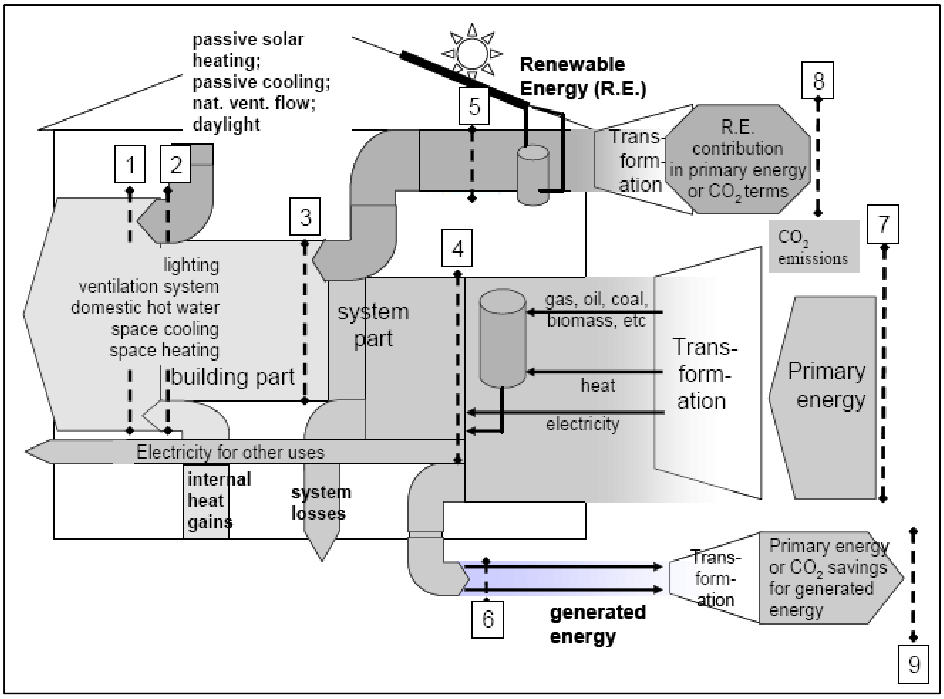


Figure 1.1 – Schematic illustration of the calculation scheme

<u>Key for Figure 1.1:</u>

1. represents the energy needed to fulfil the user's requirements for heating, cooling, lighting etc, according to levels that are specified for the purposes of the calculation.

2. represents the "natural" energy gains – passive solar heating, passive cooling, natural ventilation, day lighting – together with internal gains (occupants, lighting, electrical equipment, etc)

3. represents the building's energy needs, obtained from {1} and {2} along with the characteristics of the building itself.

4. represents the delivered energy, recorded separately for each energy carrier and inclusive of auxiliary energy, used by space heating, cooling, ventilation, domestic hot water and lighting systems, taking into account renewable energy sources and co-generation. This may be expressed in energy units or in units of the energy ware (kg, m³, kWh, etc).

5. represents renewable energy produced on the building premises.

6. represents generated energy, produced on the premises and exported to the market; this can include part of {5}.

7. represents the primary energy usage or the CO_2 emissions associated with the building.

8. represents the primary energy or CO_2 emissions associated with on-site generation which is used on-site and thus is not subtracted from {7}.

9. represents the primary energy or CO_2 savings associated with energy exported to the market, which is thus subtracted from {7}.

The overall calculation process involves following the energy flows from the left to the right of Figure 1.2

1.3 Calculation of primary energy

The primary energy is the way to describe and evaluate the energy efficiency of a building. This factor is the total of the energy demand of the building. The calculation is formed from various procedures in order to determine the calculation of different type of energy delivered to building.

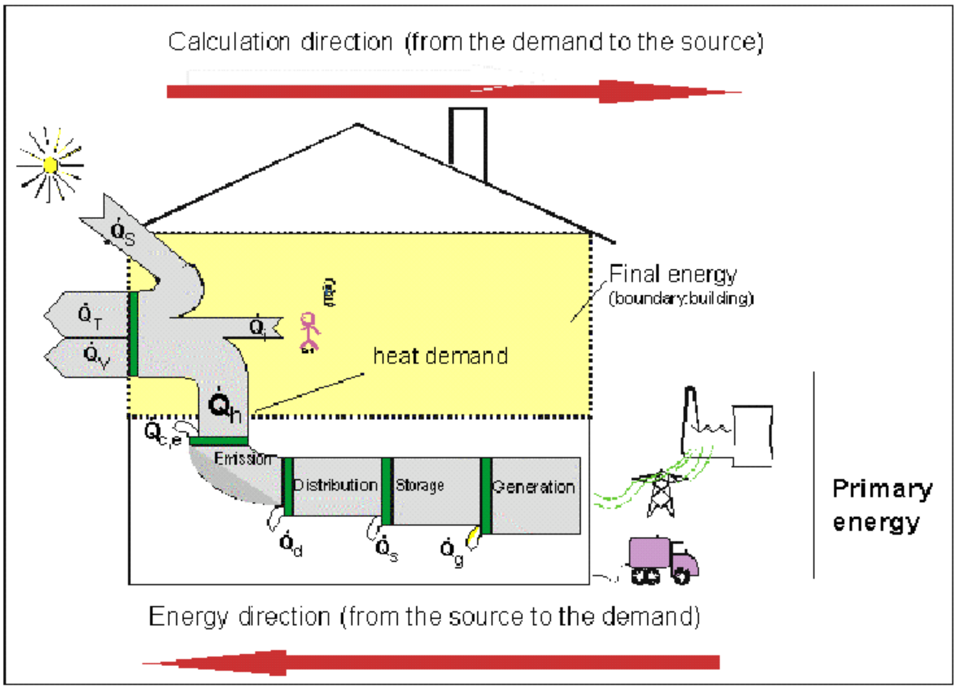


Figure 1.2 - Calculation direction of the primary energy

To illustrate there is two levels of calculation. The first is the calculation of the net energy, that is the balance between solar, internal gains and transmission and ventilation losses. The second is the calculation of the total delivered energy .It is based on analysis of the following parts of a space heating and domestic hot water system, the emission system energy performance , the distribution system energy performance, the storage system energy performance and generation system energy performance (e.g. boilers, solar panels, heat pumps etc.)The energy required for space heating and domestic hot water depends on the distinct input:

⇒ The heat demand for space heating (building thermal properties and the indoor and outdoor climate) and the request for domestic hot water ;
⇒ The space heating and domestic hot water system characteristics and the interaction with the building;
⇒ The whole energy flow from the source to the demand.

In the calculation method the system losses are calculate separately for thermal energy and electrical energy, in order to determine the final energy. Subsequently, the final energy is converted into primary energy. For this purpose it has to multiplied by a conversion factor. The primary energy strategy is done in order to allow for simple addition of contributions from different types of energy (e.g. thermal, electrical) and may be used for comparison of energy requirements of different types of heating systems.

1.4 Ways of expressing energy performance

The energy performance can be expressed at different levels:

- Global energy performance in terms of total primary energy, costs or CO_2 emissions
- Delivered energy

- Net energy of the building regarding the construction or the technical equipment system (e.g. transmission heat transfer coefficient of a building)

- Characteristics of the fabric and system components (e.g. thermal transmittance of walls, efficiency of boilers)

The respective requirements should also be set in order to comply with the performance. The energy requirement can be set by fixing a minimum or maximum value to the different performance indicators.

2 The thermal performance of a building

The thermal performance is determined on the basis of EN ISO 13790. The standard presents a coherent set of calculation methods at different levels of detail, for the energy use for the space heating and cooling of a building and the influence of the heating and cooling system losses, heat recovery and the utilisation of renewable energy sources.
The calculation follows the monthly quasi-steady state calculation method, described in the standard.

In this report the method includes the calculation of:

1. the heat transfer by transmission and ventilation of the building when heated constant internal temperature;

2. the contribution of internal and solar heat sources to the building heat balance;

3. the annual energy needs for heating, to maintain the specified set-point temperatures in the building;

4. the annual energy required by the heating systems of the building for space heating, using heating system characteristics which are to be found in specific EN

Details are shown in Appendix A.

3 Building delivered energy - EN 15316

The building delivered energy is calculated from the building net-energy (see section 2 and Annex A) and adding the calculated losses in the heat emission (section 3.1), heat distribution (section 3.2) and heat generation system (section 3.3). Included in these calculations are the electrical energy use.

3.1 Heat losses for the heat emission system (EN15316-2.1)

The thermal energy required for heat emission $Q_{em,in}$ is given by the following equation:

$$Q_{em,in} = Q_{em,out} - k \cdot W_{em} + Q_{em,ls} \quad \textbf{[J]} \qquad \textbf{(1)}$$

where:

$Q_{em,out}$	thermal output of the heat emission system, which is equal to the energy demand of the building $Q_{H,}$	[J]
k	part of recoverable auxiliary energy in percentage	[%]
W_{em}	auxiliary energy	[J]
$Q_{em,ls}$	heat energy losses	[J]

The auxiliary energy, normally in the form of electrical energy, is used for fans which help the emission. Part of the auxiliary energy can be recovered as heat by this equation:

$$Q_{em,aux,rvd} = k \cdot W_{em} \quad \textbf{[J]} \qquad \textbf{(2)}$$

Emission losses are due to three factors, namely, non-uniform temperature distribution, losses to the outside from embedded heating devices in the structure, and losses due to non-perfect control of the indoor temperature. The heat energy losses of heat emission are calculated as:

$$Q_{em,ls} = Q_{em,str} + Q_{em,emb} + Q_{em,ctr} \quad [J] \qquad (3)$$

where:
$Q_{em,str}$ heat loss due to non-uniform temperature distribution in Joule (J);
$Q_{em,emb}$ heat loss due to emitter position (e.g. embedded) in Joule (J);
$Q_{em,ctr}$ heat loss due to control of indoor temperature in Joule (J).

Two methods are recommended in the standard. The two methods do not give exactly the same results, but the same trend. The two methods shall not be mixed.

3.1.1 Method using efficiencies of the emission system

The evaluation of $Q_{em,ls}$ takes place monthly or by another time period in accordance with equation (4).

$$Q_{\mathrm{em,ls}} = \left(\frac{f_{\mathrm{Radiant}} f_{\mathrm{int}} f_{\mathrm{hydr}}}{\eta_{\mathrm{em,ls}}} - 1 \right) Q_{\mathrm{H}} \qquad (4)$$

where
$Q_{em,ls}$ is the additional loss of the heat emission (time period), in kWh;
Q_H is the net heating energy (time period) (EN ISO 13790), in kWh;
f_{hydr} is the factor for the hydraulic equilibrium.
f_{im} is the factor for intermittent operation (as intermittent operation is to be understood the time-dependent option for temperature reduction for each individual room space);
f_{rad} is the factor for the radiation effect (only relevant for radiant heating systems);
η_{em} is the total efficiency level for the heat emission in the room space.
The total efficiency level η_{em} is fundamentally evaluated as

$$\eta_{em} = \frac{1}{(4 - (\eta_{str} + \eta_{ctr} + \eta_{emb}))} \qquad (5)$$

where
η_{str} is the part efficiency level for a vertical air temperature profile;
η_{ctr} is the part efficiency level for room temperature control regulation;
η_{emb} is the part efficiency level for specific losses of the external components (embedded systems).
In individual application cases this breakdown is not required. The annual expenditure for the heat emission in the room space is calculated as

$$Q_{\mathrm{em,ls,a}} = \sum Q_{\mathrm{em,ls}} \qquad (6)$$

where
$Q_{em,ls,a}$ is the annual loss of the heat emission, in kWh;
$Q_{em,ls}$ is the loss of the heat emission (in the time period) in accordance with equation (4), in kWh.

Default values fro the different efficiencies and factors can be found in an informative annex to the standard. Some of these values are based on real data from experiments and/or computer simulations, while others are made by agreement. Examples of the values included in the annexes are given in table 1 to 3.

3.1.2 Method using equivalent increase in internal temperature

The internal temperature is increased by:

- The spatial variation due to the stratification, depending on the emitter;
- The control variation depending on the capacity of the control device to assure a homogeneous and constant temperature.

The equivalent internal temperature, $\theta_{int,inc}$ taking into account the emitter, is calculated by:

$$\theta_{\mathrm{int},inc} = \theta_{\mathrm{int},ini} + \Delta\theta_{str} + \Delta\theta_{ctr} \quad (°C) \qquad (7)$$

where:

$\theta_{int,ini}$ initial internal temperature (°C);
$\Delta\theta_{str}$ spatial variation of temperature;
$\Delta\ \theta_{ctr}$ control variation.

The influence of an equivalent increase in internal temperature. of the heat emission system may be calculated in two different ways:

- by multiplying the calculated building heat demand, Q_H, with a factor based on the ratio between the equivalent increase in internal temperature, $\Delta\theta_{int,inc}$, and the average temperature difference for the heating season between the indoor and outdoor temperature for the space:
  $Q_{em,ls} = Q_H \cdot (1 + \Delta\theta_{int,inc} / (\theta_{int,inc} - \theta_{e,avg}))$ [J] (8)

- by recalculation of the building heat energy requirements, according to EN ISO 13790, using the equivalent increased internal temperature. as the set point temperature of the conditioned zone. This second approach leads to a better accuracy.

For η_{str} an average value is to be formed from the data for the main influence parameters "over-temperature" and "specific heat losses via external components".

$$\eta_{str} = (\eta_{str1} + \eta_{str2})/2 \qquad (9)$$

Table 3.1 — Efficiencies for free heating surfaces (radiators); room heights ≤4 m

Influence parameters		Efficiencies			
		η_{str}		η_{ctr}	η_{emb}
Room space temperature regulation	unregulated, with central supply temperature regulation			0.80	
	Master room space			0.88	
	P-controller (2 K)			0.93	
	P-controller (1 K)			0.95	
	PI-controller			0.97	
	PI-controller (with optimisation function, e.g. presence management, adaptive controller)			0.99	
		η_{str1}	η_{str2}		
Over-temperature (reference Θ_i = 20 °C)	60 K (e.g. 90/70)	0.88			
	42.5 K (e.g. 70/55)	0.93			
	30 K (e.g. 55/45)	0.95			
specific heat losses via external components (GF = glass surface area)	radiator location internal wall		0.87		1
	radiator location external wall				
	- GF without radiation protection		0.83		1
	- GF with radiation protection[a]		0.88		1
	- normal external wall		0.95		1

[a] The radiation protection must prevent 80% of the radiation losses from the heating body to the glass surface area by means of insulation and/or reflection.

EXAMPLE radiator external wall; over-temperature 42.5 K; P-controller (2 K)

$\eta_{str} = (\eta_{str1} + \eta_{str2})/2 = (0.93 + 0.95)/2 = 0.94$; $\eta_{ctr} = 0.93$; $\eta_{emb} = 1$
$\eta_{em} = 1/(4 - (0.94 + 0.93 + 1)) = 0.88$

Factor for intermittent operation f_{im} = 0.97
Factor for radiation effect: f_{rad} = 1.0

Table 3.2 — Factor for hydraulic balancing: f_{hydr}

	Influencing parameters	Factor for hydraulic balancing, f_{hydr}
Hydraulic balance	non balanced systems	1.03
	Signed balancing report and in compliance with EN 14336 • more than 8 emitters per automatic differential pressure control or only static balanced systems	1.02
	Signed balancing report and in compliance with EN 14336, • Max 8 emitters per automatic differential pressure control	1.00

For η_{emb} an average value is to be formed from the data for the main influence parameters "system" and "specific heat losses via laying surfaces".

$$\eta_{emb} = (\eta_{emb1} + \eta_{emb2})/2 \tag{10}$$

Table 3.3 Efficiencies for component integrated heating surfaces (panel heaters); room heights ≤4m

influence parameters		Part efficiencies			
		η_{str}	η_{ctr}	η_{emb}	
Room space temperature regulation	Heat carrier medium water				
	- unregulated		0.75		
	- unregulated, with central supply temperature regulation		0.78		
	- unregulated with average value formation ($\vartheta_V - \vartheta_R$)		0.83		
	- Master room space		0.88		
	- two-step controller/P-controller		0.93		
	- PI-controller		0.95		
	Electrical heating				
	-two-step controller		0.91		
	- PI-controller		0.93		
System	Floor heating			η_{emb1}	η_{emb2}
	- wet system	1		0.93	
	- dry system	1		0.96	
	- dry system with low cover	1		0.98	
	Wall heating	0.96		0.93	
	Ceiling heating	0.93		0.93	
Specific heat losses via laying surfaces	Panel heating without minimum insulation in accordance with DIN EN 1264				0.86
	Panel heating with minimum insulation in accordance with DIN EN 1264				0.95
	Panel heating with 100% better insulation than required by DIN EN 1264				0.99

EXAMPLE Floor heating - wet system (water); two-step controller; floor heating with high level of heat protection

η_{str} = 1.0; η_{ctr} = 0.93; $\eta_{emb} = (\eta_{emb1} + \eta_{emb2})/2 = (0.93 + 0.95)/2 = 0.94$

$\eta_{em} = 1/(4 – (1.0 + 0.93 + 0.94)) = 0.88$

Factor for intermittent operation: f_{im} = 0.98
Factor for radiation effect: f_{rad} = 1.0
Factor for hydraulic balancing: f_{hydr} same as for radiators

Table 3.4 — Efficiencies for room spaces with heights > 10 m

Influence parameters			Part efficiencies				
			η_{str}			η_{ctr}	η_{emb}
			12 m	15 m	20 m		
Room space temp. regulation	Unregulated					0.80	
	Two-step controller					0.93	
	P-controller (2 K)					0.93	
	P-controller (1 K)					0.95	
	PI-controller					0.97	
	PI-controller with optimisation					0.99	
	Warm air without additional vertical recirculation	Outlet horizontal	0.78	0.72	0.63		1
		Outlet vertical	0.84	0.78	0.71		1
	Warm air with additional vertical recirculation	Outlet horizontal	0.88	0.84	0.77		1
		Outlet vertical	0.91	0.88	0.83		1
	Warm water panels		0.94	0.92	0.89		1
	Radiant tube heaters		0.94	0.92	0.89		1
	Luminous heaters		0.94	0.92	0.89		1
	Floor heating (high heat protection level)		0.94	0.92	0.89		
		Floor heating component integrated					0.95
		Floor heating thermally decoupled					1

Warm air heating systems with increased induction ratio of air distribution:
The parameters are determined by the arithmetic averaging of the parameters for the systems with air outlet horizontal or vertical.
The determination of the total efficiency η_{em} takes place in accordance with equation (A2).
EXAMPLE Room height 12 m. dark radiators, P-controller (2 K)

η_{str} = 0.94
η_{ctr} = 0.93
η_{emb} = 1
η_{em} = 1/(4 –(0.94 + 0.93 + 1)) = 0.88

Factor for radiation effect: f_{rad} = 0.85 for warm water panels, luminous heaters, radiant tube heaters and floor heating.
The energy parameters of the efficiencies of heating systems in large indoor spaces and the factor f_{rad} represent average values for the heating systems and types of products, which can also approximately be used for configurations that deviate from these.

3.2 Space heating distribution system

In a distribution system energy is transported by a fluid from the heat generation to the heat emission. The European Standard EN 15316-2-3 [11] presents methods for calculation of the system thermal loss of water based distribution system for heating and the auxiliary energy demand, as well as the recoverable part of each.
The standard gives three methods of calculation to obtain different levels of accuracy, corresponding to the needs of the user and the input data available at each design stage of the project. The methods are:

- a detailed calculation method
- a simplified calculation method
- a method based on tabulated values

The general method of calculation can be applied for any time-step (hour, day, month, or year).

The detailed method for calculation of distribution losses in the standard gives the most exact results for net energy and emission losses. Normally specific data from the project is needed.
The simplified method is used when only a few data are available, so that some assumptions are made, (for example the length of pipes are calculated by approximations depending on the outer dimensions of a building). Whit this method the calculate energy demand is higher than the calculated energy demand by the detailed method.
The tabulated method based on the simplified method takes some more assumptions into account. It can be done with a minimum of input data. The energy demand calculated in this way is higher than calculated in the simplified method.

The calculation method for the electrical energy demand of pumps has two parts. The first is to calculate the hydraulic demand of the distribution system and the second is to calculate the expenditure energy factor of the pump. For this part it is possible to mix the detailed method with the simplified method. For example the calculation of pressure loss and mass flow can be calculated by the detailed method and the expenditure energy factor may be calculated by the simplified method or vice versa. The method of calculation of the distribution system and the auxiliary demand is given in Annex B..

3.3 Space heating generation

The European Standard (EN15316-4.1) presents methods for calculation of the additional energy requirements of heat generation system. The calculation is based on the performance of the products given in product standards and on other characteristics required to evaluate the performance of the products as included in a system.

The calculation input and output parameters for the generation sub-system are shown on Figure 3.3:

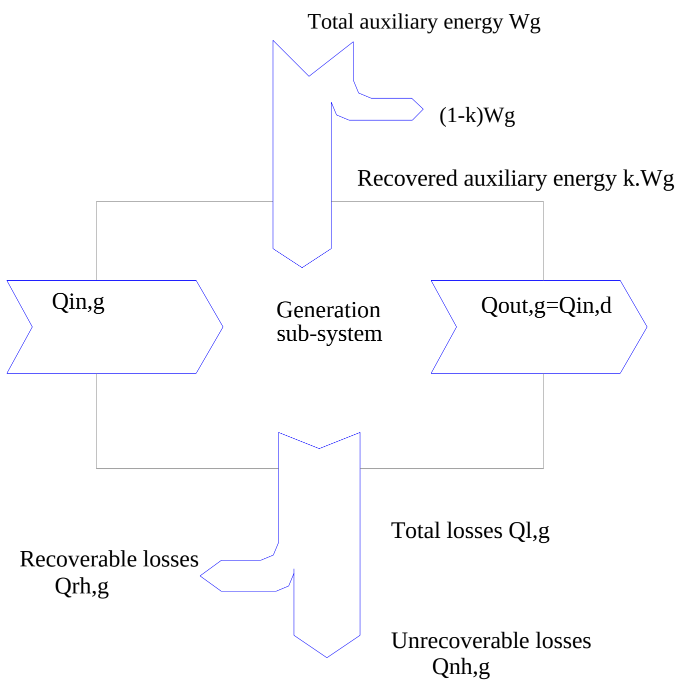


Figure 3.3 - Generation sub-system

where:

W_g total auxiliary energy required by the generation subsystem
$Q_{g,out}$ heat supplied to the distribution systems
$Q_{g,in}$ heat requirement of the generation subsystem
$Q_{l,g}$ total losses of the generation subsystem
$Q_{rh,g}$ recoverable losses of the generation subsystem
$Q_{g,,nh}$ unrecoverable losses of the generation subsystem

Thermal energy required for heat generation

The relationship between energies, within the generation subsystem, is given by:

$$Q_{g,in} = Q_{g,out} - K_{g,rd} \cdot W_g + Q_{g,l} \qquad \textbf{[J]}$$

where

$K_{g,rd}$ part of recovered auxiliary energy by the generation sub-system (i.e: burner fan)

Auxiliary energy

Energy, other than fuel, necessary for the operation of the burner and for the primary pump and all equipment related to the heat generation subsystem operation. The auxiliary energy is normally in the form of electrical energy, it can partially be recovered as heat for space heating or for the generation sub-system.

Not all the calculate system losses are lost. Some of them are recoverable and only a part of the recoverable system heat losses are really recovered. The generation losses recovered by the generation subsystem are directly taken into account in the generation performance.

Details are shown in Annex C for Boilers (EN15316-4.1) and Annex D for Heat pumps (EN15316-4.2).

3.4 Primary energy

The primary energy calculation strategy (EN15317) is necessary in order to sum up the values calculated for several types of energies (e.g. electrical and thermal). It is useful for a comparison of energy requirements of different types of heating systems.

Primary energy input

Over a given period (e.g. year, month) the primary energy input E_p to the space heating and domestic hot water system, is given by:

$$E_p = \sum Q_{f,h} \cdot f_{p,i} + \sum W_h \cdot f_{p,i} + \sum Q_{f,w} \cdot f_{p,i} + \sum W_w \cdot f_{p,i} \qquad \text{[J]}$$

where

$Q_{f,h}$	final energy required by the space heating system in Joule	[J]
$f_{p,i}$	primary energy conversion factor for each type of energy used (e.g. thermal, electrical, solar). This factor shall be given on a national basis	[-]
W_h	auxiliary energy needed for space heating in Joule	[J]
$Q_{f,w}$	final energy required by the domestic hot water system in Joule	[J]
W_w	auxiliary energy needed for domestic hot water production in Joule	[J]

Final energy required for space heating

The final energy required for space heating is given by the following equation:

$$Q_{f,h} = (Q_h - Q_{rhh} - Q_{rwh}) + Q_{th} \qquad \text{[J]}$$

where

Q_h	heat demand (net energy) for space heating	[J]
Q_{rhh}	heat recovered from the space heating system (thermal and electrical)	[J]
Q_{rwh}	heat recovered from the domestic hot water system (thermal and electrical) for the space heating demand	[J]
Q_{th}	total of the heat losses due to the space heating system. This term is got by summing the emission ,distribution and generation losses of heating system. The total space heating system loss includes the recovered space heat loss.	[J]

Auxiliary energy

Auxiliary energy normally in the form of electrical energy is used for circulation pumps, fans, valves and controls. The auxiliary energy requirement may be available as a value for each sub-system W_x , or as a value for the whole system.

4 Description of the cases studied

This report is using an excel spreadsheet which follows the procedures, described in the standardsnts using equations and data for input parameters. The calculations contain the determination of the design heat load. The calculations contain also the determination of the system losses of emission, distribution and generation and primary energy. In the calculation energy demand and losses due to DHW (domestic hot water) are not taken in to account.

4.1 Description of the buildings

4.1.1 Residential house

The house is a small family house with total floor area of 101 m^2. The house was based on an example from the EN 12831[7]. Although, for the purpose of the calculation, a more simplified case of the referent example given in the standard is assumed.

The seven premises of the house are situated on one floor. The house is of light weight material with heavy thermal insulation. The floor is in contact with the ground.
A table of input data for the house is showed below: Table 4.1

Table 4.1 - Input data for heat demand of the family house

Orientation	North-South
Glazing fraction from the whole facade	25%
Occupants	4
Solar protection	Curtains
Total floor heated area	101m^2
Room height	2.5m
Internal gains	5W/m^2
U_{wall}	0.43W/m^2K
U_{floor}	0.48W/m^2K
U_{roof}	0.2W/m^2K
$U_{windows}$	1.7W/m^2K
U_{door}	1.7W/m"K

The measures of the house are L=11.75 [m] B= 8.6 [m]

A layout of the floor is given on Figure 4.1 (next page).

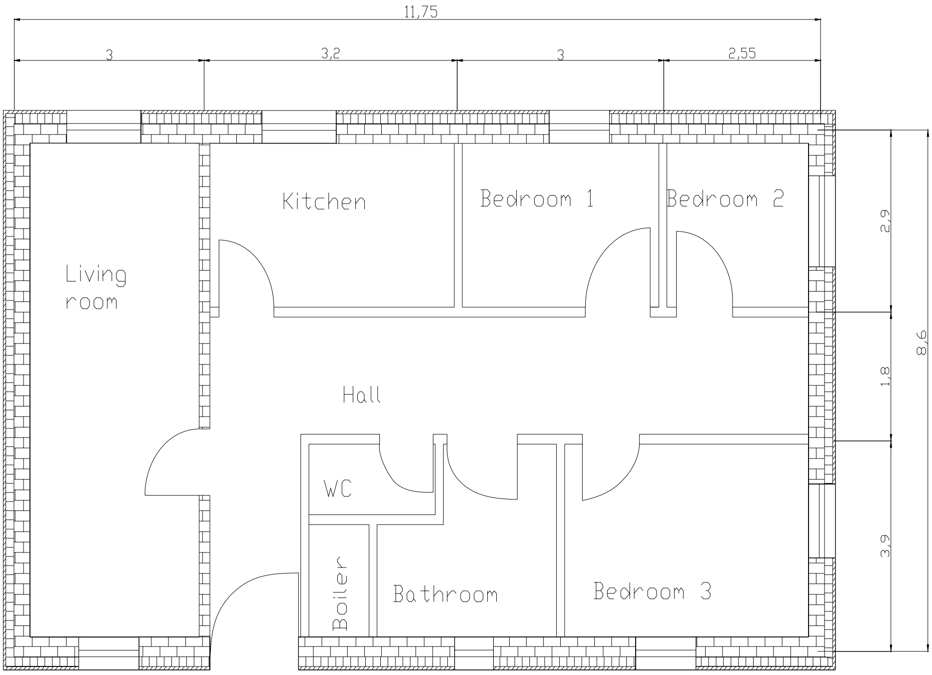


Figure 4.1 - Layout of the house

4.1.2 Office building

The building is a middle-size office building with office modules aligned on two facades, separated by a central corridor, with staircase/service spaces at both ends of the building.
The office building comprises 210 office modules, distributed over 7 floors and 2 orientations, see Figure 4.2.
A table of input data for the house is showed below: Table 4.2

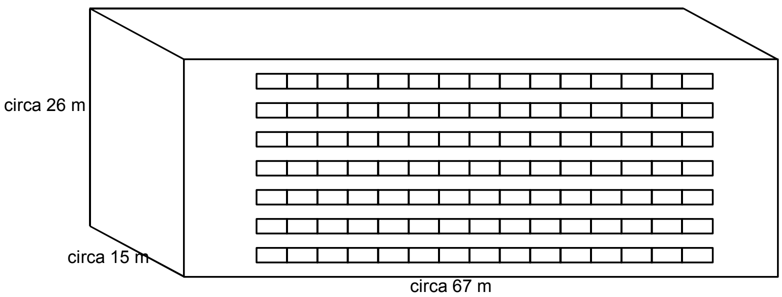


Figure 4.2 Front view with rough main measures (from outside to outside)

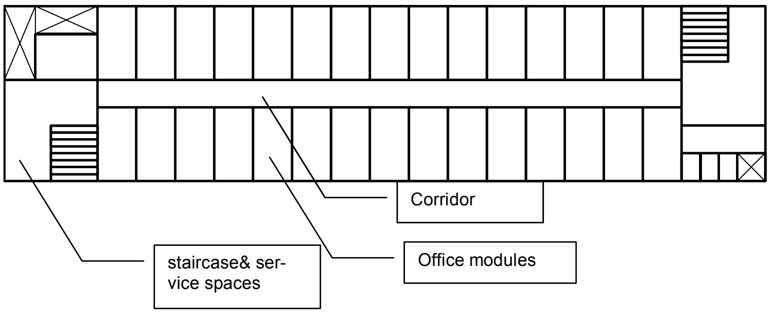


Figure 4.3 - Top view on floor

Table 4.2 Input data for heat demand of office building

Orientation	North-South
Occupants	315
Total floor heated area	5670 m^2
Room height	2.7 m
Internal gains	30,36 W/m^2
U_{wall}	0.301 W/m^2K
U_{floor}	0.337 W/m^2K
U_{roof}	0.324 W/m^2K
$U_{windows}$	1.62 W/m^2K

The building is a 7 storey office building with measures as shown in Figure 4.4 – 4.6

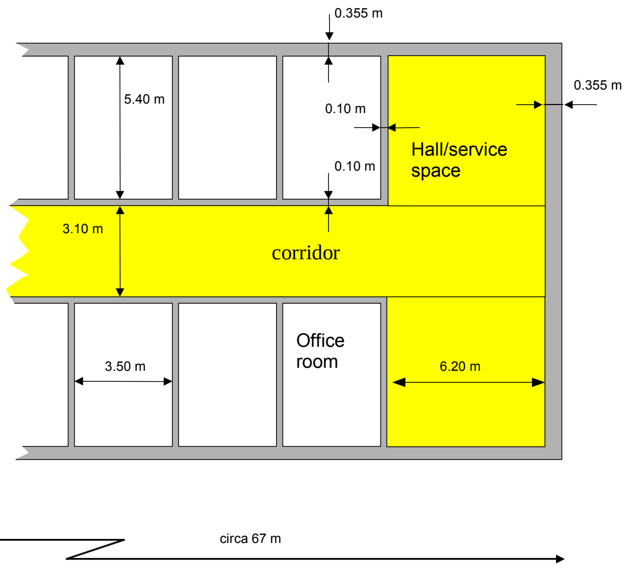


Figure 4.4 - Horizontal cross section of 6 office modules plus hall, plus part of corridor with main measures

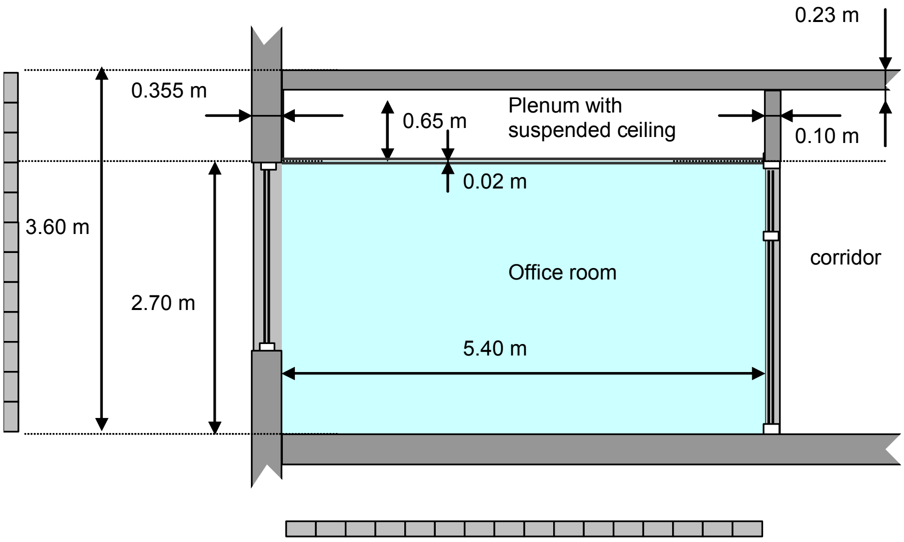


Figure 4.5 - Vertical cross section of office module with main measures

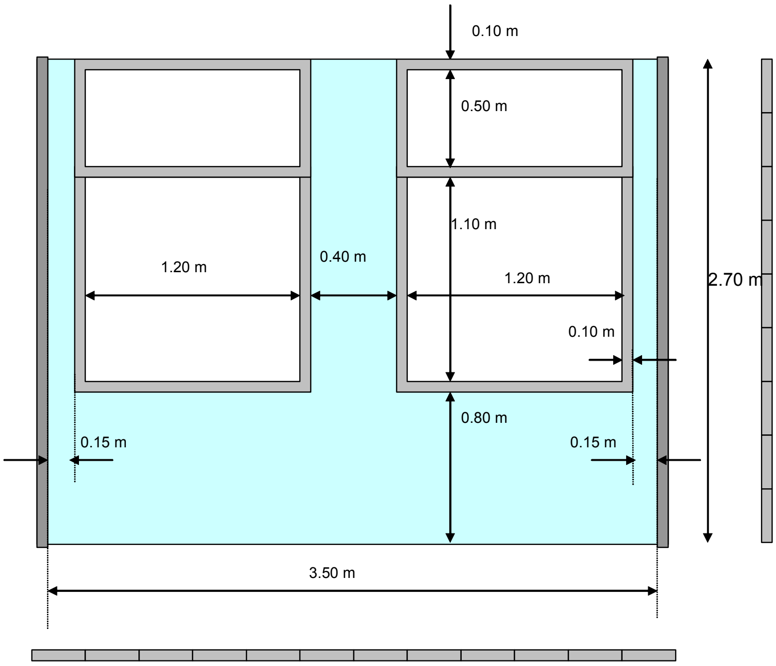


Figure 4.6 - Facade layout

4.1.3 Industrial building

The building is a middle-size industrial building with total floor area of 2400 m^2. The roof is with a glazing fraction of 1/7 of the total floor area. Two main doors (10x7m) are situated on two adjacent side of the building. Figure 4.7

Table 4.3 - Input data for heat demand of industrial building

Orientation	North-South
Glazing fraction	1/7 floor area
Occupants	
Total floor heated area	$2400m^2$
Medium height	15m
Internal gains	W/m^2
U_{wall}	$0.43W/m^2K$
U_{floor}	$0.48W/m^2K$
U_{roof}	$0.2W/m^2K$
$U_{windows}$	$1.7W/m^2K$
U_{door}	$1.7W/m^{"}K$

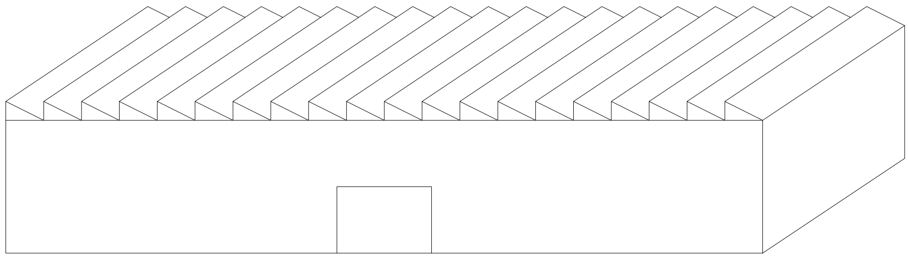


Figure 4.7 - Front view

5 Calculation of building net energy

The net energy calculation procedure is derived from EN ISO 13790.
The heat load is calculated with a procedure founded on the standard using an Excel spreadsheet document (Anderson, 2004).
In the calculation the heating-up capacities of heated spaces is not taken into account. The calculation of heat load is made for three locations; Stockholm, Brussels and Venice.
The temperature correction factors used in the calculation of the transmission heat loss is chosen, considering the building's thermal bridges insulated, for the external walls.

- For the family house the internal design temperature was chosen 20 ° C for all rooms. The minimum external air exchange to guarantee indoor air quality was chosen to be 0,5/h air changes per hour for all premises.

- For the office building the internal design temperature was chosen 20°C for all the office modules. The minimum external air exchange was chosen 1,2/h for heated space in all the premises. Staircase and service spaces were not considered in the calculation.

- For the industrial building the internal design temperature was chosen 16 °C for all spaces. The minimum external air exchange was chosen 1/h. The entire building is assumed to be one open space.

The buildings are considered as single zone because all the premises are heated to the same set point temperature. For family house's bathroom there was made an approximation because the in the spreadsheet all the rooms are assumed to have the same temperature.
In the calculations the residential house was considered continuously heated, while the office and industrial building were considered heated from Monday to Friday and only during day time (from 6.00 to 20.00).
The heating season is set to be 9 months in Stockholm, 7 months in Brussels and 6 months in Venice. Monthly values for external average air temperature and solar irradiance are given in Appendix E.
First of all the net energy (building energy demand) was calculated according to prEN13790 for a residential building located in three different climatic zones: Stockholm, Brussels, and Venice. Table 5.1 show the results together with values for the design heat load, design outdoor temperature and heating season average outdoor temperature

Table 5.1. Energy data for a residential building used in the calculations.

			Climatic zone		
Location			Stockholm	Brussels	Venice
Design outdoor temperature,		°C	-16	-10	-5
Average heating season outdoor temperature		°C	3,3	6,6	7,8
Residential	Design heat load	W/m²	54	45	38
	Yearly net energy demand	kWh/m²a	142	88	66
	Domestic Hot Water		22	22	22
Office	Design heat load	W/m²	50	42	35
	Yearly net energy demand	kWh/m²a	71	48	36
	Domestic Hot Water		8	8	8
Industrial	Design heat load	W/m²	104	105	84
	Yearly net energy demand	kWh/m²a	72	46	42

The use of domestic hot water (see table 5.1) is not included in the delivered and primary energy values in the next chapters. It is, however included in sizing the heat generators (boilers, heat pump). The residential building has a specific net energy demand higher than office and industrial buildings since the system runs for 24 hours instead of 14 hours on week days.

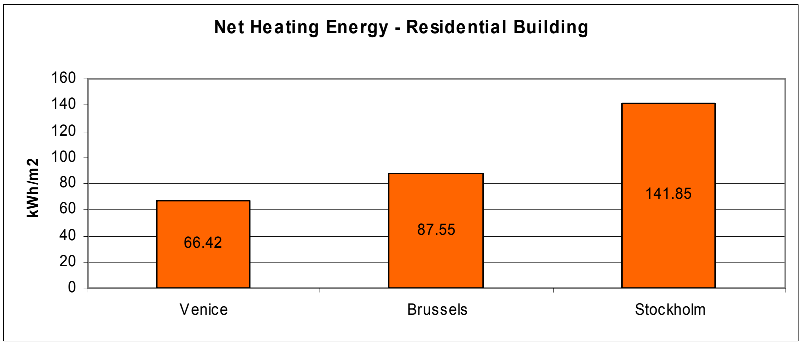


Figure 5.1 – Specific net heating energy (residential building)

The specific net heating energy demand of the office building is comparable with the specific net energy demand of the industrial building.

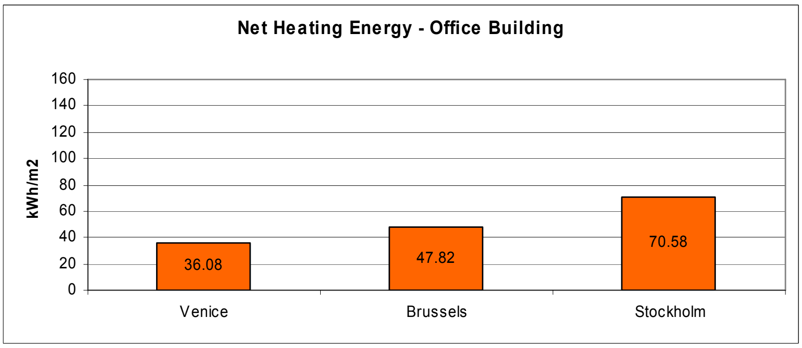


Figure 5.2 – Specific net heating energy (office building)

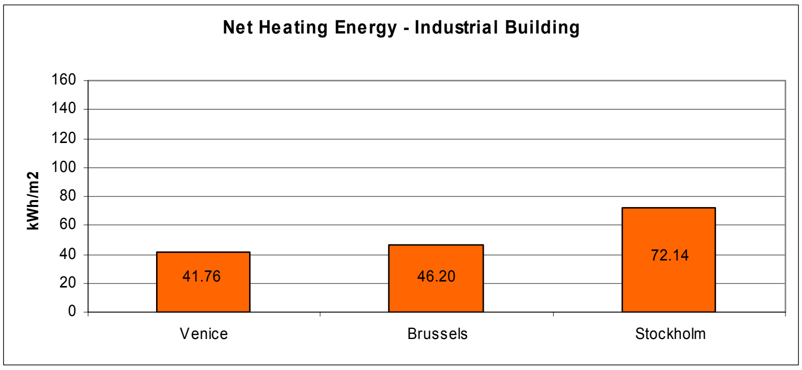


Figure 5.3 – Specific net heating energy (office building)

Logically the heat requirements are higher in colder climate.

6 Calculation of building delivered energy

6.1 Emission losses

Losses due to emission from radiators, floor heating and convective system, are calculated for all climatic conditions. The building heat energy requirements Q_H, calculated for each situation in the excel sheets based on the EN 13790 standard, are used in the calculation of the emission losses.

The emission losses are calculated after the two methods in EN15316-2-1 [9].
Emission losses are calculated for different control systems and different system water temperatures. Table 6.1 gives a description of the system types and there locations.

Table 6.1 - Type of heat emission systems

	Residential	**Office**	**Industrial**
Floor heating	x	x	x
Radiators	x	x	
Radiant panel system			x
Int. Design temperature C°	20	20	16
Floor area m²	101	5670	2400
Emission system	**ΔT**	**Control system**	
Radiators 70/55/20	42.5	Radiator thermostats: P(2K) P(1K) Wall mounted PI	
Radiators 55/45/20	30		
Radiators 50/30/20	22.5		
Floor heating	<40	P-controller and PI-controller	
Warm water panels			

Table 6.2 Calculation heat emission losses in a residential building

Residential		ΔT	η_{str1}	η_{str2}	η_{emb}	η_{ctr}	η_{str}	η_{em}	Stockholm $Q_{em,ls}$ Qh = 141,85 KWh/m²	Brussels $Q_{em,ls}$ Qh = 87,55 KWh/m²	Venice $Q_{em,ls}$ Qh = 66,42 KWh/m²
Radiators (boiler) 70/55/20	P(2K)	42,5	0,93	0,95	1	0,93	0,94	**0,88**	18,4	11,4	8,6
	P(1K)					0,95		**0,90**	15,6	9,6	7,3
	PI					0,97		**0,92**	12,8	7,9	6,0
Radiators (boiler) 55/45/20	P (2K)	30	0,95	0,95	1	0,93	0,95	**0,89**	17,0	10,5	8,0
	P (1K)					0,95		**0,91**	14,2	8,8	6,6
	PI					0,97		**0,93**	11,3	7,0	5,3
Radiators (Heat Pump) 50/35/20	P (2K)	22,5	0,96	0,95	1	0,93	0,955	**0,90**	16,3	10,1	7,6
	P (1K)					0,95		**0,91**	13,5	8,3	6,3
	PI					0,97		**0,93**	10,6	6,6	5,0
			η_{emb1}	η_{emb2}	η_{emb}	η_{ctr}	η_{str}	η_{em}			
Floor heating	P-control		0,93	0,95	0,94	0,93	**1**	**0,89**	18,4	11,4	8,6
35/28	PI-control					0,95	**1**	**0,90**	15,6	9,6	7,3
Floor heating extra insulation	P-control		0,93	0,99	0,96	0,93	1	**0,90**	15,6	9,6	7,3
	PI-control					0,95		**0,92**	12,8	7,9	6,0
Floor heating No downwards loss	P-control		1	1	1	0,93	1	**0,93**	9,9	6,1	4,6
	PI-control					0,95		**0,95**	7,1	4,4	3,3

Table 6.3 Calculation of heat emission losses in an office building

Office		ΔT	η_{str1}	η_{str2}	η_{emb}	η_{ctr}	η_{str}	η_{em}	Stockholm $Q_{em,ls}$ Qh = 70,58 KWh/m²	Brussels $Q_{em,ls}$ Qh = 47,82 KWh/m²	Venice $Q_{em,ls}$ Qh = 36,08 KWh/m²
Radiators (boiler) 70/55/20	P(2K)	42,5	0,93	0,95	1	0,93	0,94	**0,88**	9,2	6,2	4,7
	P(1K)					0,95		**0,90**	7,8	5,3	4,0
	PI					0,97		**0,92**	6,4	4,3	3,2
Radiators (e.g.) 55/45/20	P (2K)	30	0,95	0,95	1	0,93	0,95	**0,89**	8,5	5,7	4,3
	P (1K)					0,95		**0,91**	7,1	4,8	3,6
	PI					0,97		**0,93**	5,6	3,8	2,9
Radiators (HP) 50/35/20	P (1K)	22,5	0,96	0,95	1	0,93	0,955	**0,90**	8,1	5,5	4,1
	P (1K)					0,95		**0,91**	6,7	4,5	3,4
	PI					0,97		**0,93**	5,3	3,6	2,7
			η_{emb1}	η_{emb2}	η_{emb}	η_{ctr}	η_{str}	η_{em}			
Floor heating No down-wards loss	P-control		1	1	1	0,93	1	**0,93**	4,9	3,3	2,5
	PI-control					0,95		**0,95**	3,5	2,4	1,8

Table 6.4 Calculation of heat emission losses in an industrial building

Industri										Stockholm $Q_{em,ls}$	Brussels $Q_{em,ls}$	Venice $Q_{em,ls}$
										Qh = 72,14	Qh = 46,20	Qh = 41,76
		η_{str}	η_{ctr}	η_{emb}	$\boldsymbol{\eta_{em}}$	f_{rad}	f_{im}	f_{hydr}	*Emission factor*	KWh/m²	KWh/m²	KWh/m²
Warm water panels	PI-controller	0,92	0,97	1	**0,90**	0,85	1	1	-0,06	-4,1	-2,6	-2,4
Warm Air, horizontal	PI-controller	0,72	0,97	1	**0,76**	1	1	1	0,31	22,4	14,3	12,9
Floor heating, integrated	PI-controller	0,92	0,97	0,95	**0,86**	0,85	1	1	-0,01	-1,0	-0,6	-0,6
Floor heating insulation	PI-controller	0,92	0,97	1	**0,90**	0,85	1	1	-0,06	-4,1	-2,6	-2,4

As described earlier the standard also include a second method, the french method.; the building net heat energy requirements Q_H, are recalculated according to EN ISO 13790, using the equivalent increased internal temperature (French method), as the set point temperature of the conditioned zone. The difference of the original Q_H and the new Q_{H+em} is the emission losses.

The following diagram show the differences between the two calculation methods.
Figure 6.1 shows the emission losses for each emission system in every location. In most cases the German method give less emission losses than the French method. Only for PI-control and in Stockholm the German method give a little higher emission losses than the French method.
According to the results the smallest emission losses for each location are with a radiator system with PI-(on-off) room temperature control. The overall lowest emission losses are with radiator system 55/35/20 (ΔT = 22, 5) with PI - room temperature control.
In the diagram is floor heating with additional insulation or with no downwards losses (multi-story buildings) not included. From table 6.2 and 6.3 it is clear that in those cases floor heating get a much better performance.

In case of a floor heating the German method takes into account the emission losses through the floor, when floor is in contact with the ground. This is not included in the French method. The German method allows one to use extra insulation in the floor. The effect of using extra insulation for a floor system is presented in Figure 6.2. An even lower value for the heat emission losses can be seen in table 6.2 for the floor with no downwards losses.

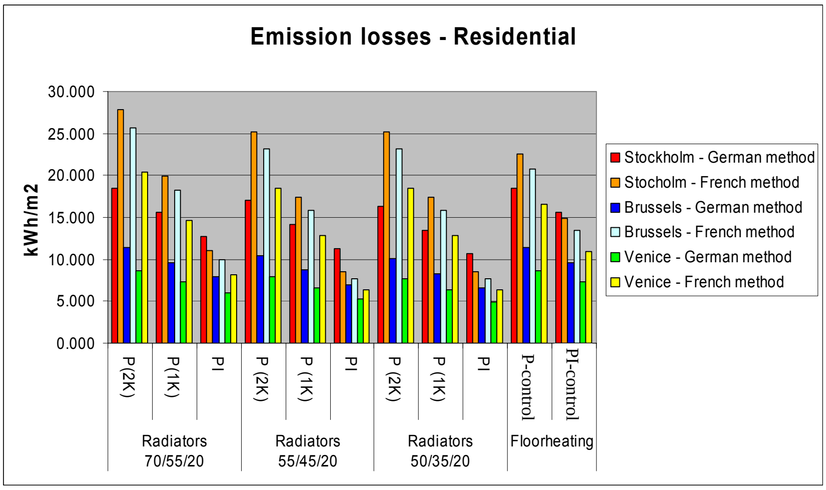


Figure 6.1 – Specific emission losses (residential building)

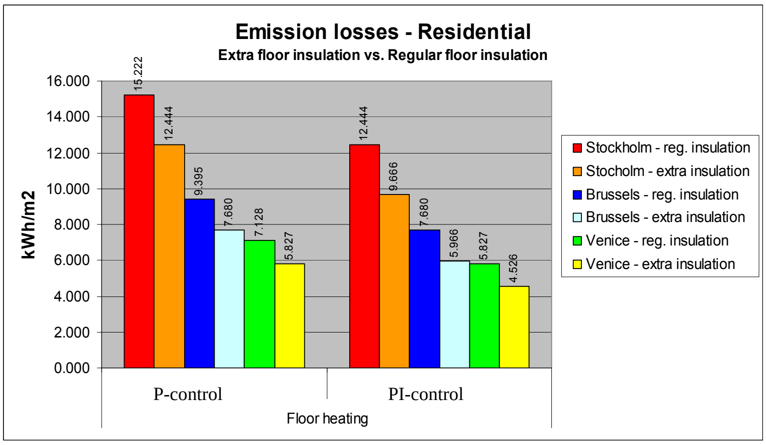


Figure 6.2 – Emission losses and insulation (residential building)

In the case of a industrial building table 6.3 clearly shows how floor heating have much smaller emission losses than a warm air system. The reason why the values are negative is the improved performance given by the factor for radiant heating, 0.85. Warm ceiling panels and floor heating is in the standard given the same values, which should be discussed.

All three previous diagrams clearly show how improved room temperatures control regulation and lower mean emission design temperature, results in smaller emission losses.

The possible energy savings by using extra insulation are presented in Table 6.5

Location	Q_H	Energy savings [kWh/m2]						
		P-control	P-control and insulation	%	PI-contr.	%	PI-contr. and insul.	%
Stockholm	141.74	0	2.78	2	2.78	2	5.56	4
Brussels	87.48	0	1.71	2	1.71	2	3.43	4
Venice	66.37	0	1.30	2	1.30	2	2.60	4

Table 6.5 – Possible energy savings in extra floor insulation

Since the German method is a total efficiency factors multiplied to the building net energy needs [Q_H], the savings are relatively the same for each location, although more energy will be saved in Stockholm than in Brussels or Venice since the energy demands are higher there and therefore the energy savings higher.

Heat losses through the floor have a very big influence on the results. Figure 6.3 shows the difference of the results when calculation were made for the office building, when heat losses were assumed to take place through every floor of the building (7 floors).

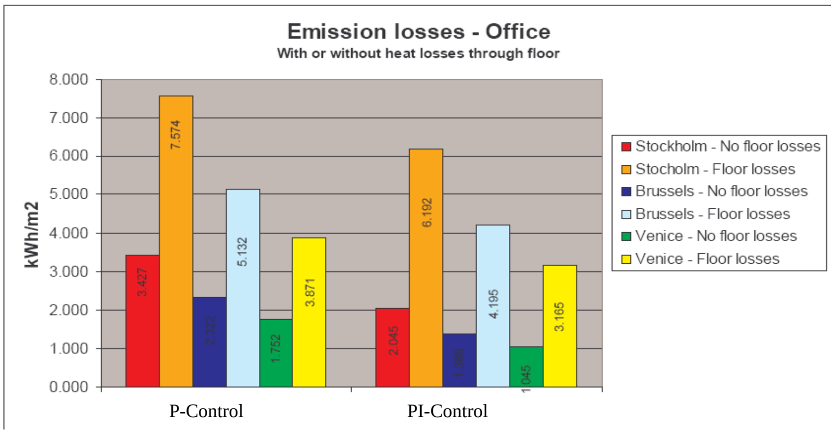


Figure 6.3 – Emission losses with or without floor losses (office building)

It is interesting that the room temperature control does not influence the difference between the results of heat losses through floor and no heat losses through floor. That is there is always the same difference, regardless which room temperature control is chosen. This is because the control losses are always the same, regardless of embedded losses. Therefore in both cases the only chances made is the embedded losses which are the same for each control system.

6.2 Distribution losses

The calculation procedure for the distribution heat losses is done according to EN 15316-2-3 [11]. The calculation procedure utilizes the “simplify method” described in the standard. It is used to calculate the auxiliary energy demand and also to calculate the heat emission of distribution systems. The distribution system is considered a two pipes system. The methods lend attention particularly at part load factor $\beta_{D,}$ important for auxiliary energy demand and for the heat emission of the pipes.

The part load factor gets on the energy required including emission and control, the design heat load, and the heating hours in the zone per time step. The heating hours in the time step for calculation is 6480 for Stockholm 5040 for Brussels and 4320 for Venice. These values are obtained considering the hours of heating season, 9 months for Stockholm, 7 months for Brussels, 6 months for Venice.

Auxiliary energy

The flow is calculated in the distribution system. The calculations need some input parameters;

a) design heat load
b) the specific heat capacity
c) density of fluid used
d) the design temperature difference $\Delta\theta_{HK}$ from supply and return temperature of fluid (table 6.4)

In the calculation of Δp there is used tabulated default value given in the standard [9] for additional pressure loss for floor heating systems and for pressure loss for generators.

The values are:

Δp_{FBH}= 25 [kPa]
Δp_{WE}= 20 [kPa]

For radiators there is not values of additional pressure loss, therefore Δp_{FBH}=0.
For the calculation of maximum length of the heating circuit, to insert in the Δp equation, is used the real length of the circuit.

In the calculation of hydraulic energy demand $W_{d,e}$ there is used two characteristic correction factor of layout system:

- two-pipe heating system f_{Sch}= 1
- hydraulic balanced heating systems f_{Abgl}=1

The efficiency factor f_e used in the calculation of expenditure energy for circulating pump operation is calculated assuming the unknown value of pump and new building (b=1).

Heat distribution system:

The pipe length is calculated considering the real length of the pipes within the building. The method considers the effective pipes length for both losses calculation, of the pumps and heating systems.

The examples of real system layout of the three buildings are presented in Appendix F
The position of pipes is considered to be in the heated space.
The calculation of heat emission is made considering the distribution systems formed by parts with same U-Value and the same mean medium and surrounding temperature. The mean medium temperature is calculated considering the heating circuits with outdoor temperature compensation of the supply temperature, it depends on the mean emission system design temperature above the room temperature:

$$\Delta\theta_a = \frac{\theta_{va} + \theta_{ra}}{2} - \theta i$$

Where the supply θ_{va} and return θ_{ra} temperature for the heating systems are shown in the previous, table 6.1. The internal temperature θ_i is 20°C.
The mean medium temperature depend also from mean part load of the distribution system according to the equation:

$$\theta_m = (\beta_D) = \Delta\theta_a \cdot \beta_D^{\ 1/n} + \theta_i$$

The standard value of exponent used is:

- floor heating=1,1
- radiator=1,33

In the procedure there is used U-value tabulated in the standard. They are chosen as considering a new building.
The surrounding temperature and the U-value tabulated are shown in the following table 6.6

Table 6.6 - Surrounding temperature and U-value tabulate in the standard

Surrounding temperature		U-value
Heated space	20°C	0,255 W/mk
Unheated space	13°C	0,2 W/mk

Distribution thermal losses are higher for radiators and convective system than floor heating, even in the case of low temperature radiators couple with heat pump.
The heat losses from the pipes increase with the length of the heating circuit, and decrease with the decrease of average water temperature between the supply and return water for the same floor area.
As for distribution auxiliary energy, floor heating has always higher losses respect of radiators an convective system. If however we look at the sum of the thermal and auxiliary losses a floor heating systems will have less distribution losses.

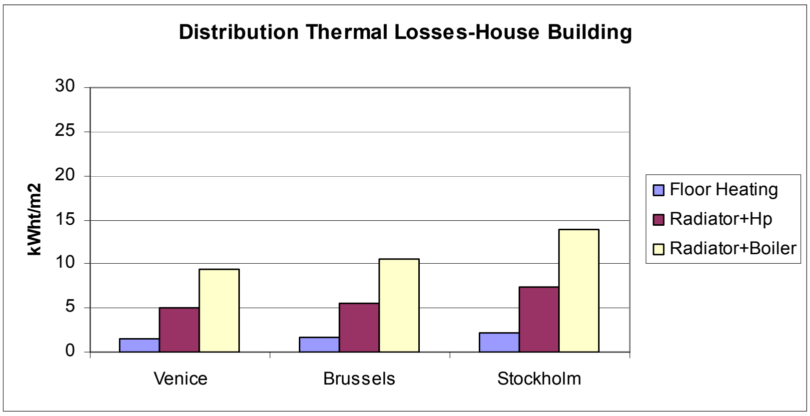


Figure 6.4 - Specific thermal distribution losses (house building)

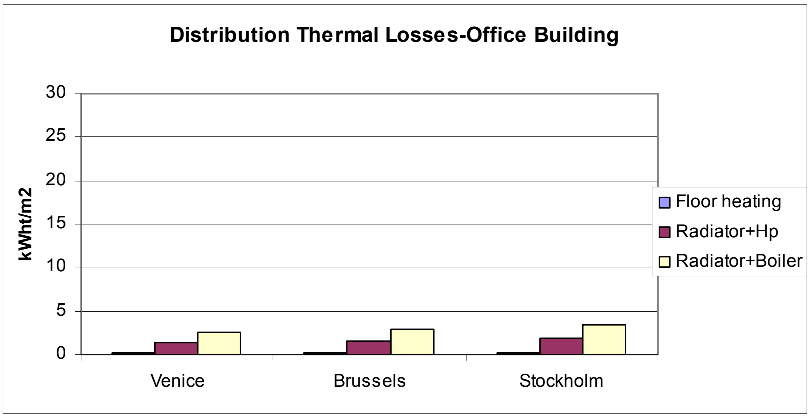


Figure 6.5 - Specific thermal distribution losses (office building)

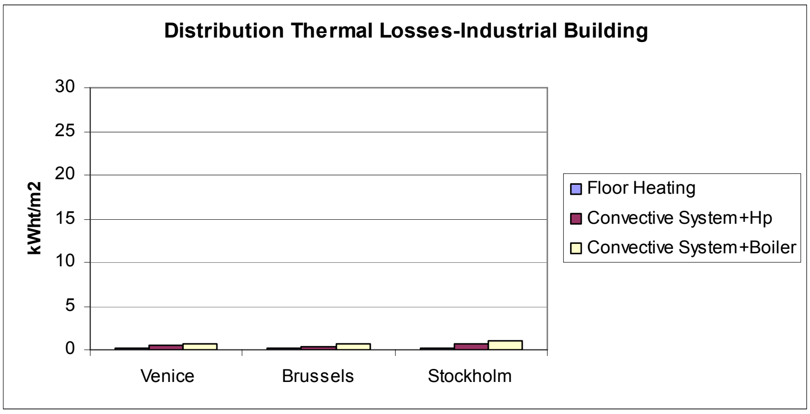


Figure 6.6 - Specific thermal distribution losses (industrial building)

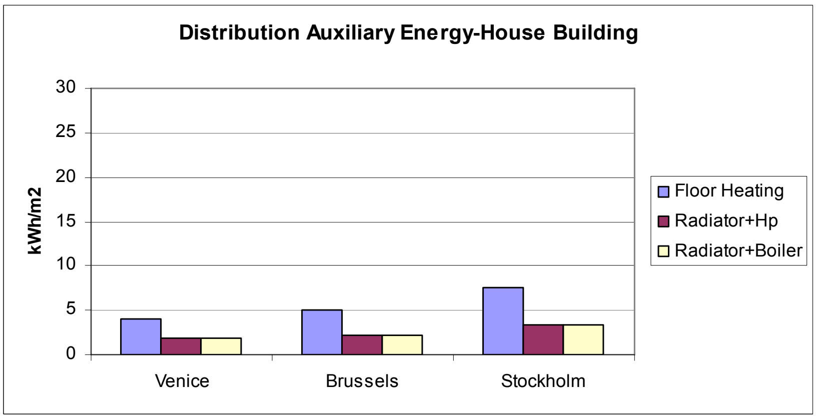


Figure 6,7 - Specific distribution auxiliary primary energy (house building)

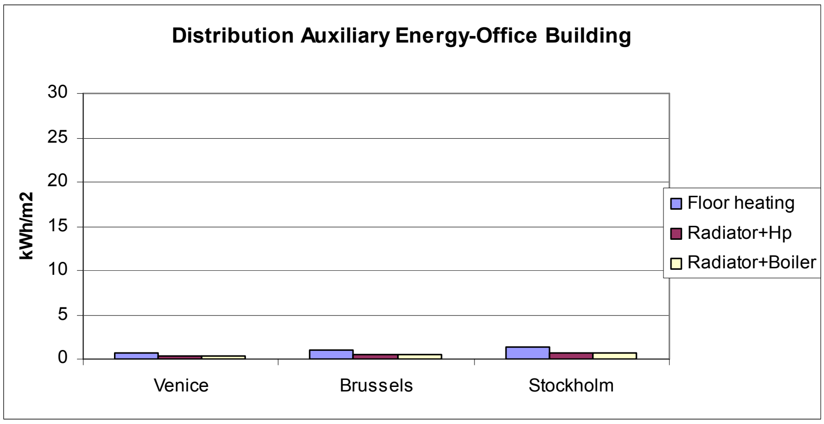


Figure 6.8 - Specific distribution auxiliary energy (office building)

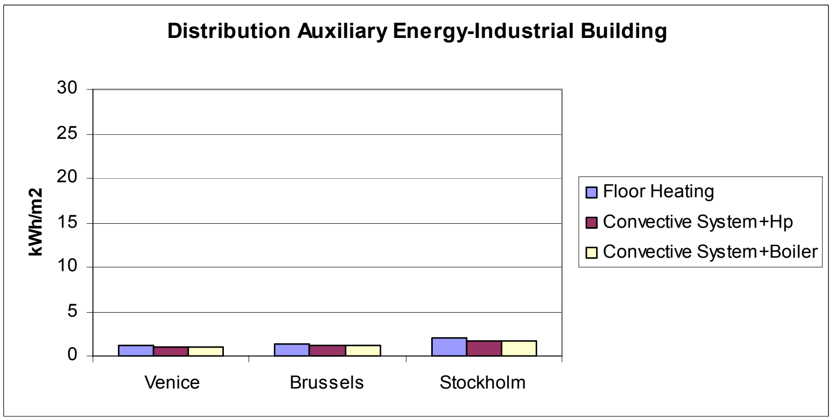


Figure 6.9 - Specific distribution auxiliary energy (industrial building)

6.3 Generation losses

Condensing boiler

The methods for calculation of generation system losses used are the typology method. The boiler is positioned inside the heated space and chosen in respect of calculation of design heat load formerly calculated. The type of boiler considered in the calculation is a condensing boiler.
The requirement for domestic hot water is covered by separate generator and is therefore not considered in this calculation.

Typology method

The fuel used to feed the boiler is natural gas. The ignition method is not permanent pilot flame and the burner type is modulating fan assisted.
The nominal power of the boiler is shown in Table 6.7:

Table 6.7- Nominal power of the boiler [5]

	Stockholm	Brussels	Venice
House Building [kW]	6	5	4
Office Building [kW]	290	240	200
Industrial Building [kW] floor heating **convective system**	255 305	255 310	205 250

The efficiencies test results taken into account are $\eta_{P,n} = 93\%$ (full-load net efficiency) and $\eta_{P,\text{int}} = 99\%$ (30% part-load net efficiency) . These values are produced in accordance with standard tests as required for the Boiler Efficiency Directive and independently certified. With these values the reduction to maximum net efficiency values according to EN 15316-4-1 [12] is not necessary. The conversion from net values to gross values using the net-to-gross conversion factor *f*=0.901 (depending on the fuel type) is done.
After the conversion, the boiler was characterized and the suitable seasonal efficiency equation was chosen in the standard. The equation chosen for calculation of gross seasonal efficiency is:

$$\eta_{gross} = 0.5 \cdot (\eta_{full,gross} + \eta_{part,gross}) - 2 - 4p \qquad [\%]$$

For boiler without a permanent pilot light the value of p is set to 0.
After the gross seasonal efficiency is calculated the net value of seasonal efficiency is calculated:

$$\eta_{net} = \frac{\eta_{gross}}{f} \qquad [\%]$$

where *f* is the net-gross-conversion factor.

The fuel heat requirement is calculated as follows:

$$Q_{g,in} = \frac{Q_{d,in} \cdot 100}{f} \qquad [J]$$

The input of distribution system is considered equal to the output of generation system.

$$Q_{d,in} = Q_{g,out}$$

The total generator heat loss is calculated by means of difference from the fuel heat requirement and the heat requirement for distribution system. The total generation heat loss $Q_{g,l,t,}$ is calculated for 6480 h (Stockholm), 5040h for (Brussels) and 4320h for (Venice).
The calculation of the auxiliary consumption is done according to the following equation:

$$\Phi_{aux,gn} = G + H \cdot \Phi_{Pn} \qquad [W]$$

where

G=20 and H=1.8 are parameters depending on the generation and burner type. Defaults values are contained in the standard [12].
Φ_{Pn} is the nominal power for different locations.

The running time of generator is calculated by dividing the value of output of generation system with the nominal power used.
The recoverable generation heat loss is not taken into account.

Heat Pump

The methods for calculation of generation system losses used are describe in the section 1.2.2
The generators chosen are three different electrically driven heat pumps:

- Air-to-water heat pump switched on for 0°<t<15° (with a back-up system)
- Air-to-water heat pump switched on for t>0° (with a back-up system)
- Water-to-water heat pump with ground source.

Meteorological data

The total energy requirement was shared in 3°C bin, begging with the minimum outside temperature. The heating requirement in bin i can be calculated with a weighting factor, which is derived from evaluating the frequency of the outside dry bulb temperature by means of heating degree hours (HDH). The evaluation of the heating degree hours based on the hourly outside temperature is described in Appendix N.
The weighting factors are calculated by the equation

$$w_i = \frac{HDH_{\theta_{upper}} - HDH_{\theta_{lower}}}{HDH_t} \qquad [-]$$

The energy requirement is taken from EN ISO 13790. The energy requirement in the respective bin is hence
calculated by the equation

$$Q_{out,g,h,i} = Q_{out,g,h} \cdot w_i \qquad [J]$$

COP

In every bin the COP could be consider constant and it is calculated by this equation:

$$COP_{pl} = COP_{fl} \cdot f_{pl} \qquad [-]$$

COP at full load operation is tabulated in the standard, in function of source and supply temperature, for air-to-water and water-to-water heat pump. In the calculation the supply temperature chosen was 35°C for heating and 50°C for DHW; to determine the source temperature for air-to-water heat pump the external dry bulb temperature was chosen, while for ground source heat pump the source temperature was chosen 2°C less than the ground temperature.
The correction factors for part load operation are depending on the type of the emitters. For floor heating was chosen light type with a distance of pipe of 15 cm, for radiators an equivalent water content of 10 l/kW.

The valuation of the correction factors for part load operation needs also the nominal powers off the heat pumps. Those were chosen to maximize the load factor, the result are shown in the following table:

With this data and the relative output capacity, for air-to-water and water-to-water heat pump with outlet sink temperature of 35°C, the load factor was determined.
Default value are contained in the standard.
For DHW only Full load operation was considered.

Storage losses

The default value for maximum storage losses are showed in the standard.
For a storage with a volume of 50 litres the maximum heat losses taken was 0,9 kWh/24h.

Auxiliary energy

The control system has to be taken into account only for the stand-by operation of the heat pump.

$$W_{g,ctrl} = \Phi_{ctrl} \cdot t_{s\tan d-by} \qquad \text{[J]}$$

The power of the control system taken into account was 20 W for family house, 200 W for office and industrial building.

Recoverable losses

The recoverable losses was determine by this equation:

$$W_{g,rl} = W_g \cdot (1-b) \cdot p_{aux,g} \qquad \text{[J]}$$

The temperature reduction factor taken into account was *b*=1, so no recoverable losses was considered.

E**nergy consumption**

The electricity input to the heat pump can be calculated by summing the electricity input of the respective bins according to the equation:

$$E_{in,g,h} = \sum_{i=1}^{n_{bin}} \frac{Q_{out,g,h,\sin,i}}{COP_{\sin,i}} \qquad \text{[J]}$$

The electricity operation for DHW operation can be calculated according to the equation

$$E_{in,g,DHW} = \sum_{i=1}^{n_{bin}} \frac{Q_{out,g,DHW,\sin,i}}{COP_{DHW,\sin,i}} \qquad \text{[J]}$$

The Total electrical energy input to operate the back-up heater can be calculated addicting the energy requirement in bins not cover by the heat pump.

The total electricity input is the sum over all single electricity inputs:

$$E_{in,g} = E_{in,g,h} + E_{in,g,DHW} + E_{in,g,bu,h} + W_g \qquad \text{[J]}$$

7 Calculation of primary energy and CO_2 emission.

A building generally uses more than one fuel (e.g. gas and electricity). The primary energy approach makes possible the simple addition from different types of energies (e.g. thermal and electrical) because this approach integrate the losses of the whole energy chain. Therefore the primary energy consumption may be used for comparison of different types of energy systems.

The conversion factors are listed on the national level. Standard EN15317 includes default values suggested as primary energy factors.
The energy used for different purpose and by different fuels is recorded separately.

For natural gas the conversion factor is f_P= 1.1, electrical power is converted by factor f_P=2.8.
The results of primary energy consumptions are presented as pie-diagrams for residential building and also as diagrams for the other type of buildings.

For the calculation of CO_2 emission the following specific CO_2 emission, taken from “Energy and global warming impact of HFC Refrigerants and Energy Technologies” (AFEAS, DOE 1997), was used :

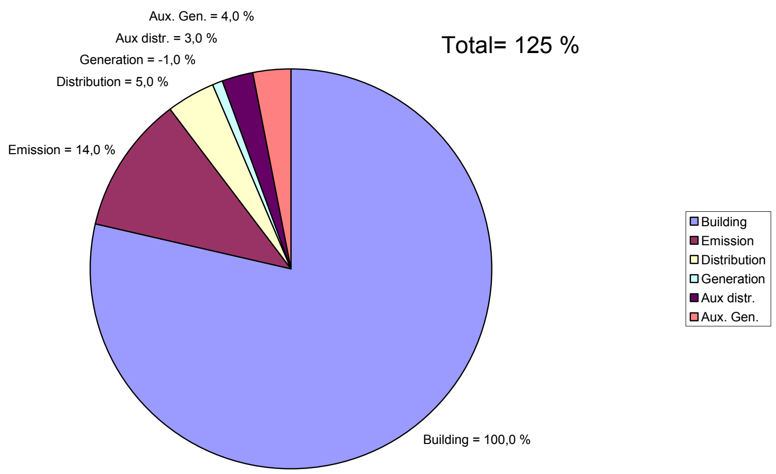
- For the valuation of the CO_2 emission of natural gas: $\alpha_{CO_2} = 1{,}86\ [kgCO_2 / m^3]$
- For the valuation of the CO_2 emission in the production of electric energy, α_{CO_2} is showed in the following table:

Table 7.1

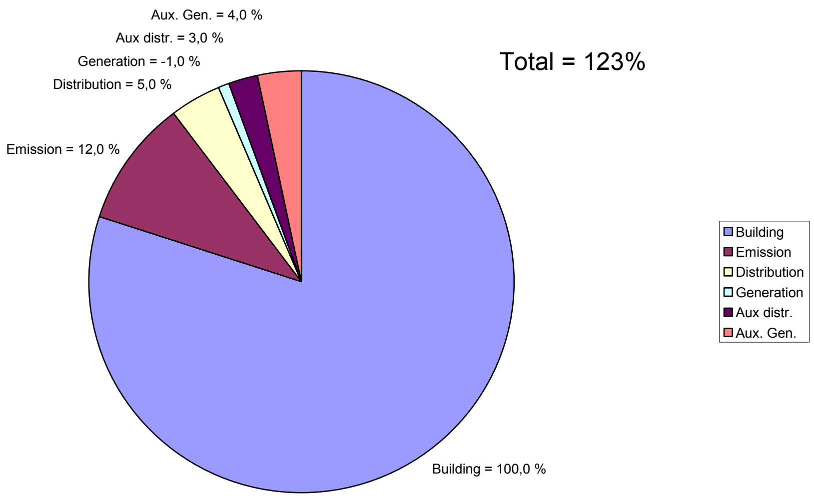
	$\alpha_{CO_2} [kgCO_2 / kWh]$
Stockholm	**0,04**
Brussels	**0,29**
Venice	**0,59**

The following diagrams show for Brussels the distribution of losses for radiator and floor heating. The distribution for other cities will be about the same

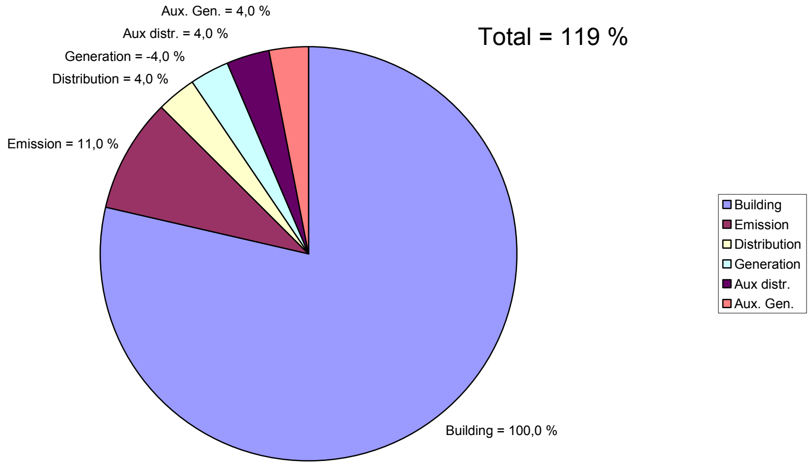
Residential - Brussels - Radiator 77/55-P(2) control- Condensing Boiler - Regulated Pumps



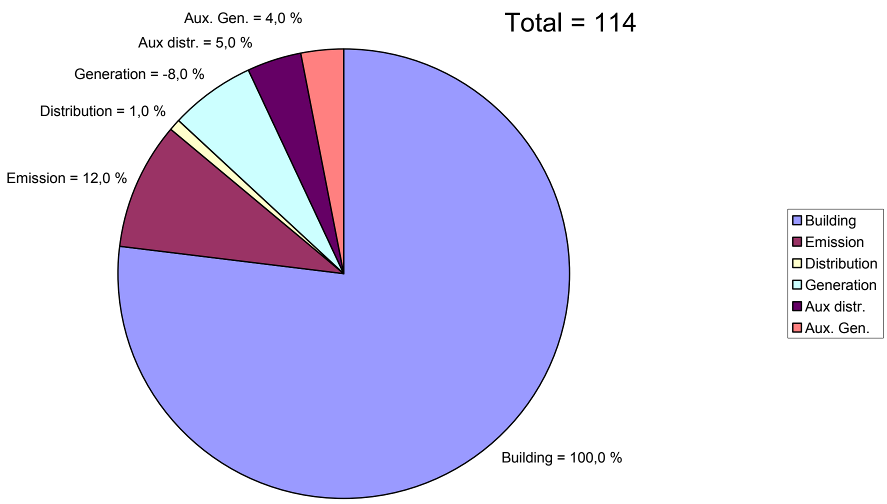
Residential - Brussels - Radiator 77/55-P(1) control- Condensing Boiler - Regulated Pumps



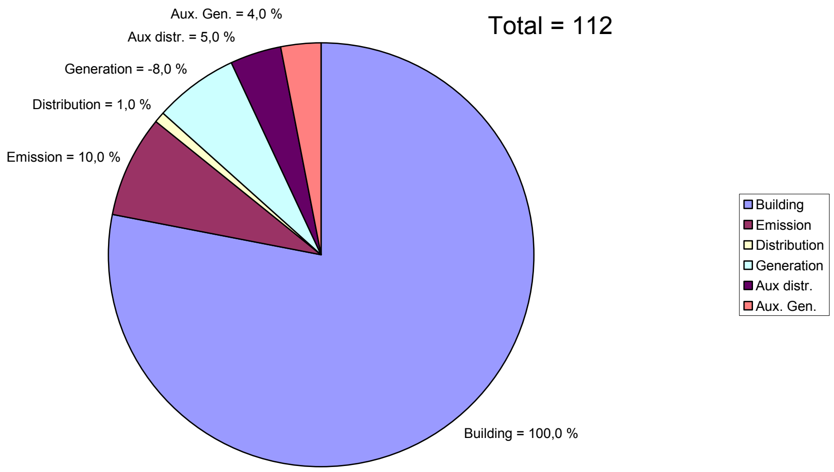
Residential - Brussels - Radiator 55/45-P(1) control- Condensing Boiler - Regulated Pumps



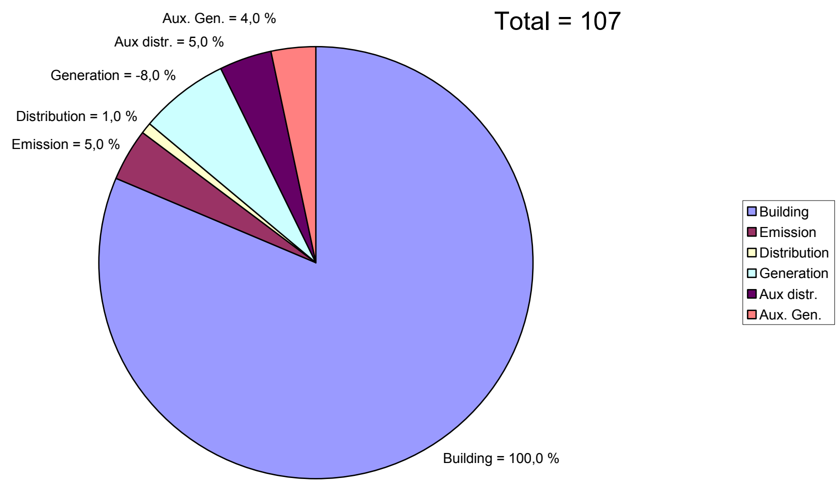
Residential - Bruxelles - Floor 35/28-ON-OFF(PI) control- Condensing Boiler - Regulated Pumps



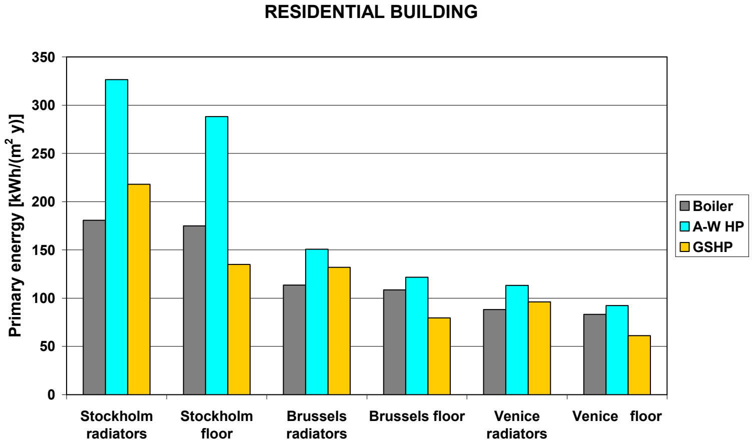
Residential - Bruxelles - Floor 35/28-ON-OFF(PI) control- better insulation Condensing Boiler - Regulated Pumps

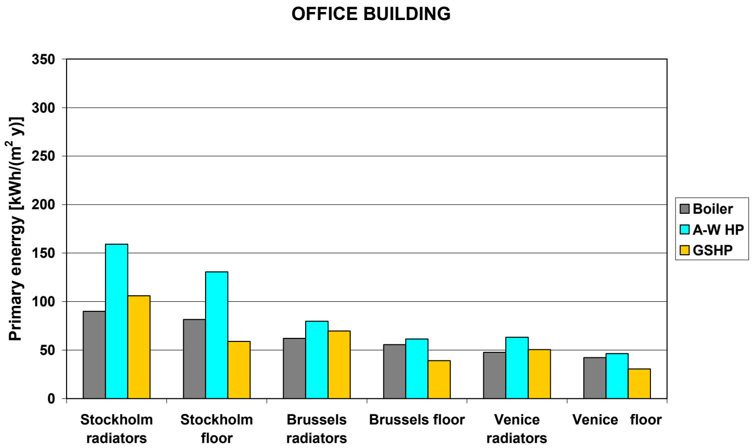


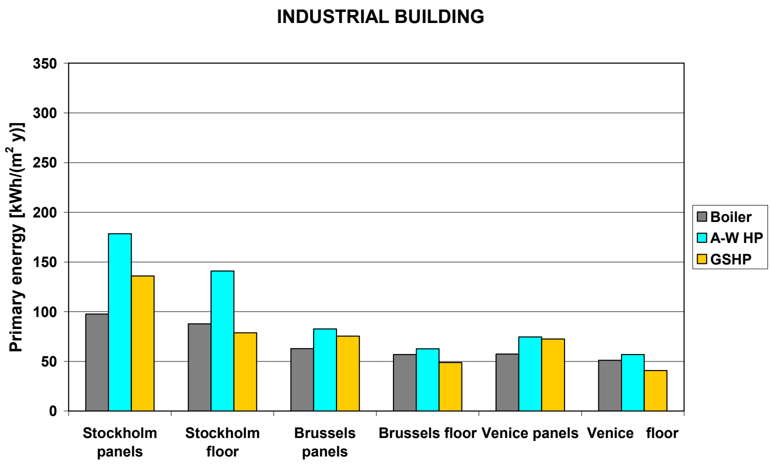
Residential - Bruxelles - Floor 35/28-ON-OFF(PI) control- no downward loss Condensing Boiler - Regulated Pumps



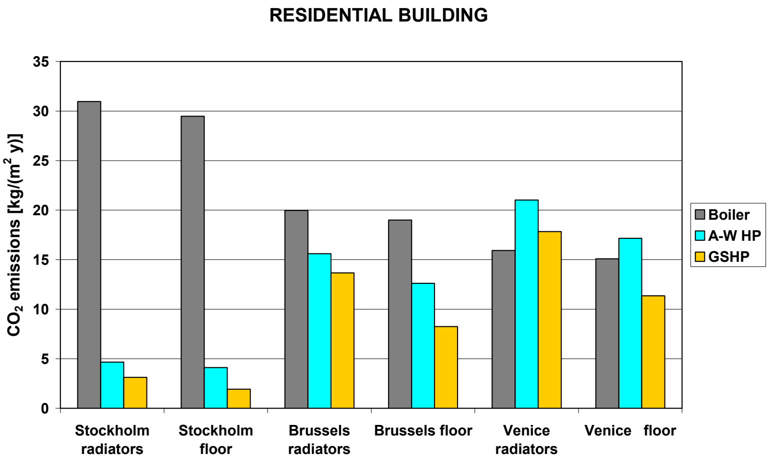
The following diagrams are for:
Standard wet floor system, 35/28 supply/return water temperature, On-Off control (PI),
Radiator with Heat Pump, 50/35 supply/return water temperature, wall mounted PI-control
Radiator with Boiler, 77/55 supply/return water temperature, wall mounted PI-control

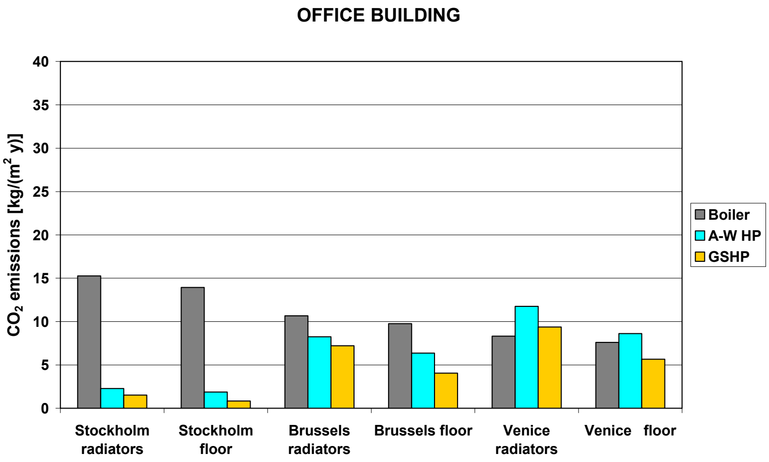


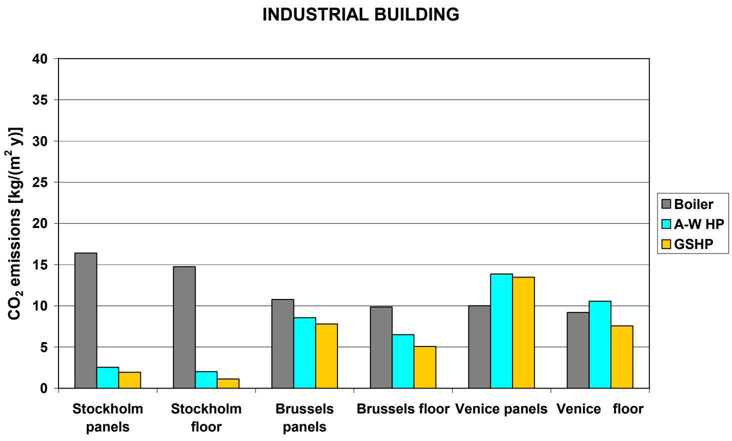




The following diagrams are for:
Standard wet floor system, 35/28 supply/return water temperature, On-Off control (PI),
Radiator with Heat Pump, 50/35 supply/return water temperature, wall mounted PI-control
Radiator with Boiler, 77/55 supply/return water temperature, wall mounted PI-control







References

[1] Directorate – General Transport and Energy (European Institution)

[2] Rod Janssen, Energy Consultant – Towards Energy efficient Buildings in Europe

[3] prCEN/TR 15615:2006 (E) – Umbrella Document V7

[4] National Agency for Enterprise and Construction (www.naec.dk)

[5] Matteo L. (2005) Comparison of energy consumption between radiators and radiant floor systems in heating period, based on the new European standards. (Master Thesis) Universita´ Degli Studia Di Padova

[6] EN ISO 13790:2005 – Thermal performance of buildings – Calculation of energy use for space heating and cooling. CEN/TC 89, Brussels

[7] EN 12831:2001-07 – Heating systems in buildings – Method for calculation of he design heat load. CEN/TC 228, Brussels

[8] Anderson. B 2004 Personal communication, BRE, UK

[9] EN 15316-2-1:2007 – Heating systems in buildings – Method for calculation of system energy requirements and system efficiencies – Part 2-1: Space heating emission systems. CEN/TC 228, Brussels. March 2007

[10] EN 15316-2-1:2005 – Heating systems in buildings – Method for calculation of system energy requirements and system efficiencies – Part 2-1: Space heating emission systems. CEN/TC 228, Brussels October 2005

[11] EN 15316-2-3:2007 - Heating systems in buildings – Method for calculation of system energy requirements and system efficiencies – Part 2-3: Space heating distribution systems. CEN/TC 228, Brussels. March 2007

[12] EN 15316-4-1:2007 - Heating systems in buildings – Method for calculation of system energy requirements and system efficiencies – Part 4-1: Space heating generation systems, combustion systems (boilers). CEN/TC 228, Brussels. March 2007

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Annex A Building net heating energy - EN ISO 13790

A.1 Total heat transfer by transmission

The total heat transfer by transmission is calculated for each month is calculated as follows:

$$Q_T = \Sigma_k \{H_{T,k} \cdot(\theta_i - \theta_{e,k})\}\cdot t$$

where

Q_T	is the total heat transfer by transmission	[MJ]
$H_{T,k}$	is the heat transfer coefficient by transmission of element k to adjacent environment with temperature $\theta_{e,k}$	[W/K]
θi	is the internal temperature of the building	[°C]
$\theta_{e,k}$	is the temperature of the adjacent environment of element k	[°C]
t	is the duration of the calculation period	[Ms]

A.2 Heat transfer by ventilation

For the monthly method, the total heat transfer by ventilation from the conditioned space is calculated for each month as follows:

$$Q_V = \Sigma_k \{H_{V,k} \cdot(\theta_i - \theta_{s,k})\} \cdot t$$

where

Q_V	is the total heat transfer by ventilation	[MJ]
$H_{V,k}$	is the heat transfer coefficient by ventilation of air of flow element *k* entering the zone with supply temperature $\theta_{e,k}$	[W/K]
θi	is the internal temperature of the building	[°C]
$\Theta_{S,k}$	is the supply temperature of the air flow element *k* entering the building or building zone by ventilation or infiltration	[°C]
t	is the duration of the calculation period	[Ms]

The ventilation heat transfer coefficient $H_{V,k}$ is calculated as follows:

$$H_{V,k} = \rho_a \cdot c_a \cdot V_{V,k}$$

where

$\rho_a\ c_a$	is the heat capacity of air per volume ≈ 1200 J/(m^3·K)	[J/(m^3K]
$V_{V,k}$	is the airflow rate through the conditioned space	[m^3/s]

A.3 Internal heat sources

For monthly method, the heat from internal heat sources in the considered building zone for the considered month is calculated as follows:

$$Q_i = \sum_k Q_{i,k}$$

with

$$Q_{i,k} = \Phi_{i,mean,k} \cdot t$$

where

Q_i	is the sum of internal heat sources during the considered month or season	[MJ]
$Q_{i,k}$	is the heat from internal heat source k in the considered conditioned zone during the considered month	[MJ]
$\Phi_{i,mean,k}$	is the time-average heat flow rate from internal heat source *k*	
t	is the length of the considered month	[Ms]

A.4 Total solar heat sources

For the monthly method, the heat from solar sources in the considered building zone for the considered month or season is calculated from:

$$Q_s = Q_{s,c}$$

with

$$Q_{s,c} = \sum_k \left[I_{s,k} F_{s,o,k} A_{s,k} \right]$$

where

Q_s	is the sum of solar heat sources during the considered month, including the effect of solar heat sources in adjacent unconditioned spaces	[MJ]
$Q_{s,c}$	is the sum of solar heat sources during the considered month or season in the considered conditioned zone itself	[MJ]
$F_{s,Ok}$	is the shading reduction factor for external obstacles for the solar effective collecting area of surface *k*	
$A_{s,k}$	Is the effective collecting area of surface k with given orientation and tilt angle, in the considered zone	[m^2]
$I_{s,k}$	is the solar irradiance, the total energy of the solar irradiation during the calculation period per m² of collecting area of surface k, with given orientation and tilt angle	[MJ/m^2]

A.5 Gain utilisation factor for heating

The gain utilisation factor for heating, η_H is a function of the gain/loss ratio, γ_H and a numerical parameter, a_H
that depends on the building inertia, according to the following equation:

$$if\ \gamma_H \neq 1: \qquad \eta_{G,H} = \frac{1-\gamma_H^{\alpha_H}}{1-\gamma_H^{\alpha_{H+1}}}$$

$$if\ \gamma_H = 1: \qquad \eta_{G,H} = \frac{\alpha_H}{\alpha_H + 1}$$

with

$$\gamma_H = \frac{Q_{G,H}}{Q_{L,H}}$$

where

η_H	is the dimensionless gain utilisation factor for heating	
γ_H	is the dimensionless gain/loss ratio for the heating mode	
$Q_{L,H}$	are the total heat losses for the heating mode	[MJ]
$Q_{G,H}$	are the total heat gains for the heating mode	[MJ]
α_H	is a dimensionless numerical parameter depending on the time constant	

with

$$\alpha_H = \alpha_{0,H} + \frac{\tau_H}{\tau_{0,H}}$$

$\alpha_{0,H}$	is the dimensionless reference numerical parameter	
τ_H	Is the time constant of the building or building zone	[h]
$\tau_{0,H}$	Is a reference time constant	[h]

A.6 Energy use for space heating

$$Q_{NH,yr} = \sum_i Q_{NH,i}$$

$Q_{NH,yr}$	Is the annual energy need for heating of the considered zone	[MJ]
$Q_{NH,i}$	Is the energy need for heating of the considered zone per calculation period (hours or month)	[MJ]

In this thesis the impact of intermittent heating and the effect of adjacent unconditioned space are not taken into account for the buildings net heating energy.

Annex B Heat distribution system

B.1 Auxiliary energy demand

The auxiliary energy demand of hydraulic networks depends on the distributed mass flow, the pressure drop and the operation condition of the pump. The design mass flow and pressure drop is important for the pump size, while the part load factor (β_D) determines the energy demand in a time step.

The electrical energy demand of circulating pumps for hot-water heating system is calculated by the following formula:

$$W_{d,e} = W_{d,hydr} \cdot e_{d,e} \qquad \textbf{[kWh/a]}$$

where

$W_{d,e}$	electrical energy demand	[kWh/a]
$W_{d,hydr}$	hydraulic energy demand	[kWh/a]
$e_{d,e}$	expenditure energy for circulating pump operation	[-]

The hydraulic energy demand for the circulating pumps is calculated through the hydraulic power in dimensioning point and several correction factors, which are the most important parameters regarding the dimensioning of the heating system:

$$W_{d,hydr} = \frac{P_{hydr}}{1000} \cdot \beta_D \cdot t_H \cdot f_V \cdot f_{Sch} \cdot f_A \cdot f_{Ab} \qquad \text{[kWh/a]}$$

where:

P_{hydr} hydraulic power in dimensioning point, [W]
β_D mean distribution load, [-]
t_H heating hours per year, [h/a];
f_V correction factor for flow temperature control, [-]
f_{Sch} correction factor for heating surface dimensioning, [-]
f_A correction factor for heating surface dimensioning, [-]
f_{Ab} correction factor for hydraulic balance

The correction factors regarding the heating system dimensioning are selected as follows:

- Correction factor for flow temperature control f_V :

  f_V= 1 for systems with outdoor temperature compensation;
  f_V for systems without outdoor temperature compensation (i.e) constant flow temperature) or excessive temperature values are given in a chart .

- Correction factor for pipe system layout f_{Sch}:

  f_{Sch}=1 for horizontal layout (on each floor):
  f_{Sch} for other types of layout values are given in a table.

- Correction factor for dimensioning of heating surface f_A:

f_A=1 for dimensioning according to design heat load
f_A=0.96 in case of additional over sizing of the heating surfaces

- Correction factor for hydraulic balance f_{AB}:

f_{AB}=1 for balanced systems;
f_{AB}=1.25 for unbalanced systems

In the distribution the mean part load is given by:

$$\beta_D = \frac{Q_{em,in}}{\dot{\Phi}_{em} \cdot t_H}$$

where

$Q_{em,in}$	is the energy including emission and control per time step	[W]
Φ_{em}	is the nominal power of the installed heat emitters per zone or desing heat load per zone at design stage	[W]
t_H	is the heating hours in the zone per time step	[h]

The hydraulic power in dimensioning point is given by:

$$P_{hydr} = 0,2778 \cdot \Delta p \cdot \dot{V} \qquad \textbf{[W]}$$

where

$\dot{V}$	flow in dimensioning point	[m³/h]
Δp	differential pressure in dimensioning point	[kPa]

The flow is calculated from the heat load $\Phi_{H,em,out}$ of the zone (the design heat load shall be according to EN 12831) and the design temperature difference $\Delta \upsilon_{dis,des}$ of the heating system:

Comment [WU1]:

$$\dot{V} = \frac{3600 \cdot \dot{\Phi}_{em}}{c_p \cdot \rho \cdot \Delta \vartheta_{HK}} \qquad \textbf{[m}^3\textbf{/h]}$$

The differential pressure in dimensioning point according with simplified method is given by following equation:

$$\Delta p = 0.13 \cdot L_{\max} + 2 + \Delta p_{FBH} + \Delta p_{WE}$$

where

$L_{\max}$	Maximum length of the heating circuit	[m]
Δp_{FBH}	additional pressure loss for floor heating system	[kPa]
Δp_{WE}	pressure loss for generators	[kPa]

In the simplified method, the maximum length of the circuit of heating zone can be calculated approximately for a zone from the outer dimension of the zone, with the following equation:

$$L_{\max} = 2 \cdot (L + \frac{B}{2} + n_G \cdot h_G + l_c)$$

where

L	Length of the zone (part of building)	[m]
B	Width of the zone (part of building)	[m]
n_G	number of heated levels in the zone (part of building)	[-]
h_G	mean height of the levels in the zone (part of building)	[m]
l_c	=10 for two-pipe heating systems, = L+B for one-pipe systems	[-]

The expenditure energy of pumps depends on several factors, which take into account the most important influences of the energy demand,
In the simplified method the expenditure energy is calculated making some assumptions in according to the detailed method.
The expenditure energy in this case is calculated to:

$$e_{d,e} = f_e \cdot (C_{P1} + C_{P2} \cdot \beta_D^{-1})$$

where

C_{P1} C_{P2}	constant given by a table in the standard	[-]
f_e	efficiency factor, given for unknown pumps by this equation:	[-]

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

with b=1 for new buildings and b=2 for existing buildings.

The efficiency factor is also given for known pumps by:

$$f_e = \frac{P_{Pump}}{P_{hydr}}$$

During the work of the pumps a part of the electrical energy demand is converted in to thermal energy which is transferred into the water. Another part of thermal energy is transferred into the surrounding air. Both these parts are partial recoverable, together it represent the 25 % of the hydraulic energy demand $W_{d,e}$.

Expenditure energy
For assessment of control performance of the circulating pump the following formula applies:

$$e_{d,e} = f_\eta \cdot f_{TL} \cdot f_{Ausl} \cdot f_R$$

Where:

f_η	correction factor for efficiency [-]
f_{TL}	correction factor for partial load [-]
f_{Ausl}	correction factor for dimensioning point selection [-]
f_R	correction factor for control

Correction factors for efficiency f_η

It is given by the relation between the reference power input at the dimensioning point and the hydraulic power at the dimensioning point:

$$f_\eta = \frac{P_{pump,ref}}{P_{hydr}}$$

The reference power input is calculated by means of the characteristic line equation:

$$P_{pump,ref} = P_{hydr} \cdot \left(1.25 + \left(\frac{200}{Phydr}\right)^{0.5}\right)$$

Correction factors for efficiency f_{TL}

It considers the hydraulic characteristics of non-controlled pumps. This correction factor is a function of the mean distribution load β_D

Correction factor for dimensioning point selection f_{Ausl}

This factor is a ratio between the power input of the real pump and the reference power input:

$$f_{Ausl} = \frac{P_{Pumpe}}{P_{pump,ref}} \qquad [-]$$

Where:

P_{Pumpe}	actual power input of pump, [W]
$P_{pump,ref}$	reference power input, [W]

Correction factor for pump control f_R

f_R=1	non controlled pumps
f_R	for controlled pumps is given in a chart in the standard.

Expenditure energy for simplified method

The expenditure energy of pumps can be calculated in a simplified method in according to the detailed method with same assumptions. These assumptions are :

- for control factor $\frac{P_{Pump,\max}}{P_{pump}} = 1.11$
- correction factor for dimensioning point selection f_{Ausl}= 1.5
- efficiency factor f_e=$f_\eta \cdot f_{Ausl}$ and approximation of efficiency curve of pumps

B.2 System thermal loss of distribution system

The heat losses of a distribution system depend on the mean temperature of the supply and return water as well as the temperature of the surrounding environment.
For the heat emission in a time step the following formula applies:

$$Q_D = \sum_i \Psi_{L,i} \cdot (\theta_m - \theta_a) \cdot L \cdot t_H \quad \textbf{[kWh/year]}$$

where

$\Psi_{L,i}$	U-value per length	[W/mK]
θ_m	mean medium temperature	[°C]
θ_a	surrounding temperature	[°C]
L	length of the pipe	[m]
t_H	heating hours in the time step	[h]

For parts of distribution systems with the same U-value and the same mean medium and surrounding temperature the heat emission is given by a shorter equation:

$$Q_D = \sum_i \dot{q}_D \cdot L \cdot t_H \quad \textbf{[J]}$$

In case of heating circuits with outdoor temperature compensation of the supply temperature, the mean medium temperature depends on the mean emission system design temperature above the room temperature and mean part load of the distribution system.

Therefore the heat emission per length in a space with surrounding temperature ϑ_a depends on the mean part load of the distribution system and is given by the following equation:

$$\dot{q}_D(\beta_D) = \Psi_{L,i} \cdot (\theta_m(\beta_D) - \theta_a) \quad \textbf{[kWh/(m·year)]}$$

The calculation of the mean medium temperature is made by this procedure:

$$\theta_m(\beta_D) = \Delta\theta_a \cdot \beta_D^{\frac{1}{n}} + \theta_i \quad \textbf{[°C]}$$

where

$\Delta\theta_a$	mean emission system design temperature above the room temperature $$\Delta\theta_a = \frac{\theta_{va} + \theta_{ra}}{2} - \theta_i$$	[°C]
β_D	mean part load in the process area	[-]
n	exponent of the emission system (standards values= 1,33 for radiators, 1,1 for floor heating systems)	[-]
θ_i	room temperature	[°C]

B.3 Approximation of the length of pipes in distribution systems

In the simplified calculation method it is possible to make some approximation of the length of the pipes in a building. The assumptions are established on the length (L) and width (B) of the building or zone, on the height (h_G) and the number of storage (n_G). Figure 5.2

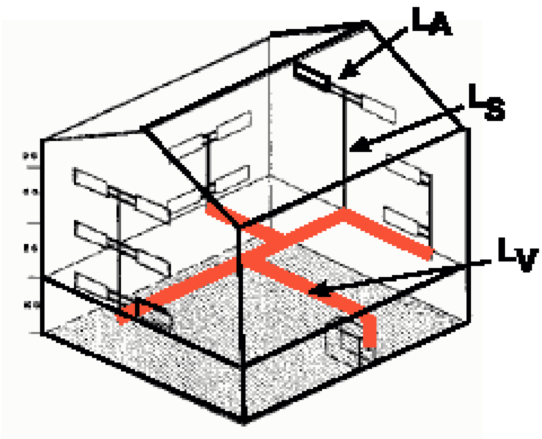

Figure B1 - Layout of the pipes as indicated in the EN 15316-2-3 [11]

Index for figure B1:

- L_v the pipe length between generator and vertically shafts. These (horizontal) pipes could be in unheated space (basement, attic) or in heated space.
- L_s is the pipe length in shafts (e.g. vertically). These pipes are in heated space, in outside-walls or in the inside of the building.
- L_A is the connection pipes. These pipes are flow controlled by the emission system in heated spaces.

The standard gives also in a simplified calculation method approximations of the U-Value, which are constant values.

Annex C Heat generation-Boiler

Seasonal boiler performance based on system typology (typology method)

The method assumes that climatic conditions, operating regime, and typical occupancy patterns of the relevant building sector have been considered and incorporated in a procedure to convert boiler efficiency standard test results (as used for the Boiler Efficiency directive) into a seasonal efficiency for the relevant building sector. The step within the seasonal efficiency calculation procedure are: to adapt test results for uniformity, taking account of boiler type, fuel, and specific conditions for testing imposed by the Boiler Efficiency Directive; adjust for annual performance in installed conditions, taking account of regional climate, operating regime etc.
The seasonal efficiency calculation procedure is selected from the appropriate national annex, based on climatic characteristics in which the building is situated and the type of building sector (housing, commercial, industrial). If there is no appropriate national annex the method can not be used, because default value are not given. The method is applicable only to boilers for which the full load and the 30% part load efficiency values, obtained by the method considered to satisfy Council Directive 92/42/EEC, (Boiler Directive) are available. These are net efficiency values (higher efficiencies values, referenced to the lower heat value of fuels). It is essential that both test results are available and that the tests are appropriate to the type of boiler as defined in Council Directive, otherwise the calculation can not proceed.
In the procedure the data are first converted to gross efficiency (lower efficiencies values, referenced to the higher heat value of fuels) under test conditions, and then converted to a seasonal efficiency that applies under typical conditions of use in a dwelling.

The procedure goes within the following order:

- Determination fuel for boiler type
- The fuel for boiler type must be one of natural gas, LPG (butane or propane), or oil (kerosene or gas oil).
- Obtaining of full-load net efficiency and 30% part-load net efficiency test data.
- Reduction of greater test values of net efficiency to appropriate values (maximum allowed net efficiency values given in the standard) for each fuel.
- Conversion of the full and 30% part load efficiencies from net values to gross using the following equation:

$$\eta_{Px,gross} = f \cdot \eta_{Px,net} \qquad \textbf{[\%]}$$

where

f net – to gross conversion factor.

- Selection of boiler category
- Calculation of seasonal efficiency

The appropriate equation, which determines the gross efficiency value, must be selected from the standard. The gross full and part load efficiencies previously calculated, must be substituted within it. Finally the net value of the seasonal efficiency is obtained converting the gross seasonal efficiency with the following equation:

$$\eta_{P,net} = \frac{1}{f \cdot \eta_{P,x,gross,t}} \qquad [\%]$$

Calculation of generator heat loss

It is necessary to express the seasonal performance of generation in absolute values in order to fit the general structure of EN 14335.

The total generation heat loss $Q_{l,g}$ is calculated by the following equation:

$$Q_{g,l,t} = Q_{g,out} \cdot \frac{1-\eta_{g,net}}{\eta_{g,net}} \qquad [J]$$

Calculation of fuel requirement

The fuel heat requirement $Q_{g,in}$ can be calculated with this equation:

$$Q_{g,in} = \frac{Q_{g,out}}{\eta_{g,net}} \qquad [J]$$

Calculation of auxiliary consumption

The auxiliary consumption is given by :

$$W_g = \Phi_{aux,gn} \cdot t_g \qquad [J]$$

where

t_g	running time of the generator	[s]
$\Phi_{aux,gn}$	power of auxiliary equipment	[W]

If the performance of a product has been certified, the data are available and can be taken into account it. If no values are available, default values are tabulated in the standard (WI 9 Part 2.2.1).

The running time in typology method can be calculated according to the following:

$$t_g = \frac{Q_{g,out}}{\Phi_{Pn}} \qquad [s]$$

where

$Q_{g,out}$	delivered energy to distribution system	[J]
Φ_{Pn}	generator power at full load	[W]

No calculation of recoverable heat from the generation heat losses are taken into account

Case specific boiler efficiency method

This method is related to the European Boiler Directive. It is based on expressing the losses for three different load ratios or power outputs.

- the losses at 100% load $\Phi_{gn;l,Pn}$;
- the losses at intermediate load $\Phi_{gn,l,P\text{int}}$;
- the losses at 0% load $\Phi_{gn,l,Po}$;

These values are calculable using the boilers performance certified according with European Boiler Directive, if these performance values are not available it can be used the default values within the standard given a function of the generator power.

The calculation of the losses for a specific load is obtained by linear interpolation between these three power outputs.
All powers and load factor FC are refereed to generation subsystem output.

Generation heat loss calculation at 100% load

For oil and gas fired boiler, according to boiler directive, the efficiency at full load is measured with an average water boiler temperature of 70° C. This efficiency has to be corrected in accordance with the running temperature of the individual installation.

Therefore for different temperatures, the temperature corrected efficiency $\eta_{gn,Pn,cor}$ is calculated by:

$$\eta_{gn,Pn,cor} = \eta_{gn,Pn} + f_{cor,Pn} \cdot (\theta_{gn,test,pn} - \theta_{gn,w}) \qquad [\%]$$

where

$\eta_{gn,Pn}$	generator efficiency at full load	[%]
$f_{cor,Pn}$	correction factor taking into account the variation of the efficiency as a function of the average water temperature. The values are given in the national annex. In the absence of national values default values are given in the standard. If the performance of a product has been certified, it can be taken into account.	[-]
$\theta_{gn,test,pn}$	boiler water temperature at test conditions, 70° C according to the boiler directive at full load	[°C]
$\theta_{gn,w}$	water temperature in the boiler, function of the specific running conditions (running temperature) showed below.	[°C]

The generation losses at 100% load $\Phi_{gn,l,Pn,cor}$ are calculated by:

$$\Phi_{gn,l,Pn,cor} = \frac{(100 - \eta_{gn,Pn,cor})}{\eta_{gn,Pn,cor}} \cdot \Phi_{Pn} \cdot 1000 \qquad [W]$$

where

Φ_{Pn}	generator output at full load	[kW]

Generation heat loss calculation at intermediate load

The efficiency depending on the variation of the generator running temperature is calculated by:

$$\eta_{gn,Pin,cor} = \eta_{gn,P\text{int}} + f_{cor,P\text{int}} \cdot (\theta_{gn,test,P\text{int}} - \theta_{gn,w}) \qquad [\%]$$

where

$\eta_{gn,P\text{int}}$	efficiency at intermediate load. If the performance of a product has been tested and given by the manufacture notified, they can be taken into account. If no values are available, default values are given in the standard based on the nominal power of generator.	[%]
$f_{cor,P\text{int}}$	correction factor taking into account the variation of the efficiency as a function of the average water temperature. Default value are given in the standard. If the performance of a product has been tested according to the boiler directive and certified it can be taken into account	[-]
$\theta_{gn,test,P\text{int}}$	average temperature of the boiler test conditions at intermediate load. It is given in the European standard WI 9 Part 2.2.1	[°C]

The intermediate load depends on the generator type. For gas and oil generators the intermediate load is $0.3F_{Pn}$, that is 30% of generator output at full load.

The generation heat loss at intermediate load $\Phi_{gn,lP\text{int},cor}$ is given by:

$$\Phi_{gn,lP\text{int},cor} = \frac{(100-\eta_{gn,P\text{int},cor})}{\eta_{gn,P\text{int},cor}} \cdot \Phi_{P\text{int}} \cdot 1000 \qquad [\%]$$

where

$\Phi_{P\text{int}}$	generator output at intermediate load	[kW]

Generation heat loss calculation at 0% load

The calculation of the generation heat loss at 0% load is determined for a temperature difference of 30 K between the water temperature in the boiler and the indoor temperature of the boiler room.

The corrected losses at 0% load $\Phi_{gn,lPO,cor}$ are given by:

$$\Phi_{gn,lPO,cor} = \Phi_{gn,l,PO} \cdot \left[\frac{\theta_{gn,w}-\theta_{i,gn}}{30} \right]^{1.25} \qquad [W]$$

where

$\Phi_{gn,l,PO}$	standby losses. Is possible to calculate it using performance of products certified according with standard boilers. If no boilers performance values are available , default value are given in the annex of the standard	[W]
$\theta_{i,gn}$	indoor temperature of the boiler room	[°C]

Generation heat loss at specific load ratio FC and power output

The calculation of specific load ratio FC of generator is showed below. The specific load ratio is used for the calculations of losses.
If load ratio FC is between 0% load (power output F_{Po}=0) and intermediate load (power output F_{Pint}) then the generation heat loss $\Phi_{gn,l,Px}$ is calculate by the following equation:

$$\Phi_{gn,l,Px} = \frac{\Phi_x}{\Phi_{P\text{int}}} \cdot (\Phi_{gn,l,P\text{int},cor} - \Phi_{bn,l,PO,cor}) + \Phi_{gn,l,PO,cor} \qquad [W]$$

If load ratio FC is between intermediate load (power output F_{Pin}) and nominal load (power output $F_{Pn)}$ then the generation heat loss $\Phi_{gn,l,Px}$ is calculated by:

$$\Phi_{gn,l,Px} = \frac{\Phi_{Px}-\Phi_{P\text{int}}}{\Phi_{Pn}-\Phi_{P\text{int}}} (\Phi_{gn,l,Pn,cor} - \Phi_{gn,l,P\text{int},cor}) + \Phi_{gn,l,P\text{int},cor} \qquad [W]$$

The total generation heat loss $Q_{gn,l,t}$ calculated during the considered period is showed below:

$$Q_{gn,l,t} = \Phi_{gn,l,Px} \cdot t_{ci} \qquad [J]$$

Load of each generator

If there is only one generator installed the load factor FC is calculated according with following equation:

$$FC = \frac{\Phi_{d,in}}{\Phi_{Pn}} \qquad [\%]$$

Where

$\Phi_{d,in}$	mean power of heat delivered to the distribution system	[kW]
Φ_{Pn}	nominal power output of the generator	[kW]

If there are several heat generators, the repartition of the load depends on control. Two types of control are distinguished:

- without priority

All generators are running at the same time, therefore the load FC is the same for each generator and calculated by:

$$FC = \frac{\Phi_{d,in}}{\sum \Phi_{Pn,g1} + \Phi_{Pn,g2} + ..} \qquad [\%]$$

- with priority

The generators which have higher priority are running first. Only if a generator with high priority is running at full load, the following generator in the priority list is added. The load FC for the intermittent running generator is calculated by:

$$FC = \frac{\Phi_{Pgx} - (\Phi_{Pn,gJ} + \Phi_{Pn,gx} + ...)}{\Phi_{Pn,gz}} \qquad [-]$$

where

$\Phi_{Pn,gJ}$, $\Phi_{Pn,gx}$	nominal power of generators running at full load	[kW]
$\Phi_{Pn,gz}$	nominal power of generator running not at full load	[kW]

Auxiliary consumption

The generation auxiliary energy consumption is given by:

$$W_g = \Phi_{aux,gn} \cdot t_{ON,gn} \qquad [J]$$

where

$t_{ON,gn}$	running time of the generator	[s]
$\Phi_{aux,gn}$	power of auxiliary equipment	[W]

The running time is calculated according to the following:

$$t_{ON,gn} = \frac{\Phi_{gn,l,Px} + \Phi_{Px} \cdot 1000}{\Phi_{gn,l,Px} + \Phi_{Pn} \cdot 1000} \cdot t_{ci} \qquad \text{[s]}$$

where

$\Phi_{gn,l,Px}$	average generation loss during considered period	[W]
Φ_{Px}	average generator power output during considered period	[kW]
Φ_{Pn}	generator output	[kW]
t_{ci}	calculation interval	[s]

Recoverable heat generation loss

For the recoverable auxiliary loss it is distinguished between the recovered auxiliary and recoverable auxiliary energy. It is considered that the auxiliary energy transmitted to the energy vector normally water is totally recovered.

Auxiliary consumption

The recoverable auxiliary energy losses transmitted to the heated space is given by:

$$W_{gn,rl} = W_g \cdot (1 - b_g) \cdot p_{aux,g} \qquad \text{[J]}$$

where

$p_{aux,g}$	part of the nominal electrical power transmitted to the ambiance, the values are given in national annex . If no national values are specified the default values are given in the standard. If the performance of the product certified is available, it can be taken into account.	[-]
b_g	temperature reduction factor linked with localization of the boiler in the house, the values can be defined in national annex . If no national value are specified the default value are given in the standard	[-]

Generator heat loss (heat losses through generator envelope)

Only the heat losses through the generator envelope $Q_{gn,env}$ are considered as recoverable. For oil and gas fired boilers, the heat losses through the generator envelope are given as a part of the standby losses, which depends on the burner type. Therefore the recoverable generator envelope losses are obtained by the following equation:

$$Q_{gn,env,rl} = \Phi_{gn,l,PO,cor} \cdot (1 - b_g) p_{gn,env} \cdot t_{ci} \qquad \text{[J]}$$

where

t_{ci}	calculation time interval	[s]
$p_{gn,env}$	heat losses through the generator envelope as a part of the standby losses	[J]

Total recoverable generation heat loss

$$Q_{t,g,rl,} = Q_{env,l,env,rl} + W_{rl,gn}$$

Running temperature of the generator

The running temperature depends on:

- the control type;
- the technical limit of the generator (taken into account by the temperature limitation);
- the temperature of the distribution system connected to the generator.

The running temperature of the generator can be calculated by:

$$\theta_{gn,w} = \max(\theta_{gn,\min}, \theta_{em}) \qquad \textbf{[°C]}$$

where

$\theta_{gn,\min}$	running temperature limitation for each generator. If the installation is formed with several generators, the running temperature limitation used for calculation is the highest value of the temperature limitations of the generators running at the same time. Can be used, if national values are not available, values given in the standard.	[°C]
θ_{em}	temperature for the heat distribution during the considered period. This temperature is calculate as indicated below. If there are different heat distributions are connected to the generator, the highest temperature is used for the calculation.	[°C]

Control depending on the inside temperature

The average power of the emitter's Φ_{em} during the calculation period is given according to the following equation:

$$\Phi_{em} = \frac{Q_{d,out}}{t_{ci}} \qquad [W]$$

where

$Q_{d,out}$	average energy supplied by the distribution subsystem. The data is coming from the distribution standard WI 10 Part 2.3.It is used because the heat to be supplied by the emitters must include emission and control losses whilst distribution losses shall be excluded.	[J]
t_{ci}	calculation interval	[s]

The average temperature of the emitters is given by:

$$\theta_{em} = \theta_i + \left(\frac{\Phi_{em}}{\Phi_{em,n}}\right)^{\frac{1}{n}} \cdot \Delta\theta_{em,n} \qquad [°C]$$

where

θ_i	internal temperature of the heated space	[°C]
$\Phi_{em,n}$	nominal power of installed emitters (this data coming from the emission part of the standard WI 8 Part 2.1)	[kW]
$\Delta\theta_{em,n}$	nominal temperature difference of emitters. Default value is given in the standard. This is the difference between average emitter temperature and air temperature in test conditions)	[K]
n	is the characteristic exponent of emitters Default value are given in the standard.	[-]

Control depending on the outside temperature and constant internal temperature

It is calculate by the following equation:

$$\theta_{em} = \theta_d + f_c \cdot (\theta_i - \theta_d) \qquad [°C]$$

Where

θ_d	sizing temperature for heat distribution; If different heat distributions are connected to the generator, the highest temperature is used for calculation.	[°C]
f_c	correction factor taking into account the type of control and default values during operation periods.	[-]

The difference between control depending on the inside temperature and the control depending on the outside temperature is, that the first take into account the heat gains and the emission law of the emitters. The second instead take into account only the difference of sizing temperature for heat distribution and the internal temperature.

Generators with double service (heating and domestic hot water production)

In the heating season the heat generator may produce energy for the heating installation and for domestic hot water (double service). The calculation of the heat losses of the domestic hot water production is not calculated in this thesis, but the hot water production has an influence on the heating part of the generator. It can influence with the running temperature of the generator, the running time, and the load. The running temperature of the generator can be modified if domestic hot water production is required. The domestic hot water production increases the load of the generator. This effect is expressed in increasing the mean generator power output during the considered period by:

$$\phi_{Px} = \phi_{Px,h} + \phi_{Px,dhw} \qquad [W]$$

where

$$\phi_{Px,dhw} = \frac{Q_{dhw}}{t_{ci}}$$

ANNEX D Heat pumps

In this work the calculation of heat pump systems is made.
Three type of heat pumps are considered in this report:

- Air to water heat pump that work from 0°C to 15°C
- Air to water heat pump that work over 0°C
- Water to water ground source heat pump.

In the first and the second case, an electrical resistance is used to cover the heat load when the pump is off.
The requirement for domestic hot water is covered by the heat pump with alternate hot water production.

Alternate operation switches the heat pump operation from the heating system to the domestic hot water system in case of domestic hot water demand, e.g. in the system configuration shown in Figure 4 with a domestic hot water storage in parallel. The domestic hot water operation has a priority, i.e. heating operation is interrupted in case of domestic hot water demand.

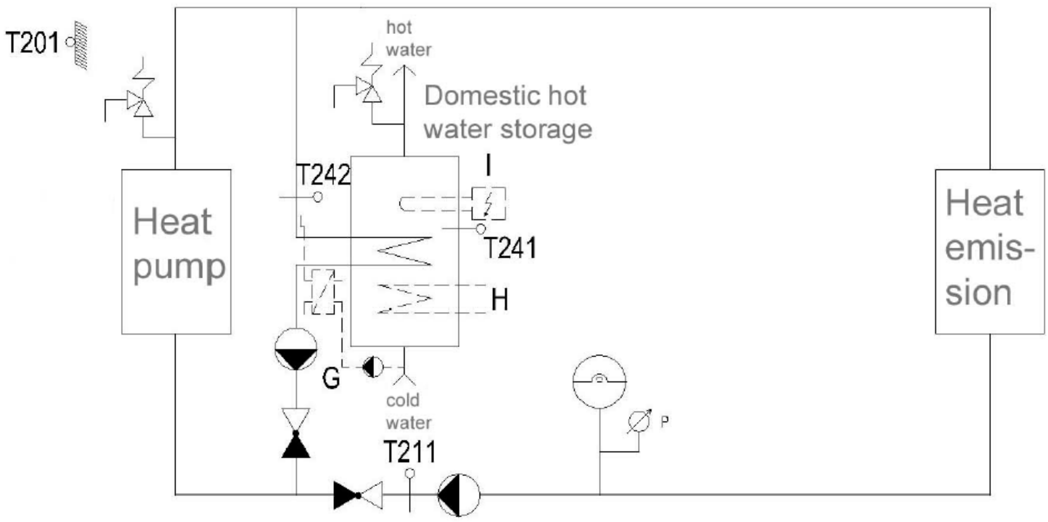

Figure D1 - Heat pump with alternate hot water production by switching the heat pump from the heating system to the domestic hot water system

Case specific heat pump seasonal performance method based on efficiency data

Principle of the method

As heat pump efficiency strongly depends on the operating conditions, i.e. source and sink temperature, the calculation is performed for periods defined by the source and sink temperature. The source and sink temperature level has the most significant impact on heat pump performance.

The calculation method is based on an evaluation of the outside dry bulb air temperature. The annual frequency, which is derived from hourly average values of the outside air temperature, is divided into temperature intervals (bins), which are limited by an upper temperature θ_{upper} and a lower temperature θ_{lower}.

Operating conditions of the bin are characterised by operating points in the centre of each bin. The method assumes, that the operating point defines the operating condition of the heat pump for the whole bin.

For each bin, the output capacity and the COP is evaluated from standard test measurements. The difference between the heat requirements and the output energy of the heat pump has to be supplied by the back-up system. Losses associated to the heat pump operation and electricity input to auxiliaries are calculated for each bin, too.

Weighting of the single bin and summation is performed to receive the total energy input in form of electricity or fuel for the whole period of operation and the seasonal performance factor of the generation subsystem respectively. Depending on the existence of a back-up system and its operating mode, supplied back-up energy is determined and summed up to receive the overall energy consumption.

Calculation steps to be performed

In this paragraph an overview of the calculation steps to be performed is given.

Step 1: Determination of energy requirement in the single bins.

Step 2: Determination of back-up energy in the single bins

Step 3: If required, correction of steady state output capacity / COP (EN 14511) for bin source and sink temperature.

Step 4: Correction of COP for part load operation.

Step 5: Calculation of the running time of the heat pump in different operating modes.

Step 6: Calculation of auxiliary energy input.

Step 7: Calculation of generator heat losses and recoverable generator losses.

Step 8: Calculation of total energy input to cover the requirements, optional calculation of seasonal performance factor based on used energy or primary energy.

Heating and domestic hot water requirement for the calculation periods

Heating mode

The total heating requirement is given by the distribution subsystem $Q_{d,in,h}$.

The heating requirement in bin i can be calculated with a weighting factor, which is derived from evaluating the frequency of the outside dry bulb temperature by means of heating degree hours (HDH). The evaluation of the heating degree hours based on the hourly outside temperature is described in APPENDIX N.

The weighting factors are calculated by the equation

$$w_i = \frac{HDH_{\theta_{upper}} - HDH_{\theta_{lower}}}{HDH_t} \qquad [-]$$

where:

w_i	weighting factor in bin i	[-]
HDH_t	total heating degree hours up to upper temperature limit for heating	[Kh]
$HDH_{\theta upper}$	heating degree hours up to the temperature at upper limit of bin i	[Kh]
$HDH_{\theta lower}$	heating degree hours up to the temperature at lower limit of bin	[Kh]

The heating degree hours for the respective climatic regions shall be given in a national annex or taken from national standardisation.
The energy requirement is taken from EN ISO 13790. The energy requirement in the respective bin is hence calculated by the equation

$$Q_{out,g,h,i} = Q_{out,g,h} \cdot w_i \qquad [J]$$

Where:

$Q_{out,g,h,I}$	heating energy requirement in bin I	[J]
$Q_{out,g,h}$	total heating energy requirement	[J]
W_i	weighting factor in bin i	[-]

DHW mode

The total domestic hot water requirement is given by the distribution subsystem $Q_{d,in,DHW}$.
The DHW requirement in bin i can be calculated with the bin time in bin i. It can be calculated by the equation:

$$Q_{out,g,DHW,i} = Q_{out,g,DHW} \cdot \frac{n_{hours,i}}{n_{hours,t}} \qquad [J]$$

$Q_{out,g,DHW,i}$	domestic hot water requirement in bin I	[J]
$Q_{out,g,DHW}$	total domestic hot water requirement	[J]
$n_{hours,i}$	cumulated number of hours in bin I	[h]
$n_{hours,t}$	total number of hours (8760 for domestic hot water operation)	[h]

Calculation for back-up heating

Heating mode

Operation of back-up heating is determined by the system design criteria and can be characterised by the operating mode (alternate operation, parallel operation, partly parallel operation) and the respective temperatures, heat pump low-temperature cut-off and balance point temperature. By these temperatures the energetic fraction of the heat pump and back-up operation can be determined and energy consumption can thus be calculated.

Alternate operating mode of the back-up heating

In alternate operating mode of the back-up heating, the heat pump generator is switched-off at the balance point temperature, and only the back-up heating supplies the full heat energy requirement below the balance point.
Figure 3.4 shows the areas under cumulative annual frequency of the dry bulb ambient temperature, which correspond to the energetic fractions. The area A_2 represents the energetic fraction delivered by the back-up heating.

The fraction of the back-up heating for alternate operation can be calculated by the equation

$$p_{bu,h} = \frac{A_2}{A_t} = \frac{HDH(\theta_{bp})}{HDH_t} \qquad [-]$$

where:

$p_{bu,h}$	energy fraction of the back-up generator	[-]
A_2	area A_2 in Figure 7	[m2]
(Kh)	total area under the cumulative annual frequency	[m2]
HDH(θ_{bp})	cumulated heating degree hours up to the balance point temperatur θ_{bp}	[Kh]
HDH_t	total heating degree hours	[Kh]

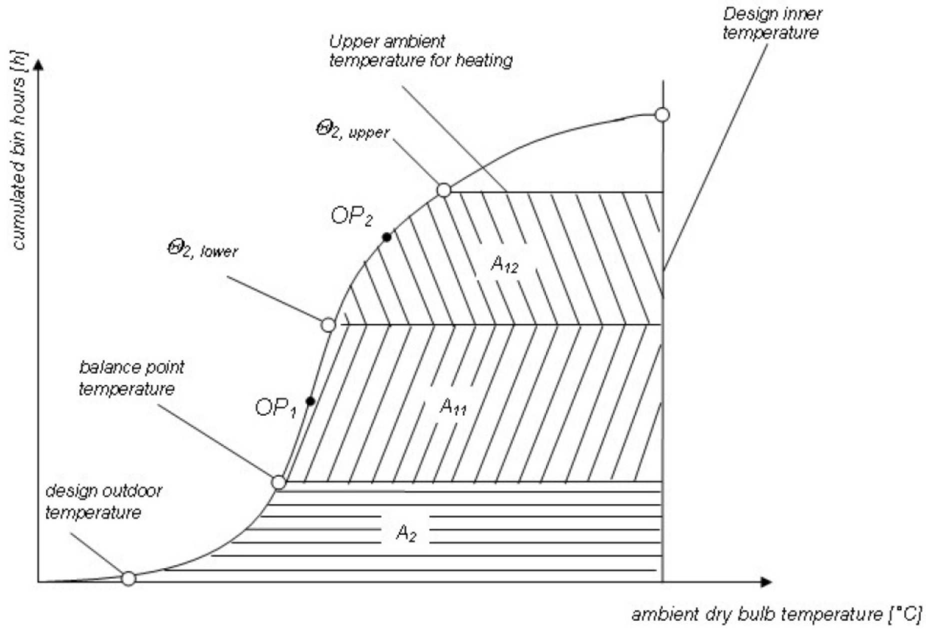

Figure D2 - bin hours for alternative operating mode of back-up heating

DHW mode

In case of an installed back-up resistance heating for the domestic hot water production the amount of backup energy is often determined by a temperature limit up to which the heat pump delivers the energy, e.g. 55°C, and above this limit, the missing energy is supplied by the back-up system. The calculation of the domestic hot water energy is done in the distribution of domestic hot water part of this thesis. The fraction of back-up energy supplied to the domestic hot water system is described by the equation

$$Q_{bu,DHW} = \rho_w \cdot V_w \cdot c_w(\theta_w - \theta_{upper,hp}) \qquad \text{[J]}$$

where

$Q_{bu,DHW}$	domestic hot water energy generated by the back-up system	[J]
ρ_w	density of water	[kg/m3]
V_w	volume of the tapped water	[m3]

c_w	specific heat capacity	[J/(kgK)]
$\theta_{upper,hp}$	upper temperature limit for the operation of the heat pump	[°C]
θ_w	temperature of the delivered hot water	[°C]

Thus the fraction of the back-up energy for the domestic hot water operation can be calculated by the equation

$$p_{bu,DWH} = \frac{Q_{bu,DWH}}{Q_{out,g,DWH}} \qquad [-]$$

where

$p_{bu,DHW}$	fraction of domestic hot water energy requirement	[-]
$Q_{bu,DHW}$	domestic hot water energy requirement generated by the back-up heater	[J]
$Q_{out,g,DHW}$	domestic hot water energy requirement	[J]

Output capacity and COP at full load (steady-state operation)

Heating mode

The steady state output capacity and COP is taken from standard test results according to EN 14511 (formerly EN 255-2). In EN 14511 standards testing is performed at standard rating conditions and several application rating conditions. Since the COP characteristic has the most significant impact on the heat pump performance it shall be taken care, that COP-values are reliable. All available testing points have to be taken into account.

To receive data for the whole range of the outdoor temperature linear inter- and extrapolation between the testing points is applied both for the source as for the sink temperature. Interpolation is performed between the temperatures of the two nearest testing points.

To receive an adequate exactness by interpolation,

- at least 4 testing point on two temperature levels of the heat sink are to be used in case of air-to-water or air-to-air heat pump systems.
- at least 2 testing points on two temperature levels of the heat sink are to be used in case of brine-to-water and water-to-water systems.

If not sufficient data are available from testing institutes, manufacturer data measured according to EN 14511 (or older test results based on EN 255-2) can be used. If, nevertheless, only little data is available correction for source and sink temperature can be done with the approach using the exergetic efficiency described in standard WI 9 part 2-2.2 instead of interpolating the data.

If no data are available, default values are given in APPENDIX I.

The source of the data shall be stated clearly in the calculation report.

Interpolation of output capacity and COP for the temperature conditions

Based on the respective measurements of the output capacity and the COP according to EN 14511 (formerly EN 255-2), the interpolation for the actual temperature conditions at the operating point of the respective bin is performed. As stated above interpolation is performed between the temperatures of the two nearest testing points.

- In the case of outside air heat pump the source temperature is given by the outside temperature of the meteorological data.
- In the case of ground- or water-source heat pumps, the temperature of the ground or water must be used, respectively. As ground and water temperature depend on the site, they should be given in a national annex. If a national annex is not available, a standard profiles are given in WI 9 part 2-2.2
- In the case of exhaust-air heat pumps without heat recovery the source temperature corresponds to the indoor temperature.

The actual sink temperature can be calculated according to the controller settings of the heating systems. If the controller settings of the heating system is not known, typical controller settings for the sink temperature dependent on the outside temperature (heating characteristic curve) for different kinds of heat emission systems are given in WI 9 part 2-2.2.

DHW mode

Domestic hot water systems are tested as unitary systems including the domestic hot water storage in the system boundary according to the standard EN 255-3. The standard delivers the COP-value for the extraction of domestic hot water, called $COP_{t,\,DHW}$. In case of air-to-water heat pumps, the source temperature is 7°C, in case of brine-to-water heat pumps the source temperature is 0°C.

This $COP_{t,DHW}$ value is only valid for the extraction of domestic hot water and not for the loading of the storage without extraction of domestic hot water (stand-by operation), since the inlet temperature to the condenser and thus the COP of the heat pump changes significantly, if stand-by losses have to be covered as well.

However the standard delivers an electrical power input to cover the storage losses, hence electricity consumption to cover stand-by losses can be expressed by this value.

The sink temperature conditions of domestic hot water system may change during the year. However, for calculation purposes the sink temperature can be considered constant over the whole operating range as long as the tapping temperature of the domestic hot water does not change much.

Due to varying source temperatures, the operation period and thus COP values have to be corrected for these conditions. As only one standard testing point is defined in EN 255-3, a temperature correction of theCOP by interpolation is not possible. Thus for the correction, the approach using a fixed exergetic or Carnot efficiency described in WI 9 part 2-2.2 should be applied.

COP at part load operation

Principle

Heat pumps with fixed speed compressor operate in part load operation by cycling between on and off status. Therefore, in part load operation losses due to cycling of the compressor occur and reduce the COPof the heat pump.

Variable capacity units, controlled step wise or continuously by means of an inverter have a better efficiencyat part load.
The calculation method requires as input data the part load COP for the output capacity corresponding to the operating point of each bin. The part load COP is an input determined on the basis of test measurements provided by an accredited institute.

To perform the calculation with a suitable accuracy COP values corresponding to 25 %, 50 % and 75 % of the maximum output capacity of the heat pump should be taken into account. At least COP at 50 %, measured according to the test procedure described in CEN/TS 14825 (testing and rating at part load conditions), shall be provided.

Default values

If no measurements data for part load operation are available default values can be used to perform the calculation. COP at part load, COP_{pl}, is given by the following relationship:

$$COP_{pl} = COP_{fl} \cdot f_{pl} \qquad [-]$$

where

COP_{pl}	COP at part load operation	[W/W]
COP_{fl}	COP at full load operation	[W/W]
f_{pl}	correction factor for part load operation	[-]

COP_{fl} is the coefficient of performance of the heat pump, in steady state, for the same sink and source temperatures.

f_{pl} is a coefficient taking into account the thermal inertia of the distribution system served by the heat pump and the intrinsic characteristics of the unit.

fpl is given in APPENDIX I, Table I1 for floor heating emission systems (electrically driven heat pumps) and Table I2 for radiators.

f_{pl} depends on the load factor FC. The load factor can be calculated by the equation

$$FC = \frac{t_{ON,g,in}}{t_i} \qquad [-]$$

where

FC	load factor	[-]
$t_{ON,g,i}$	running time of the generator in bin i	[s]
t_i	total time in bin i	[s]

DHW mode

Start up losses of the heat pump are taken into account in the $COP_{t,DHW}$-value according to EN 255-3 and do not have to be corrected.

Running time of the heat pump

Operation time of the heat pump depends on the output capacity, given by the operating conditions, and the heat requirement, given by the building load and the distribution system. It can be calculated by the equation:

$$t_{ON,g,i} = \frac{Q_{g,i}}{\Phi_{g,i}} \qquad \text{[s]}$$

where

$t_{ON,g,i}$	running time of the generator in bin i	[s]
$Q_{g,i}$	energy requirement of distribution system and generator losses in bin i	[J]
$\Phi_{g,i}$	output capacity of the heat pump generator in bin i	[W]

As operation time of the generator depends on the heat energy requirement, the operating mode of the heat generator has to be taken into account.

Heat pumps operating alternately on space heating and domestic hot water generation

Total running time of the generator is determined by the sum of the heating and domestic hot water energy requirements, produced at the respective output capacity of the generator according to the temperature conditions.

Auxiliary energy

Heating mode

Auxiliary input to operate the heat pump depends on the type of heat pump (e.g. air-to-water, liquid-to-water) and the system configuration (with or without storage, combined domestic hot water production etc.). Auxiliary energy is required e.g. to operate the source pump of the generator.

Auxiliary energy is accounted to the generation subsystem as long as no transport energy is transmitted to the distribution system. This means, in case of a hydraulic decoupling of the generation and the distribution subsystems, e.g. by a storage in parallel or a hydraulic distributor, the primary pump is accounted to the generation subsystems. In case of no hydraulic decoupling the pump of the heat sink in accounted to the distribution part.

Operation of the source pump is associated with the heat pump generator operation during operation time t_{ON}.

Operation of the primary pump is associated with the system configuration and the control strategy. It is either running through the whole activation time of the generator, i.e. the heating period, or it is related to the running time of the generator, if a corresponding control strategy is applied.

In case that the system contains a heating buffer storage in parallel, the operation of the storage pump is related to the running time of the heat pump t_{ON}. In systems without storage, the primary pump eventually runs through the whole operation period of the heating system, e.g. the heating period.

To calculate the auxiliary energy, the respective power of the pumps has to be given as input. Calculation is performed according to the following equation.

$$W_g = \Phi_{aux,g} \cdot t_{ON,aux} \qquad [J]$$

where:

W_g	auxiliary energy	[J]
$\Phi_{aux,g}$	power of the auxiliary component	[W]
$t_{ON,aux}$	running time of the respective auxiliary component	[s]

Air-to-water heat pump

Air-to-water heat pumps are tested as unitary components, so that the auxiliary energy for fan at the source side is already taken into account during testing according to EN 14511 (formerly EN 255). Thus, no additional auxiliary energy has to be considered for air-to-water heat pumps.

Liquid-to-water heat pump

In the case of liquid-to-water heat pumps the source pump is only partly considered in the standard testing values, thus the remaining the electricity input of the source pump has to be taken into account.

System configuration containing a hydraulic decoupling

In case of a hydraulic decoupling of the generation and the distribution subsystem, the primary pump is accounted to the generation subsystem. The primary pump is operated the whole activation period or associated to the running time of the generator depending on the control strategy.

Energy consumption of the control system

Control of the heating systems is activated during the whole heating period. However, during the operating time of the heat pump, the energy for the control system is already included in the COP values according to EN 14511 (formerly EN 255-2). Thus, the control system has to be taken into account only for the stand-by operation of the heat pump.

$$W_{g,ctrl} = \Phi_{ctrl} \cdot t_{s\tan d-by} \qquad [J]$$

In system configurations for both heating and domestic hot water the stand-by time can be evaluated as the whole year diminished by the total operating time of the heat pump, e.g. the sum for heating operating time and domestic hot water operation time. An allocation of the stand-by operation to the single operating modes can be done as for the single system configurations.

DHW mode

As the storage loading pump is already included in the $COP_{t,DHW}$-value, only the source pump has to be taken into account. The source pump is associated to the running time of the generator.

Heat generator loss and recoverable heat generator loss

Auxiliary consumption

Auxiliary energy is partly transformed to used energy and partly to thermal losses. The ratio between used energy and thermal losses can be derived by the component efficiency (η_{aux}), which should be given in a national annex. If no values are available, default values are given in APPENDIX I, table I4. Recoverable thermal losses are partly recovered, e.g. in the heat transfer medium or if the component is in the heated space.
Losses to the ambiance are assumed recoverable

$$W_{g,rl} = W_g \cdot (1-b) \cdot p_{aux,g} \qquad \text{[J]}$$

Where

$W_{g,rl}$	recoverable auxiliary energy transferred to the ambiance	[J]
W_g	auxiliary energy consumption of the generator	[J]
$p_{aux,g}$	fraction of nominal electrical power transmitted to the ambiance. These values should be defined in a national annex. If no national values are specified, default values given in WI 9 part 2-2.2 shall be used.	[J]
b	temperature reduction factor linked to erection site. The values of b should be defined in a national annex. If no national values are specified, the default values are given in APPENDIX I, table I3.	[-]

Generator heat losses

Heating mode

In case of a heat pump without integrated domestic hot water storage, the losses to the ambiance are negligible, since a heat pump normally is delivered in a insulated housing. The condenser of the generator has the temperature in the order of magnitude of the supply temperature of the heating system, while the evaporator has a temperature less than the ambiance. Thus losses at the hot condenser are balanced by the gain at the evaporator. Possibly installed heating buffer storages are not considered here concerning the storage losses. Thus for heating operation no generator losses are taken into account.

DHW mode

In the case of a heat pump with integrated domestic hot water storage, the storage has losses to the ambiance, that can be calculated by

$$Q_{l,g,s,i} = U \cdot A \cdot (\theta_{s,avg} - \theta_{sur}) \cdot t_i \qquad \text{[J]}$$

where:

$Q_{l,g,s,i}$	generator heat loss by storage heat loss to the ambiance in bin i	[J]
$\theta_{s,avg}$	average storage temperature	[°C]
θ_{sur}	temperature of the generator surroundings	[°C]
U	heat loss coefficient of the storage. This value should be taken from a national annex or manufacturers data. If no values are available, default values are given in WI 9 part 2-2.2	[W/(m2·K)]

A	surface area of the storage. This value should be taken from a national annex or manufacturers data.	[m^2]
t_i	bin time i	[s]

The average storage temperature $\theta_{s,avg}$ is calculated as average temperature of the controller setting for switching-on and switching-off the storage loading according to the equation

$$\theta_{s,avg} = \frac{\theta_{s,ON} - \theta_{s,OFF}}{2} \qquad [°C]$$

where:

$\theta_{s,avg}$	average storage temperature	[°C]
$\theta_{s,ON}$	switch-on temperature of storage reheating	[°C]
$\theta_{s,OFF}$	switch-off temperature of storage reheating	[°C]

Losses through the generator envelope are considered recoverable. Recoverable generator losses caused by the losses of the built-in storage can be calculated according to the equation

$$Q_{l,g,s} \cdot (1-b) \qquad [J]$$

where:

$Q_{l,g,rl}$	recoverable losses of the generator	[J]
$Q_{l,g,s}$	heat losses of the generator	[J]
b	temperature reduction factor linked to erection site. The values of b should be defined in a national annex.If no national values are specified, the default values are given in ANNEX B, Table B 14	[-]

Total recoverable generator losses

The total recoverable losses can be obtained by a summation according to the equation

$$Q_{t,g,rl} = Q_{l,g,rl} + W_{g,rl} \qquad [J]$$

where:

$Q_{t,g,rl}$	total recoverable generation subsystem losses (in form of storage losses of an integrated storage)	[J]
$Q_{l,g,rl}$	recoverable generation subsystem losses	[J]
$W_{g,rl}$	recoverable auxiliary energy	[J]

Calculation of total energy input

Electricity input to the heat pump for heating operation

The electricity input to the heat pump can be calculated by summing the electricity input of the respective bins according to the equation

$$E_{in,g,h} = \sum_{i=1}^{n_{bin}} \frac{Q_{out,g,h,\sin,i} - (1 - p_{h,combi}) \cdot k_{rd,g} \cdot W_{g,h,i}}{COP_{\sin,i}} + \sum_{i=1}^{n_{bin}} \frac{Q_{out,g,h,combi,i} - p_{h,combi} \cdot k_{rd,g} \cdot W_{g,h,i}}{COP_{combi,i}} \quad [J]$$

where:

$E_{in,g,h}$	electrical energy input to operate the heat pump in heating mode	[J]
$Q_{out,g,h,sin,i}$	heating energy requirement covered in single operation in bin i	[J]
$Q_{out,g,h,combi.i}$	heating energy requirement covered in combined operation in bin i	[J]
$k_{rd,g}$	fraction of auxiliary energy recovered as thermal energy	[-]
$W_{g,h,i}$	auxiliary energy input to operate the generator in heating operation in bin i	[J]
$COP_{sin,i}$	coefficient of performance for single operation at operating point (-)	[-]
$COP_{combi,i}$	coefficient of performance for simultaneous at operating point taken as performance factor in the respective bin, for the whole bin	[-]
$p_{h,combi}$	fraction of combined operation in case of simultaneous operating systems	[-]
n_{bin}	number of bins	[-]

Electricity input to the heat pump for DHW operation

The electricity operation for DHW operation can be calculated according to the equation

$$E_{in,g,DHW} = \sum_{i=1}^{n_{bin}} \frac{(1 - p_{bu,DHW}) \cdot Q_{out,g,DHW,\sin,i}}{COP_{t,DHW,\sin,i}} + P_{es,\sin,i} \cdot t_i + \sum_{i=1}^{n_{bin}} \frac{(1 - p_{bu,DHW}) \cdot Q_{out,g,DHW,combi,i}}{COP_{t,DHW,combi,i}} + P_{es,combi,i} \cdot t_i \quad [J]$$

where:

$E_{in,g,DHW}$	electrical energy input to operate the heat pump in DHW mode	[J]
$p_{bu,DHW}$	fraction of domestic hot water energy, covered by backup	[-]
$Q_{out,g,DHW,sin,i}$	DHW energy requirement covered by single operation	[J]
$Q_{out,g,DHW,combi,i}$	DHW energy requirement covered by simultaneous operation	[J]
$COP_{t,DHW,sin,}$	coefficient of performance for the extraction of domestic hot water in single operation according to EN 255-3 taken as performance factor for the whole bin	[-]
$COP_{t,DHW,combi,i}$	coefficient of performance for the extraction of domestic hot water in simultaneous operation taken as performance factor	[-]
$P_{es,sin,i}$	electricity power input to cover storage losses at single operation according to EN 255-3	[W]
$P_{es,combi,i}$	electricity power input to cover storage losses at combined operation according to EN 255-3	[W]
t_i	time in bin i	[h]
n_{bin}	number of bins	[-]

Auxiliary energy input

$$W_g = \sum_{i=1}^{n_{bin}} W_{g,i} \quad [J]$$

Where:

W_g	total auxiliary energy to operate the heat	[J]
$W_{g,i}$	electrical energy input for auxiliaries to operate the heat pump in bin	[J]
n_{bin}	number of bins	[-]

Energy input to backup system

$$E_{in,g,bu} = Q_{out,g,h} \cdot p_{bu,h} + Q_{out,g,DHW} \cdot p_{bu,DHW} \qquad [J]$$

Where:

$E_{in,g,bu}$	total electrical energy input to operate the back-up heater	[J]
$Q_{out,g,h}$	energy requirement for space heating	[J]
$p_{bu,h}$	fraction of heating energy, covered by backup heater	[-]
$Q_{out,g,DHW}$	energy requirement for DHW	[J]
$p_{bu,DHW}$	fraction of domestic hot water energy, covered by backup heater	[-]

Total energy input

The total electricity input is the sum over all single electricity inputs

$$E_{in,g} = E_{in,g,h} + E_{in,g,DHW} + E_{in,g,bu,h} \qquad [J]$$

where:

$E_{in,g}$	electrical energy input to operate the generator (heat pump and back-up)	[J]
$E_{in,g,h}$	electrical energy input to operate the heat pump in heating mode	[J]
$E_{in,g,DHW}$	electrical energy input to operate the heat pump in DHW mode	[J]
$E_{in,g,bu}$	electrical backup energy input	[J]

Seasonal performance factor of the generator subsystem

The seasonal performance factor can be calculated for the single operation, e.g. heating and domestic hot water and combined to an overall seasonal performance, or directly calculated as an overall seasonal performance.
Overall seasonal performance can be calculated according to the equation

$$SPF_{g,t} = \frac{Q_{out,g,h} + Q_{out,g,DHW} + Q_{l,g,s}}{E_{in,g}} \qquad [-]$$

where:

$SPF_{g,t}$	total seasonal performance factor of generator	[-]
$Q_{out,g,h}$	total heating energy requirement for space heating	[J]
$Q_{out,g,DHW}$	total heating energy requirement for DHW	[J]
$Q_{l,g,s}$	total heating energy to cover storage losses	[J]
$E_{in,g}$	total electrical energy input	[J]

As the seasonal performance factor is the reciprocal value of the expenditure factor it can be also calculated by the equation

$$e_g = \frac{1}{SPF_{g,t}} \qquad [-]$$

where:

e_g	expenditure factor for generator	[-]
$SPF_{g,t}$	total seasonal performance factor	[-]

For respective operating modes, heating and domestic hot water, can be calculated

$$SPF_{g,h} = \frac{Q_{out,g,h}}{E_{in,g,h}} \qquad [-]$$

where:

$SPF_{g,h}$	seasonal performance factor for heating	[-]
$Q_{out,g,h}$	total heating requirement for space heating	[J]
$E_{in,g,h}$	total electricity requirement for space heating	[J]

and for the domestic hot water operation respectively

$$SPF_{g,DHW} = \frac{Q_{out,g,DHW}}{E_{in,g,DHW}} \qquad [-]$$

where:

$SPF_{g,DHW}$	seasonal performance factor for DHW	[-]
$Q_{out,g,DHW}$	total heating requirement for DHW	[J]
$E_{in,g,DHW}$	total electricity requirement for DHW	[J]

Seasonal performance regarding primary energy

The total primary energy input is the sum over all single equivalent primary energy inputs.

$$E_{prim,g} = E_{in,g} \cdot f_{el} \qquad [J]$$

where:

$E_{prim,g}$	total primary energy input to operate the generator (heat pump and backup)	[J]
$E_{in,g}$	total electricity energy input to operate the generator (heat pump and backup)	[J]
f_{el}	primary energy conversion factor for electricity	[-]

The overall seasonal performance can be calculated as follows :

$$SPF_{g,prim} = \frac{Q_{out,g,h} + Q_{out,g,DHW}}{E_{prim,g}} \qquad [-]$$

where:

$SPF_{g,prim}$	seasonal performance factor for generator regarding primary energy	[-]
$Q_{out,g,h}$	total energy requirement for space heating	[J]
$Q_{out,g,DHW}$	total energy requirement for DHW	[J]
$E_{prim,g}$	total primary energy input to operate the heat pump	[J]

For respective operating modes heating and domestic hot water it can be calculated :

$$SPF_{h,prim} = \frac{Q_{out,g,h}}{E_{prim,g,h}} \qquad [-]$$

where:

$SPF_{h,prim}$	seasonal performance factor for heating regarding to primary energy	[-]
$Q_{out,g,h}$	total energy requirement for space heating	[J]
$E_{prim,g,h}$	total primary energy input to operate the heat pump in heating mode	[J]

Domestic hot water mode is calculated according to the equation

$$SPF_{DHW,prim} = \frac{Q_{out,g,DHW}}{E_{prim,g,DHW}} \qquad [-]$$

where:

$SPF_{DHW,prim}$	seasonal performance factor for DHW regarding primary energy	[-]
$Q_{out,g,DHW}$	total energy requirement for DHW production	[J]
$E_{prim,g,DHW}$	total primary energy input to operate the heat pumps in DHW mode	[J]

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Appendix E - Climatic data input for calculation

Table E.1 - Climatic data for Stockholm , Brussels and Venice weather stations

Climatic data												
Stockholm												
Month	January	February	March	April	May	June	July	August	September	October	November	December
Outside average air temperature,°C	-2.9	-3.1	-0.7	4.4	10.1	14.9	17.8	16.6	12.2	7.1	2.8	0.1
Global irradiation, Wh/m^2	333	960	2187	3627	5280	5907	5207	4173	2567	1227	253	240
Brussels												
Month	January	February	March	April	May	June	July	August	September	October	November	December
Outside average air temperature,°C	3.2	3.9	5.9	9.2	13.3	16.2	17.6	17.5	15.2	11.1	6.3	3.5
Global irradiation, Wh/m^2	647	1273	2207	3287	4487	4967	4560	3933	3027	1753	793	507
Venice												
Month	January	February	March	April	May	June	July	August	September	October	November	December
Outside average air temperature,°C	4,4	4,9	7,6	13,1	17,9	22,7	23,5	22,1	17,6	15,8	11,5	7,1
Global irradiation, Wh/m^2	1189,2	2453,2	3290,9	4018,9	5770,1	6221,3	6020,4	5280,7	3900,4	2265,9	1370,6	1146,3

Appendix F – Pipe's layout

House Building

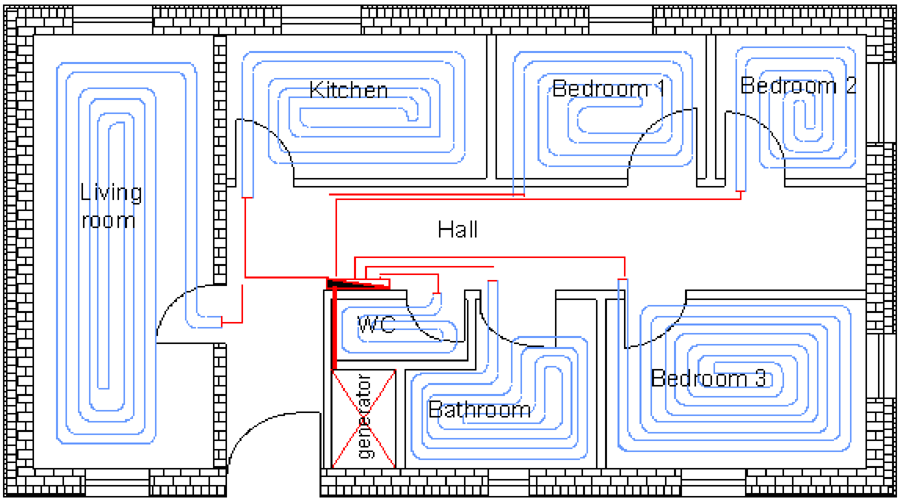


Figure L1 Layout of floor heating system

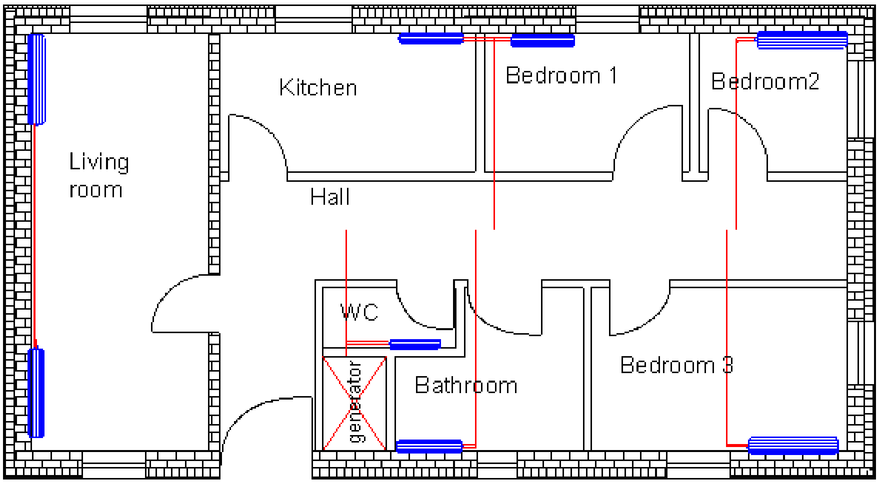


Figure L2 Layout of radiator heating system

Office Building

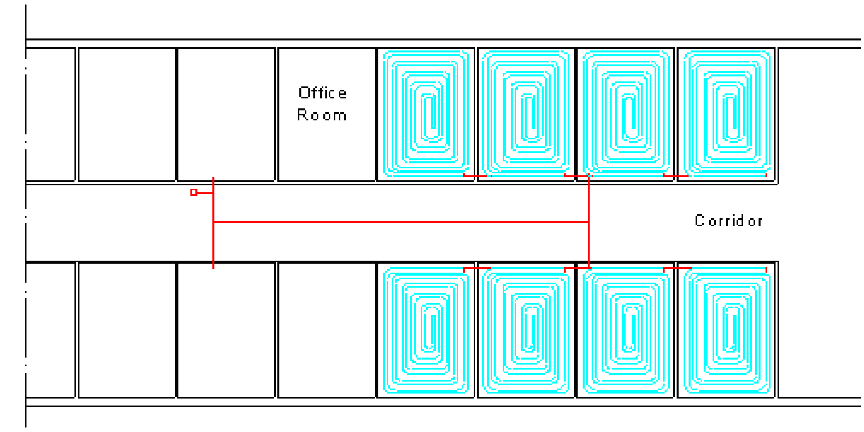


Figure L3 - Layout of floor heating system

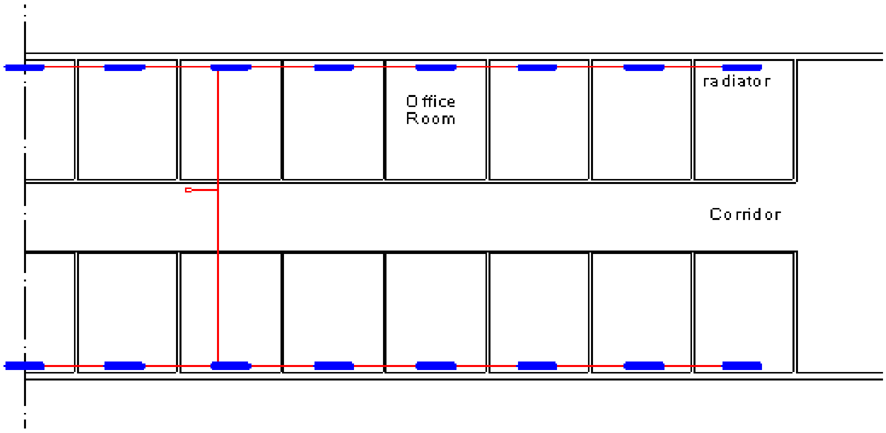


Figure L4 - Layout of radiators heating system

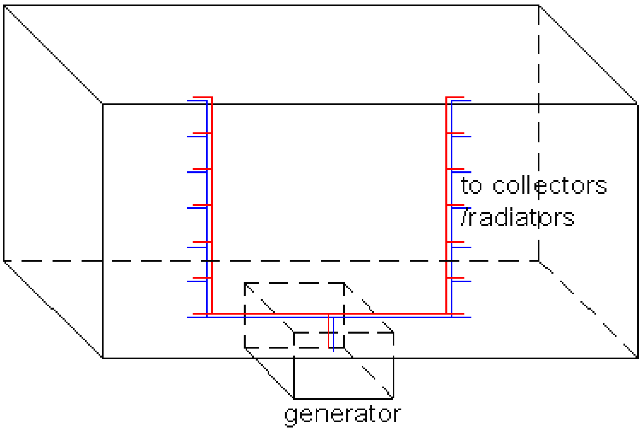


Figure L5 - Frontal view office building

Industrial Building

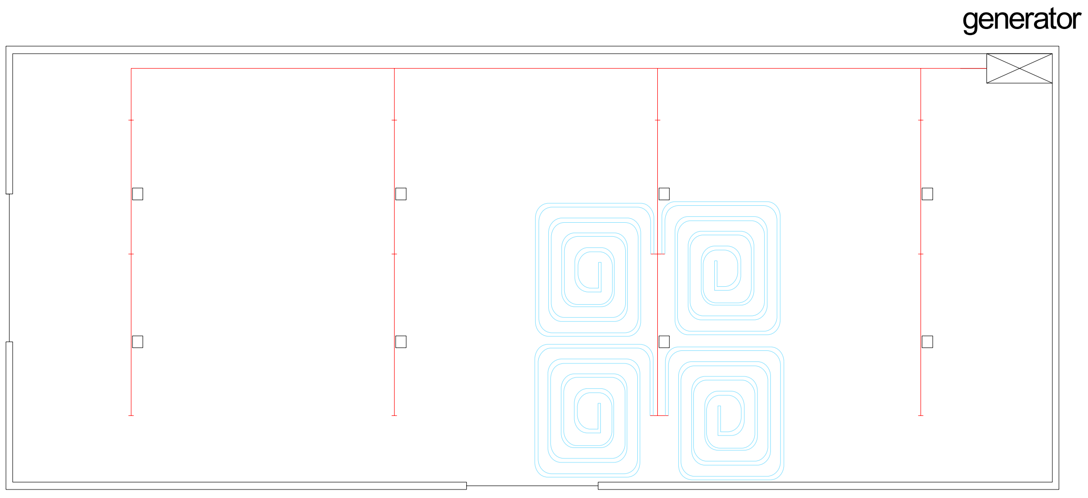


Figure L6 - Layout of floor heating system

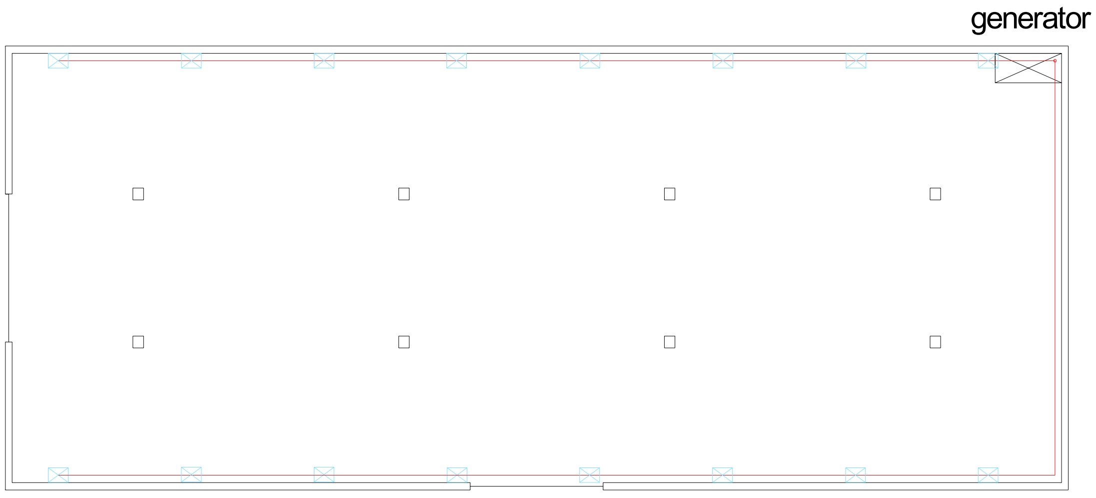


Figure L7 - Layout of radiators heating system

ANNEX G Table values

Emission heat loss Residential house			ΔT	η_{str1}	η_{str2}	<u>η_{emb}</u>	<u>η_{ctr}</u>	<u>η_{str}</u>	η_{em}	Stockholm $Q_{em,ls}$ Qh = 141,85 KWh/m²	Brussels $Q_{em,ls}$ Qh = 87,55 KWh/m²	Venice $Q_{em,ls}$ Qh = 66,42 KWh/m²
	Radiators (boiler) 70/55/20	P(2K)					0,93		**0,88**	18,4	11,4	8,6
		P(1K)					0,95		**0,90**	15,6	9,6	7,3
		PI	42,5	0,93	0,95	1	0,97	0,94	**0,92**	12,8	7,9	6,0
	Radiators (e.g.) 55/45/20	P (2K)					0,93		**0,89**	17,0	10,5	8,0
		P (1K)					0,95		**0,91**	14,2	8,8	6,6
		PI	30	0,95	0,95	1	0,97	0,95	**0,93**	11,3	7,0	5,3
	Radiators (HP) 50/35/20	P (1K)					0,93		**0,90**	16,3	10,1	7,6
		P (1K)					0,95		**0,91**	13,5	8,3	6,3
		PI	22,5	0,96	0,95	1	0,97	0,955	**0,93**	10,6	6,6	5,0
				η_{emb1}	η_{emb2}	<u>η_{emb}</u>	<u>η_{ctr}</u>	<u>η_{str}</u>	η_{em}			
	Floor heating 35/28	P-control					0,93	**1**	**0,89**	18,4	11,4	8,6
		PI-control		0,93	0,95	0,94	0,95	**1**	**0,90**	15,6	9,6	7,3
	Floor heating extra insulation	P-control					0,93		**0,90**	15,6	9,6	7,3
		PI-control		0,93	0,99	0,96	0,95	1	**0,92**	12,8	7,9	6,0
	Floor heating No downwards loss	P-control					0,93		**0,93**	9,9	6,1	4,6
		PI-control		1	1	1	0,95	1	**0,95**	7,1	4,4	3,3

Emission heat loss Office building		ΔT	η_{str1}	η_{str2}	η_{emb}	η_{ctr}	η_{str}	η_{em}	Stockholm $Q_{em,ls}$ Qh = 70,58 KWh/m²	Brussels $Q_{em,ls}$ Qh = 47,82 KWh/m²	Venice $Q_{em,ls}$ Qh = 36,08 KWh/m²
Radiators (boiler) 70/55/20	P(2K)					0,93		**0,88**	9,2	6,2	4,7
	P(1K)					0,95		**0,90**	7,8	5,3	4,0
	PI	42,5	0,93	0,95	1	0,97	0,94	**0,92**	6,4	4,3	3,2
Radiators (e.g.) 55/45/20	P (2K)					0,93		**0,89**	8,5	5,7	4,3
	P (1K)					0,95		**0,91**	7,1	4,8	3,6
	PI	30	0,95	0,95	1	0,97	0,95	**0,93**	5,6	3,8	2,9
Radiators (HP) 50/35/20	P (1K)					0,93		**0,90**	8,1	5,5	4,1
	P (1K)					0,95		**0,91**	6,7	4,5	3,4
	PI	22,5	0,96	0,95	1	0,97	0,955	**0,93**	5,3	3,6	2,7
			η_{emb1}	η_{emb2}	η_{emb}	η_{ctr}	η_{str}	η_{em}			
Floor heating	P-control					0,93		**0,93**	4,9	3,3	2,5
No downwards loss	PI-control		1	1	1	0,95	1	**0,95**	3,5	2,4	1,8

Emission heat loss Industrial building											Stockholm $Q_{em,ls}$	Brussels $Q_{em,ls}$	Venice $Q_{em,ls}$
											Qh = 72,14	Qh = 46,20	Qh = 41,76
			η_{str}	η_{ctr}	η_{emb}	$\boldsymbol{\eta_{em}}$	f_{rad}	f_{im}	f_{hydr}	*Emission factor*	KWh/m²	KWh/m²	KWh/m²
Industrial	Warm water panels	PI-controller	0,92	0,97	1	**0,90**	0,85	1	1	-0,06	-4,1	-2,6	-2,4
	Warm Air, horizontal	PI-controller	0,72	0,97	1	**0,76**	1	1	1	0,31	22,4	14,3	12,9
	Floor heating, integrated	PI-controller	0,92	0,97	0,95	**0,86**	0,85	1	1	-0,01	-1,0	-0,6	-0,6
	Floor heating insulation	PI-controller	0,92	0,97	1	**0,90**	0,85	1	1	-0,06	-4,1	-2,6	-2,4

ANNEX H Primary Energy

The following results include recovery of distribution losses from the heating pipes. Residential = 85% recovery,

Residential		Net Energy				Codensing boiler		Air-Water Heat Pump		Ground Source Heat Pump		Primary f	Primary f	Boiler	AW-HP	GS-I
Stockholm	Qh = 142	Qh KWh/m²	Qem,ls KWh/m²	$Q_{D\text{-}loss}$ KWh/m²	$W_{D\text{-}aux}$ KWh/m²	$Q_{G\text{-}loss}$ KWh/m²	$W_{G\text{-}aux}$ KWh/m²	$W_{G\text{-}use}$ KWh/m²	COP KWh/m²	$W_{G\text{-}use}$ KWh/m²	COP KWh/m²	Gasheating	Electricity	Primary KWh/m²	Primary KWh/m²	Prim KWI
Radiators (boiler) 70/55/20	P(2K)	141,85	18,44	5,48	1,51	-1,23	1,76					1,1	2,8	190		
	P(1K)	141,85	15,60	5,48	1,51	-1,23	1,76					1,1	2,8	187		
	PI	141,85	12,77	5,48	1,51	-1,23	1,76					1,1	2,8	184		
Radiators (e.g.) 55/45/20	P (2K)	141,85	17,02	3,85	1,97	-4,57	1,75					1,1	2,8	184		
	P (1K)	141,85	14,19	3,85	1,97	-4,57	1,75					1,1	2,8	181		
	PI	141,85	11,35	3,85	1,97	-4,57	1,75					1,1	2,8	178		
Radiators (HP) 50/35/20	P (2K)	141,85	16,31	2,96	1,5	-6,42	1,74	115,09	1,4	76,73	2,1	1,1	2,8	179	324	
	P (1K)	141,85	13,48	2,96	1,5	-6,42	1,74	113,06	1,4	75,37	2,1	1,1	2,8	176	318	
	PI	141,85	10,64	2,96	1,5	-6,42	1,74	111,03	1,4	74,02	2,1	1,1	2,8	173	312	
Floor heating 35/28	P-control	141,85	18,43	1,32	2,62	-9,48	1,74	101,00	1,6	46,17	3,5	1,1	2,8	180	285	
	PI-control	141,85	15,59	1,32	2,62	-9,48	1,74	99,22	1,6	45,36	3,5	1,1	2,8	176	280	
Floor heating extra insulation	P-control	141,85	15,60	1,32	2,62	-9,48	1,74	99,23	1,6	45,36	3,5	1,1	2,8	176	280	
	PI-control	141,85	12,77	1,32	2,62	-9,48	1,74	97,46	1,6	44,55	3,5	1,1	2,8	173	276	
No downwards loss	P-control	141,85	9,93	1,32	2,62	-9,48	1,74	95,69	1,6	43,74	3,5	1,1	2,8	170	271	
	PI-control	141,85	7,09	1,32	2,62	-9,5	1,74	93,91	1,6	42,93	3,5	1,1	2,8	167	266	

Residential		Net Energy				Codensing boiler		Air-Water Heat Pump		Ground Source Heat Pump		Primary f	Primary f	Boiler	AW-HP	GS-H
Brussels	Qh = 87,55	Qh KWh/m²	Qem,ls KWh/m²	$Q_{D\text{-}loss}$ KWh/m²	$W_{D\text{-}aux}$ KWh/m²	$Q_{G\text{-}loss}$ KWh/m²	$W_{G\text{-}aux}$ KWh/m²	$W_{G\text{-}use}$ KWh/m²	COP	$W_{G\text{-}use}$ KWh/m²	CO	Gasheating	Electricity	Primary KWh/m²	Primary KWh/m²	Prima KWh/
Radiators (boiler) 70/55/20	P(2K)	87,55	11,38	4,12	1,01	-0,62	1,28					1,1	2,8	119		
	P(1K)	87,55	9,63	4,12	1,01	-0,62	1,28					1,1	2,8	117		
	PI	87,55	7,88	4,12	1,01	-0,62	1,28					1,1	2,8	115		
Radiators (e.g.) 55/45/20	P (2K)	87,55	10,51	2,91	1,31	-2,95	1,27					1,1	2,8	115		
	P (1K)	87,55	8,76	2,91	1,31	-2,95	1,27					1,1	2,8	113		
	PI	87,55	7,00	2,91	1,31	-2,95	1,27					1,1	2,8	111		
Radiators (HP) 50/35/20	P (2K)	87,55	10,07	2,24	1,01	-4,23	1,27	49,93	2	45,39	2,2	1,1	2,8	112	143	1
	P (1K)	87,55	8,32	2,24	1,01	-4,23	1,27	49,05	2	44,59	2,2	1,1	2,8	110	140	1
	PI	87,55	6,57	2,24	1,01	-4,23	1,27	48,18	2	43,80	2,2	1,1	2,8	108	138	1
Floor heating 35/28	P-control	87,55	11,38	1,02	1,7	-6,36	1,27	38,44	2,6	28,56	3,5	1,1	2,8	111	112	
	PI-control	87,55	9,62	1,02	1,7	-6,36	1,27	37,77	2,6	28,05	3,5	1,1	2,8	109	111	
Floor heating extra insulation	P-control	87,55	9,63	1,02	1,7	-6,36	1,27	37,77	2,6	28,06	3,5	1,1	2,8	109	111	
	PI-control	87,55	7,88	1,02	1,7	-6,36	1,27	37,10	2,6	27,56	3,5	1,1	2,8	107	109	
Floor heating No downwards loss	P-control	87,55	6,13	1,02	1,7	-6,36	1,27	36,42	2,6	27,06	3,5	1,1	2,8	105	107	
	PI-control	87,55	4,38	1,02	1,7	-6,36	1,27	20,66	2,6	16,90	5,5	1,1	2,8	104	63	

Residential		Net Energy				Codensing boiler		Air-Water Heat Pump		Ground Source Heat Pump		Primary f	Primary f	Boiler	AW-HP	GS-H
Venice	Qh = 66,42	Qh KWh/m²	Qem,ls KWh/m²	$Q_{D\text{-loss}}$ KWh/m²	$W_{D\text{-aux}}$ KWh/m²	$Q_{G\text{-loss}}$ KWh/m²	$W_{G\text{-aux}}$ KWh/m²	$W_{G\text{-use}}$ KWh/m²	COP	$W_{G\text{-use}}$ KWh/m²	COP	Gasheating	Electricity	Primary KWh/m²	Primary KWh/m²	Prima KWh/
Radiators (boiler) 70/55/20	P(2K)	66,42	8,63	3,69	0,81	0,34	1,07					1,1	2,8	92		
	P(1K)	66,42	7,31	3,69	0,81	0,34	1,07					1,1	2,8	91		
	PI	66,42	5,98	3,69	0,81	0,34	1,07					1,1	2,8	89		
Radiators (e.g.) 55/45/20	P (2K)	66,42	7,97	2,61	1,03	-1,84	1,06					1,1	2,8	89		
	P (1K)	66,42	6,64	2,61	1,03	-1,84	1,06					1,1	2,8	87		
	PI	66,42	5,31	2,61	1,03	-1,84	1,06					1,1	2,8	86		
Radiators (HP) 50/35/20	P (2K)	66,42	7,64	2	0,8	-3,03	1,06	38,03	2	33,07	2,3	1,1	2,8	86	109	
	P (1K)	66,42	6,31	2	0,8	-3,03	1,06	37,36	2	32,49	2,3	1,1	2,8	84	107	
	PI	66,42	4,98	2	0,8	-3,03	1,06	36,70	2	31,91	2,3	1,1	2,8	83	105	
Floor heating 35/28	P-control	66,42	8,63	0,93	1,32	-4,93	1,06	28,14	2,7	20,54	3,7	1,1	2,8	85	82	
	PI-control	66,42	7,30	0,93	1,32	-4,93	1,06	27,65	2,7	20,18	3,7	1,1	2,8	83	81	
Floor heating extra insulation	P-control	66,42	7,31	0,93	1,32	-4,93	1,06	27,65	2,7	20,18	3,7	1,1	2,8	83	81	
	PI-control	66,42	5,98	0,93	1,32	-4,93	1,06	27,16	2,7	19,82	3,7	1,1	2,8	82	80	
Floor heating No downwards loss	P-control	66,42	4,65	0,93	1,32	-4,93	1,06	26,67	2,7	19,46	3,7	1,1	2,8	80	78	
	PI-control	66,42	3,32	0,93	4,06	-4,93	1,06	26,17	2,7	19,10	3,7	1,1	2,8	87	85	

The following results include recovery of distribution losses from the heating pipes. Office = 97% recovery

Office		Net Energy				Codensing boiler		Air-Water Heat Pump		Ground Source Heat Pump		Primary f	Primary f	Boiler	AW-HP	GS-I
Stockholm, Qh = 70,58		Qh KWh/m²	$Q_{em,ls}$ KWh/m²	$Q_{D\text{-}loss}$ KWh/m²	$W_{D\text{-}aux}$ KWh/m²	$Q_{G\text{-}loss}$ KWh/m²	$W_{G\text{-}aux}$ KWh/m²	$W_{G\text{-}use}$ KWh/m²	COP	$W_{G\text{-}use}$ KWh/m²	COP	Gasheating	Electricity	Primary KWh/m²	Primary KWh/m²	Prim KWh
Radiators (boiler) 70/55/20	P(2K)	70,6	9,2	0,66	0,68	-2,56	0,22					1,1	2,8	88		
	P(1K)	70,6	7,8	0,66	0,68	-2,56	0,22					1,1	2,8	87		
	PI	70,6	6,4	0,66	0,68	-2,56	0,22					1,1	2,8	85		
Radiators (e.g.) 55/45/20	P (2K)	70,6	8,5	0,46	0,96	-3,18	0,22					1,1	2,8	87		
	P (1K)	70,6	7,1	0,46	0,96	-3,18	0,22					1,1	2,8	86		
	PI	70,6	5,6	0,46	0,96	-3,18	0,22					1,1	2,8	84		
Radiators (HP) 50/35/20	P (1K)	70,6	8,1	0,34	0,68	-3,53	0,22	52,69	1,5	35,93	2,2	1,1	2,8	86	148	
	P (1K)	70,6	6,7	0,34	0,68	-3,53	0,22	51,75	1,5	35,28	2,2	1,1	2,8	84	146	
	PI	70,6	5,3	0,34	0,68	-3,53	0,22	50,81	1,5	34,64	2,2	1,1	2,8	82	143	
Floor heating No downwards loss	P-control	70,6	4,9	0,12	1,29	-6,03	0,22	44,49	1,7	20,44	3,7	1,1	2,8	81	125	
	PI-control	70,6	3,5	0,12	1,29	-6,03	0,22	43,66	1,7	20,06	3,7	1,1	2,8	79	123	

Office		Net Energy				Codensing boiler		Air-Water Heat Pump		Ground Source Heat Pump		Primary f	Primary f	Boiler	AW-HP	GS-HP
Brussels. Qh = 47,82		Qh KWh/m²	$Q_{em,ls}$ KWh/m²	$Q_{D\text{-}loss}$ KWh/m²	$W_{D\text{-}aux}$ KWh/m²	$Q_{G\text{-}loss}$ KWh/m²	$W_{G\text{-}aux}$ KWh/m²	$W_{G\text{-}use}$ KWh/m²	COP	$W_{G\text{-}use}$ KWh/m²	COP	Gasheating	Electricity	Primary KWh/m²	Primary KWh/m²	Primar KWh/m
Radiators (boiler) 70/55/20	P(2K)	47,8	6,2	0,53	0,47	-1,77	0,15					1,1	2,8	60		
	P(1K)	47,8	5,3	0,53	0,47	-1,77	0,15					1,1	2,8	59		
	PI	47,8	4,3	0,53	0,47	-1,77	0,15					1,1	2,8	58		
Radiators (e.g.) 55/45/20	P (2K)	47,8	5,7	0,37	0,65	-2,21	0,15					1,1	2,8	59		
	P (1K)	47,8	4,8	0,37	0,65	-2,21	0,15					1,1	2,8	58		
	PI	47,8	3,8	0,37	0,65	-2,21	0,15					1,1	2,8	57		
Radiators (HP) 50/35/20	P (2K)	47,8	5,5	0,28	0,46	-2,4	0,15	26,80	2	23,30	2,3	1,1	2,8	58	76	6
	P (1K)	47,8	4,5	0,28	0,46	-2,4	0,15	26,32	2	22,89	2,3	1,1	2,8	57	74	6
	PI	47,8	3,6	0,28	0,46	-2,4	0,15	25,84	2	22,47	2,3	1,1	2,8	56	73	6
Floor heating No downwards loss	P-control	47,8	3,3	0,1	0,88	-4,4	0,16	18,31	2,8	14,24	3,6	1,1	2,8	54	52	4
	PI-control	47,8	2,4	0,1	0,88	-4,4	0,16	17,97	2,8	13,98	3,6	1,1	2,8	53	51	4

Office		Net Energy				Codensing boiler		Air-Water Heat Pump		Ground Source Heat Pump		Primary f	Primary f	Boiler	AW-HP	GS-HP
Venice, Qh = 36,08		Qh KWh/m²	$Q_{em,ls}$ KWh/m²	$Q_{D\text{-}loss}$ KWh/m²	$W_{D\text{-}aux}$ KWh/m²	$Q_{G\text{-}loss}$ KWh/m²	$W_{G\text{-}aux}$ KWh/m²	$W_{G\text{-}use}$ KWh/m²	COP	$W_{G\text{-}use}$ KWh/m²	COP	Gasheating	Electricity	Primary KWh/m²	Primary KWh/m²	Primar KWh/m
Radiators (boiler) 70/55/20	P(2K)	36,1	4,7	0,48	0,35	-1,25	0,12					1,1	2,8	45		
	P(1K)	36,1	4,0	0,48	0,35	-1,25	0,12					1,1	2,8	45		
	PI	36,1	3,2	0,48	0,35	-1,25	0,12					1,1	2,8	44		
Radiators (e.g.) 55/45/20	P (2K)	36,1	4,3	0,33	0,5	-1,61	0,12					1,1	2,8	45		
	P (1K)	36,1	3,6	0,33	0,5	-1,61	0,12					1,1	2,8	44		
	PI	36,1	2,9	0,33	0,5	-1,61	0,12					1,1	2,8	43		
Radiators (HP) 50/35/20	P (2K)	36,1	4,1	0,25	0,35	-1,82	0,12	20,24	2	16,19	2,5	1,1	2,8	44	57	46
	P (1K)	36,1	3,4	0,25	0,35	-1,82	0,12	19,88	2	15,90	2,5	1,1	2,8	43	56	46
	PI	36,1	2,7	0,25	0,35	-1,82	0,12	19,52	2	15,61	2,5	1,1	2,8	42	55	45
Floor heating No downwards loss	P-control	36,1	2,5	0,09	0,66	-3,14	0,11	13,82	2,8	10,18	3,8	1,1	2,8	41	39	30
	PI-control	36,1	1,8	0,09	0,66	-3,14	0,11	13,56	2,8	9,99	3,8	1,1	2,8	40	38	30

The following results include recovery of distribution losses from the heating pipes. Industry = 90% recovery

Industry		Net Energy				Codensing boiler		Air-Water Heat Pump		Ground Source Heat Pump		Primary f	Primary f	Boiler	AW-HP
Stockholm		Qh	$Q_{em,ls}$	$Q_{D\text{-}loss}$	$W_{D\text{-}aux}$	$Q_{G\text{-}loss}$	$W_{G\text{-}aux}$	$W_{G\text{-}use}$	COP	$W_{G\text{-}use}$	COP	Gasheating	Electricity	Primary	Primary
Qh = 72,14		KWh/m²	KWh/m²	KWh/m²	KWh/m²	KWh/m²	KWh/m²	KWh/m²		KWh/m²				KWh/m²	KWh/m²
Warm water panels	PI-control	72,14	-4,1	1,78	1,06	-3,55	0,27	49,87	1,4	36,75	1,9	1,1	2,8	77	145
Warm air horizontal	PI-control	72,14	22,4									1,1	2,8		
Floor heating	PI-control	72,14	-1	0,25	1,98	-6,4	0,25	41,99	1,7	23,80	3	1,1	2,8	78	118
Floor heating insulated	PI-control	72,14	-4,1	0,25	1,98	-6,4	0,25	40,17	1,7	22,76	3	1,1	2,8	74	113

Industry		Net Energy				Codensing boiler		Air-Water Heat Pump		Ground Source Heat Pump		Primary f	Primary f	Boiler	AW-HP	GS
Brussels		Qh	$Q_{em,ls}$	$Q_{D\text{-}loss}$	$W_{D\text{-}aux}$	$Q_{G\text{-}loss}$	$W_{G\text{-}aux}$	$W_{G\text{-}use}$	COP	$W_{G\text{-}use}$	COP	Gasheating	Electricity	Primary	Primary	Prir
Qh = 46,20		KWh/m²	KWh/m²	KWh/m²	KWh/m²	KWh/m²	KWh/m²	KWh/m²		KWh/m²				KWh/m²	KWh/m²	KW
Warm water panels	PI-control	46,2	-2,6	1,19	0,77	-2,45	0,18	22,40	2	22,40	2	1,1	2,8	49	66	
Warm air horizontal	PI-control	46,2	14,3									1,1	2,8			
Floor heating	PI-control	46,2	-0,6	0,16	1,44	-4,09	0,17	18,30	2,5	14,76	3,1	1,1	2,8	50	52	
Floor heating insulated	PI-control	46,2	-2,6	0,16	1,44	-4,09	0,17	17,50	2,5	14,12	3,1	1,1	2,8	48	49	

Industry		Net Energy				Codensing boiler		Air-Water Heat Pump		Ground Source Heat Pump		Primary f	Primary f	Boiler	AW-HP	GS·
Venice		Qh	$Q_{em,ls}$	$Q_{D\text{-}loss}$	$W_{D\text{-}aux}$	$Q_{G\text{-}loss}$	$W_{G\text{-}aux}$	$W_{G\text{-}use}$	COP	$W_{G\text{-}use}$	COP	Gasheating	Electricity	Primary	Primary	Prir
Qh = 41,76		KWh/m²	KWh/m²	KWh/m²	KWh/m²	KWh/m²	KWh/m²	KWh/m²		KWh/m²				KWh/m²	KWh/m²	KW
Warm water panels	PI-control	41,76	-2,4	1,26	0,61	-2	0,16	20,31	2	19,34	2,1	1,1	2,8	45	60	
Warm air horizontal	PI-control	41,76	12,9									1,1	2,8			
Floor heating	PI-control	41,76	-0,6	0,19	1,13	-3,71	0,17	14,77	2,8	12,53	3,3	1,1	2,8	45	42	
Floor heating insulated	PI-control	41,76	-2,4	0,19	1,13	-3,71	0,17	14,13	2,8	11,98	3,3	1,1	2,8	43	40	

ANNEX I Table data for heat pump

For the valuation of the relative output capacity of the heat pump this graphics are used:

Figure I1- Average output capacity of air to water heat pump vs source and sink temperature

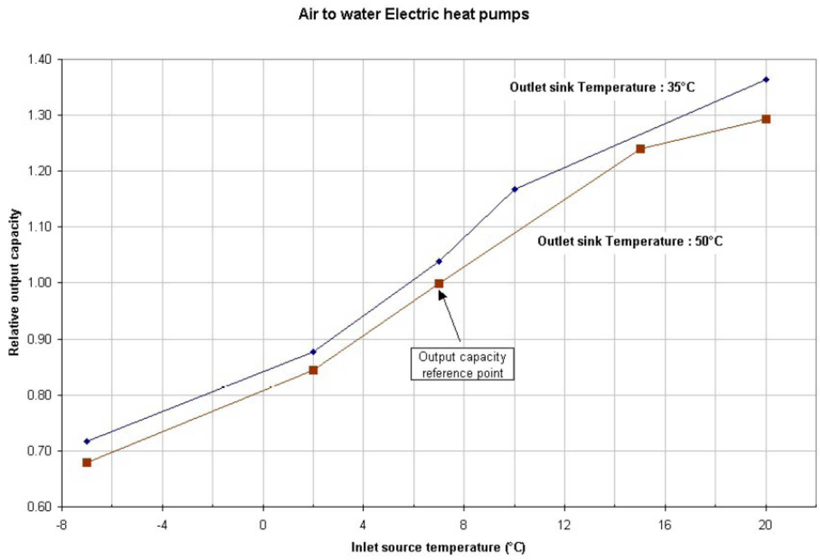
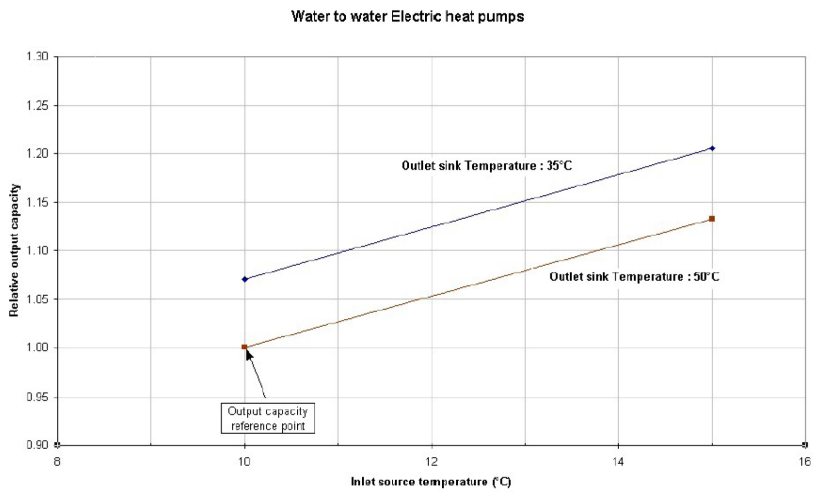


Figure I2 - Average output capacity of water to water heat pump vs source and sink temperature



For the valuation of the correction factor for the part load operation of the heat pump this tables are used:

Table I1 - Default values for the part load operation of electrically driven air-to-water heat pump with floor heating distribution system

Type of distribution system	Characteristic	Distance of pipes [cm]	Load factor [%]									
			10	20	30	40	50	60	70	80	90	99
Floor Heating	light	30	95,3%	95,4%	95,5%	95,7%	95,9%	96,1%	96,2%	96,9%	98,1%	99,9%
		20	97,1%	97,2%	97,2%	97,3%	97,4%	97,4%	97,6%	97,9%	98,4%	99,9%
		10	98,6%	98,6%	98,6%	98,6%	98,6%	98,6%	98,7%	98,9%	99,1%	99,9%
	heavy	30	96,1%	96,1%	96,1%	96,3%	96,4%	96,5%	96,8%	97,3%	98,2%	99,9%
		20	97,8%	97,8%	97,9%	98,0%	98,1%	98,1%	98,2%	98,4%	98,8%	99,9%
		10	99,1%	99,1%	99,1%	99,1%	99,1%	99,1%	99,2%	99,2%	99,4%	99,9%

Table I2 - Default values for the part load operation of electrically driven air-to-water heat pump with radiator and fan coil unit

Type of heat distribution system	Equivalent water content [l/kW]	Load factor (%)									
		10	20	30	40	50	60	70	80	90	99
Fan Coil Unit Radiator	5 l/kW	58,8%	58,8%	58,8%	58,8%	58,8%	71,4%	80,0%	85,7%	92,3%	99,5%
	10 l/kW	80,1%	80,1%	80,1%	80,1%	80,1%	84,8	89,1%	92,2%	95,5%	99,6%
	15 l/kW	85,9%	85,9%	85,9%	85,9%	85,9%	91,7%	94,4%	96,0%	97,5%	99,7%
	20 l/kW	89,1%	89,1%	89,1%	89,1%	89,1%	93,8%	95,8%	97,1%	98,3%	99,8%

For the valuation of the COPat full operation this graphics are used:

Figure I3 - COP-values of air-to water electrical heat pump vs source temperature

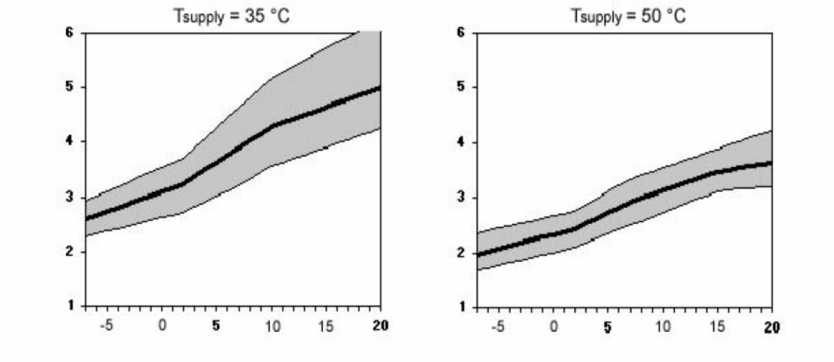
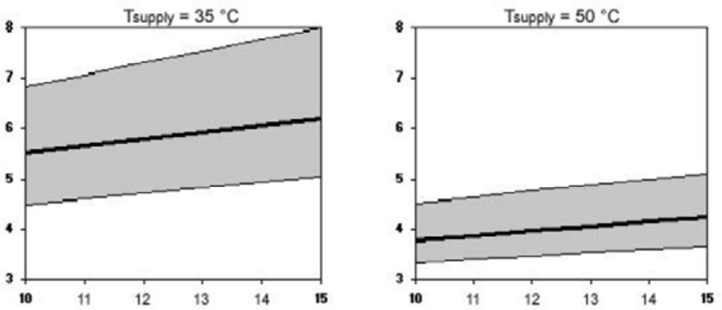


Figure I4 - COP-values of water-to water electrical heat pump vs source temperature



For the temperature reduction factor this table are used:

Table I3 - Default values of the temperature reduction factor

Generator localisation	Temperature reduction factor b
Inside heated space	1

Note: The default value is 1, i.e. nothing is recoverable.

For the valuation of the storage losses this table are used:

Table I4 Default values for maximum storage losses with an average water temperature of 65°C and an ambient temperature of 20°C without hot water tapping

Nominal volume [liters]	Max. heat lossss [kWh/24h]
30	0.75
50	0.9
80	1.1
100	1.3
120	1.4
150	1.6
200	2.1
300	2.6
400	3.1
500	3.5
600	3.8