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SUPPORT THE DISSEMINATION AND ROLL-OUT OF THE SET OF ENERGY PERFORMANCE OF BUILDING STANDARDS DEVELOPED UNDER EC MANDATE M/480

Report on Case Study to EN 15316-4-2 Heat pumps

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Final report

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Abbreviations and acronyms in this document:

CEN	**European standards organization**
EN	**European standard**
EPBD	**Energy Performance of Buildings Directive**
EPB standard	**Standard for the calculation of energy performance of buildings, that complies with the requirements given in ISO 52000-1, CEN/TS 16628 and CEN/TS 16629 or later updates**
ERP	**Energy related products directive**
ISO	**International organization for standardization**
MFH	**Multi-family house**
OFF	**Office building**
NA (/ND)	**National Annex or National Datasheet for EPB standards**
NSB	**National Standards Body of CEN and/or ISO**
RER	**Renewable energy ratio**
SFH	**Single family house**
TR	**Technical report (of CEN and/or ISO)**
XLS	**Spreadsheet**

1 Introduction

This document is focused on heat pump systems.

This document presents the case study on EN 15316-4-2 (heat pumps) and illustrates the effect of choices given in that standard.

This case study assumes that the temperatures of source and sink are known as a function of the operating conditions. More information on operating conditions and system temperature calculation is given in the case study about standard EN 15316-1 (Heating systems – general part).

This document shows the effect of operating conditions and heat pump sizing on the heat pump generation efficiency.

2 Executive summary

This case study demonstrates the calculation of the energy performance of a heat pump using the current draft of the revision of EN 15316-4-2 and the accompanying updated spreadsheet.

There are several types of heat pumps resulting from the combination of heat source, heat sink and heat pumping technology. The most relevant combinations are identified and investigated in this study.

The performance of heat pumps is strongly dependent on source temperature, sink temperature, part load operation and other conditions (like defrosting), resulting in a full load COP that is currently in the range 2 to 6 in the likely operating conditions. This requires data in several testing points to identify the whole performance map of a heat pump.

Source and sink temperature are the most impacting operating conditions.

Several calculations are performed with different operating conditions.

If the source is the external air, then its temperature is well known. If the source is a ground heat exchangers or ground water, simplified models provided by EN 15316-4-2 are used. The detailed calculation of the source temperature is out of the scope of the standard.

If the sink is internal air, then again, its temperature is well known. If the sink is technical water, then its temperature is calculated for several combinations of heat emitters type, sizing and control options.

This study also covers heat pumps providing both space heating and domestic hot water. Domestic hot water priority is assumed and operating conditions for the two services are kept separate.

The case study explores the predicted performance of heat pumps under a number of operating conditions:

- several types of heat emitters and their sizing;
- several relative sizing of the heat pump compared to building needs, from strongly oversized heat pumps (e.g. “boiler like” sizing), to correctly sized heat pumps and then down to undersized heat pumps (e.g. in the context of hybrid systems);
- varying climate, from cold to warm;
- several types of heat sources.

This is done both for air to water, water to water and brine to water heat pumps providing heating and domestic hot water and air to air heat pumps providing only heating.

The calculation was performed with energy need patterns generated with the XLS on EN ISO 52016-1 and the assumption of a known flow temperature reset function based on outdoor temperature.

Data analysis include correlations to identify the importance of the various influence factors.

The standard proved functional and the results are coherent with expectations. The main influencing factors are source and sink temperatures. Part-load operation may have an important role if the heat pump is oversized.

The standard is sensitive to operating conditions.

The module proved easy to use.

Some attention is required on all the data required depending on the heat pump technology. Heat pump is a relatively young product for heating and there is still room for new configurations and/or combinations with other services, such as heat pumps providing simultaneous heating and cooling.

Another point of attention is the consideration of sources other than air. The calculation of the operating conditions and auxiliary energy use for the source heat exchanger are not yet standardised. Simple models are available now.

3 The context of the case study

Heat pump technology has an increasing share of the heating generators market. EU and national legislations are encouraging the use of heat pumps, which provide both high efficiency and possibility to use renewable energy when electric driven heat pumps are coupled with PV generation (similarly absorption heat pump could use biogas but this is less common).

Heat pumping is only a concept. There are several technologies available on the market, using several types of heat sources and sinks and new configurations are being introduced on the market, such as machines providing simultaneous heating and cooling and heat pumps with solar heated evaporator. These may require an adaptation of the calculation procedures.

Real “heat pumps” is a wide and various world:

- there are several heat pumping technologies being used in commercial products:
  - the most popular is gas compression cycle driven by an electric motor;
  - the gas compression cycle may also be driven by an internal combustion engine;
  - absorption and adsorption heat pumps are driven by a high temperature source, that can be externally supplied to the heat pump or produced by an integrated combustion device;
- there are several types of heat sources being used:
  - external air, probably the most available and used but it makes the performance of the heat pump strongly dependent on climate conditions;
  - ground heat exchangers, makes the performance less dependent on climatic conditions but needs an extensive and expensive heat exchanger (vertical bore hole or horizontal network);
  - ground water, which needs pumping energy according to the required up-rise of water;
  - surface water, only where available;
- there are several heat sinks in use:
  - indoor air;
  - technical water, e.g. water circulating in the heating system;
  - domestic hot water, for domestic hot water heaters;
- the main energy carrier can be electricity, a fuel, waste heat…

and then the heat pump can be single stage, staged, modulating, splitted, etc.

The performance of a heat pump is extremely sensitive to operating conditions. A typical electric heat pump may have a COP from 2 to 6 within the operating range. The dependency of efficiency on operating conditions is non-linear and the main factors to be taken into account are:

- source and sink temperatures, where each °C more or less in temperature difference means 2…3% less or more efficiency;
- part load operation;
- defrosting cycles, when outdoor air is used as a source.

This makes it challenging to represent accurately the whole performance map of a heat pump with values tested only in a few reference test points.

The market shares of the main types are shown in figure 1.

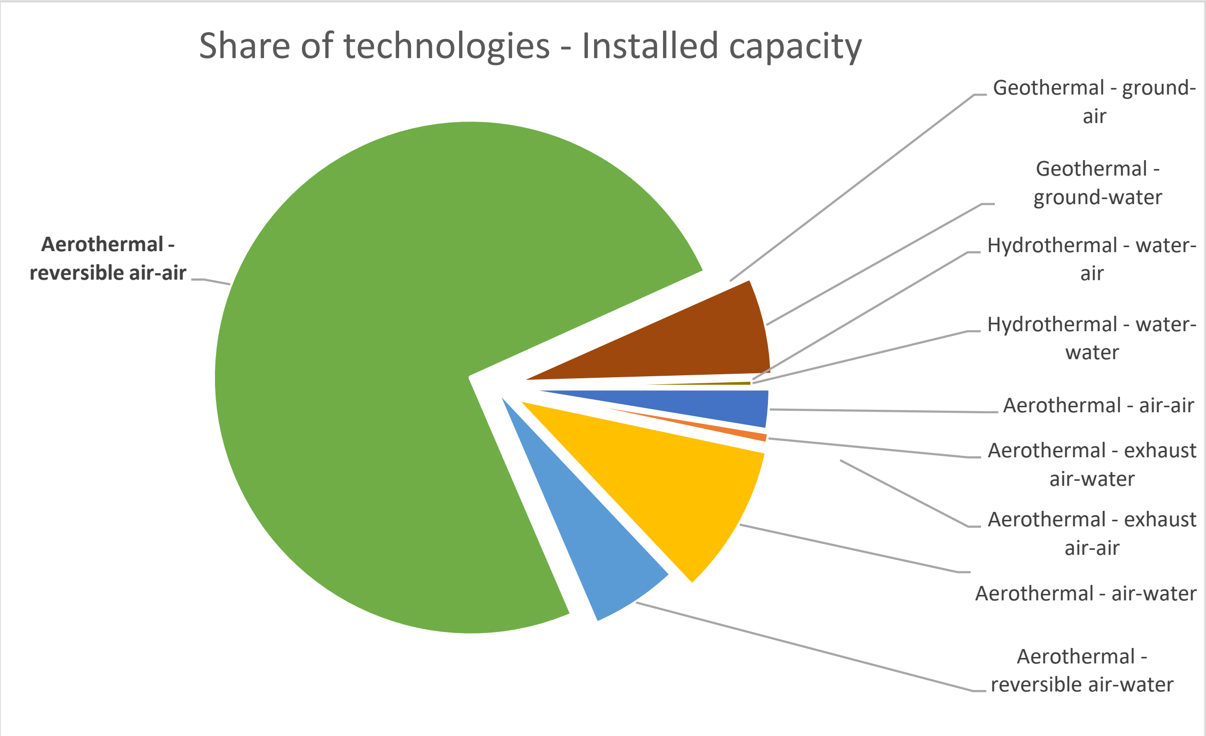

Figure 1 – Share of installed capacities per heat pump technology (year 2020, source Eurostat)

The data needs some “reading”: as an example, reversible air to air heat pumps includes both small room air conditioners that can be used also for heating as well as large VRF or VRV systems.

Concerning the source, air is the dominant choice, as shown in figure 2.

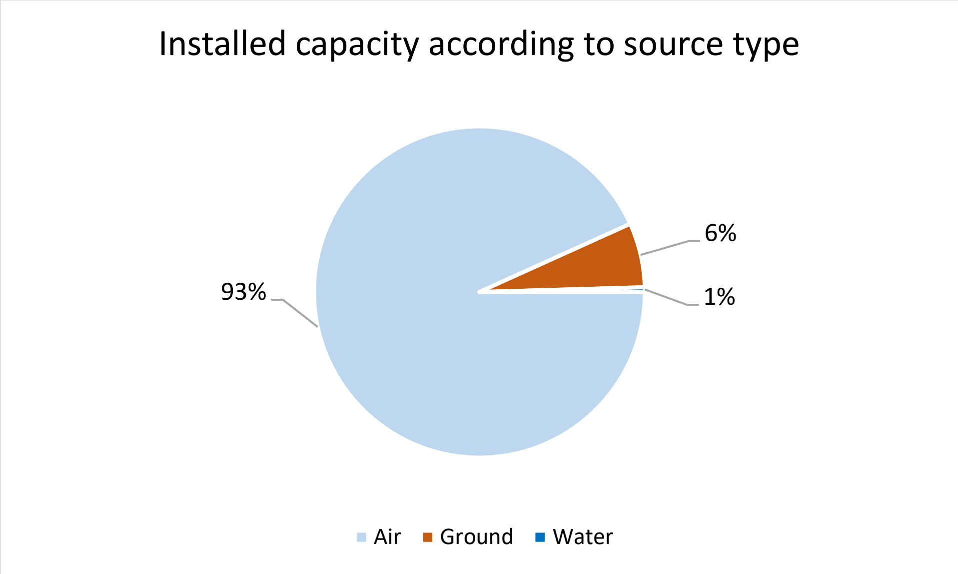

Figure 2 – Share of installed capacities per source type (year 2020, computed from Eurostat data)

The dominant groups of heat pump typologies are indeed:

- external air to internal air;
- external air to water;
- external air to domestic hot water;
- ground to water.

Standardisation is still fragmented (dedicated product standards for each product group) and not yet well coordinated between product standards and system standards.

Table 1 shows the main EU standards. There are several more in each country:

- both for energy performance calculation for EU Directive EPBD purpose;
- and for design purpose.

Table 1: List of considered cases

Context	Standard		Notes
Product standard	EN 14511	Air conditioners, liquid chilling packages and heat pumps for space heating and cooling and process chillers, with electrically driven compressors Part 1: Terms and definitions	
		Part 2: Test conditions	
		Part 3: Test methods	
		Part 4: Requirements	
	EN 16247	Heat pumps with electrically driven compressors - Testing, performance rating and requirements for marking of domestic hot water units	
	EN 15879	Testing and rating of direct exchange ground coupled heat pumps with electrically driven compressors for space heating and/or cooling - Part 1: Direct exchange-to-water heat pumps	

Context	Standard		Notes
		Part 2: Water(brine)-to-direct exchange and direct exchange-to-direct exchange heat pumps	Under drafting
	EN 12309	Gas-fired sorption appliances for heating and/or cooling with a net heat input not exceeding 70 kW Part 1: Terms and definitions	Under review
		Part 2: Safety	
		Part 3: Test conditions	
		Part 4: Test methods	
		Part 5: Requirements	
		Part 7: Specific provisions for hybrid appliances	
	EN 16905	Gas-fired endothermic engine driven heat pumps Part 1: Terms and definitions	
		Part 2: Safety	Under review
		Part 3: Test conditions	
		Part 4: Test methods	Under review
EU Directive EPBD application	EN 15346-4-2	Energy performance of buildings - Method for calculation of system energy requirements and system efficiencies Part 4-2: Space heating generation systems, heat pump systems, Module M3-8-2, M8-8-2	Under review
EU Directives ERP (Ecodesign) and Ecolabeling	EN 14825	Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling, commercial and process cooling - Testing and rating at part load conditions and calculation of seasonal performance	
	EN 16247	Heat pumps with electrically driven compressors - Testing, performance rating and requirements for marking of domestic hot water units	
	EN 12309	Gas-fired sorption appliances for heating and/or cooling with a net heat input not exceeding 70 kW Part 6: Calculation of seasonal performances	
	EN 16905	Gas-fired endothermic engine driven heat pumps Part 5: Calculation of seasonal performances in heating and cooling mode	Under review
System design	EN 15450	Heating systems in buildings - Design of heat pump heating systems	Under review

This case study is focused on the use of EN 15316-4-2, which is a system standard. A system standard aims at calculating the performance of any assembly of products when used within a specified building in a specific location (external climate) and with a specified use schedule.

The standard EN 15316-4-2 is currently under review. The revised draft was ready for public enquiry at the time when this case study was written. This case study is based on this revised version for public enquiry and on the accompanying spreadsheet.

4 Coverage of the scope

4.1 Introduction

EN 15316-4-2 has a general calculation frame which allows two calculations paths, named “path A” and “path B”, that can be nationally selected depending on the type of heat pump, type of source and sink and availability of data.

- “Path A” is based on EN 14511 test data at full load. For each calculation interval, the performance is calculated taking into account:
  - first source and sink temperature;
  - then part load effect.
- “Path B” is based on EN 14825 test data at part load. For each calculation interval, the performance is calculated taking into account:
  - first part load effect, assuming that the II principle efficiency (see note below) only depends on the power output;
  - then source and sink temperature.

NOTE: II principle efficiency is the ratio between the COP of an actual heat pump and that of an ideal heat pump working between the same source and sink temperature (or evaporation and condensation temperature).

In principle, path A can be used for all types of heat pumps.

In this case study path B is used for heat pumps using indoor air as a sink (air to air example).

4.2 Coverage of technologies

The module covers all the current technologies: electric driven vapour compression, absorption, thermal engine driven vapour compression.

The module doesn’t cover heat pump that are simultaneously providing heating and cooling, which appeared on the market recently. Covering this technology will require a coordination with the chiller standard EN 16798-13.

4.3 Coverage of sources

The module covers all common sources. It refers to specific calculation models for special sources, like heat exchange with the ground. Should this not be available, simple default models are given in the module.

This case study covers the following sources:

- external air;
- ground heat exchanger;
- ground water.

For the source external air, the climatic data for hot, average and cold climate are used. The data is the default used for the case studies (Athens, Strasbourg and Oslo). See the preparatory work for reference.

For other sources, the default simple models proposed in EN 15316-4-2 are used. They are linked to the climatic data.

4.4 Coverage of sink

The module covers all sinks in use.

This case study covers heat pumps heating technical water and air.

4.5 Coverage of installation configurations

The module takes into account a separate operation for heating and domestic hot water production services. It is designed to support additional services (e.g. direct storage heating) in the same calculation intervals in the future revisions.

The default sequence of operation is the following:

- domestic hot water service has priority, with full load operation;
- heating operation follows in the remaining time in each calculation interval, at part load.

This configuration covers nearly all practical cases with few exceptions. The module is designed to support more sophisticated logics that could be defined in future revisions, e.g. in connection with BACS functions.

This case study will assume the default sequence of operation.

Another special feature which is not yet considered explicitly in this module is the presence of a de-superheater to provide some heat at high temperature for e.g. domestic hot water service.

4.6 Coverage of performance indicators

The module provides specific partial performance indicators for the individual calculation interval:

- COP of the heat pump, without integrated back-up and external auxiliaries;
- COP of the heat pump generation sub-system, which includes the effect of integrated back-up and external auxiliaries.

The COP of the system can be defined only if the compressor, the auxiliaries and the integrated back-up all use the same energy carrier.

Partial performance indicators related to the seasonal performance of the heat generation sub-system with heat pump can be generated by accumulating input and output data of the module for one season or one year.

4.7 Coverage of calculation intervals

The module is primarily intended to be used for an hourly calculation interval. Actually, it can be used for any calculation interval, including bins and monthly.

The limitation is not in the calculation module itself but in the potential accurateness of a monthly calculation methods in determining if the heat pump can fulfil the required heat output.

5 Definition of the cases

5.1 Rationale of the selection of cases

The cases are selected to stress and test the following features of the module:

- influence of the operating conditions;
- influence of the climate;
- influence of the type of source and sink.

Suitable input data has been prepared to generate consistent operating conditions and check the reaction of this module.

5.2 Types of buildings

The following type of buildings have been considered to create relevant use patterns:

- single family house, with continuous operation and domestic hot water production;
- single family house, with intermittent operation and domestic hot water production;

See calculation details for more information.

5.3 Technologies

This case study deals mainly with vapour compression, electric driven heat pumps.

Gas-fired absorption heat pumps are also considered.

Thermal engine driven heat pumps are not included in the case study. They require special data and they are a small fraction of the market.

5.4 List of selected cases and variations

5.4.1 Case 1 – SFH with domestic hot water production – AW heat pump

5.4.1.1 Description

The assumed load is the single-family house, with an insulation level suitable for heat pump operation.

The domestic hot water needs are calculated with default values provided by EN 12831-3 and the tapping profile is XL.

The heat pump is an air to water providing both space heating and domestic hot water heating.

The base case is:

- energy needs calculated for the average climate;
- floor heating with flow temperature reset on outdoor temperature;
- the heat pump is correctly sized for the building.

ID code of this case: 10-SFH-M-AVG-A-WFL-NRM

5.4.1.2 Variant 1: Temperature level

The calculation is repeated with three temperature levels, to show the influence of temperature level of emitters: .

- floor heating (28…45 °C flow temperature)
- fan-coil (constant 45 °C flow temperature)
- medium temperature radiators (30…55 °C flow temperature)

ID code of these cases:

- 10-SFH-M-AVG-A-WFL-NRM (reference)
- 11-SFH-M-AVG-A-WFC-NRM
- 12-SFH-M-AVG-A-WRD-NRM

5.4.1.3 Variant 2 - Sizing

The calculation is repeated with three possible relative sizing of the heat pump and a cut-off option.

- Correct sizing with a 9 kW nominal power heat pump

- Undersized heat pump, 5 kW nominal power heat pump
- Undersized heat pump, 5 kW nominal power heat pump with cut-off
- Oversized heat pump, 14 kW nominal power heat pump
- Oversized heat pump, 14 kW nominal power heat pump, intermittent service

The last option simulates the contribution of a heat pump in the context of an hybrid unit.

ID code of these cases:

- 21-SFH-M-AVG-A-WFL-UND
- 22-SFH-M-AVG-A-WFL-UND-CUT
- 23-SFH-M-AVG-A-WFL-OVR
- 24-SFH-M-AVG-A-WFL-OVR-INT

5.4.1.4 Variant 3 - Climate

The calculation is repeated with the three test climates.

The correctly sized heat pump is used with floor heating in 3 possible climates.

The needs are recalculated as well.

- Average climate
- Cold climate
- Warm climate

ID code of these cases:

- 10-SFH-M-AVG-A-WFL-NRM (reference)
- 31-SFH-M-WRM-A-WFL-NRM
- 32-SFH-M-CLD-A-WFL-NRM

5.4.1.5 Variant 4 – Source type

The calculation of variant 3 is repeated with a water to water heat pump and borehole exchanger.

The correctly sized heat pump is used with floor heating in 3 possible climates.

- Average climate
- Cold climate
- Warm climate

ID code of these cases:

- 40-SFH-M-AVG-G-WFL-NRM
- 41-SFH-M-WRM-G-WFL-NRM
- 42-SFH-M-CLD-G-WFL-NRM

5.4.1.6 Variant 5 – Technology

The calculation of variant 3 is repeated with a gas fired, air to water absorption heat pump.

ID code of these cases:

- 50-SFH-M-AVG-A-WFL-NRM-ABS
- 51-SFH-M-WRM-A-WFL-NRM-ABS
- 52-SFH-M-CLD-A-WFL-NRM-ABS

5.4.2 Variant 6 - SFH without domestic hot water production – air to air heat pump

The heating needs pattern is the same, single family house.

The heat pump is an air to air only providing heating service.

Domestic hot water profile is not considered and it is assumed to be satisfied by another generator.

The base case is

- energy needs calculated for the average climate;
- the heat pump is correctly sized.

Calculation is performed with path B.

The calculation is repeated with two possible climates.

- Average climate
- Cold climate

ID code of these cases:

- 60-SFH-M-AVG-A-AAA-NRM
- 61-SFH-M-AVG-A-AAA-UND

5.4.3 Calculation cases summary

The list of the resulting calculation cases is given in the table 2.

Table 2: List of considered cases

CASE	Building	Insulation	Climate	Source	Sink	Sizing	Other
10-SFH-M-AVG-A-WFL-NRM	Single family	Medium	Average	Air	Floor heating	Normal	
11-SFH-M-AVG-A-WFC-NRM	Single family	Medium	Average	Air	Fan-coil	Normal	
12-SFH-M-AVG-A-WRD-NRM	Single family	Medium	Average	Air	Radiator	Normal	
21-SFH-M-AVG-A-WFL-UND	Single family	Medium	Average	Air	Floor heating	Undersize	
22-SFH-M-AVG-A-WFL-UND-CUT	Single family	Medium	Average	Air	Floor heating	Undersize	Cut-off
23-SFH-M-AVG-A-WFL-OVR	Single family	Medium	Average	Air	Floor heating	Oversize	
24-SFH-M-AVG-A-WFL-OVR-INT	Single family	Medium	Average	Air	Floor heating	Oversize	Intermittent
31-SFH-M-WRM-A-WFL-NRM	Single family	Medium	Warm	Air	Floor heating	Normal	
32-SFH-M-CLD-A-WFL-NRM	Single family	Medium	Cold	Air	Floor heating	Normal	
40-SFH-M-AVG-G-WFL-NRM	Single family	Medium	Average	Ground	Floor heating	Normal	
41-SFH-M-WRM-G-WFL-NRM	Single family	Medium	Warm	Ground	Floor heating	Normal	
42-SFH-M-CLD-G-WFL-NRM	Single family	Medium	Cold	Ground	Floor heating	Normal	
50-SFH-M-AVG-A-WFL-NRM-ABS	Single family	Medium	Average	Air	Floor heating	Normal	Absorption heat pump
51-SFH-M-WRM-A-WFL-NRM-ABS	Single family	Medium	Warm	Air	Floor heating	Normal	Absorption heat pump
52-SFH-M-CLD-A-WFL-NRM-ABS	Single family	Medium	Cold	Air	Floor heating	Normal	Absorption heat pump
60-SFH-M-AVG-A-AAA-NRM	Single family	Medium	Average	Air	Air	Normal	
61-SFH-M-AVG-A-AAA-UND	Single family	Medium	Warm	Air	Air	Normal	

The individual cases are identified with a code which is built in the following way:

NN-BBB-X-YYY-SRC-SNK-SZ-SPC

Where:

- **NN** is a progressive number identifying the case and variant
- **BBB** is the type of building:
    - SFH for single family house
    - MFH for multi-family house
    - OFF for the office building
- **X** can be:
    - E for existing building (low insulation level)
    - M for improved building (medium insulation level)
    - N for new building (high insulation level)
- **YYY** is the climate code

  - AVG for average climate
  - CLD for cold climate
  - WRM for warm climate
- **SRC** is the source code
  - A for air
  - G for ground
- **SNK** is the sink code
  - AAA for air
  - WFL for water and floor heating
  - WFC for water and fan-coils
  - WRD for water and radiators
  - WRO for water and oversized radiators
- **SZ** is the sizing code
  - UND for under-sizing
  - NRM for normal sizing
  - OVR for oversizing
- **SPC** is the special option code
  - INT for intermittent operation
  - CUT for cut-off
  - ABS for absorption heat pump

The code is incorporated in the name of the corresponding main calculation file. See annex A

6 Calculation details

6.1 Calculation tools

6.1.1 EN 15316-4-2 spreadsheet

6.1.1.1 General

This is the main module under examination.

An enhanced version of the spreadsheet about EN 15316-4-2 has been prepared for this case study.

This spreadsheet is based on the last revised version of prEN 15316-4-2 ready for public enquiry.

A couple of sheets ("Graphs" and "Analysis") with data presentation and analysis features have been added to provide insight into the results.

The text of this case study only shows a sample of them. Full details are available in the complete set of spreadsheets.

6.1.1.2 Additional feature in case of transient insufficient heating power.

A supplementary feature has been added to allow a delay in the heat pump output. When there is a request for domestic hot water in one hour, it has priority over heating and it takes significant time to restore the set-point conditions into the storage. During peak heating request, the remaining time available in the hour can be too short to satisfy the heating demand. Computationally there is a part of the heating demand which is not satisfied. In reality, it the heat pump is correctly sized, this is just a transient deficit that will be recovered in the following hours. Due to the building time constant, the effect on comfort (temperature drop) is not perceivable. If the heat pump is undersized, the heat output deficit will not be recovered, it will increase day by day. This check is done internally by:

- saving as a calculation output the total heat deficit at the end of the current hour;
- summing that total heat deficit to the heating needs at the beginning of the next hour.

If the total deficit is continuously increasing for several hours, this means that the heat pump is undersized.

If the total deficit has a sudden rise when domestic hot water service is requested and then decays in the next few hours, then this is accepted.

With this feature, no advantage is given because needs are not reduced by a diminished internal temperature, which would be the case if the information about the actual reduced available power were passed to the heating needs module. In total, the heat pump will produce the whole heating needs but this will happen partly in the next hours with a higher load factor, just like things happen in reality.

An example of such pattern is provided in figure 3.

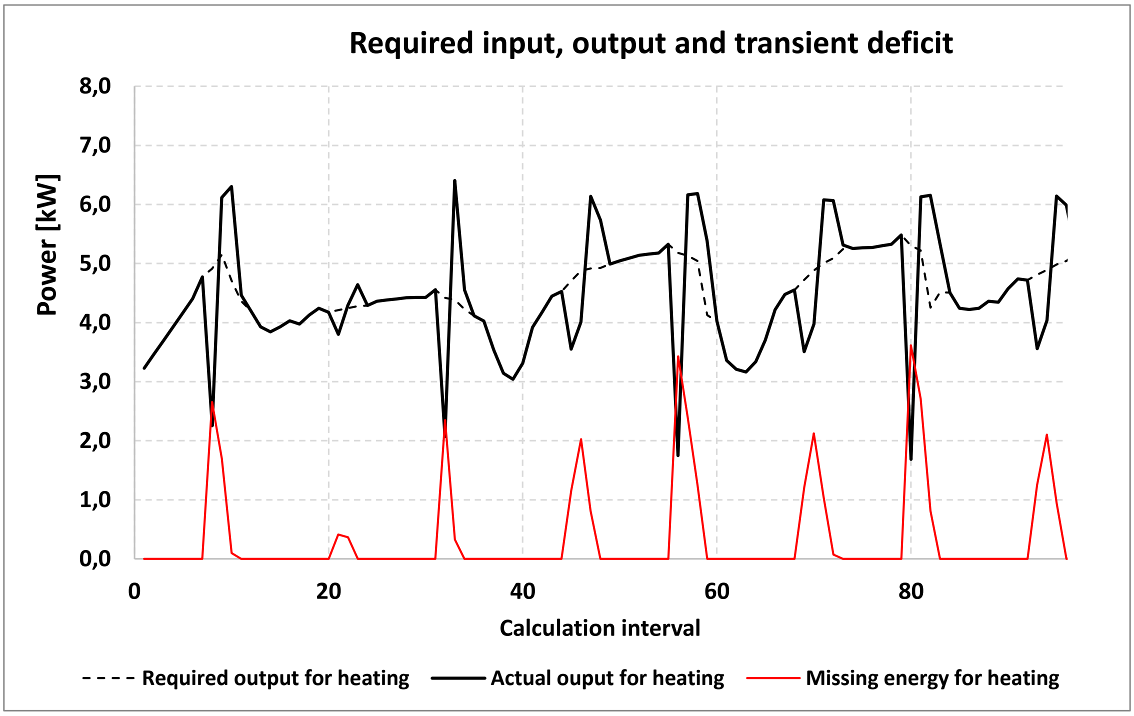

Figure 3 – Example of transient heating power deficit

Each peak of missing energy for heating is due to the heat request for the domestic hot water preparation (thermostat asking to restore the temperature in the domestic hot water storage).

A possible criterion is that the sizing can be considered correct if:

- there are no more than 3 consecutive hours of increasing total heat deficit;
- the deficit is again zero in a maximum of 6 hours.

If these criteria are not met, then the calculation in not valid.

This is also useful as a filter to sudden surges of heating needs power generated by EN ISO 52016-1, that are due to the assumption of perfect temperature control. A step in gains is automatically transformed into an instantaneous step in heating (or cooling) needs whilst in reality it takes some time and some temperature drift for the system to react.

6.1.1.3 Additional information

More information is available on EPB Center web-site. A video about the use of the spreadsheet on EN 15316-4-2 has been prepared and will be published.

6.1.2 Supporting calculations

6.1.2.1 Climatic data – EN ISO 52010-1

Climatic data are calculated with EN ISO 52010-1 module, using data from the JRC data-base.

The 3 locations used are Athens, Strasbourg and Oslo.

See preparatory work document and case study on EN ISO 52010-1 for further details.

A copy of the 3 files with the climatic data for the three locations in included in the case study material.

6.1.2.2 Use profiles – EN 16798-1

Use profiles are taken from EN 16798-1.

The profile for residential, detached house was used as shown in figure 4.

Space category :

RESIDENTIAL_Det_house_with_HUDU		**12**
Source data sheet	**RES_det_house_HUDU**	
Space area	m²	142
Space volume	m³	357,4
Comfort category		II
Type of building		Low polluting
Ventilation calculation option		Method 3 - Air exchange rate

Figure 4 – Selection of the user profile to generate heating needs

More details on the use of this spreadsheet are given in the specific case study on EN 16798-1.

Cases explored:

- continuous operation;
- night set-back from 22.00 to 6.00, only for heating.

6.1.2.3 Domestic hot water needs – EN 12831-3

Domestic hot water needs have been calculated for a residential house according to EN 12931-3. Use profiles are taken from EN 16798-1.

The profile for residential, detached house was used.

Figure 5 shows a summary of the yearly values and the selection made to generate the hourly profile for domestic hot water needs and the average climate.

Domestic hot water	Calculated average yearly daily needs (EN 15378-3)					l/day	205,5	$V_{W;nd;d}$
Tapping profile selection	ERP - XL					*Selection:*	6	
Reference data for dhw needs	Cold water temperature	11,2	°C	Draw off temperature			42	°C
Results for dhw	Yearly needs	2.680	kWh	75,0	m³	18,9	kWh/m² year	

Figure 5 – Yearly results for domestic hot water needs and tapping profile selection

The tapping profile is shown in figure 6.

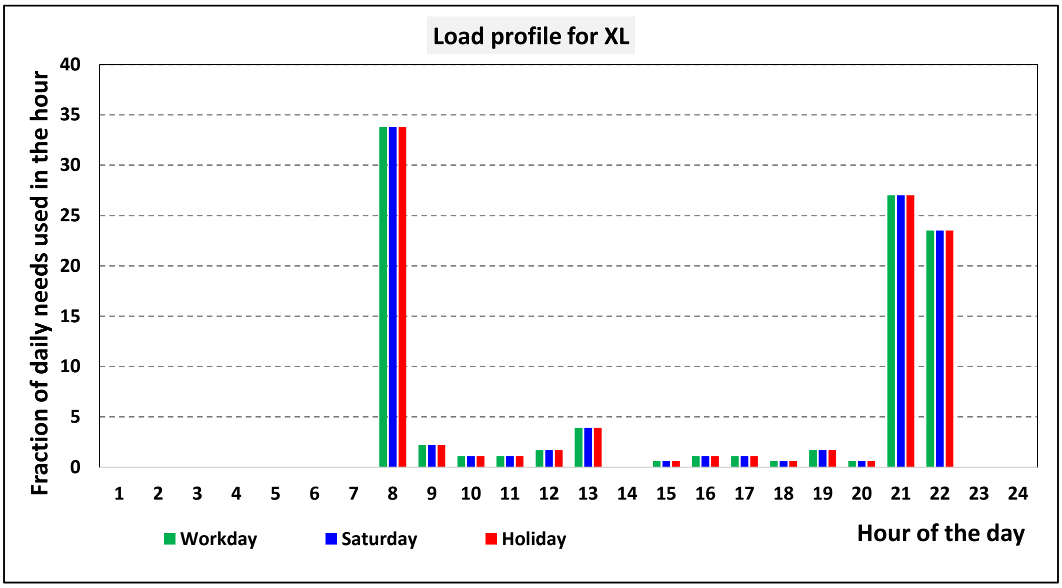

Figure 6 – XL tapping profile: percentage of daily draw-off in each hour

The cold water temperature has been considered constant and equal to the average externa temperature for the location. The yearly needs are then:

- Warm climate: 2284 kWh/year 16,1 kWh/m² year
- Average climate: 2680 kWh/year 18,9 kWh/m² year
- Cold climate: 3389 kWh/year 23,8 kWh/m² year

6.1.2.4 Heating needs – EN ISO 52016-1

Energy needs calculation were performed with the demo spreadsheet on EN ISO 52016-1.

Needs are calculated with infinite power available for heating and the following specification of building envelope insulation:

- U value walls: 0,35 W/m^{2}K
- U value roof: 0,25 W/m^{2}K
- U value windows: 1,50 W/m^{2}K
- U value floor: 0,80 W/m^{2}K

This is a good level of insulation, even though not what can be expected for a new NZEB.

For simplicity no change in the building characteristics is assumed according to climate.

The configuration file has been saved.

Cases explored:

- average, cold and warm climate;
- continuous and intermittent operation.

6.1.2.5 General part for heating and domestic hot water – EN 15316-1

Between the needs and the generation there is the whole heating and domestic hot water system.

It determines:

- emission and distribution heat losses, which add-up to the heating needs and to the domestic hot water needs;
- a required flow temperature, which is a critical influence parameter to determine the efficiency of the heat pump. The flow temperature depends on the type of emitters and their control strategy.

These features are calculated with the spreadsheet about EN 15316-1.

A simple network with one thermal zone and one domestic hot water zone is assumed.

Emission and control losses as well as distribution losses for heating and domestic hot water are simulated with a simplified model.

The most important output of this module is the required flow temperature for heating, which is a main influencing factor of heat pump efficiency.

As a default option, this module calculates the required flow temperature depending on the load and the desired control strategy. The spreadsheet has been enhanced with additional options for two common flow temperature control strategies:

- flow temperature reset according to external temperature, used on most systems in practice;
- constant flow temperature, which is the common choice for fan-coils.

Cases explored:

- floor heating, with flow temperature depending on outdoor temperature;
- radiators, with flow temperature depending on outdoor temperature;
- fan-coils, with constant flow temperature.

To allow a fair comparison, depending on climate, the nominal power of emitters is adapted to:

- the heat load;
- the desired maximum flow temperature.

Also, the range of the outdoor temperature is adapted to the respective external temperature.

The result for the SFH is shown in table 3.

Table 3: Adaptation of emitters and outdoor temperature reset to climate

Climate	Emitters type	Emitter nominal power	Flow temperature range	External temperature range
Average	Floor heating	8	28…45 °C	16…-10 °C
Warm		5,5		16…0 °C
Cold		11		16…-20 °C
Average	Fan-coil	8	45 °C (constant)	N.A.
Warm		5,5		
Cold		11		
Average	Radiators	10	32…55 °C	16…-10 °C
Warm		15		16…0 °C
Cold		20		16…-20 °C

6.1.2.6 Domestic hot water storage– EN 15316-5

The heat pump is not heating directly the domestic hot water. It is heating a storage which will call for heat only when partly depleted.

The storage acts as a buffer between the domestic hot water demand and the heat pump.

This has been calculated using the spreadsheet for EN 15316-5, with the following assumptions:

- storage volume, 150 litres;
- the heat exchanger is in the lower half;
- heat loss coefficient from ecolabelling data is 2,50 W/K.

Layers 1 and 2, which are normally used for the part of the storage heated by the thermal solar, have been assigned a negligible volume.

Selections in the related spreadsheet are shown in figure 7.

Product technical data

Total volume	$V_{sto;tot}$	*V_sto_tot*	L	150
Fraction for layer 4	$V_{sto;vol,4}$		l	75
Fraction for layer 3	$V_{sto;vol,3}$		l	72
Fraction for layer 2	$V_{sto;vol,2}$		l	1,5
Fraction for layer 1	$V_{sto;vol,1}$		l	1,5
Default stand-by losses coefficient	$H_{sto;ls;def}$		W/K	1,96
Product stand-by losses coefficient			W/K	2,50
Your choice for stand-by losses coefficient				Product value
	$H_{sto;ls}$	*H_sto_ls*	W/K	2,50
Stand-by losses correction factor	$f_{sto;dis;ls}$	*f_sto_dis_ls*	-	1
Set temperature	$\vartheta_{sto;set;off;bu}$	*theta_sto_set_on*	°C	60
Heat exchanger - lower connection	$H_{sto;H;exh;vol;1}$	*H_sto_H_exh_vol_1*	W/K	750
Heat exchanger - upper connection	$H_{sto;H;exh;vol;3}$	*H_sto_H_exh_vol_3*	W/K	500
Heat exchanger - space heating service	$H_{sto;H;exh;out}$	*H_sto_H_exh_out*	W/K	
Set temperature for back-up heater ON	$\vartheta_{sto;set;on;bu}$	*theta_sto_set_on_bu*	°C	50

Figure 7 – Input data for storage calculation

The resulting effect is the concentration of required power output for domestic hot water in only a few hours a day, as shown in figure 8.

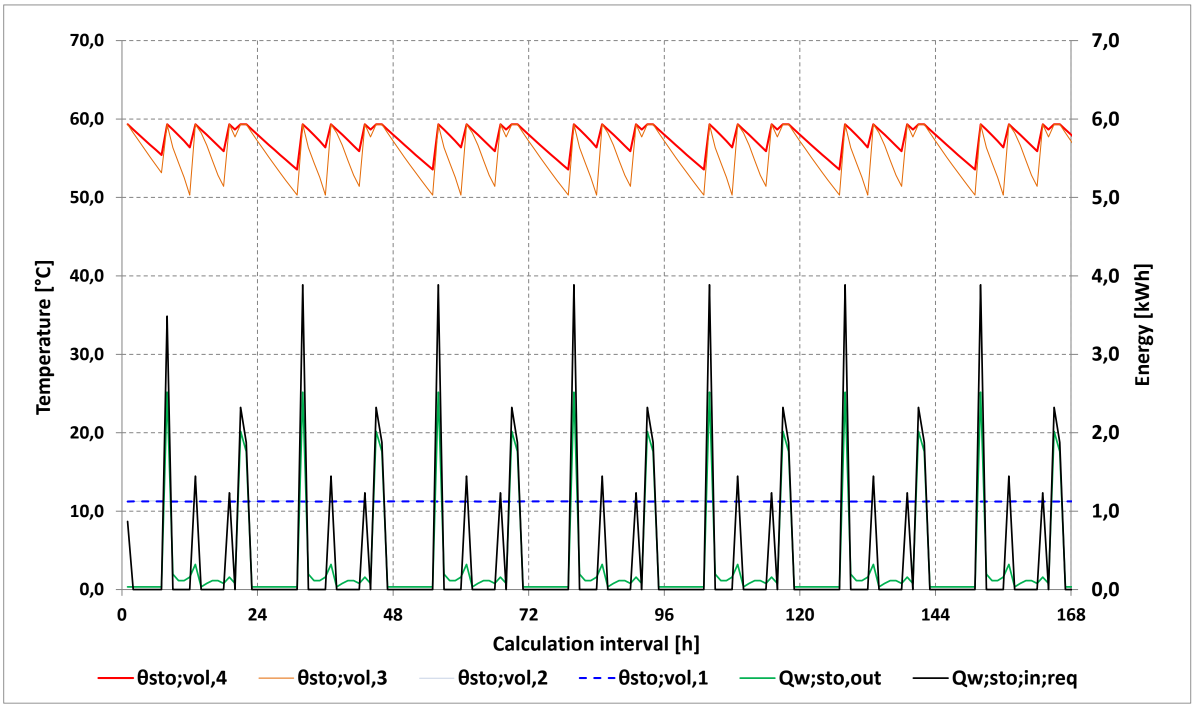

Figure 8 – Storage temperature and energy input and output during atypical week

6.2 Calculation chain

The calculation was performed in the order shown in table 4.

Table 4: Calculation sequence

Calculation step	File
Calculate climatic data for the three climates	00 – ISO_52010-1_TMY_XXXXX_8_planes.xlsx
Calculate the domestic hot water needs	10 – EN 12831-3 – SFH-DHW_needs.xlsx
Calculate the use profiles according to climate and operation schedule	10 – EN_16798-1_SFH-X-CCC-II-YYY_HUDU.xlsm
Define configuration for heating needs calculation depending on operation schedule and building insulation	20 – ISO_52016-1_SFH_M_YYY-II-INT_DESC.xlsx
Calculate heating needs according to climate and configuration	21 – ISO_52016-1_SFH_M-AVG-II-CNT-CALC.xlsm
Calculate required heat output and flow temperature for heating and cooling	30 – EN_15316-1_SFH_CLD_FL_HC.xlsm
Calculate required heat input to domestic hot water storage	35 – EN 15316_5_SFH_AVG.xlsm
Calculate heat pump performance	EN_15316-4-2 - CC-SFH-M-AVG-A-WFL-NRM.xlsm

The coding of the file names is according to the convention established in clause 5.4.3.

6.3 Case 10 – Single family house, average climate, AW heat pump floor heating

6.3.1 Description of the case

CASE	Building	Insulation	Climate	Source	Sink	Sizing	Other
10-SFH-M-AVG-A-WFL-NRM	Single family	Medium	Average	Air	Floor heating	Normal	

This is the reference case that will be used for comparison with most other variations.

It is the case a modulating, gas compression, electric drive air to water heat pump, providing both heating and domestic hot water, correctly sized for the building.

The assumptions about the building and systems for this base case have been described in clause 6.1.2. and are summarised in the coding of the case.

6.3.2 Data input

6.3.2.1 General

Data input includes:

- calculation path selection
- product descriptive data;
- product technical data;
- process design and control data.

6.3.2.2 Calculation path selection

As stated in clause 4, there are several heat pumping technologies and several product standards.

This module includes two main calculation paths (A and B) and some detailed option to best suit the available data depending on the heat pump type.

There is a proposed default selection which can be adapted nationally.

For AW heat pumps the default selection is path A.

For the correction for part load, the DIN method is used.

The selection can be found in the sheet “Calculation_Path”.

6.3.2.3 Product descriptive data

Product descriptive data are qualitative data describing the heat pump typology, capabilities and functions, such as:

- type of source and sink (e.g. air, water, ground);
- heat pump technology (e.g. electric, absorption, combustion engine driven);
- type of power control (e.g. single stage, modulating);
- presence of an integrated back-up;
- services provided by the heat pump (e.g. heating, domestic hot water);
- energy carrier (e.g. electricity, gas)
- source energy carrier (e.g. environment heat, exhaust air)

These are obvious characteristics which are needed to select the calculation options (e.g. how to calculate source and sink temperature, which weighting factors to use) .

Qualitative product data can be found in the sheet “Product_descriptive data”.

6.3.2.4 Product technical data

For path A, the main product data is the performance map of the heat pump at full load according to EN 14511, which is provided by the manufacturer. It is a couple of grids of maximum power output and COP as a function of source and sink temperature. Then the data is interpolated to the actual operating condition. The performance map is shown in table 5 and 6.

Table 5: Full load power output of the heat pump

		Source temperature						
		-7,0 °C	2,0 °C	7,0 °C	12,0 °C	15,0 °C	20,0 °C	35,0 °C
		Full load power output [kW]						
Sink temperature	35,0 °C	6,0	6,5	9,2	10,5	11,2	12,0	13,8
	45,0 °C	5,7	6,2	8,7	9,3	10,6	11,3	13,1
	55,0 °C	5,2	5,9	7,9	8,5	10,1	10,8	12,2

Table 6: Full load COP of the heat pump

		Source temperature						
		-7,0 °C	2,0 °C	7,0 °C	12,0 °C	15,0 °C	20,0 °C	35,0 °C
		Full load COP [-]						
Sink temperature	35,0 °C	3,01	3,79	4,4	4,83	5,1	5,37	5,6
	45,0 °C	2,65	3,01	3,4	3,88	4	4,18	4,48
	55,0 °C	1,99	2,42	2,79	2,94	3,3	3,42	3,6

To adjust the size of the heat pump, the power output is multiplied by a scale factor and it is assumed that the COP doesn't change when scaling the machine. External auxiliaries (not include in COP) are also scaled proportionally.

The equivalent graphical format is given in the next figures 9 and 10.

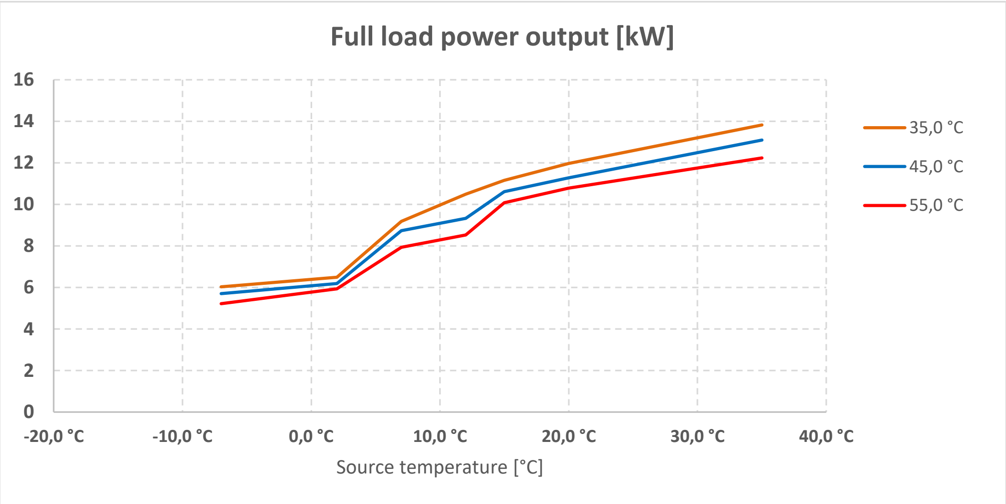

Figure 9 – Full load power output

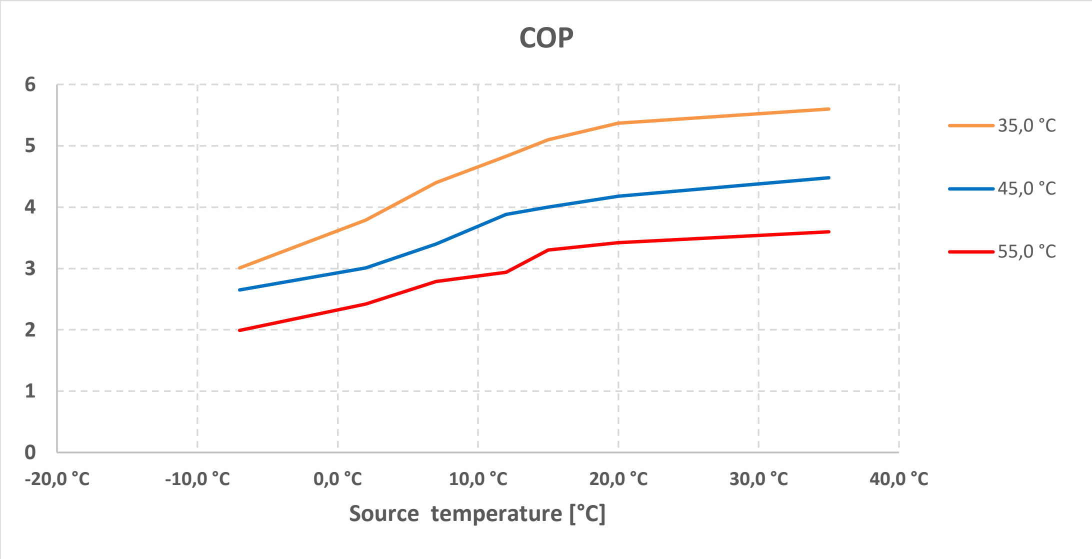

Figure 10 – COP at full load

The performance map is input in sheet "Matrix_Full"

The remaining product data is specified in sheet "Product_tech_data_All_&_A". This includes:

- stand-by auxiliary energy use, taken from the technical fiche according to EU ERP regulation;

Stand-by auxiliary energy	All calculation paths		
Auxiliary power in power off mode	$\Phi_{aux;off}$	kW	0,054
Limit temperature for crankcase heater	θ_{ckh}	°C	12,0
Auxiliary power in crackcase heating mode	$\Phi_{aux;ckh}$	kW	0,000
Auxiliary power in stand-by mode	$\Phi_{aux;sby}$	kW	0,068

Figure 11 – Stand-by auxiliary energy

- operational limits (max and min source and sink temperature), which are declared by the manufacturer.

Operational limits	All calculation paths	
Min source temperature	$\theta_{src;min}$	-20
Max source temperature	$\theta_{src;max}$	40
Min sink temperature	$\theta_{snk;min}$	15
Max sink temperature	$\theta_{snk;max}$	60

Figure 12 – Product operational limits

- minimum value of the part-load ratio, which is declared by the manufacturer, otherwise a default data applies (0,2);

Part load COP correction, path A	Path A, constant internal auxiliaries		
Minimum value of the part load ratio	$LR_{cont,min}$	-	0,20

Figure 13 – Minimum value of part load

- default part load correction factors for the selected method;

Part load COP correction, path A	Path A, DIN V 18599		
Optimum part load ratio	LR_{opt}	-	0,6
Increase at optimum load (addition)	$COP_{inc;opt}$		0,3
Increase at minimum load (addition)	$COP_{inc;min}$		-0,5

Figure 14 – Default correction factors for part load operation

- integrated back-up maximum power and efficiency (not required in this base case);
- external auxiliary power (no external auxiliaries in this base case).

6.3.2.5 Data input according to path B

If path B is selected, then the input data is found in the product fiche according to ERP EU regulation and EN 14825. According to the to their scope (which is the determination of the SCOP assuming a set of predefined operating condition) this data set isn't enough for an accurate coverage of the full operating range of an AW heat pump.

6.3.2.6 Process design and control data

In this base case source and sink temperature are the known external temperature (depending on location) and the required flow temperature (calculated in other modules).

The sequence of operation is the default: domestic hot water service has priority and is fulfilled at full load. Heating service is provided in the remaining part of the calculation interval at the required part load.

Temperature operating limits are those decided by a control function. In this base case there is no operational limit.

6.3.2.7 Operating conditions data coming from other modules

The calculation chain that feed the input to this module is detailed in clause 6.2.

This provides:

- the required heat output for domestic hot water preparation;
- the required flow temperature for domestic hot water preparation;
- the required heat output for space heating;
- the required flow temperature for space heating.

6.3.3 Calculation results

The calculations have been performed hourly for the entire year.

Some sample hourly graphs are shown but most results are presented as monthly aggregation of hourly values or correlation graphs.

Tables 7 and 8 present the main energy results for heating and domestic hot water.

Table 7: Results for heating service

Interval	Needs	HP out	HP in	COP_H	LR(H)	Flow temp.
	$Q_{H;nd}$	$Q_{H;hp;out}$	$Q_{H;hp;in}$	COP_H		$\theta_{H;hp;out}$
	kWh	kWh	kWh	-	-	°C
January	2.356	2.651	741	3,58	0,59	36,74
February	2.183	2.456	672	3,65	0,62	37,23
March	1.103	1.245	337	3,69	0,35	34,68
April	881	994	264	3,76	0,24	33,20
May	4	4	1	3,35	0,15	32,88
June	0	0	0			
July	0	0	0			
August	0	0	0			
September	119	135	45	3,04	0,14	32,51
October	743	839	246	3,42	0,24	32,53
November	1.816	2.045	535	3,82	0,43	35,00
December	1.981	2.229	561	3,97	0,43	34,95
Year	**11.187**	**12.599**	**3.403**	**3,70**		35,05
kWh/m^2	78,8	88,7				

Table 8: Results for domestic hot water service

Interval	Needs	HP out	HP in	COPW
	$Q_{W;nd}$	$Q_{W;hp;out}$	$Q_{W;hp;in}$	COP_W
	kWh	kWh	kWh	-
January	228	337	149	2,26
February	206	304	136	2,23
March	228	337	134	2,52
April	220	326	122	2,67
May	228	337	110	3,05
June	220	326	106	3,08
July	228	337	108	3,13
August	228	337	107	3,14
September	220	326	113	2,89
October	228	337	125	2,70
November	220	326	135	2,42
December	228	337	138	2,43
Year	**2.680**	**3.967**	**1.484**	**2,67**
kWh/m^2	18,9	27,9		

Monthly average COP for heating and domestic hot water is shown in figure 15.

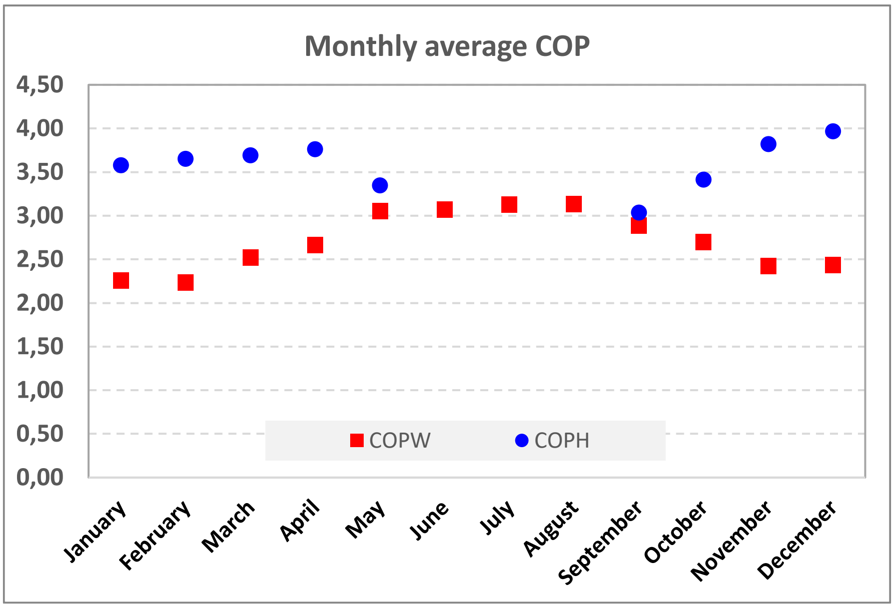

Figure 15 – Average monthly COP

As expected, the COP for domestic hot water is influenced by the outdoor air temperature.

For space heating, the improving full load COP in the beginning and end of the season is overcompensated by the part load correction factor.

The graph in figure 16 shows the distribution of required power for heating according to external temperature. Each dot is one hour. This is an input to this module, based on an energy calculation. This presentation of input data clearly shows the required sizing of the heat pump. A sizing of 6 kW at -5°C looks appropriate. The heat load would provide a much higher sizing.

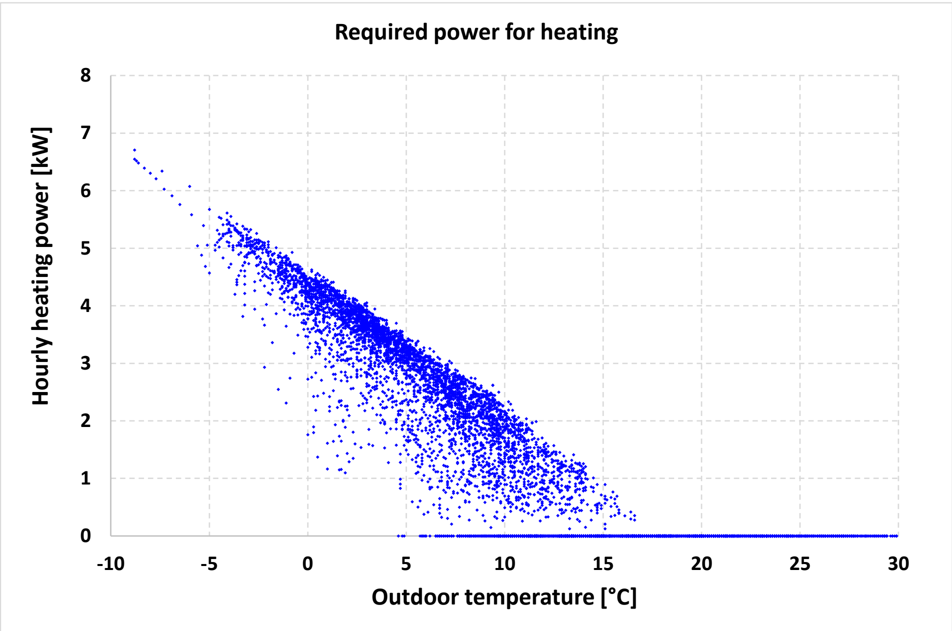

Figure 16 – Required power output for heating as a function of outdoor temperature

The graph in figure 17 shows the distribution of the part load factor for space heating service according to external temperature. Each dot is one hour. This is a calculation result of this module. This figure shows:

- the effect of domestic hot water service, which forces the heat pump to maximum load for heating after domestic hot water storage heat requests (contoured areas);
- the low part loaf factor during most of the time.

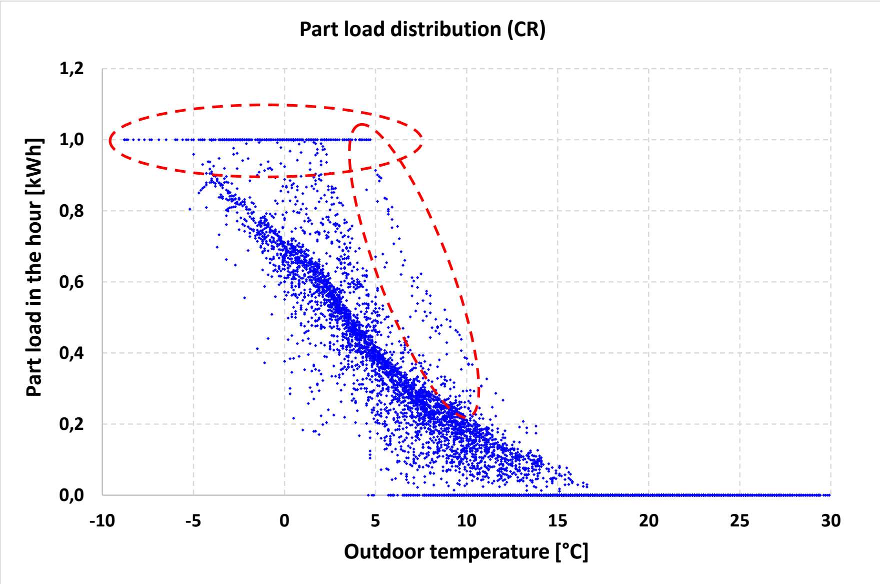

Figure 17 –Heating part load distribution a function of outdoor temperature

The effect of domestic hot water service is described ion clause 6.1.1.2, where the transient deficit and successive recovery is explained.

The graph in figure 18 shows the distribution of the COP for space heating service according to external temperature. Each dot is one hour. This figure shows:

- the main impact of outdoor temperature (and correlated water flow temperature) on the full load COP;
- The decay of COP with high outdoor temperature due to the low load (contoured area).

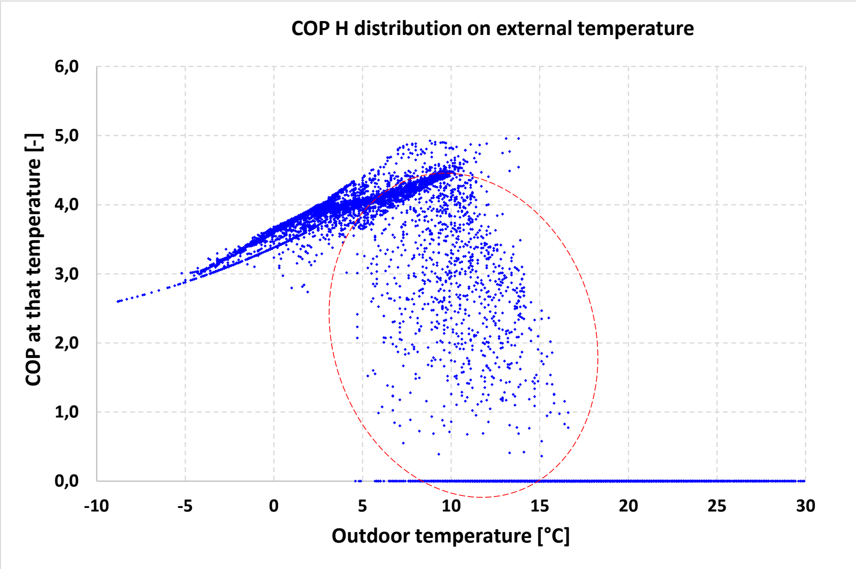

Figure 18 –Heating COP distribution as a function of outdoor temperature

Even though there is a significant effect of part load correction, this impacts hours when the required power is low. Figure 19 shows the energy output distribution as a function of part load.

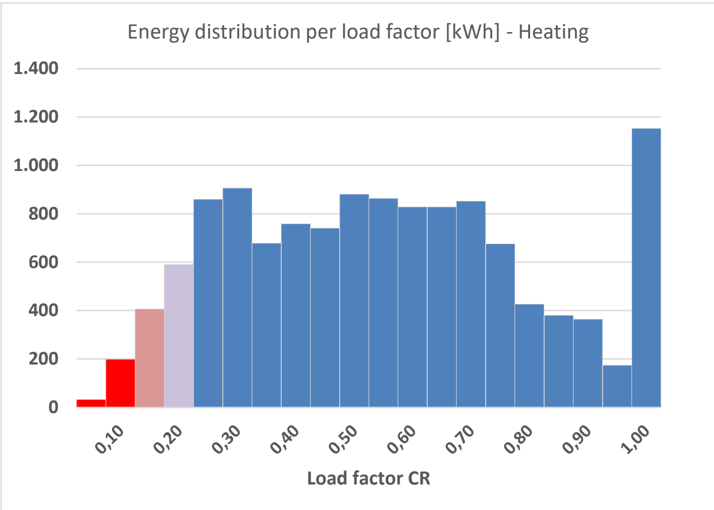

Figure 19 –Heating energy distribution as a function of load factor

The peak on 1,00 corresponds to the full load operation to recover after a domestic hot water service demand. To understand the consequences of this graphs, one must note that for a typical air to water heat pump:

- the COP at part load slightly increases when part load decreases form 1,0 to about 0,6 where it peaks;
- going down from 0,6 to a part load of about 0,3, the COP decreases slowly and goes slightly below the full load value;
- going down from 0,3 to 0 then the COP drops quickly.

However, most of the energy is provided when the COP is very close to full load value and only a small part of the energy is provided with reduced COP.

This is confirmed in the graph in figures 20 and 21, that show the energy output distribution as a function of part load correction factor and of COP.

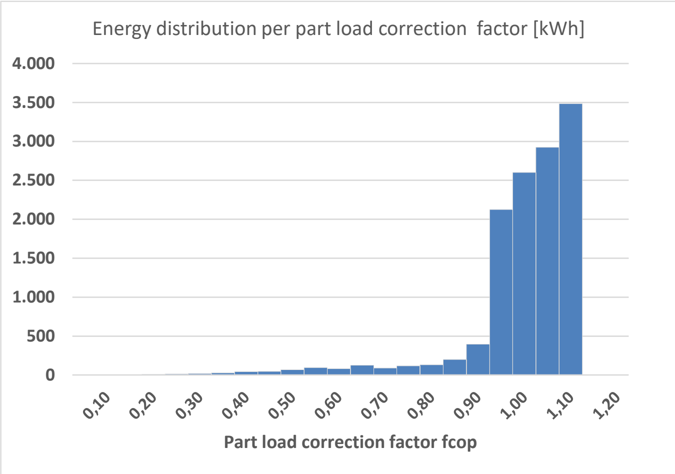

Figure 20 –Heating energy distribution as a function of part-load correction factor of COP

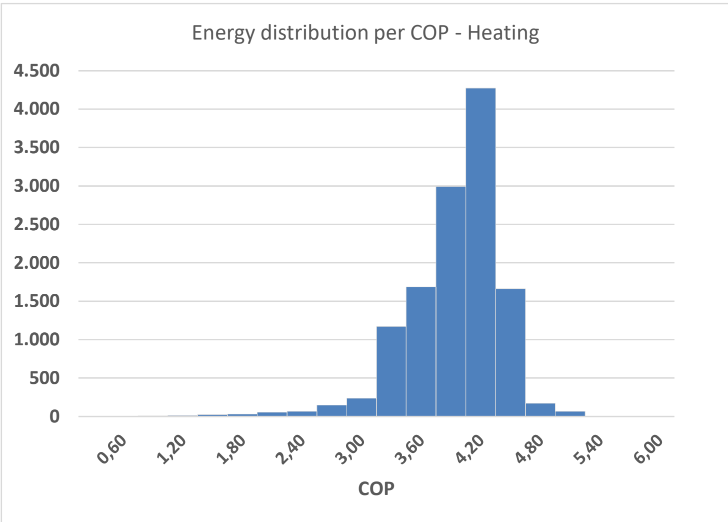

Figure 21 –Heating energy distribution as a function of COP

An overall summary is provided in figure 22, that shows the energy output distribution as a function of the load factor and per temperature ranges. This graph also gives further visual evidence of the correct sizing of the heat pump.

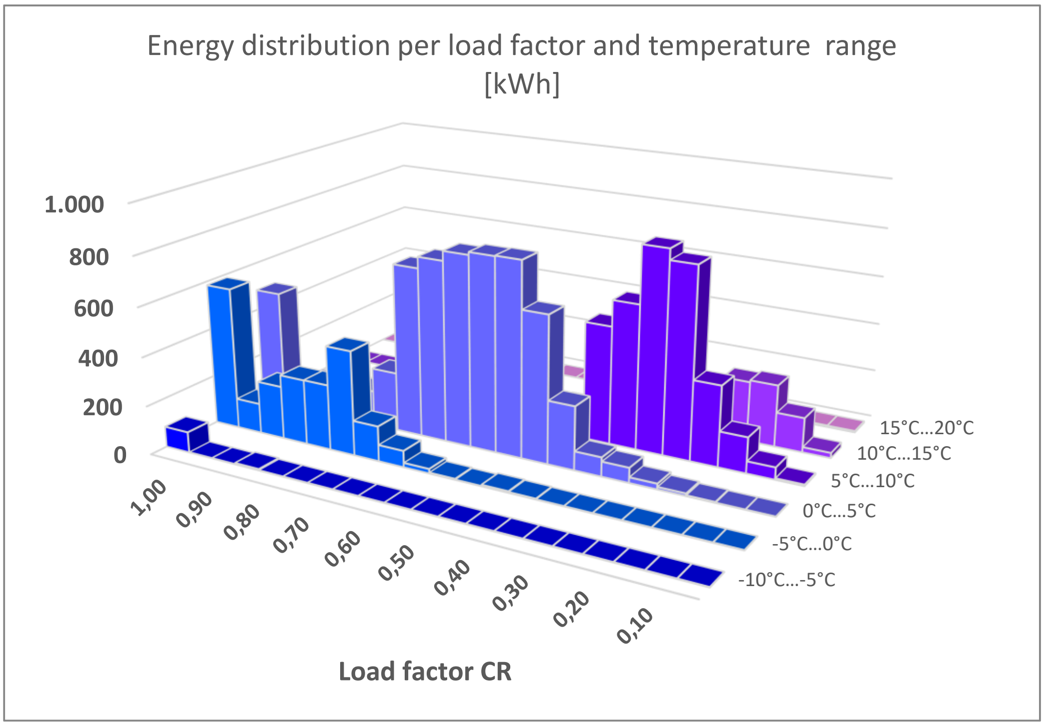

Figure 22 –Heating energy distribution as a function of load factor for several outdoor temperature ranges

The graph in figure 23 shows the distribution of the COP for domestic hot water service according to external temperature. Each dot is one hour. This figure shows clearly the exclusive dependency on outdoor temperature since this service is always provided at full load.

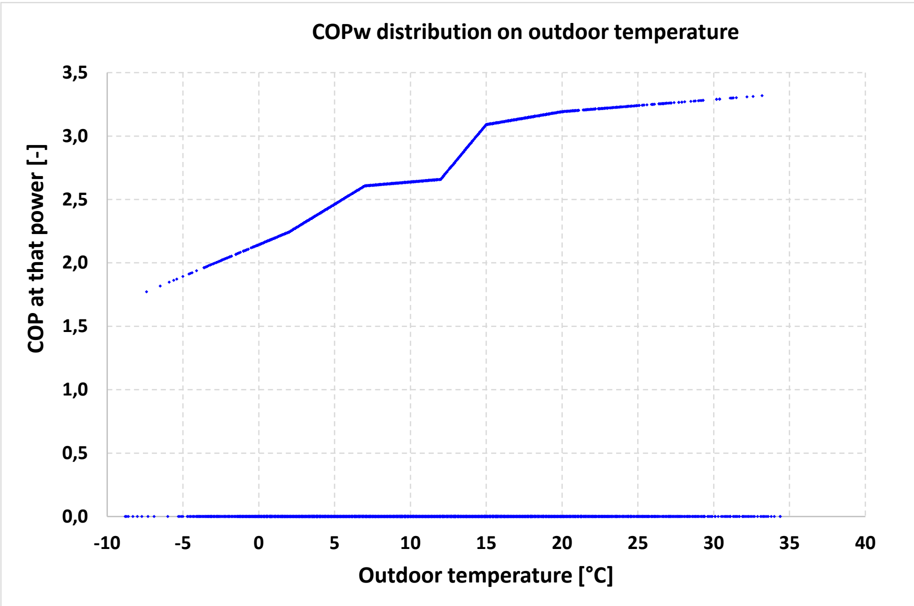

Figure 23 –Domestic hot water COP distribution as a function of outdoor temperature

Figure 24 shows the energy output for domestic hot water as a function of COP.

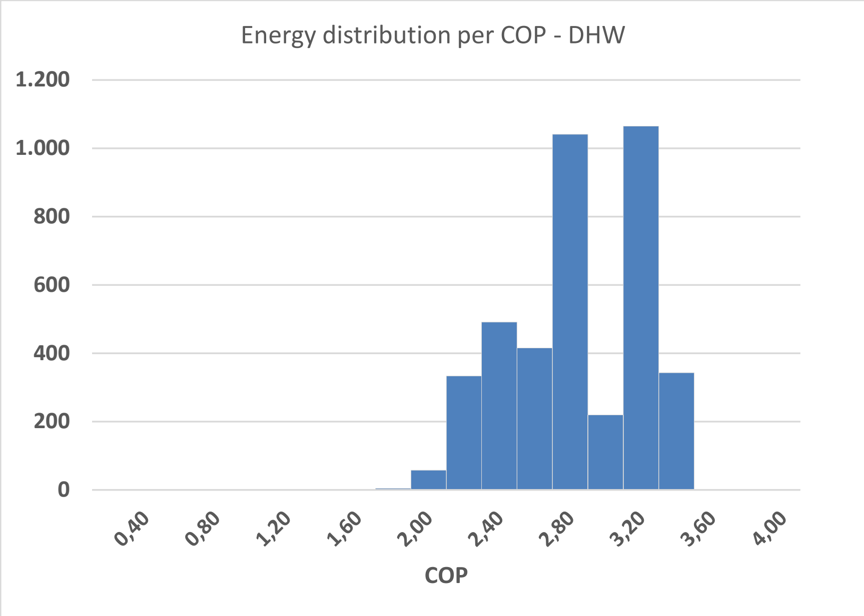

Figure 24 –Domestic hot water energy distribution as a function of COP

6.3.4 Discussion

The data shown clearly shows that the hourly calculation of the heat pump, coupled with the hourly calculation of operating conditions highlights and takes into account the several influencing factors, including the interaction between domestic hot water and space heating service.

It has to be stressed that the hourly calculation does not ask any additional data compared to a monthly calculation. The same calculation module and data input would be used for a monthly calculation or a bin calculation.

The data shown also show the sensitivity of heat pump performance to operating conditions. It is therefore critical that these be determined accurately. In the (CEN and ISO) EPB standards this is the task of the general part for heating and domestic hot water, EN 15316-1.

This case study also demonstrates the combined operation of nearly all the modules for a complete calculation of the energy performance of a building for heating and domestic hot water. The remaining calculation would be weighting (EN ISO 52000-1). Two modules have been replaced by simplified models, emission and distribution, but these are just simple corrections slightly increasing the required energy for heating.

In the following only changes compared to the base case will be highlighted for simplicity.

The complete set of graphs and tables can be found in the individual calculation files for each case and variant.

6.4 Cases 11 and 12: different emitters

6.4.1 Description of the case

CASE	Building	Insulation	Climate	Source	Sink	Sizing	Other
11-SFH-M-AVG-A-WFC-NRM	Single family	Medium	Average	Air	Fan-coil	Normal	
12-SFH-M-AVG-A-WRD-NRM	Single family	Medium	Average	Air	Radiator	Normal	

Compared to the base case, these two variations differ in the type of heat emitters: fan-coil and radiators.

The difference is the flow temperature regime.

For the fan-coil, a constant flow temperature of 45 °C is assumed (low temperature fan-coil).

For the radiators, it is assumed that they are sized so that the flow temperature in design conditions do net exceed 55 °C. A traditional sizing with a higher maximum flow temperature would obviously bring to worse COP and the heat pump may not be able to operate at the highest temperatures.

Heating needs are the same for all three cases.

The heat pump required heat output slightly increases due to the higher distribution losses.

6.4.2 Calculation results

Tables 9 and 10 present the main space heating energy performance results for fan-coils and radiators.

The reason for the difference is the changing flow temperature regime.

Table 9: Results for heating service, fan coil

Interval	Needs	HP out	HP in	COP_H	LR(H)	Flow temp.
	$Q_{H;nd}$	$Q_{H;hp;out}$	$Q_{H;hp;in}$	COP_H		$\theta_{H;hp;out}$
	kWh	kWh	kWh	-	-	°C
January	2.356	2.681	878	3,05	0,61	45,0
February	2.183	2.481	799	3,11	0,65	45,0
March	1.103	1.273	425	2,99	0,37	45,0
April	881	1.024	348	2,94	0,27	45,0
May	4	5	2	2,68	0,17	45,0
June	0	0	0			
July	0	0	0			
August	0	0	0			
September	119	142	58	2,45	0,16	45,0
October	743	869	314	2,77	0,26	45,0
November	1.816	2.079	666	3,12	0,46	45,0
December	1.981	2.266	712	3,18	0,46	45,0
Year	**11.187**	**12.819**	**4.201**	**3,05**	0,45	45,0
kWh/m^2	78,8	90,3				

Table 10: Results for heating service, radiators

Interval	Needs	HP out	HP in	COP_H	LR(H)	Flow temp.
	$Q_{H;nd}$	$Q_{H;hp;out}$	$Q_{H;hp;in}$	COP_H		$\theta_{H;hp;out}$
	kWh	kWh	kWh	-	-	°C
January	2.356	2.659	876	3,04	0,61	43,8
February	2.183	2.463	794	3,10	0,65	44,5
March	1.103	1.245	390	3,19	0,36	41,0
April	881	993	301	3,30	0,25	39,0
May	4	4	1	2,99	0,16	38,6
June	0	0	0			
July	0	0	0			
August	0	0	0			
September	119	134	50	2,71	0,15	38,1
October	743	838	276	3,03	0,24	38,1
November	1.816	2.049	621	3,30	0,45	41,5
December	1.981	2.235	653	3,42	0,45	41,4
Year	**11.187**	**12.620**	**3.962**	**3,19**	0,44	41,5
kWh/m²	78,8	88,7				

6.4.3 Discussion

A comparison of the average COP for heating as a function of the average flow temperature gives the result shown in table 11.

Table 11: Comparison of results for different emitters – reference is floor heating

Description	unit	Floor heating	Radiators	Fan-coils
Average flow temperature	°C	35,1	41,5	45,0
Average COP	-	3,70	3,19	3,05
Difference in COP	%	0%	-13,8%	-17,6%

As expected, the COP is very sensitive to the difference between the sink and source temperature. In this comparison, the source is the same so the COP only depends on sink temperature.

Sink temperature is the result of the sizing of emitters and actual flow temperature in operation is set by controls. This highlights the importance of the careful design and then commissioning of a heat pump system to obtain a good energy performance.

6.5 Cases 21 and 22: under sizing of the heat pump

6.5.1 Description of the case

CASE	Building	Insulation	Climate	Source	Sink	Sizing	Other
21-SFH-M-AVG-A-WFL-UND	Single family	Medium	Average	Air	Floor heating	Undersize	
22-SFH-M-AVG-A-WFL-UND-CUT	Single family	Medium	Average	Air	Floor heating	Undersize	Cut-off

Compared to the base case, these variations differ in the sizing of the heat pump.

Un undersized heat pump is assumed first (case 21) with a back-up heater. The capability of the module to catch the missing power is tested here.

In the next case (case 22), the same heat pump is used with an external temperature cut-off at 4,5 °C. This is the rationale for use within a hybrid system. The capacity of the module to identify the load to the boiler is tested here.

6.5.2 Calculation results

Tables 12 and 13 present the main space heating energy performance results for the undersized heat pump.

Tables 14 and 15 present the main domestic hot water energy performance results for the undersized heat pump.

Table 12: Results for heating service, undersized heat pump

Interval	Needs	HP out	HP in	COP_H	LR(H)	Back-up	Missed
	$Q_{H;nd}$	$Q_{H;hp;out}$	$Q_{H;hp;in}$	COP_H		$Q_{H,gen,out,bu}$	$Q_{H,out,add}$
	kWh	kWh	kWh	-	-	kWh	kWh
January	2.356	2.017	532	3,79	0,81	370	260
February	2.183	1.915	509	3,76	0,88	309	228
March	1.103	1.101	269	4,09	0,57	53	89
April	881	940	210	4,47	0,46	8	45
May	4	4	1	4,46	0,27	0	0
June							
July							
August							
September	119	131	31	4,21	0,31	2	2
October	743	765	183	4,18	0,42	29	44
November	1.816	1.790	436	4,11	0,70	112	139
December	1.981	1.970	464	4,25	0,71	111	144
Year	11.187	10.632	2.634	4,04	0,66	992	952
kWh/m²	78,8	74,9					

Table 13: Results for heating service, undersized heat pump with cut-off

Interval	Needs $Q_{H;nd}$ kWh	HP out $Q_{H;hp;out}$ kWh	HP in $Q_{H;hp;in}$ kWh	COP_H COP_H -	LR(H) -	Back-up $Q_{H,gen,out,bu}$ kWh	Missed $Q_{H,out,add}$ kWh
January	2.356	573	122	4,68	0,53	7,3	19,1
February	2.183	303	67	4,51	0,61	4,6	5,5
March	1.103	593	133	4,47	0,42	5,2	32,8
April	881	830	182	4,55	0,42	5,5	39,7
May	4	4	1	4,46	0,27	0,0	0,0
June	0	0	0			0,0	0,0
July	0	0	0			0,0	0,0
August	0	0	0			0,0	0,0
September	119	131	31	4,21	0,31	1,9	2,5
October	743	525	120	4,37	0,32	5,7	17,6
November	1.816	731	161	4,53	0,49	10,5	17,9
December	1.981	1.021	220	4,65	0,55	13,6	39,9
Year	11.187	4.710	1.038	4,54	0,45	54	175
kWh/m²	78,8	33,2					

Table 14: Results for domestic hot water service, undersized heat pump

Interval	Needs $Q_{W;nd}$ kWh	HP out $Q_{W;hp;out}$ kWh	HP in $Q_{W;hp;in}$ kWh	COPW COP_W -	Back-up $Q_{W,gen,out,bu}$ kWh	Missed $Q_{W,out,add}$ kWh
January	228	337	149	2,26	16	0
February	206	304	136	2,23	17	0
March	228	337	134	2,52	7	0
April	220	326	122	2,67	0	0
May	228	337	110	3,05	0	0
June	220	326	106	3,08	0	0
July	228	337	108	3,13	0	0
August	228	337	107	3,14	0	0
September	220	326	113	2,89	0	0
October	228	337	125	2,70	2	0
November	220	326	135	2,42	9	0
December	228	337	138	2,43	7	0
Year	**2.680**	**3.967**	**1.484**	**2,67**	**59**	**0**
kWh/m²	18,9	27,9				

Table 15: Results for domestic hot water service, undersized heat pump with cut-off

Interval	Needs	HP out	HP in	COPW	Back-up	Missed
	$Q_{W;nd}$	$Q_{W;hp;out}$	$Q_{W;hp;in}$	COP_W	$Q_{W,gen,out,bu}$	$Q_{W,out,add}$
	kWh	kWh	kWh	-	kWh	kWh
January	228	114	44	2,58	0	0
February	206	45	18	2,51	0	0
March	228	250	95	2,63	0	0
April	220	315	118	2,68	0	0
May	228	334	109	3,05	0	0
June	220	323	105	3,07	0	0
July	228	334	107	3,13	0	0
August	228	334	106	3,14	0	0
September	220	323	112	2,88	0	0
October	228	296	107	2,77	0	0
November	220	147	56	2,62	0	0
December	228	186	72	2,57	0	0
Year	2.680	3.000	1.049	2,86	1	0
kWh/m^2	18,9	27,9				

6.5.3 Discussion

A comparison between results gives the result shown in table 16.

Table 16: Comparison of results for undersized heat pump

Description	unit	Normal	Under sized	Under sized with cut-off
Output for heating	kWh	12.599	10.632	4.710
Energy from back-up	kWh	0	992	54
Missing output for heating	kWh	465 (*)	952	175 (**)
Average COP	-	3,70	4,04	4,54
LR(H)	%	0,43	0,66	0,45

(*) This is not missing energy but energy displaced to the next hour

(**) This is the energy missing in that hour, only when above cut-off

As expected, the undersized heat pump cannot fulfil the whole load. Also the back-up output should be counted as missing energy. The module correctly asked first energy from the back-up and after that the rest was missing energy. Domestic hot water is fulfilled with the help of the back-up because this service has priority.

Due to under sizing and trying to fulfil the whole load, the energy distribution per load factor is concentrated on full load operation as shown in figure 25.

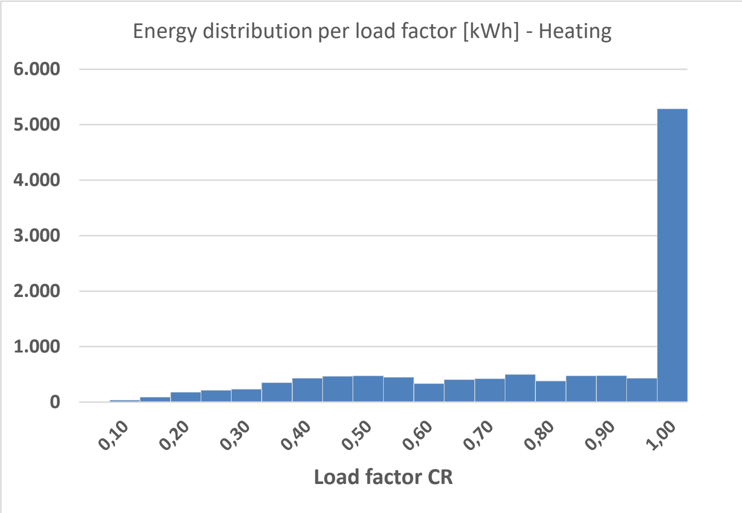

Figure 25 –Undersized heat pump, energy output distribution per load factor

The same is shown in the distribution per outdoor temperature range shown in figure 26.

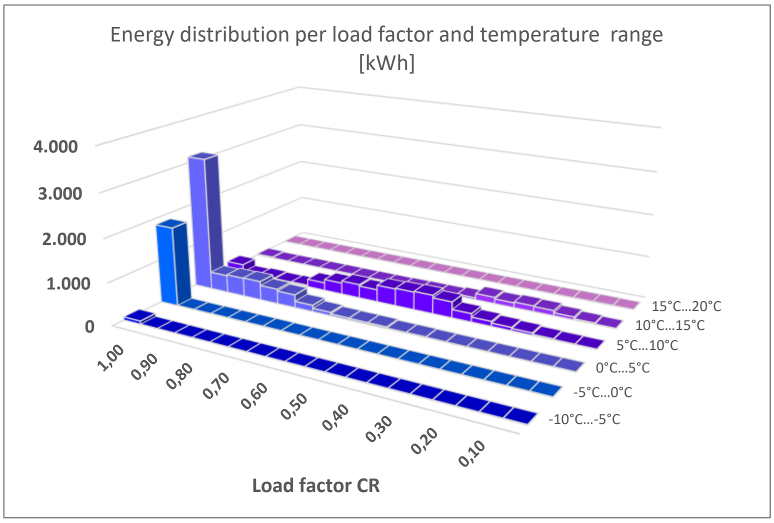

Figure 26 –Undersized heat pump, energy output distribution per load factor and per temperature range

The graph of part load as a function of temperature (figure 27) clearly shows that the heat pump can satisfy the load only to an outdoor temperature of about 3 °C. To keep some room for domestic hot water, the cut-off limit was set at 4,5 °C

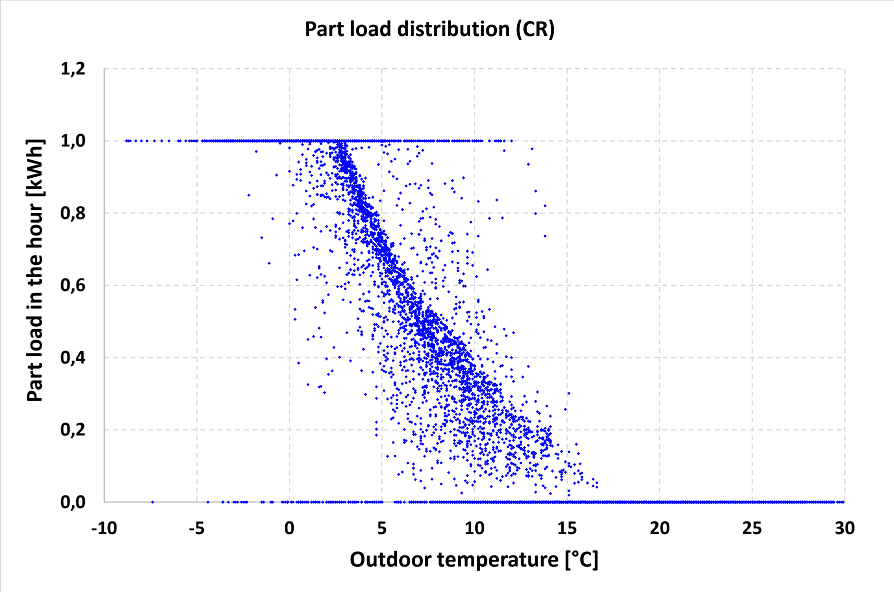

Figure 27 –Undersized heat pump, part load as a function of outdoor temperature

<u>For the heat pump with cut-off</u>, the energy distribution per load factor in figure 28 confirms that the sizing is correct. The peak demand to recover after domestic hot water service is well visible but then the load is cantered on mid-range load factors.

Since the heat pump is not working at the lower external temperature the COP achieved is higher.

It shall be noted that even in the coldest months the COP of the heat pump is still high enough to make this solution more efficient than a combustion boiler using non-renewable fuel. Actually, the cut-off temperature is chosen according to economic criteria and then the heat pump is sized to satisfy the resulting load.

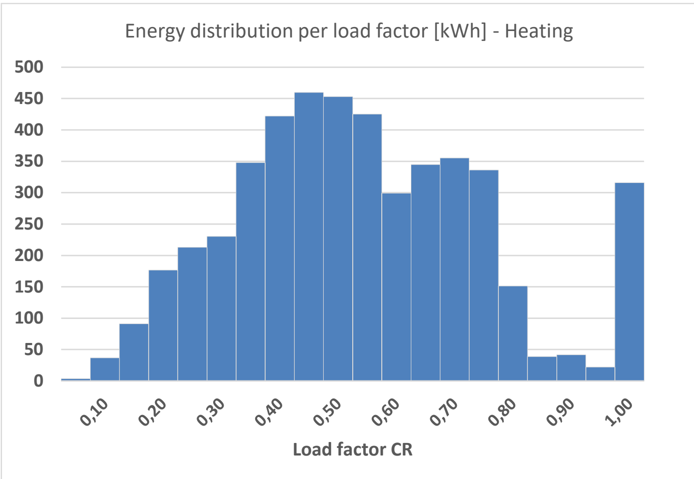

Figure 28 –Undersized heat pump with cut-off, energy output distribution per load factor

6.6 Cases 23 and 24: oversized heat pump

6.6.1 Description of the case

CASE	Building	Insulation	Climate	Source	Sink	Sizing	Other
23-SFH-M-AVG-A-WFL-OVR	Single family	Medium	Average	Air	Floor heating	Oversize	
24-SFH-M-AVG-A-WFL-OVR-INT	Single family	Medium	Average	Air	Floor heating	Oversize	Intermittent

Compared to the base case, these two variations differ in the sizing of the heat pump.

An oversized heat pump is assumed first (case 23). This can be the result of a design based on heat load without any consideration for the specific characteristics of the heat pump. The resulting oversizing should lower the load factor and hence the seasonal COP.

Then an intermittent operation is assumed. This should allow to avoid operation of the heat pump during the coldest hours and raise the load factor in the operation hours.

6.6.2 Calculation results

Table 17 presents the space heating energy performance results for the oversized heat pump.

Table 18 presents the space heating energy performance results for the oversized heat pump with intermittent operation.

Table 17: Results for heating service, oversized heat pump

Interval	Needs	HP out	HP in	COP_H	LR(H)	Flow temp.
	$Q_{H;nd}$	$Q_{H;hp;out}$	$Q_{H;hp;in}$	COP_H		$\theta_{H;hp;out}$
	kWh	kWh	kWh	-	-	°C
January	2.356	2.647	778	3,40	0,34	35,20
February	2.183	2.452	703	3,49	0,35	35,60
March	1.103	1.243	411	3,03	0,20	33,50
April	881	992	347	2,85	0,14	32,28
May	4	4	2	2,17	0,09	32,02
June	0	0	0			
July	0	0	0			
August	0	0	0			
September	119	135	69	1,95	0,08	31,71
October	743	838	332	2,52	0,13	31,73
November	1.816	2.041	607	3,36	0,25	33,77
December	1.981	2.225	630	3,53	0,25	33,73
Year	**11.187**	**12.576**	**3.879**	**3,24**	**0,24**	**33,81**
kWh/m^2	78,8	88,6				

Table 18: Results for heating service, oversized heat pump, intermittent operation

Interval	Needs	HP out	HP in	COP_H	LR(H)	Flow temp.
	$Q_{H;nd}$	$Q_{H;hp;out}$	$Q_{H;hp;in}$	COP_H		$\theta_{H;hp;out}$
	kWh	kWh	kWh	-	-	°C
January	2.229	2.490	695	3,58	0,49	36,71
February	2.077	2.315	635	3,65	0,51	37,05
March	1.033	1.043	289	3,61	0,30	34,40
April	817	835	233	3,59	0,21	33,09
May	13	0	0			
June	0	0	0			
July	0	0	0			
August	0	0	0			
September	97	93	31	2,94	0,14	32,88
October	688	734	226	3,24	0,21	32,67
November	1.723	1.921	523	3,67	0,36	35,14
December	1.887	2.112	548	3,85	0,36	35,04
Year	**10.563**	**11.542**	**3.180**	**3,63**	**0,37**	**35,13**
kWh/m^2	74,4	81,3				

6.6.3 Discussion

A comparison of the energy performance for heating as a function of the oversizing gives the result shown in table 19.

Table 19: Comparison of results for normal and oversized heat pump

Description	unit	Correct sizing	Oversized	Oversized with intermittent operation
Heating needs	kWh	11.187	11.187	10.563
Required output	kWh	12.599	12.576	11.542
Average COP	-	3,70	3,24	3,63
Difference in COP	%	0%	-12,4%	-1,9%
Part load factor	-	0,43	0,24	0,37
External temperature	°C	5,22	5,22	5,64

As expected, the COP decreases for the oversized heat pump due to the lower part load factor.

This is confirmed in the following figures 29 and 30. The part load exceeds 0,6 only in transients after domestic hot water production.

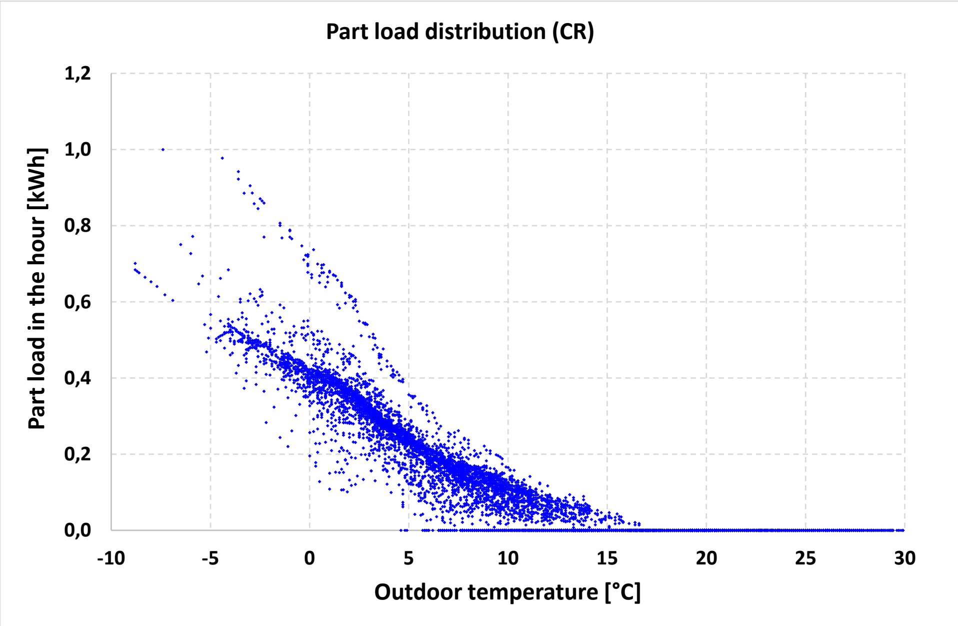

Figure 29 – Oversized heat pump, part load as a function of outdoor temperature

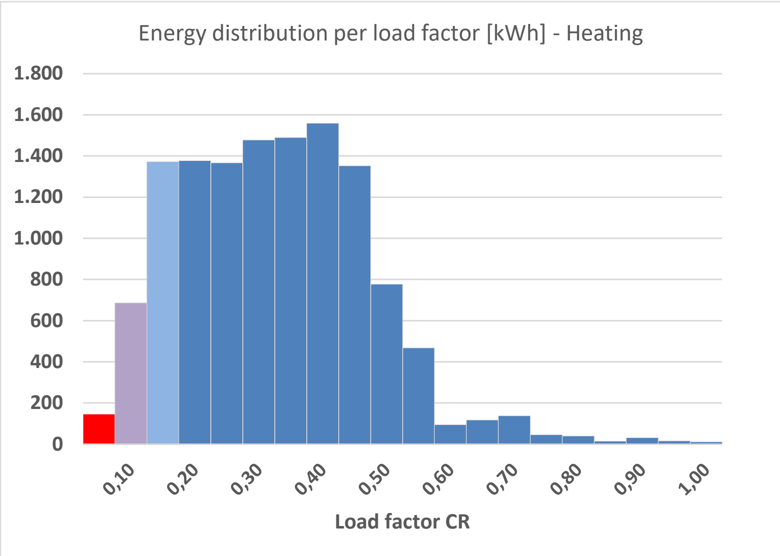

Figure 30 – Oversized heat pump, energy distribution as a function part load

The intermittency reduces the energy needs by 5,6% but also reduces the operation time from 24 h/day to 16 h/day.

This allows a better part load and a slightly higher average external temperature during heat pump operation (+ 0,4°C) because set-back occurs during the night.

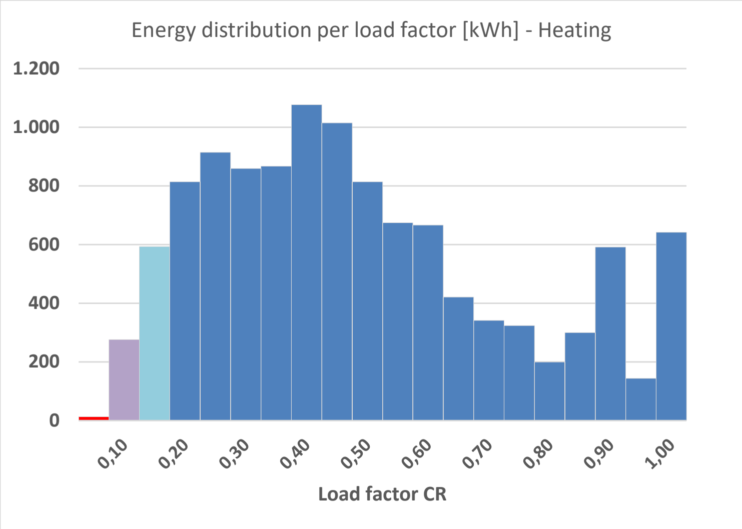

Figure 31 – Oversized heat pump with intermittent operation, energy distribution as a function part load

6.7 Cases 31 and 32: different climate

6.7.1 Description of the case

CASE	Building	Insulation	Climate	Source	Sink	Sizing	Other
31-SFH-M-WRM-A-WFL-NRM	Single family	Medium	Warm	Air	Floor heating	Normal	
32-SFH-M-CLD-A-WFL-NRM	Single family	Medium	Cold	Air	Floor heating	Normal	

Compared to the base case, these two variations differ for the climate.

To get a fair comparison:

- the size of the emitters has been adapted to the heat load;
- the range of the heating curve has been extended to the design external temperature
- the size of the heat pump has been adapted to keep a similar load factor.

as shown in table 20, so that the only real influence is the climate.

Table 20: Adaptation to climate

Climate	Warm	Average	Cold
Design temperature	0 °C	-10 °C	-20 °C
Emitters power	5,3 kW	8 kW	10,7 kW
Flow temperature at design conditions	45 °C	45°C	45 °C
Heat pump nominal power (A7W35)	6,1 kW	9,2 kW	15,3 kW

The resulting flow and temperature temperatures in the heating systems for the three climates are shown in figures 32 to 34.

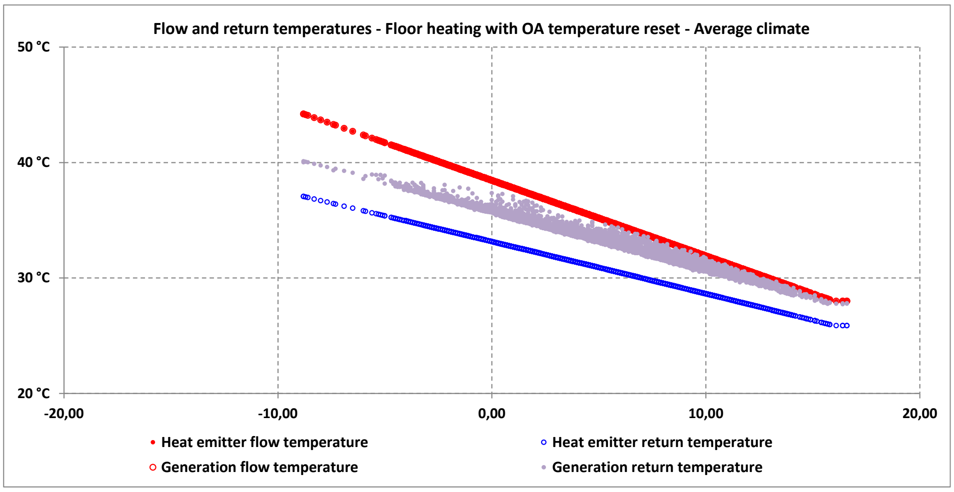

Figure 32 – Heating system temperatures as a function of outdoor temperature – Average climate

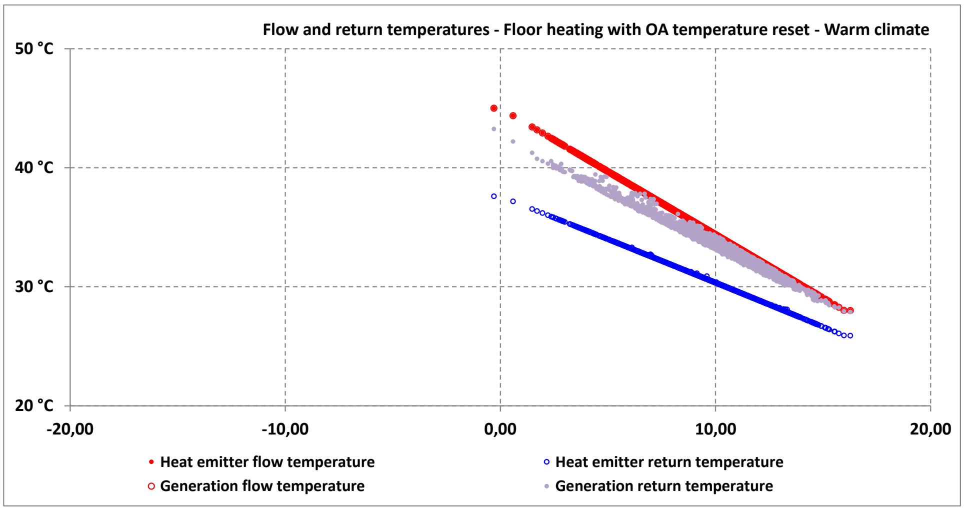

Figure 33 – Heating system temperatures as a function of outdoor temperature – Warm climate

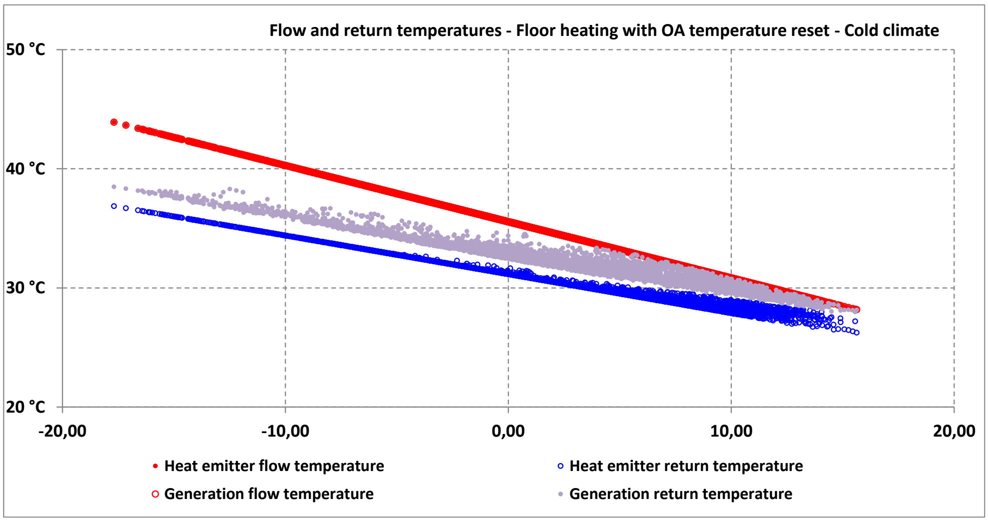

Figure 34 – Heating system temperatures as a function of outdoor temperature – Cold climate

The flow temperature is driven by outdoor temperature. Due to ON-OFF operation, the flow rate in the floor heating is variable and lower than that in the heat pump. Therefore, the return temperature to the heat pump is higher than the return temperature in the heat emitters.

6.7.2 Calculation results

Tables 21 and 22 present the space heating energy performance results for warm and cold climate.

Tables 23 and 24 present the space heating energy performance results for warm and cold climate.

The same tables for average climate are given in clause 6.3.3.

Obviously, the seasonal performance of the AW heat pump reflects the change in external air temperature.

Table 21: Results for heating service, warm climate

Interval	Needs $Q_{H;nd}$ kWh	HP out $Q_{H;hp;out}$ kWh	HP in $Q_{H;hp;in}$ kWh	COP_H COP_H -	LR(H) -	Flow temp. $\theta_{H;hp;out}$ °C	Ext. temp. θ_{ext} °C
January	761	867	229	3,78	0,29	34,7	9,7
February	861	980	257	3,82	0,35	36,1	8,4
March	225	258	72	3,57	0,20	34,0	10,4
April	58	67	26	2,56	0,11	32,7	11,6
May	1	1	1	0,69	0,02	29,5	14,6
June	0	0	0				
July	0	0	0				
August	0	0	0				
September	0	0	0				
October	0	0	0				
November	0	0	0				
December	478	546	150	3,63	0,23	34,1	10,3
Year	**2.384**	**2.718**	**735**	**3,70**	**0,27**	**34,8**	**9,6**
kWh/m^2	16,8	19,1					

Table 22: Results for heating service, cold climate

Interval	Needs	HP out	HP in	COP_H	LR(H)	Flow temp.	Ext. temp.
	$Q_{H;nd}$	$Q_{H;hp;out}$	$Q_{H;hp;in}$	COP_H		$\theta_{H;hp;out}$	θ_{ext}
	kWh	kWh	kWh	-	-	°C	°C
January	3.151	3.531	990	3,57	0,48	35,7	-0,2
February	3.673	4.118	1.414	2,91	0,69	39,2	-7,7
March	2.696	3.020	873	3,46	0,41	35,3	0,5
April	1.658	1.865	565	3,30	0,26	33,7	4,0
May	755	852	295	2,88	0,14	32,0	7,5
June	17	19	23	0,84	0,03	30,2	11,4
July	20	23	13	1,73	0,06	30,2	11,3
August	1	1	2	0,63	0,02	31,1	9,4
September	832	935	384	2,44	0,10	30,8	10,0
October	1.976	2.222	641	3,47	0,28	33,9	3,5
November	2.499	2.803	781	3,59	0,37	34,6	1,9
December	3.397	3.807	1.112	3,42	0,53	36,5	-2,0
Year	**20.675**	**23.198**	**7.095**	**3,27**	**0,38**	**34,8**	**1,6**
kWh/m^2	145,6	163,4					

Table 23: Results for domestic hot water service, warm climate

Interval	Needs	HP out	HP in	COPW
	$Q_{W;nd}$	$Q_{W;hp;out}$	$Q_{W;hp;in}$	COP_W
	kWh	kWh	kWh	-
January	179	273	103	2,66
February	162	246	95	2,60
March	179	273	96	2,83
April	173	264	91	2,89
May	179	273	86	3,17
June	173	264	82	3,23
July	179	273	84	3,25
August	179	273	84	3,25
September	173	264	82	3,21
October	179	273	86	3,16
November	173	264	86	3,08
December	179	273	100	2,74
Year	**2.106**	**3.212**	**1.075**	**2,99**
kWh/m^2	14,8	22,6		

Table 24: Results for domestic hot water service, cold climate

Interval	Needs	HP out	HP in	COPW
	$Q_{W;nd}$	$Q_{W;hp;out}$	$Q_{W;hp;in}$	COP_W
	kWh	kWh	kWh	-
January	265	381	180	2,12
February	240	343	200	1,72
March	265	380	177	2,15
April	257	368	154	2,39
May	265	380	139	2,73
June	257	368	123	2,98
July	265	380	121	3,15
August	265	380	127	2,99
September	257	368	137	2,68
October	265	380	163	2,34
November	257	368	164	2,24
December	265	380	188	2,02
Year	**3.124**	**4.477**	**1.874**	**2,39**
kWh/m^2	22,0	31,5		

6.7.3 Discussion

A comparison of the energy performance for heating and domestic hot water as a function of climate gives the result shown in table 25.

Table 25: Comparison of results for normal and oversized heat pump

Description	unit	Warm climate	Average climate	Cold climate
Heating needs	kWh	2.384	11.187	20.675
Required output for heating	kWh	2.718	12.599	23.198
Load factor for heating	-	0,27	0,43	0,38
Average external temperature during heating		9,6	5,2	1,6
Average COP for heating	-	3,70	3,70	3,27
Difference in COP	%	0%	0%	- 12%
Domestic hot water needs	kWh	2.106	2.680	3.124
Required output for domestic hot water	kWh	3.212	3.967	4.477
Average COP for domestic hot water	-	2,99	2,67	2,39
Difference in COP	%	+ 12%	0%	- 10 %

As expected, the COP decreases because of external temperature.

For the warm climate, the COP is the same as for average climate. This is due to the lower load factor. The load factors show that a lower sizing was required for the warm climate.

Actually, the building insulation should have been adapted as well. For simplicity only the sizing of the heating system was adapted to the changing climate and the same building.

The domestic hot water performance shows the influence of the climate on an yearly average. The sizing has no effect on this service because this is satisfied at full load to keep a maximum available time for heating.

It has to be noted that for the warm climate domestic hot water energy needs and energy use exceed that for heating. If the building is very well insulated, this is true also for average and even cold climate in the residential sector.

6.8 Cases 40, 41 and 42: water to water heat pump with ground heat exchanger

6.8.1 Description of the case

CASE	Building	Insulation	Climate	Source	Sink	Sizing	Other
40-SFH-M-AVG-G-WFL-NRM	Single family	Medium	Average	Ground	Floor heating	Normal	
41-SFH-M-WRM-G-WFL-NRM	Single family	Medium	Warm	Ground	Floor heating	Normal	
42-SFH-M-CLD-G-WFL-NRM	Single family	Medium	Cold	Ground	Floor heating	Normal	

These cases are the same as 10, 31 and 32 but the source is ground heat, through a vertical bore-hole. The heat pump is brine to water.

The calculation of the return water to the heat pump from the heat exchanger is performed with a simplified model linked to the average monthly temperature.

The size of the heat emitters and of the heat pump has been adapted to the changing heat load of the building.

6.8.2 Calculation results

Tables 26 to 31 present the space heating and domestic hot water energy performance results for the brine to water heat pump for all three climates.

Table 26: Results for heating service, average climate, brine to water heat pump

Interval	Needs	HP out	HP in	COP$_H$	LR(H)	Flow temp.	Source temp.	Missed
	$Q_{H;nd}$	$Q_{H;hp;out}$	$Q_{H;hp;in}$	COP_H		$\theta_{H;hp;out}$	θ_{src}	$Q_{H;out;add}$
	kWh	kWh	kWh	-	-	°C	°C	kWh
January	2.356	2.651	661	4,01	0,53	36,74	0,90	46
February	2.183	2.456	607	4,05	0,55	37,23	0,83	40
March	1.103	1.245	314	3,97	0,35	34,68	1,67	9
April	881	994	249	3,99	0,28	33,20	2,02	0
May	4	4	1	3,85	0,18	32,88	3,06	0
June	0	0	0					0
July	0	0	0					0
August	0	0	0					0
September	119	135	39	3,47	0,18	32,51	2,68	0
October	743	839	220	3,81	0,26	32,53	2,18	3
November	1.816	2.045	500	4,09	0,42	35,00	1,32	16
December	1.981	2.229	535	4,17	0,44	34,95	1,31	15
Year	**11.187**	**12.599**	**3.126**	**4,03**	**0,42**	**35,05**	**1,42**	**129**
kWh/m^2	78,8	88,7						

Table 27: Results for domestic hot water service, average climate, brine to water heat pump

Interval	Needs	HP out	HP in	COPW
	$Q_{W;nd}$	$Q_{W;hp;out}$	$Q_{W;hp;in}$	COP_W
	kWh	kWh	kWh	-
January	228	337	150	2,25
February	206	304	136	2,25
March	228	337	147	2,29
April	220	326	141	2,31
May	228	337	143	2,36
June	220	326	137	2,37
July	228	337	141	2,38
August	228	337	142	2,38
September	220	326	139	2,35
October	228	337	145	2,32
November	220	326	143	2,27
December	228	337	148	2,27
Year	**2.680**	**3.967**	**1.713**	**2,32**
kWh/m^2	18,9	27,9		

Table 28: Results for heating service, warm climate, brine to water heat pump

Interval	Needs	HP out	HP in	COP$_H$	LR(H)	Flow temp.	Source temp.	Missed
	$Q_{H;nd}$	$Q_{H;hp;out}$	$Q_{H;hp;in}$	COP$_H$		$\theta_{H;hp;out}$	θ_{src}	$Q_{H;out;add}$
	kWh	kWh	kWh	-	-	°C	°C	kWh
January	761	867	212	4,09	0,47	34,71	2,07	92
February	861	980	242	4,04	0,53	36,06	1,91	113
March	225	258	64	4,00	0,36	33,96	2,48	9
April	58	67	20	3,36	0,20	32,68	2,57	0
May	1	1	1	1,05	0,04	29,47	3,42	0
June	0	0	0					0
July	0	0	0					0
August	0	0	0					0
September	0	0	0					0
October	0	0	0					0
November	0	0	0					0
December	478	546	135	4,05	0,40	34,04	2,27	40
Year	**2.384**	**2.718**	**674**	**4,03**	**0,44**	**34,75**	**2,15**	**255**
kWh/m^2	16,8	19,1						

Table 29: Results for domestic hot water service, warm climate, brine to water heat pump

Interval	Needs	HP out	HP in	COPW
	$Q_{W;nd}$	$Q_{W;hp;out}$	$Q_{W;hp;in}$	COP$_W$
	kWh	kWh	kWh	-
January	179	273	118	2,31
February	162	246	107	2,30
March	179	273	117	2,33
April	173	264	113	2,34
May	179	273	114	2,38
June	173	264	109	2,42
July	179	273	112	2,44
August	179	273	112	2,44
September	173	264	110	2,40
October	179	273	115	2,38
November	173	264	112	2,36
December	179	273	117	2,32
Year	**2.106**	**3.212**	**1.356**	**2,37**
kWh/m^2	14,8	22,6		

Table 30: Results for heating service, cold climate, brine to water heat pump

Interval	Needs	HP out	HP in	COP_H	LR(H)	Flow temp.	Source temp.	Missed
	$Q_{H;nd}$	$Q_{H;hp;out}$	$Q_{H;hp;in}$	COP_H		$\theta_{H;hp;out}$	θ_{src}	$Q_{H;out;add}$
	kWh	kWh	kWh	-	-	°C	°C	kWh
January	3.151	3.531	841	4,20	0,55	35,65	0,43	18
February	3.673	4.118	1.092	3,77	0,74	39,21	-0,61	193
March	2.696	3.020	735	4,11	0,47	35,30	0,60	12
April	1.658	1.865	472	3,96	0,33	33,68	1,22	0
May	755	852	228	3,75	0,22	32,00	2,13	0
June	17	19	14	1,38	0,05	30,2	3,02	0
July	20	23	8	2,77	0,11	30,2	3,33	0
August	1	1	1	1,05	0,04	31,1	2,11	0
September	832	935	266	3,51	0,17	30,81	2,08	0
October	1.976	2.222	549	4,05	0,35	33,89	1,04	0
November	2.499	2.803	671	4,18	0,45	34,64	0,77	9
December	3.397	3.807	921	4,13	0,60	36,52	0,19	34
Year	**20.675**	**23.198**	**5.798**	**4,00**	**0,44**	**34,79**	**0,81**	**267**
kWh/m²	145,6	163,4						

Table 31: Results for domestic hot water service, cold climate, brine to water heat pump

Interval	Needs	HP out	HP in	COPW
	$Q_{W;nd}$	$Q_{W;hp;out}$	$Q_{W;hp;in}$	COP_W
	kWh	kWh	kWh	-
January	265	381	171	2,23
February	240	343	158	2,17
March	265	380	170	2,23
April	257	368	162	2,27
May	265	380	164	2,31
June	257	368	156	2,35
July	265	380	160	2,38
August	265	380	162	2,35
September	257	368	159	2,31
October	265	380	168	2,26
November	257	368	164	2,24
December	265	380	172	2,21
Year	**3.123**	**4.477**	**1.967**	**2,28**
kWh/m²	22,0	31,5		

6.8.3 Discussion

A comparison of the energy performance for heating and domestic hot water as a function of the climate gives the result shown in table 32.

Table 32: Comparison of results for water to water heat pumps

Description	unit	Warm climate	Average climate	Cold climate
Heating needs	kWh	2.384	11.187	20.675
Required output for heating	kWh	2.718	12.599	23.198
Load factor for heating	-	0,44	0,42	0,44
Average source temperature during heating	°C	2,15	1,42	0,81
Average COP for heating	-	4,03	4,03	4,00
Difference in COP	%	0%	0%	-1%
Domestic hot water needs	kWh	2.107	2.680	3.123
Required output for domestic hot water	kWh	3.212	3.967	4.477
Average source temperature during domestic hot water production	°C	3,17	2,18	1,42
Average COP for domestic hot water	-	2,37	2,32	2,28
Difference in COP	%	+2%	0%	-2%

For this case, the COP is only influenced by the temperature of the emitters and by the return temperature of the water from the ground heat exchanger (which is the inlet temperature to the evaporator).

The flow temperature is quite similar for all three cases, since the emitters have been adapted to the heat load, as they will be in actual systems.

The dependency of the source temperature from climate looks weak (underestimated). The default simplified model has been used, which is a constant base temperature plus a fraction of the monthly external temperature. A better model is required to get more accurate results and sensitivity to changing operating conditions, which include:

- the influence of the average yearly temperature, which is the temperature of the ground in the undisturbed region (deeper than about 10 m), should be added;
- the influence of the ground heat exchanger sizing
- the possible depletion of the ground around the ground heat exchanger, if undersized.

6.9 Cases 50, 51 and 52: air to water, absorption heat pump

6.9.1 Description of the case

CASE	Building	Insulation	Climate	Source	Sink	Sizing	Other
50-SFH-M-AVG-A-WFL-NRM-ABS	Single family	Medium	Average	Ground	Floor heating	Normal	Absorption heat pump
51-SFH-M-WRM-A-WFL-NRM-ABS	Single family	Medium	Warm	Ground	Floor heating	Normal	Absorption heat pump
52-SFH-M-CLD-A-WFL-NRM-ABS	Single family	Medium	Cold	Ground	Floor heating	Normal	Absorption heat pump
50-SFH-M-AVG-A-WFL-NRM-ABS-RED	Single family	Medium	Average	Ground	Floor heating	Normal	Absorption heat pump – well sized

These cases are the same as 10, 31 and 32 but the heat pump is a gas fired absorption type, using natural gas. This heat pump has an integrated burner that produces the required heat to drive the absorption process.

The fourth case (53-…red) is the repetition of the first (50-…) with correct sizing.

6.9.2 Calculation results

Tables 33 to 37 present the space heating and domestic hot water energy performance results for the air to water absorption heat pump for average and cold climate.

Table 33: Results for heating service, average climate, absorption heat pump

Interval	Needs	HP out	HP in	COP_H	LR(H)	Source temp.	Aux. energy
	$Q_{H;nd}$	$Q_{H;hp;out}$	$Q_{H;hp;in}$	COP_H		θ_{src}	$W_{H;hp;aux}$
	kWh	kWh	kWh	-	-	°C	kWh
January	2.356	2.651	2.065	1,28	0,21	2,60	285
February	2.183	2.456	1.899	1,29	0,22	2,12	269
March	1.103	1.245	1.071	1,16	0,13	6,41	165
April	881	994	895	1,11	0,11	8,69	140
May	4	4	5	0,95	0,08	15,40	37
June	0	0	0				35
July	0	0	0				36
August	0	0	0				36
September	119	135	163	0,83	0,07	10,19	49
October	743	839	835	1,00	0,10	9,67	124
November	1.816	2.045	1.648	1,24	0,16	5,21	246
December	1.981	2.229	1.741	1,28	0,17	5,24	266
Year	**11.187**	**12.599**	**10.322**	**1,22**	**0,16**	**5,46**	**1.688**
kWh/m²	78,8	88,7					

Table 34: Results for domestic hot water service, average climate, absorption heat pump

Interval	Needs	HP out	HP in	COPW	Aux. energy	Source temp.
	$Q_{W;nd}$	$Q_{W;hp;out}$	$Q_{W;hp;in}$	COP_W	$W_{W;hp;aux}$	θ_{src}
	kWh	kWh	kWh	-	kWh	°C
January	228	337	264	1,28	13	2,58
February	206	304	239	1,27	12	2,19
March	228	337	244	1,38	12	8,15
April	220	326	228	1,43	11	10,40
May	228	337	226	1,49	11	17,11
June	220	326	219	1,49	11	18,65
July	228	337	226	1,49	11	19,49
August	228	337	226	1,49	11	19,14
September	220	326	221	1,48	11	14,67
October	228	337	234	1,44	12	11,64
November	220	326	243	1,34	12	5,32
December	228	337	250	1,35	12	5,15
Year	**2.680**	**3.967**	**2.820**	**1,41**	**139**	**11,28**
kWh/m²	18,9	27,9				

Table 35: Results for heating service, cold climate, absorption heat pump

Interval	Needs	HP out	HP in	COP_H	LR(H)	Source temp.	Aux. energy
	$Q_{H;nd}$	$Q_{H;hp;out}$	$Q_{H;hp;in}$	COP_H		$\theta_{H;hp;out}$	$W_{H;hp;aux}$
	kWh	kWh	kWh	-	-	°C	kWh
January	3.151	3.531	2.613	1,35	0,28	-0,54	327
February	3.673	4.118	3.238	1,27	0,40	-7,26	305
March	2.696	3.020	2.306	1,31	0,24	0,61	300
April	1.658	1.865	1.533	1,22	0,16	4,37	222
May	755	852	785	1,09	0,11	8,11	125
June	17	19	55	0,34	0,03	12,33	37
July	20	23	32	0,74	0,06	13,62	38
August	1	1	6	0,25	0,02	13,55	36
September	832	935	949	0,99	0,09	9,94	133
October	1.976	2.222	1.765	1,26	0,17	3,58	261
November	2.499	2.803	2.120	1,32	0,22	1,75	295
December	3.397	3.807	2.836	1,34	0,30	-2,08	331
Year	**20.675**	**23.198**	**18.237**	**1,27**	**0,23**	**1,73**	**2.412**
kWh/m²	145,6	163,4					

Table 36: Results for domestic hot water service, cold climate, absorption heat pump

Interval	Needs	HP out	HP in	COPW	Aux. energy	Source temp.
	$Q_{W;nd}$	$Q_{W;hp;out}$	$Q_{W;hp;in}$	COP_W	$W_{W;hp;aux}$	θ_{src}
	kWh	kWh	kWh	-	kWh	°C
January	265	381	311	1,22	15	-0,65
February	240	343	329	1,04	15	-6,99
March	265	380	308	1,24	15	0,81
April	257	368	277	1,33	13	5,22
May	265	380	265	1,43	13	11,39
June	257	368	247	1,49	12	16,22
July	265	380	255	1,49	13	19,39
August	265	380	256	1,49	13	15,82
September	257	368	254	1,45	13	10,69
October	265	380	291	1,31	14	3,96
November	257	368	290	1,27	14	1,86
December	265	380	322	1,18	15	-2,08
Year	**3.123**	**4.477**	**3.403**	**1,32**	**165**	**6,41**
kWh/m²	22,0	31,5				

Table 37: Results for heating service, average climate, absorption heat pump correctly sized

Interval	Needs	HP out	HP in	COP_H	LR(H)	Source temp.	Aux. energy
	$Q_{H;nd}$	$Q_{H;hp;out}$	$Q_{H;hp;in}$	COP_H		θ_{src}	$W_{H;hp;aux}$
	kWh	kWh	kWh	-	-	°C	kWh
January	2.356	2.651	1.751	1,51	0,57	2,60	333
February	2.183	2.456	1.602	1,53	0,58	2,12	300
March	1.103	1.245	835	1,49	0,37	6,41	224
April	881	994	670	1,48	0,30	8,69	207
May	4	4	3	1,37	0,19	15,40	36
June	0	0	0				34
July	0	0	0				35
August	0	0	0				35
September	119	135	101	1,34	0,19	10,19	66
October	743	839	585	1,44	0,28	9,67	183
November	1.816	2.045	1.333	1,53	0,45	5,21	302
December	1.981	2.229	1.438	1,55	0,46	5,24	325
Year	**11.187**	**12.599**	**8.317**	**1,51**	**0,44**	**5,46**	**2.078**
kWh/m²	78,8	88,7					

6.9.3 Discussion

The results for the warm climate are not presented because of the low power requirement of the single-family house in the warm climate. The smallest heat pump that was found had a too low load factor and the COP was severely reduced by the part load correction factor.

A comparison of the energy performance for heating and domestic hot water as a function of the climate gives the result shown in table 38.

Table 38: Comparison of results for air to water absorption heat pumps

Description	unit	Average climate	Cold climate	Average climate correctly sized
Heating needs	kWh	11.187	20.675	11.187
Required output for heating	kWh	12.599	23.198	12.599
Load factor for heating	-	0,16	0,23	0,44
Average source temperature during heating	°C	5,46	1,73	5,46
Average COP for heating	-	1,22	1,27	1,51
Fuel input for heating	kWh	10.322	18.237	8.317
Auxiliary energy for heating	kWh	1.688	2.412	2.078
Domestic hot water needs	kWh	2.680	3.123	2.680
Required output for domestic hot water	kWh	3.967	4.477	3.967
Average source temperature during domestic hot water production	°C	11,28	6,41	11,28
Average COP for domestic hot water	-	1,41	1,32	1,41
Fuel input for domestic hot water	kWh	2.820	4.477	2.820
Auxiliary energy for domestic hot water	kWh	139	165	348

The COP is lower than that of an electric heat pump but this is compensated by the lower weighting factor o the fuel compared to electricity.

The module also calculates the auxiliary energy, which is not negligible for this type of heat pumps and it is not included in the declared COP.

In these examples, the COP is severely affected by part load. The performance has been recalculated fort the average climate, assuming a correct sizing. The average load factor has increased from 0,16 to 0,44 and the COP from 1,22 to 1,51 for heating. This confirms once more the importance of the correct sizing of a heat pump.

6.10 Cases 60 and 61: air to air heat pump with 2 climates

6.10.1 Description of the case

CASE	Building	Insulation	Climate	Source	Sink	Sizing	Other
60-SFH-M-AVG-A-AAA-NRM	Single family	Medium	Average	Air	Air	Normal	
61-SFH-M-AVG-A-AAA-UND	Single family	Medium	Warm	Air	Air	Normal	

These cases are the same as 10, 31 and 32 but an air-to-air heat pump is used.

No domestic hot water is provided in this case. Another generation device will provide independently.

The size of the heat pump has been adapted to the changing heat load of the building.

To simplify the calculation, the same required energy output is assumed as in the previous examples. Actually, distribution heat losses should not be included because there is no hydronic distribution system. Distribution losses, in case of multi-split systems, should be included in the declared COP.

6.10.2 Calculation results

Tables 39 and 40 present the space heating energy performance results for the air to air heat pump for all three climates.

Table 39: Results for heating service, average climate, air to air heat pump

Interval	Needs	HP out	HP in	COP_H	LR(H)
	$Q_{H;nd}$	$Q_{H;hp;out}$	$Q_{H;hp;in}$	COP_H	
	kWh	kWh	kWh	-	-
January	2.356	2.651	792	3,35	0,51
February	2.183	2.456	738	3,33	0,53
March	1.103	1.245	283	4,40	0,34
April	881	994	180	5,51	0,28
May	4	4	1	5,80	0,21
June	0	0	0		
July	0	0	0		
August	0	0	0		
September	119	135	23	5,83	0,18
October	743	839	170	4,94	0,26
November	1.816	2.045	505	4,05	0,42
December	1.981	2.229	520	4,28	0,43
Year	**11.187**	**12.599**	**3.213**	**3,92**	**0,40**
kWh/m²	78,8	88,7			

Table 40: Results for heating service, warm climate, air to air heat pump

Interval	Needs $Q_{H;nd}$ kWh	HP out $Q_{H;hp;out}$ kWh	HP in $Q_{H;hp;in}$ kWh	COP_H COP_H -	LR(H) -
January	761	867	176	4,93	0,38
February	861	980	225	4,35	0,45
March	225	258	42	6,09	0,29
April	58	67	10	6,82	0,18
May	1	1	0	6,20	0,04
June	0	0	0		
July	0	0	0		
August	0	0	0		
September	0	0	0		
October	0	0	0		
November	0	0	0		
December	478	546	99	5,51	0,32
Year	**2.384**	**2.718**	**552**	**4,92**	**0,36**
kWh/m^2	16,8	19,1			

6.10.3 Discussion

A comparison of the energy performance for heating as a function of the climate gives the result shown in table 42.

Table 41: Comparison of results for normal and oversized heat pump

Description	unit	Warm climate	Average climate
Heating needs	kWh	2.384	11.187
Required output	kWh	2.718	12.599
Average COP	-	4,92	3,92
Difference in COP	%	+ 25%	0%
Part load factor	-	0,36	0,40
External temperature	°C	10,04	5,46

As expected, the COP depends on the outdoor air temperature.

The dependency of COP according to the load factor looks quite different for the air to air heat pumps, where there is an increase of COP at part load, which should be justified by the reduced temperature difference of indoor air across the evaporator and the reduced approach between leaving air temperature from the evaporator and condensing temperature. This behaviour is illustrated in figures 35 and 36 for the average climate.

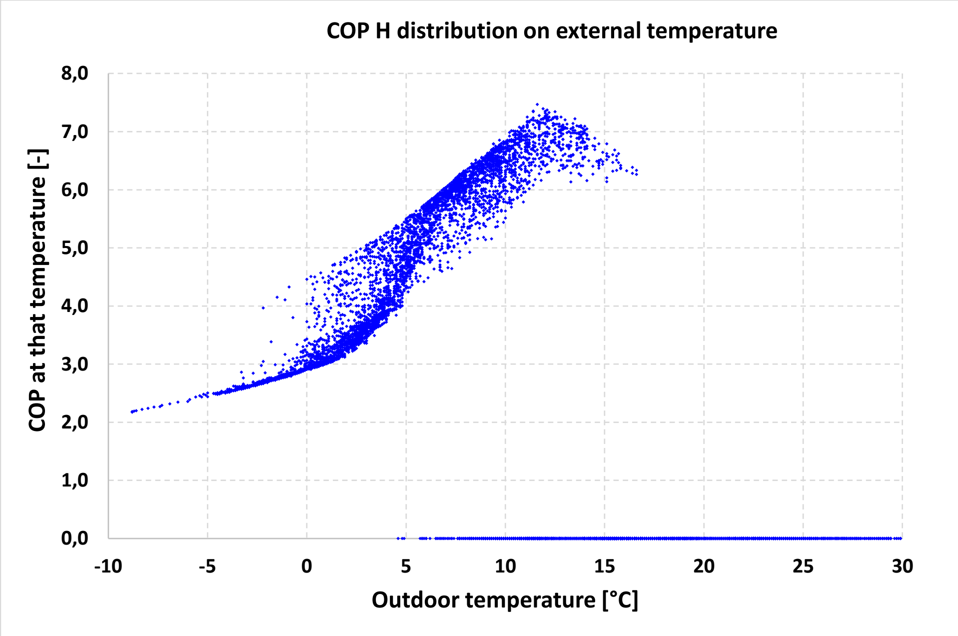

Figure 35 – Space heating COP as a function of outdoor temperature, air to air heat pump, average climate

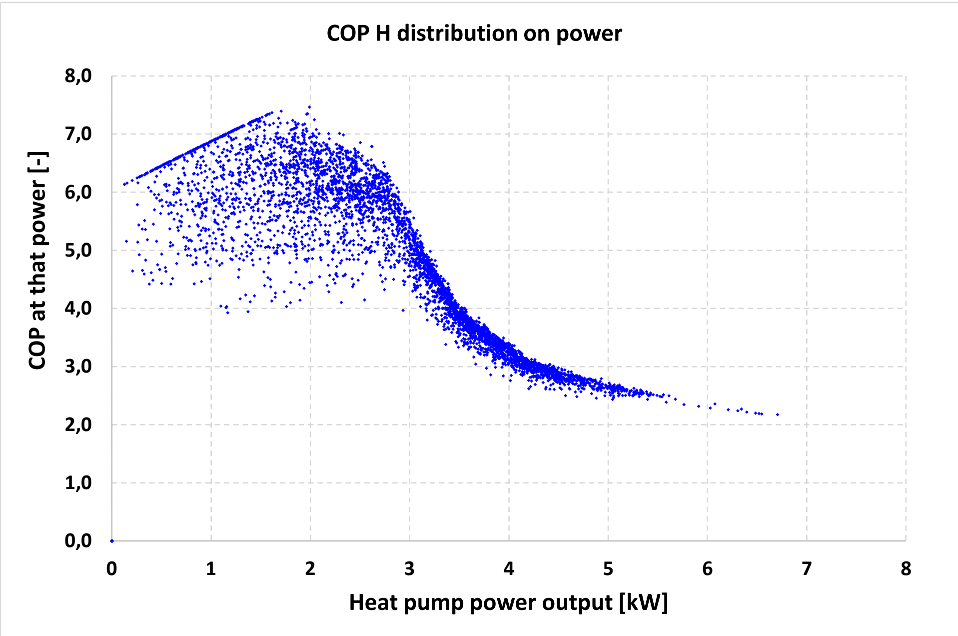

Figure 36 – Space heating COP as a function of output power, air to air heat pump, average climate

7 Analysis

7.1 Completeness

In this case the most common heat pumping technologies and sources have been demonstrated. The standard allows more (e.g. combustion engine driven heat pumps, exhaust air) and this covers all available technologies on the market.

The standard allows to specify independently heat pump technology, source type, sink type, calculation path and all combinations are theoretically possible.

One exception is heat pumps that may provide simultaneous heating and cooling (so called 4 pipes machines). They appeared on the market recently and it is likely that they will be included in the next revisions of EN 15316-4-2. This has to be coordinated with the standard dealing with chillers, EN 16798-13.

A useful additional feature, which has been added in the spreadsheet and used in this case study, is the possibility to shift to the next hour the missing load. It has been explained in clause 6.1.1.2. This is correct when it is only a short transient due to a sudden peak or to the domestic hot water priority. It is also correct that after a peak, the heat pump will operate at full load until the missing energy is restored.

7.2 Functionality

The standard provided the expected results.

It has to be stressed that the heat pump performance is extremely sensitive to operating conditions. In particular, water flow temperature shall be calculated with the EN 15316-1 module, taking into account the control strategy. This has been done in this case study and demonstrated that the several influences may compensate or sum. An example was the change of climate for air to water heat pumps, where the advantage of the higher source temperature for the warmer climate was compensated by the oversizing of the heat pump.

7.2.1 Sensitivity

This module proved sensitive to the expected parameters.

Product data and operating conditions are taken into account.

It has to be noted that the hourly method is required to correctly identify if the heat pump is able to satisfy the required load for space heating and domestic hot water preparation.

The modeling of special sources, like ground heat exchangers, should be improved. The default model looks not sensitive enough to local climate and heat exchanger sizing (seasonal drift of ground temperature around the heat exchanger).

7.3 Usability

The standard is easy to use.

The only issue is the availability of the product data. Ideally, all required data should be found in the manufacturer data-sheet, which is not yet always the case due to the lack of coordination of the standardisation efforts on products and systems.

The data for the case study were found, indeed, and there are a number of reasonable default values and procedures to integrate the available data.

8 Conclusions and recommendations

The standard is easy to use and also provides a lot of useful information with the intermediate data produced, as shown in the additional display and statistic features added in the worksheet. This information is particularly useful to size correctly the heat pump.

The performance of a heat pump is very sensitive to operating conditions. EN 15316-4-2 needs the support of other EPB standards, especially EN 15316-1 that allows that calculation of the required flow temperature.

The structure of the standard easily accommodates several typologies of heat pumps.

Coordination work between the relevant CEN or ISO committees and working groups is required to ensure that the product standards provide all the required data for the energy performance calculation.

Some work is required concerning the operating conditions and auxiliary energy use of special sources, such as ground heat exchangers.

It is suggested to introduce in this standard also the method to take into account transient heat output deficits, as described in clause 6.1.1.2. The required equations can be easily extracted from the spreadsheet.

Annex A

List of calculation files

A.1 Main files

- 10 - EN_15316-4-2 - 10-SFH-M-AVG-A-WFL-NRM.xlsm
- 11 - EN_15316-4-2 - 11-SFH-M-AVG-A-WFC-NRM.xlsm
- 12 - EN_15316-4-2 - 11-SFH-M-AVG-A-WRD-NRM.xlsm
- 21 - EN_15316-4-2 - 21-SFH-M-AVG-A-WFL-UND.xlsm
- 22 - EN_15316-4-2 - 22-SFH-M-AVG-A-WFL-UND-CUT.xlsm
- 23 - EN_15316-4-2 - 23-SFH-M-AVG-A-WFL-OVR.xlsm
- 24 - EN_15316-4-2 - 24-SFH-M-AVG-A-WFL-OVR-INT.xlsm
- 31 - EN_15316-4-2 -31-SFH-M-WRM-A-WFL-NRM.xlsm
- 32 - EN_15316-4-2 - 32-SFH-M-CLD-A-WFL-NRM.xlsm
- 40 - EN_15316-4-2 - 40-SFH-M-AVG-G-WFL-NRM.xlsm
- 41 - EN_15316-4-2 - 41-SFH-M-WRM-G-WFL-NRM.xlsm
- 42 - EN_15316-4-2 - 42-SFH-M-CLD-G-WFL-NRM.xlsm
- 50 - EN_15316-4-2 - 50-SFH-M-AVG-A-WFL-NRM-ABS.xlsm
- 51 - EN_15316-4-2 - 51-SFH-M-WRM-A-WFL-NRM-ABS.xlsm
- 52 - EN_15316-4-2 - 52-SFH-M-CLD-A-WFL-NRM-ABS.xlsm
- 53 - EN_15316-4-2 - 53-SFH-M-AVG-A-WFL-NRM-ABS-red.xlsm
- 60 - EN_15316-4-2 - 50-SFH-M-AVG-A-AAA-NRM.xlsm
- 61 - EN_15316-4-2 - 50-SFH-M-WRM-A-AAA-NRM.xlsm

A.2 Supporting files

- 00 - ISO_52010-1_TMY_Athens_8_planes.xlsx
- 00 - ISO_52010-1_TMY_Oslo_8_planes.xlsx
- 00 - ISO_52010-1_TMY_Strasbourg_8_planes.xlsx
- 10 - EN 12831-3 - SFH-DHW_needs.xlsx
- 10 - EN_16798-1_SFH-X-AVG-II-CNT_HUDU-DHW.xlsm
- 10 - EN_16798-1_SFH-X-AVG-II-CNT_HUDU.xlsm
- 10 - EN_16798-1_SFH-X-AVG-II-INT_HUDU.xlsm
- 10 - EN_16798-1_SFH-X-CLD-II-CNT_HUDU-DHW.xlsm
- 10 - EN_16798-1_SFH-X-CLD-II-CNT_HUDU.xlsm
- 10 - EN_16798-1_SFH-X-WRM-II-CNT_HUDU-DHW.xlsm
- 10 - EN_16798-1_SFH-X-WRM-II-CNT_HUDU.xlsm
- 20 - ISO_52016-1_SFH_I_YYY-II-CNT_DESC.xlsx
- 20 - ISO_52016-1_SFH_M_YYY-II-CNT_DESC.xlsx
- 20 - ISO_52016-1_SFH_M_YYY-II-INT_DESC.xlsx
- 21 - ISO_52016-1_SFH_I-AVG-II-CNT-CALC.xlsm
- 21 - ISO_52016-1_SFH_M-AVG-II-CNT-CALC.xlsm
- 21 - ISO_52016-1_SFH_M-AVG-II-CNT-CALC_Low_air.xlsm
- 21 - ISO_52016-1_SFH_M-AVG-II-INT-CALC.xlsm
- 21 - ISO_52016-1_SFH_M-AVG-II-INT-CALC_Low_air.xlsm
- 21 - ISO_52016-1_SFH_M-CLD-II-CNT-CALC.xlsm
- 21 - ISO_52016-1_SFH_M-WRM-II-CNT-CALC.xlsm
- 30 - EN_15316-1-red_SFH_AVG_WFC_HC.xlsm
- 30 - EN_15316-1-red_SFH_AVG_WFL_HC.xlsm
- 30 - EN_15316-1-red_SFH_AVG_WRD_HC.xlsm
- 30 - EN_15316-1-red_SFH_CLD_WFL_HC.xlsm
- 30 - EN_15316-1-red_SFH_WRM_WFL_HC.xlsm
- 30 - EN_15316-1_SFH_AVG_FL_HC.xlsm
- 30 - EN_15316-1_SFH_CLD_FL_HC.xlsm
- 30 - EN_15316-1_SFH_WRM_FL_HC.xlsm
- 35 - EN 15316_5_SFH_AVG.xlsm
- 35 - EN 15316_5_SFH_CLD.xlsm
- 35 - EN 15316_5_SFH_WRM.xlsm

Bibliography

More information can be found on EPB-Center website and in the following other case studies.

[1] ENERC32017-437-SI2-785.185, Case study on EN ISO 52000-1, Overarching standard October 31, 2021

[2] ENERC32017-437-SI2-785.185, Case study on EN ISO 52000-1, Overarching standard, simplified spreadsheets, October 31, 2021

[3] ENERC32017-437-SI2-785.185, Case study on EN ISO 52010-1, Climatic data October 31, 2021

[4] ENERC32017-437-SI2-785.185, Case study on EN 15316-1, Heating and domestic hot water systems, general part, October 31, 2021

[5] ENERC32017-437-SI2-785.185, Case study on EN ISO 52016-1, Heating and cooling needs and internal temperatures October 31, 2021

[6] ENERC32017-437-SI2-785.185, Case study on EN ISO 52016-1, Annex F, Solar shading reduction factors October 31, 2021

[7] ENERC32017-437-SI2-785.185, Case study on EN 16798-1, Conditions of use October 31, 2021

[8] ENERC32017-437-SI2-785.185, Case study on EN 16798-7, Natural ventilation October 31, 2021

[9] ENERC32017-437-SI2-785.185, Case study on EN 16798-7 and EN 16798-5-1, Mechanical ventilation October 31, 2021

[10] ENERC32017-437-SI2-785.185, Case study on Single-family House October 31, 2021

[11] ENERC32017-437-SI2-785.185, Case study on Multi-family House October 31, 2021

[12] ENERC32017-437-SI2-785.185, Case study on Office building October 31, 2021

Please check the EPB Center website for the overview and most recent versions of the other case study reports.

Link: EPB Center support documents

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