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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 Single family house

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Prepared by Laurent Socal with contributions by the Project Team

Final document

Project Leader and contact point:

Mr Jaap (J.J.N.M.) Hogeling

Stichting ISSO

Weena 505, NL 3013 AL Rotterdam, The Netherlands

PO Box 577, NL 3000 AN Rotterdam, The Netherlands

T: Mobile: +31 65 31 61 973 |

E: j.hogeling@isso.nl

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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**
ISO	**International organization for standardization**
MFH	**Multi Family House**
MS	**EU Member State(s)**
NA (/ND)	**National Annex or National Datasheet for EPB standards**
NSB	**National Standards Body of CEN and/or ISO**
OFF	**Office building**
RER	**Renewable energy ratio**
SFH	**Single Family House**
TR	**Technical report (of CEN and/or ISO)**

1 Introduction

This document is the report of the case study on a sample single-family house to show how the energy performance can be calculated with the new (CEN and ISO) EPB standards.

This case study uses several key modules one at a time using the demo excel files. Generally, outputs of one module are copy pasted to the input of the next module in the calculation sequence.

The focus is on the ease of use and sensitivity of the calculation method.

2 Executive summary

This case study demonstrates the complete calculation of the energy performance of a building and the related technical systems using the set of (CEN and ISO) EPB standards. The objective is to demonstrate that the connections between modules work so that it is possible to perform a complete energy performance calculation with the set of EPB standards. Some variants are also tested to cover the most likely cases coherently with the type of building. This is to check that the system works not only for a single case but for foreseeable configurations of buildings and technical systems and that the needed modules are available.

Two base cases have been selected:

- an existing single-family house (SFH), typically 20 to 30 years old that has not yet undergone a deep renovation;
- a new SFH building.

The energy performance of the existing building has been calculated at first for three typical climates, taking into account a building envelope insulation level in accordance with the climate. The basic system configuration is the same for all three climates: radiators, condensing boiler, domestic hot water production with storage, natural ventilation, no cooling system. This first run allowed to check that results are consistent with the hypothesis (there is experience on these configurations).

Then some likely renovations have been tested.

- Thermal solar has been added, with average climate, which is a common upgrade. Correctly, the energy performance was improved thanks to the thermal solar covering more than half of the domestic hot water needs.
- Thermal solar and PV have been added, with warm climate. This checked the limit in the use of thermal solar and showed that PV cannot contribute with no significant electric energy use and $k_{exp} = 0$ [1].
- On the previous configuration, cooling was added, which is another common upgrade in a warm climate context (and now also in average climate). The cooling was mostly covered by the PV, even with $k_{exp} = 0$.
- On the previous configuration, k_{exp} was set to 1. This checked the strong effect of this choice about the evaluation of exported energy.

The energy performance of the typical new building has been calculated for three typical climates, again taking into account a building envelope insulation level in accordance with the climate. The basic system configuration is the same for all three climates: floor heating, heat pump for heating and domestic hot

[1] k_{exp} is an important parameter for weighting the energy exported from the building site. For more information, see case studies and short videos on EN ISO 52000-1.

water, domestic hot water production with storage, mechanical ventilation with heat recovery, cooling system.

This first run was without PV.

Then PV was added and the new performance calculated for average climate, with k_{exp} =0 and k_{exp} =1.

The case study confirmed that the EPB standards (modules) work together and the various building and technical systems configuration can be calculated: the method is functional and complete.

Concerning usability, the hourly method increases the calculation load on the computer but it does not require a higher effort on the assessor, since the description of building and systems is not significantly changing depending on the calculation interval. Setting the whole to work hourly requires some care in defining some details like use profiles, comfort requirement schedule, system operation schedule. Once solved, the assessor is left with just the choice between schedules linked to the space category and the type of system operation (which is nothing different from using monthly methods).

The hourly calculation for the entire year was successfully done with the Excel files only. Actually, some marginal modules were simulated with simple alternative models, due to the limited availability of time and the large number of calculations required. This indeed confirms that the Excel can be used to prepare and document reference cases to test software for productive use based on the same standards.

3 The context of the case study

The new set of (CEN and ISO) EPB standards have been published in the years 2017…2018. This revision supports the hourly calculation interval.

This case study demonstrates how to perform the entire calculation for some representative configurations of a single-family house.

The productive use of the set of EPB standards would require a professional software, just like any other method currently in use. This case study uses the demo Excel of the single modules, with some enhancements, to demonstrate that it is possible, it gives consistent and useful results and it doesn't require unreasonable effort for a standard calculation.

4 Coverage of the scope

4.1 Introduction

The scope is covered if:

- technologies that are likely to be included in the building and technical systems;
- possible installation configurations;
- required performance indicators;
- calculation interval;

are covered.

Two representative base cases are defined:

- existing single-family house;
- new single-family house.

Variants on these base cases are explored to cover the most likely configurations.

4.2 Coverage of technologies

The set of EPB standards cover all the most popular technologies on the market, for new and existing buildings. The technologies tested in this case study include:

- condensing boilers;
- heat pumps;
- thermal solar;
- photovoltaic.

4.3 Coverage of installation configurations

The set of EPB standards have a modular structure that is designed to adapt to the actual installation configuration.

The concept of modularity has both the goal to adapt to virtually any configuration and to allow a progressive use of the new modules.

Coverage of more complex installation with a ventilation and air conditioning system, including an air handling unit, will be the topic of the case study on office building.

4.4 Coverage of performance indicators

The calculated performance indicators include:

- global performance indicators, such as primary energy, CO_2 emissions, etc.
- partial performance indicators, such as system efficiencies, average transmittance, etc.

4.5 Coverage of calculation intervals

The case study is focused on hourly calculation.

5 Definition of the cases

5.1 Rationale of the selection of cases

The selection of cases shall cover:

- the different climates;
- the level of insulation of the building;
- the technical systems technologies.

The intent is not to test all possible combinations with all examples but to use likely technologies at least once, in the context where they are most likely to be used.

As an example, heat pump technology for heating will be considered only for insulated buildings. This is indeed a practical pre-requisite for their use.

5.2 Types of building envelope

The following types of buildings envelope have been considered

- existing building, with poor or moderate insulation (20…30 years old);
- new building with passive house or nearly zero energy building (NZEB) insulation level.

The assumed insulation level is correlated to the climate.

5.3 Selected cases and variants

5.3.1 Case 1: Existing building

5.3.1.1 Base case

The base case is the single-family house (SFH) defined in the preparatory work.

Shape and size of the single-family house are summarised in the following figures 1 to 3.

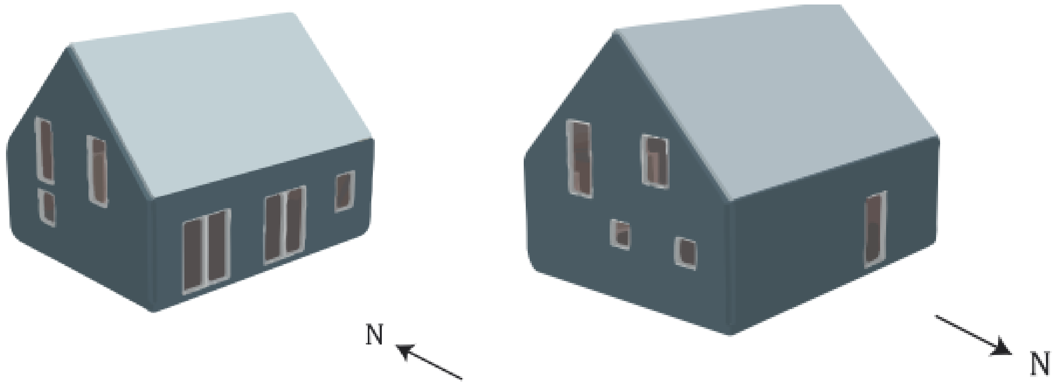


Figure 1 - Single family house view

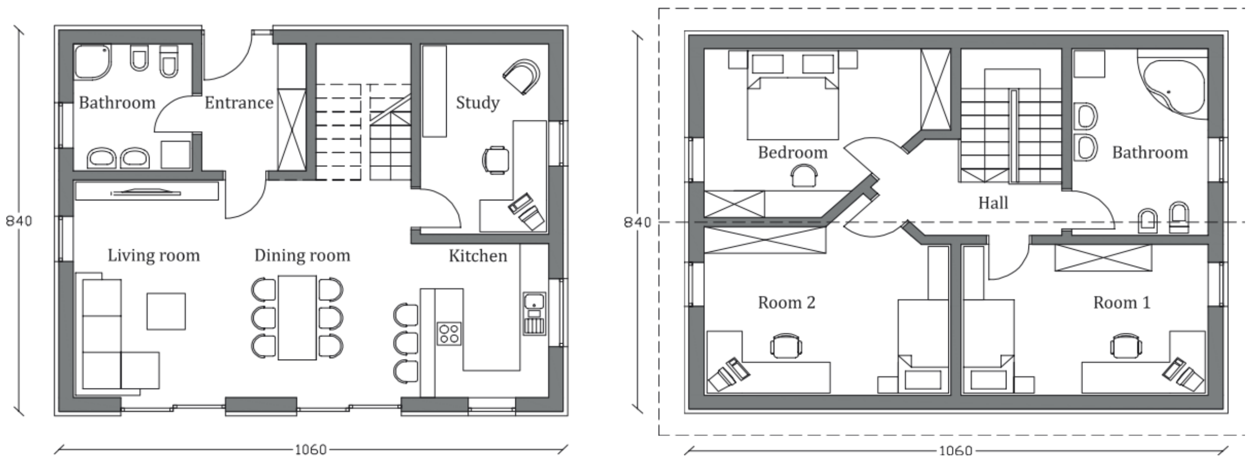


Figure 2 - Single family house plans

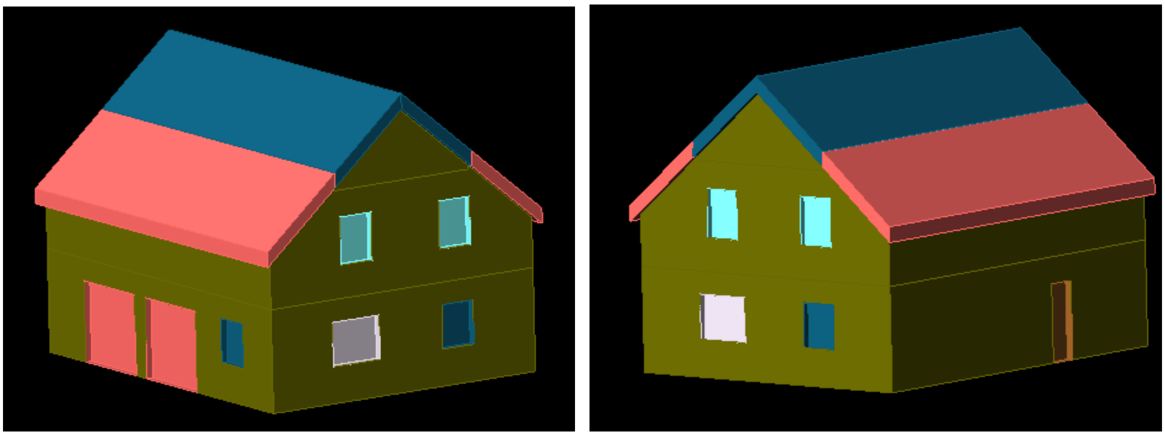


Figure 3 - 3D model of the SFH building generated by a software

Both the useful floor area and the reference area are assumed to be the net floor area for this case study. The net floor area of this sample building is 142 m^2.

NOTE The example in CEN ISO TR 52016-2 uses the overall internal area, which is 150 m^2 as useful floor area. The default definition used in EN ISO 52000-1, table B.20 excludes only the "non-bearing structures". This definition may cause ambiguities.

An insulation level that was likely 20…30 years ago is assumed, see table.

Table 1: Assumed U-value of building elements for the existing building

Building element	Cold climate	Average climate	Warm climate
Walls	0,60 W/m^{2}K	0,90 W/m^{2}K	1,20 W/m^{2}K
Roof	0,40 W/m^{2}K	0,80 W/m^{2}K	0,80 W/m^{2}K
Windows	1,40 W/m^{2}K	2,40 W/m^{2}K	3,20 W/m^{2}K
Floor	0,80 W/m^{2}K	1,30 W/m^{2}K	1,30 W/m^{2}K

Domestic hot water needs are calculated with the default values in annex B to EN 12831-3.

Technical systems configuration:

- Heating: radiators, thermostatic valves, internal two pipes distribution, standard boiler;
- Domestic hot water: domestic hot water storage heated by the standard boiler;
- Ventilation: natural ventilation, air exchange rate 0,60 h^{-1};
- Cooling: local split air conditioners, only for warm climate;
- Humidification and dehumidification: none

5.3.1.2 Variant 1: climate

The calculation is repeated for the 3 typical climates defined in the preparatory work:

- Cold climate: Oslo
- Average climate: Strasbourg
- Warm climate: Athens

5.3.1.3 Variant 2: thermal solar

Thermal solar for domestic hot water is added with the following properties:

- n°2 flat plane collectors with aperture area 2,3 m^2 each

- default values for the collector properties
- domestic hot water storage increased to 300 l
- orientation is south with 45° tilt angle

This is a viable upgrade for any climate.

5.3.1.4 Variant 3: PV

PV is added with the following properties:

- peak power: 3 kW
- orientation: south with 45° tilt angle

Default data for polycrystalline panels.

5.3.2 Case 2: New building

5.3.2.1 Base case

The description is the same as for the existing building with the following changes.

Table 2: Assumed U-value of building elements for the new building

Building element	Cold climate	Average climate	Warm climate
Walls	0,15 W/m²K	0,20 W/m²K	0,30 W/m²K
Roof	0,10 W/m²K	0,15 W/m²K	0,20 W/m²K
Windows	1,00 W/m²K	1,20 W/m²K	1,40 W/m²K
Floor	0,20 W/m²K	0,30 W/m²K	0,60 W/m²K

System configuration.

- Heating: floor heating, room thermostats, internal distribution, air to water heat pump.
- Domestic hot water: domestic hot water storage heated by the same heat pump
- Ventilation: mechanical ventilation with heat recovery, air exchange rate 0,60 h^{-1}.
- Cooling: cooling on average and warmer climate.
- Humidification and dehumidification: none.

5.3.2.2 Variant 1: climate

The calculation is repeated for the 3 typical climates defined in the preparatory work:

- Cold climate: Oslo
- Average climate: Strasbourg
- Warm climate: Athens

5.3.2.3 Variant 2 PV

PV is added with the following properties:

- peak power: 3 kW
- orientation: south with 45° tilt angle

Default data for polycrystalline panels are used.

5.3.3 Calculation cases summary

The resulting list of calculation cases is given in the following table 3.

Table 3: List of considered cases and variants

Cases and variants	Building	Climate	Thermal solar	PV	Cooling
SFH-E-AVG	Existing	Average	NO	NO	NO
SFH-E-AVG-TS	Existing	Average	YES	NO	NO
SFH-E-CLD	Existing	Cold	NO	NO	NO
SFH-E-CLD-TS	Existing	Cold	YES	NO	NO
SFH-E-WRM	Existing	Warm	NO	NO	YES
SFH-E-WRM-TS	Existing	Warm	YES	NO	YES
SFH-E-WRM-TS-PV	Existing	Warm	YES	YES	NO
SFH-N-AVG	NEW	Average	NO	NO	YES
SFH-N-AVG-PV	NEW	Average	NO	YES	YES
SFH-N-CLD	NEW	Cold	NO	NO	NO
SFH-N-CLD-PV	NEW	Cold	NO	YES	NO
SFH-N-WRM	NEW	Warm	NO	NO	YES
SFH-N-WRM-PV	NEW	Warm	NO	YES	YES

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

SFH-X-CLI- VRn

where

- **SFH** means single family house
- **X** can be:
  - **E** for existing building
  - **N** for new building
- **CLI** is the climate code
  - **AVG** for average climate
  - **CLD** for cold climate
  - **WRM** for warm climate
- **VRn** are the variants, which can be:
  - **TS** for thermal solar
  - **PV** for photovoltaic

The complete list of the calculation files is given in annex A.

6 Calculation details

6.1 Calculation chain

6.1.1 General

The following set of spreadsheets has been used:

- Climatic data: EN ISO 52010-1, TMY for Strasbourg, Athens and Oslo
- Conditions of use: EN 16798-1
- Domestic hot water needs: EN 12831-3
- Hourly heating and cooling needs or summer indoor temperature: EN ISO 52016-1

- Heating and domestic hot water, general part: EN 15316-1, with simplified models for emission and distribution
- Domestic hot water storage: EN 15316-5
- Thermal solar: EN 15316-4-3, hourly method for thermal solar coupled with storage EN 15316-5
- Photovoltaic: EN 15316-4-3, hourly method for PV
- Boiler: EN 15316-4-1
- Heat pump: EN 15316-4-2
- Cooling emission losses: emission losses have been calculated with decreased temperature set, according to EN 15316-2
- Cooling generation: EN 16798-13
- Ventilation and heat recovery: EN 16798-5-1
- Weighted energy: EN ISO 52000-1

Simplified models were used only for distribution modules.

Data transfer between modules has been done manually.

The whole sequence of files for each variant is saved in one individual folder.

See annex A for the complete list of the files.

6.1.2 Domestic hot water needs - EN 12831-3

The default draw-off temperature is 42 °C (EN 12831-3, Table B.6).

The average daily domestic hot water needs are calculated according to EN 12831-3, average value for table B.5.

The cold-water temperature is assumed equal to the yearly average of the outdoor temperature. The resulting volume needs is 205 l/day of domestic hot water at 42 °C. The energy needs depend on climate as shown in table 4.

Table 4: Domestic hot water needs

Description	Cold climate	Average climate	Warm climate
Cold water temperature	6,1 °C	11,2 °C	17,8 °C
Daily domestic hot water needs	8,56 kWh/day	7,34 kWh/day	5,77 kWh/day
Yearly domestic hot water needs	22,0 kWh/m^2 yr	18,9 kWh/m^2 yr	14,8 kWh/m^2 yr

The assumed tapping pattern is XL, which is shown in figure 4.

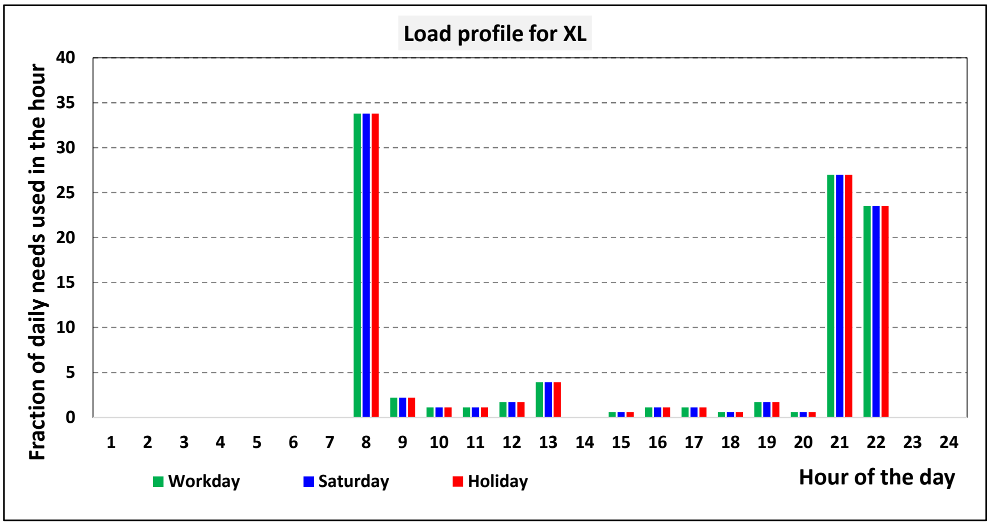


Figure 4 - XL Load profile for, as an hourly fraction of daily needs

Figure 5 illustrates the required input for this module.

Operating conditions data			
Delivery water temperature	$\vartheta_{W,draw}$	°C	42,0
Cold water temperature	$\vartheta_{W,c}$	°C	11,2
Constants and physical data			
Water density	ρ_W	kg/m³	1.000
Water specific heat	c_W	kWh/kg K	0,00116

Calculation method selection
Volume based on type of building

Floor area of dwelling	A	m²	142
Calculation method of water volume			
Use table B.5			
Volume need per equivalent adult			
single family dwellings AVG		l/p day	55
Reference hot water temperature	$\theta_{W;h;ref}$	°C	60,0
Reference cold water temperature	$\theta_{W;c;ref}$	°C	13,5

Figure 5 – Data input interface for EN 12831-3

6.1.3 Use profiles - EN 16798-1

Use profiles are taken from EN 16798-1, default profile for detached house, comfort category II.

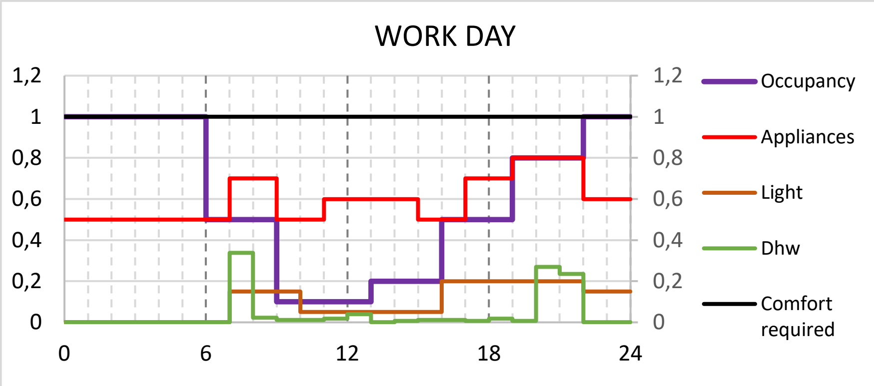


Figure 6 – Hourly profiles for residential detached houses – week-day

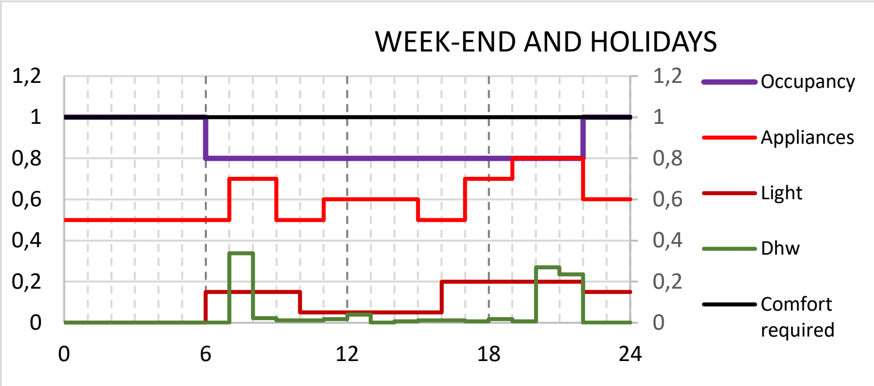


Figure 7 – Hourly profiles for residential detached houses – week-end and holidays

The following operating conditions are assumed, according to comfort category II defined in EN 16798-1 annex B:

- Heating: continuous operation, set-point 20 °C
- Cooling (when available): continuous operation, set-point 26 °C
- Ventilation: air exchange rate 0,6 h^{-1}.

Other relevant base operating conditions are summarised the following figure 8.

BASE PARAMETERS	Value	Unit
Occupancy	42,5	m^2/pers
Occupants total gains	2,8	W/m^2
Occupants sensible gains	1,9	W/m^2
Appliances sensible gains	2,4	W/m^2
Lighting	1,8	W/m^2
Lighting	0	Lux
Moisture production	1,4	g/m^2h
CO2 production	0,44	l/m^2h
Ventilation, base flow rate	0,42	l/sm^2

Figure 8 – Reference values for operating conditions according to EN 16798-1 – Annex B

The profile is generally plausible.

NOTE: The default ventilation flow rate for category II, which assumes an air exchange rate of 0,6 h^{-1} is rather high for natural ventilation. Values in the range 0,3...0,4 h^{-1} are more probable as an average value for energy performance calculation.

See case study on EN 16798-1 for further details.

6.1.4 Climatic data - EN ISO 52010-1

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

Figure shows the outdoor temperature for the typical year taken from JRC data-base

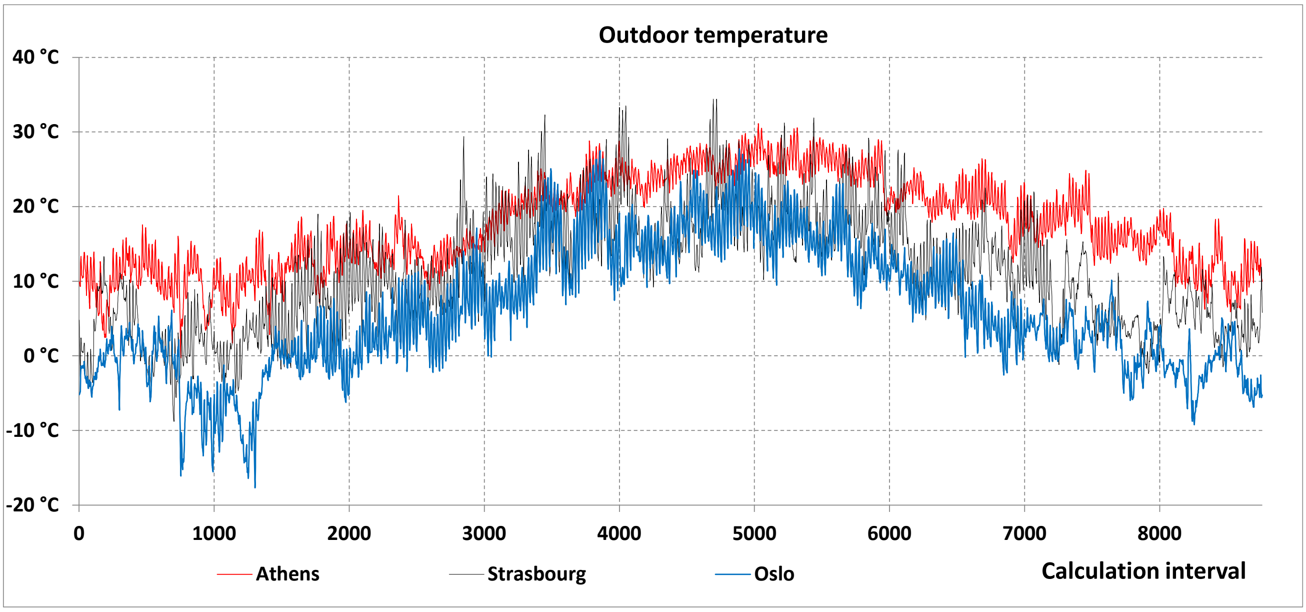


Figure 9 – Outdoor temperature for typical year taken from JRC data-base

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

6.1.5 Heating and cooling needs – EN ISO 52016-1

An enhanced version of the spreadsheet about EN ISO 52016-1 has been used for the case study.

The spreadsheet has been used without direct coupling with other sheets. When needed (mechanical ventilation with heat recovery), the interacting spreadsheets have been run several times. The saved version is the result after stabilisation.

For more details about this spreadsheet, see the case study about EN ISO 52016-1.

The input parameters have been organised in a set of supporting file:

- Climatic data:
  ISO_52010-1_TMY_[Location]_8_planes.xlsx (*)
- Building description and operating conditions:
  ISO_52016-1_SFH_[Case descriptor]_DESC.xlsx (**)

(*) [Location] may be Strasbourg, Athens or Oslo for the 3 climates

(**) [Case_descriptor] is explained in Annex A.

Detailed results can be found in the “Graph” sheet of the respective calculation spreadsheet.

The data input consists of the geometrical description of the building and relevant properties of building elements, just like any current method according to EN ISO 52016-1 (or its predecessor EN ISO 13790), monthly or hourly.

The spreadsheet uses a simplified version of the input of the building envelope, due to interface and calculation complexity limitations in Excel. The simplification concerns specifically the shading factors, which have an important influence on solar gains. Accuracy in the evaluation of the shadings is crucial for the calculation of well insulated buildings. This issue is mostly geometrical and is the same for the monthly and the hourly method. The version of the spreadsheet used for EN ISO 52016-1 (that available when running the calculations for the case study) uses constant shading coefficients. The average shading coefficients have been calibrated by comparison with results obtained with a commercial software using EN ISO 52016-1 hourly calculation method for the needs. For further information see the case study on "*EN ISO 52016-1, Annex F, Solar shading reduction factors*".

6.1.6 Heating and domestic hot water general – EN 15316-1

The demo spreadsheet on EN 15316-1 was used, primarily to calculate operating conditions and to replace the calculation of emission and distribution sub-systems with simplified modules.

The specific input required for the calculation of operating conditions is shown in figures 10 and 11.

			Heating service area 1
Emitters nominal power of service area i	$\phi_{H;em;nom;sah,i}$	kW	15
Type of emitters in service area i			Radiator

Circuit type, GEN i			Type 2 - Independent flow
Generator i nominal power	$\phi_{X;gen;n}$	kW	24
Generator i nominal Δθ	$\Delta\theta_{X;gen;n}$	°C	20

Figure 10 – Product technical data for heat emitters

The product technical data is the type of emitters and their rated power, as well as the power, nominal temperature difference of the generator. If not known, the rated power can be assumed equal to the heat load, which is easily calculated from the data input for the heating need calculation. A default value can be readily proposed by any software. Only in special cases, heat emitters may be intentionally oversized to reduce operating temperature.

Description	Symbol	Unit	Heating service area 1
Floor area	$A_{sah;1}$	m²	142
Is service area operational?			YES
Emitter power control type			Type 2 - Variable flow
Flow temperature control type			Type 2 - Based on outdoor temperature

Generator i: flow control ?	0/1	0

Figure 11 – Process design data sample

Figure 11 provides a sample of the required input data about process design, that is :

- the type of emitter control (room temperature control);
- the type of control of water flow temperature.

The remaining data are default data depending on the previous choices that may need to be changed only for very special configurations. An example of such data is provided in figure 12 and 13.

	Emitters nominal Δϑ air	Emitters exponent n	Emitters nominal Δϑ water
	°C		°C
Radiator	50	1,3	20
Floor heating	15	1,1	5
Fan-coil	25	1	10
Special option 1	30	1,2	10
Last option	50	1,3	10

Figure 12 – Typical default data depending on emitter type

Max flow temperature SAH,i	$\theta_{H;em;flw;max;sah,i}$	°C	80
Max Δθ flow / return SAH,i	$\Delta\theta_{H;em;w;max;sah,1}$	°C	20
Desired return temperature SAH,i	$\theta_{H;em;ret;req;sahz,1}$	°C	20
Mixing valve for SAH,i	$MIX_{sah,i}$	0/1	0
Mixing valve Δθ for SAH,i	$\Delta\theta_{H;em;mix;sahz,1}$	°C	2
Desired load factor with ON-OFF for SAH,i	$\beta_{H;em;req;sah,1}$	%	80
Minimum flow temperature for SAH,i	$\theta_{H;em;flw;min;tz,1}$	°C	30

Figure 13 – Typical default data depending on temperature control type

This input and the consequent calculation are crucial for a correct determination of distribution and generation performance. See the case studies on EN 15316-4-2 (heat pump) and EN 15316-1 (heating and domestic hot water system general part, this standard) for more information.

6.1.7 Domestic hot water storage: EN 15316-5

The calculation of the storage was performed using the updated version of EN 15316-5 currently undergoing public enquiry.

The required input data set is quite simple since it comprises data available on the product fiche (volume and stand-by heat loss coefficient) and the remaining data can be quickly estimated according to other available data. As an example, the heat exchanger heat exchange coefficient can be simply estimated based on the surface area of the heat exchanger (it is given in the product data sheet or it can be estimated based on the volume of the storage and common practice) and a heat exchange coefficient of 500 W/m^{2}K.

The data interface for this spreadsheet is shown in figure 14.

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
Set temperature for back-up heater ON	$\vartheta_{sto;set;on;bu}$	*theta_sto_set_on_bu*	°C	50
Heat exchanger - lower connection	$H_{sto;H;exh;vol;1}$	*H_sto_H_exh_vol_1*	W/K	750

Figure 14 – Data input for the domestic hot water storage

6.1.8 Thermal solar - EN 15316-4-3

The calculation of the thermal solar system was performed using the hourly method of EN 15316-4-3 coupled with EN 15316-5 (storage temperature and losses).

The required input data set is quite simple since it comprises geometrical data (orientation and tilt) and data available on the product fiche. The data input is exactly the same for the hourly and monthly method.

The data interface for this spreadsheet is shown in figure 15 and 16.

Product technical input data list					
Collector module reference area	$A_{sol;mod}$		m²	2,51	
Peak collector efficiency	η_0		p.u.	0,741	Product data
First order heat loss coefficient	a_1		W/m²K	3,491	Product data
Second order heat loss coefficient	a_2		W/m²K²	0,015	Product data
Hemispherical incidence angle modifier	K_{hem} (50°)		p.u.	0,94	Default data
Mass flow rate collector loop per m²	$\dot{m}_{col,h}$		kg/s m²	0,02	Default data
Power of collector pump	$P_{sol;pmp}$		W	33	Product data
Power of collector pump controller	$P_{sol;ctr}$		W	4	Product data
Collector liquid specific contents			l/m²	0,2	

Figure 15 – Product data input for the solar collectors

System design data				
Location of the main part of the collector loop	SOL_LOC	Outside the building		OUT
Number of collector modules installed	N_{col}		-	2
Tilt angle of the collector	$\alpha_{sol;tilt}$		°	45
Azimuth angle of the collector	$\alpha_{sol;ori}$		°	0
Mass flow rate solar loop	$\dot{m}_{sol}$		kg/s	0,1004
Heat losses of the solar loop supply piping	$H_{sol;loop}$		W/K	7,51
Air temperature in a heated room	$\vartheta_{i;hr}$		°C	20
Maximum set flow temperature of collector	$\vartheta_{coll;out;max}$		°C	90

Figure 16 – System design data for the solar collectors

The number of solar collectors may change according to the case and variant.

The calculation also included an additional feature that should be included in the EN standard that allow to detect the stagnation status. This allows to identify any lock-out status and decrease in efficiency because of solar collector area oversizing (see warm climate case), storage volume under-sizing or unfavorable tapping pattern.

6.1.9 Photovoltaic - EN 15316-4-3

The calculation of the thermal solar system was performed using the hourly method of EN 15316-4-3 for solar panels.

The input interface is shown in figure 17.

Area of PV module	$A_{pv;mod}$	m^2	1,63
Number of PV module	$N_{pv;mod}$	-	12
Azimuth angle of PV modules	α	°	0
Tilt angle of the PV modules	β	°	45
Type of ventilation of the photovoltaic modules	Unventilated modules		
Total area of PV modules			19,5
Peak power	P_{pk}	kW	2,93

Figure 17 – Data input for the PV solar panels

The electricity production is proportional to the installed peak power. The productivity in the 3 reference locations per kW peak installed with the given orientation and tilt is the following:

- Athens 1.513 kWh/kW
- Strasbourg 1.015 kWh/kW
- Oslo 886 kWh/kW

It has to be noted that the hourly calculation also provides the hourly distribution of this generation so that the match with electricity use can be verified.

The possible optimisation of orientation and tilt has not been explored in this case study.

6.1.10 Boiler - EN 15316-4-1

The calculation of the boiler was performed using the hourly method of EN 15316-4-1.

The data input consists of product data that are given in the product fiche according to ERP regulation, as shown in figure 18.

Generator output at full load	P_n	kW	24
Generator output at intermediate load	P_{int}	kW	7,2
Generator efficiency at full load	$\eta_{gen;Pn}$	-	0,88
Generator efficiency at intermediate load	$\eta_{gen;Pint}$	-	0,86
Generator efficiency at full load - return water temperature 60° *	$\eta_{gen;Pn;60}$	-	0,00
Generator efficiency at full load - return water temperature 30° *	$\eta_{gen;Pn;30}$	-	0,00
Stand-by heat losses as a function of generator power output	$f_{gen;ls;P0}$	-	0,02
Auxiliary energy at full load	$P_{aux;Pn}$	kW	0,21
Auxiliary energy at intermediate load	$P_{aux;Pint}$	kW	0,07
Auxiliary energy at stand-by load	$P_{aux;P0}$	kW	0,02

Figure 18 – Data input for the boiler – Standard boiler

The method also uses some default parameters, such as the fraction of recovered losses, which are identified based on qualitative information about the installation (boiler location and similar).

6.1.11 Heat pump - EN 15316-4-2

The calculation of the heat pump was performed using the hourly method of EN 15316-4-2, according to the last draft version sent to public enquiry in CEN/TC 228 (autumn 2021). The calculation is performed according to path A and data declared according to EN 14511.

Figures 18 and 19 summarize the basic data input for the heat pump.

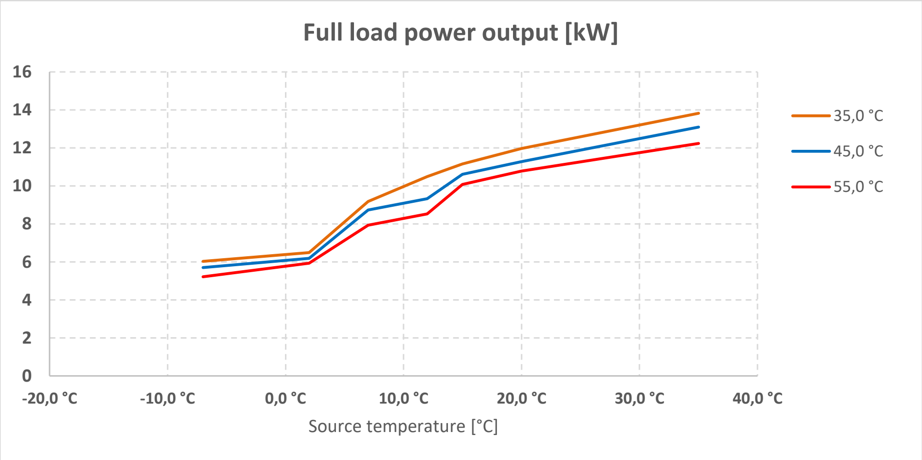


Figure 19 – Full load power output

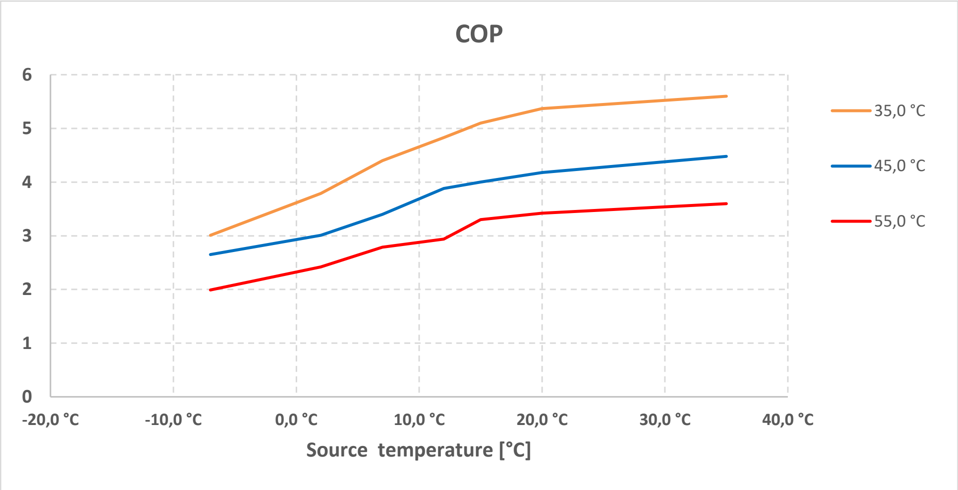


Figure 20 – COP at full load

See clause 6.3.2 of the case study about EN 15316-4-2 (heat pumps) for a detailed description of the input data.

6.1.12 Cooling generation - EN 16798-13

The calculation of the cooling generation was performed using the hourly method of EN 16798-13.

The data input consists of the nominal power and EER in 4 operating conditions declared in the product fiche, as shown in figure 21.

Nominal thermal power extracted from chilled water circuit	$\Phi_{C;gen;n}$	kW	6
Energy efficiency at part load condition A	EER_A	-	3,21
Energy efficiency at part load condition B	EER_B	-	5,12
Energy efficiency at part load condition C	EER_C	-	7,18
Energy efficiency at part load condition D	EER_D	-	10,20

Figure 21 – Data input for the cooling generation

The method also uses other parameters, such as the part load factor and the evaporator and condenser temperature in the four test points, which are standardized values for the testing conditions A to D. Data on a fifth point can be added or estimated.

6.1.13 Ventilation and heat recovery - EN 16798-5-1

The calculation of the mechanical ventilation (only for the new building case) was performed using the hourly method of EN 16798-5-1. The supply and extraction flow rate is assumed to be known and constant. Also the ducts and the ventilation unit are assumed to be located inside the conditioned space.

The configuration of the ventilation unit for the new SFH building has been set as shown in figure 22.

Air handling unit localisation	Ground air preheating and - cooling	localisation	Heat recovery type
COND	NO_CTRL	UP_HR	PLATE
Supply air temperature control	Frost protection type		only for PLATE and ROT_HYG
NO_CTRL	BYPASS		Residential
Control of the volume flow rate	Control of the frost protection		Control of the heat recovery device
NO_CONTR	DIRECT		NO_CTRL
System testing type			☑ Free-cooling
else			☑ Free-heating

Figure 22 – Mechanical ventilation configuration options

The technical data for the heat recovery unit and fans have been input as shown in figure 23 and 24.

Heat recovery			
Maximum heat transfer power of the heat recovery device	$\Phi_{hr;max}$	kW	2,00
Design air velocity in the heat recovery unit	$v_{hr;des}$	m/s	3,5
Limit for the exhaust air temperature after the heat recovery	$\vartheta_{EHA;hr;lim}$	°C	-5
Pressure drop of the heat recovery device in the supply and extract air stream at design conditions	$\Delta p_{SUP+ETA;des;hr}$	Pa	40
Plate heat recovery data			
Nominal heat recovery temperature efficiency at design air velocity	$\eta_{hr;nom}$	-	0,85
Heat recovery efficiency reduced due to defrost operation at ϑ_e = -7°C, according to EN 13053:2006	$\varepsilon_{D;-7}$	-	0,8
Heat recovery efficiency reduced due to defrost operation at ϑ_e = -15°C, accor-ding to EN 13053:2006	$\varepsilon_{D;-15}$	-	0,4
Maximum (design) supply air flow rate of the system	$q_{V;SUP;hr;nom}$	m^3/h	214

Figure 23 – Heat recovery technical data

System head losses			
Supply design pressure difference	$\Delta p_{SUP;des}$	Pa	180
Extract design pressure difference	$\Delta p_{ETA;des}$	Pa	150
Controlled portion of the design supply pressure difference	$f_{\Delta p;SUP;ctrl}$	-	0,8
Controlled portion of the design extract pressure difference	$f_{\Delta p;ETA;ctrl}$	-	0,8
Product data of fans			
Nominal efficiency of the supply fan, taken from manu-facturer's data, provided according to EN ISO 5801	$\eta_{fan;SUP;nom}$	–	0,45
Nominal pressure difference over the supply fan, taken from manufacturer's data according to EN ISO 5801	$\Delta p_{fan;SUP;nom}$	Pa	180,0

Figure 24 – Fans technical data

6.1.14 Weighted energy - EN ISO 52000-1

The calculation of the weighted energy was performed using the hourly method of EN ISO 52000-1.

The data input consists of the weighting factors and the k_{exp} value[2]. The matching factor is not required because the calculation is hourly.

The calculation was performed with the default values of the weighting factors given in annex B of EN ISO 52000-1, as shown in figure 25.

	fPnren kWh/kWh	fPren kWh/kWh	fPtot kWh/kWh	fCO2 kg_{co2}/kWh	fcost €/kWh
Natural gas	1,10	0,00	1,10	0,22	0,08
Grid delivered electricty	2,30	0,20	2,50	0,42	0,25
Grid exported electricity	2,30	0,20	2,50	0,42	0,25
Thermal solar	0,00	1,00	1,00	0,00	0,00
Photovoltaic	0,00	1,00	1,00	0,00	0,00
Environment heat	0,00	1,00	1,00	0,00	0,00

Figure 25 – Weighting factors

The cost weighting factor is an estimate. No value is provided in annex B to EN ISO 52000-1 for the cost of energy carriers.

The default value for k_{exp} given in annex B to EN ISO 52000-1 is 1,0. In this case study, the value of k_{exp} is intentionally set to 0,0 or 1,0 to demonstrate the influence of this important parameter. See case study on EN ISO 52000-1 for more information.

6.2 Case 1 – Existing building

6.2.1 Base case for average climate

6.2.1.1 Description

Case and variant ID : SFH-E-AVG								
Building	***Type***	***Climate***	***Heating***	***DHW***	***Cooling***	***Ventilation***	***PV***	***Kexp***
SFH	Existing	Average	Radiators Boiler	Boiler	None	Natural	None	1,0

Calculation assumptions:

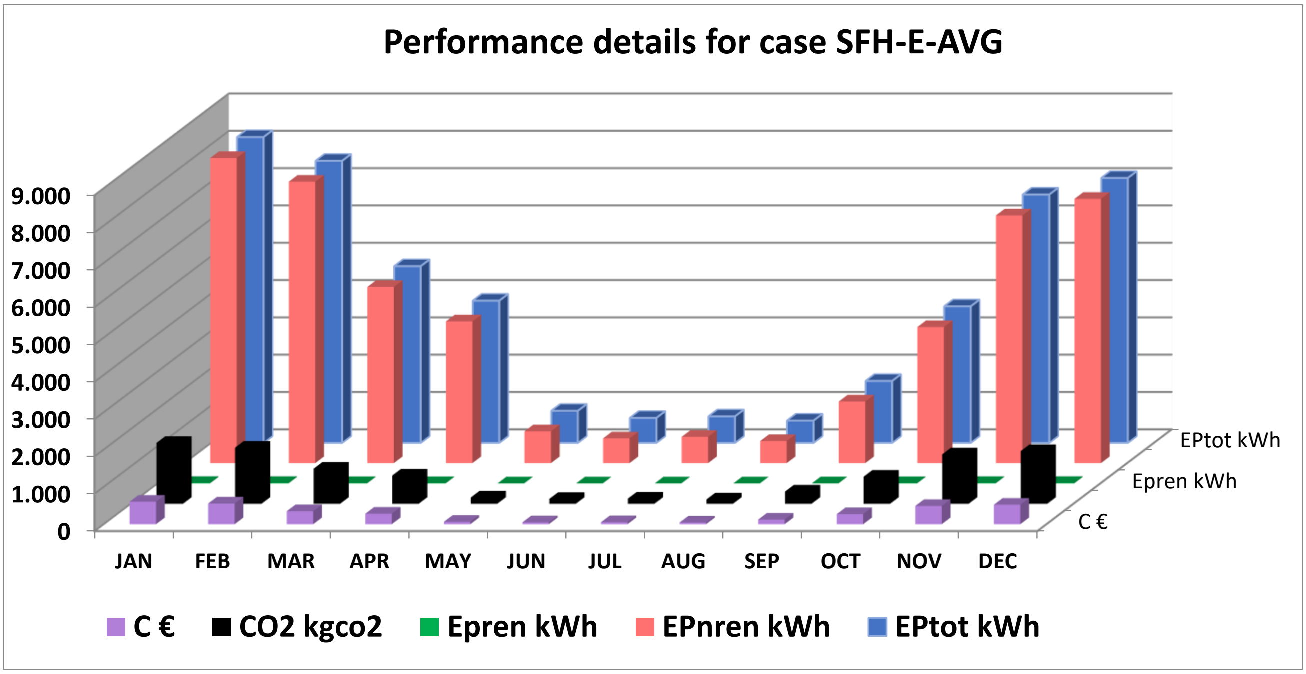
- Climate: average
- Conditions of use: according to EN 16798-1 annex B, single family house, detached, comfort category II.
- Building properties: U values according to see table 1
- domestic hot water needs according to EN 12831-3, net floor area 142 m^2, table B.5 (average value for single family house)
    - water volume 205,5 liters/day @ 42 °C
    - tapping profile XL
    - domestic hot water needs: 2.680 kWh/yr or 18,9 kWh/m^2 yr

[2] See footnote in chapter 2.

- System configuration:
  - Heating: radiators, thermostatic valves, internal distribution, standard boiler with independent flow rate
  - Domestic hot water: domestic hot water storage 120 liters, heated by the heating boiler
  - Ventilation: only natural ventilation, air exchange rate 0,60 h^{-1}.
  - Cooling: no cooling on average climate
  - Humidification and dehumidification: none

6.2.1.2 Calculation results

PERFORMANCE SUMMARY FOR CASE SFH-E-AVG					
Non renewable primary energy	E_{Pnren}	*kWh/m² yr*	**324,5**	*kWh/yr*	**46.077**
Renewable primary energy	E_{Pren}	*kWh/m² yr*	**0,7**	*kWh/yr*	**104**
Total primary energy	E_{Ptot}	*kWh/m² yr*	**325,2**	*kWh/yr*	**46.181**
CO2 emission	CO_2	*kg/m² yr*	**64,8**	*kg/yr*	**9.195**
Cost	C	*€/m² yr*	**23,90**	*€/yr*	**3.394**
Reference area	A_{ref}	m²	142		



6.2.1.3 Discussion

This is a simple case with only delivered energy.

The discomfort of the missing cooling system is negligible. This case study did not fully take into account the possibility of adaptive shading that may be enough to avoid overheating.

Results are as expected.

	$Q_{H;nd}$	$Q_{C;nd}$
January	4.693	0
February	4.343	0
March	2.498	0
April	1.924	0
May	142	12
June	45	137
July	54	121
August	0	27
September	628	0
October	1.802	0
November	3.725	0
December	3.995	0
Year total	**23.848**	**298**

Figure 26 – Heating and cooling needs

Figure 26 shows that cooling needs are negligible. Some cooling is needed only in two occasional peak conditions.

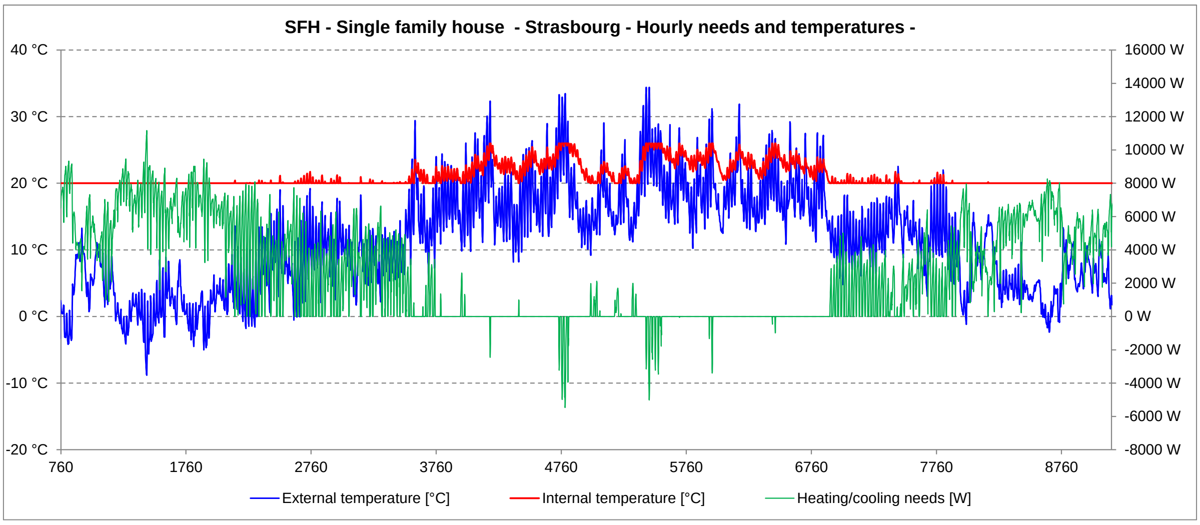


Figure 27 – Heating and cooling needs and temperatures

Figure 28 shows the operating temperatures of the heating system, which are typical values for traditional systems.

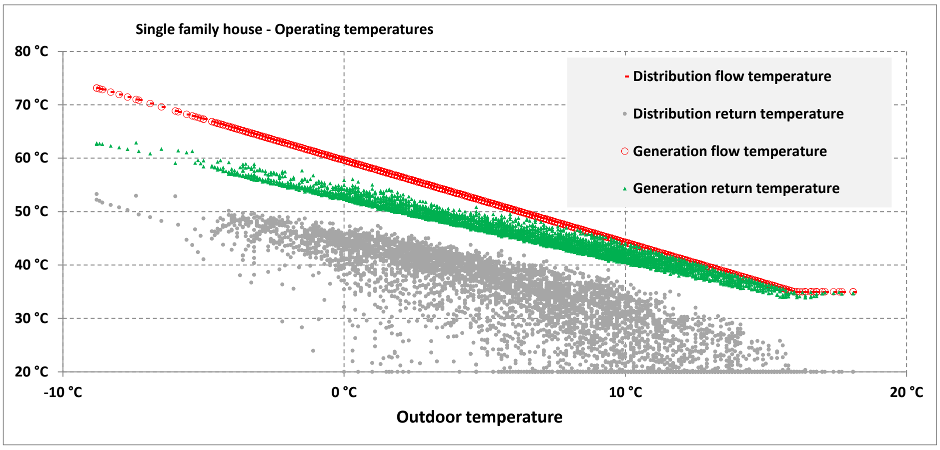


Figure 28 – Operating temperatures of the heating systems

6.2.2 Variant for thermal solar on average climate

6.2.2.1 Description

Case and variant ID : SFH-E-AVG-TS								
Building	***Type***	***Climate***	***Heating***	***DHW***	***Cooling***	***Ventilation***	***PV***	***Kexp***
SFH	Existing	Average	Radiators Boiler	Boiler Solar	None	Natural	None	1,0

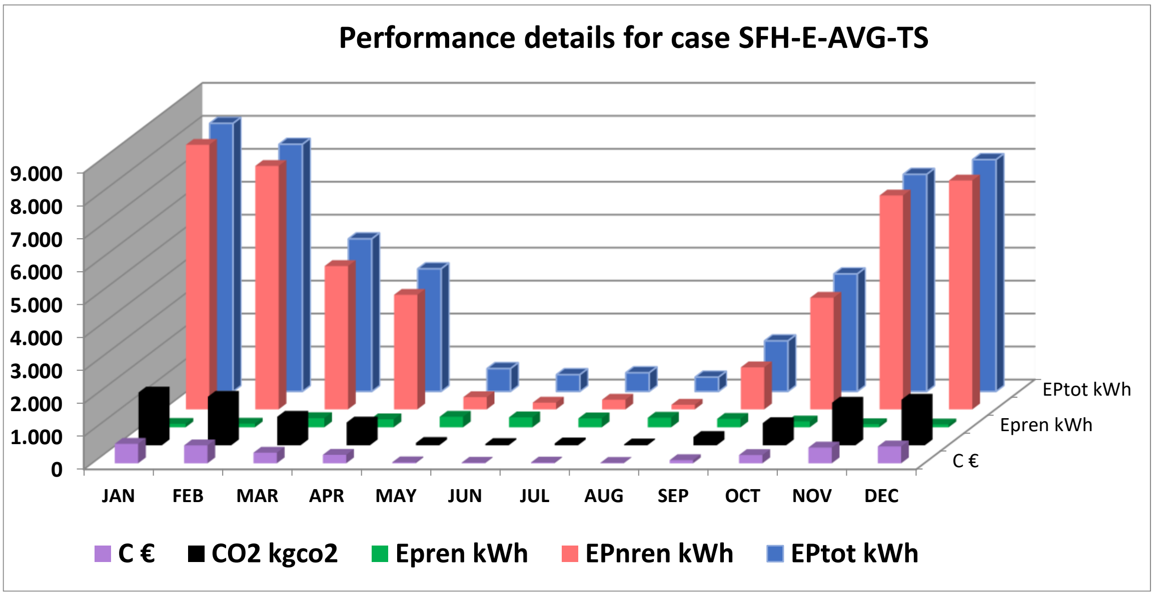
Building and technical systems are the same as for the base case, see details in clause 6.2.2.1, except for the addition of a thermal solar system for domestic hot water production with the following characteristics:

- Collector module reference area 2,51 m^2
- Number of collector modules installed 2
- Peak collector efficiency, η_0 0,741
- First order heat loss coefficient a_1 3,491 W/m^{2}K
- Second order heat loss coefficient a_2 0,015 W/m^{2}K^2
- Hemispherical incidence angle modifier IAM 0,94
- Tilt angle of the collector 45°
- Azimuth angle of the collector 0° (south)

Additionally, the size of the domestic hot water storage is increased to 300 liters.

6.2.2.2 Calculation results

PERFORMANCE SUMMARY FOR CASE SFH-E-AVG-TS					
Non renewable primary energy	E_{Pnren}	*kWh/m² yr*	**298,2**	*kWh/yr*	**42.350**
Renewable primary energy	E_{Pren}	*kWh/m² yr*	**18,0**	*kWh/yr*	**2.550**
Total primary energy	E_{Ptot}	*kWh/m² yr*	**316,2**	*kWh/yr*	**44.900**
CO2 emission	CO_2	*kg/m² yr*	**59,5**	*kg/yr*	**8.445**
Cost	C	*€/m² yr*	**22,06**	*€/yr*	**3.132**
Reference area	A_{ref}	m²	142		



6.2.2.3 Discussion

Thermal solar do contribute but it is a limited change due to the dominance of heating.

6.2.3 Variant for cold climate

6.2.3.1 Description

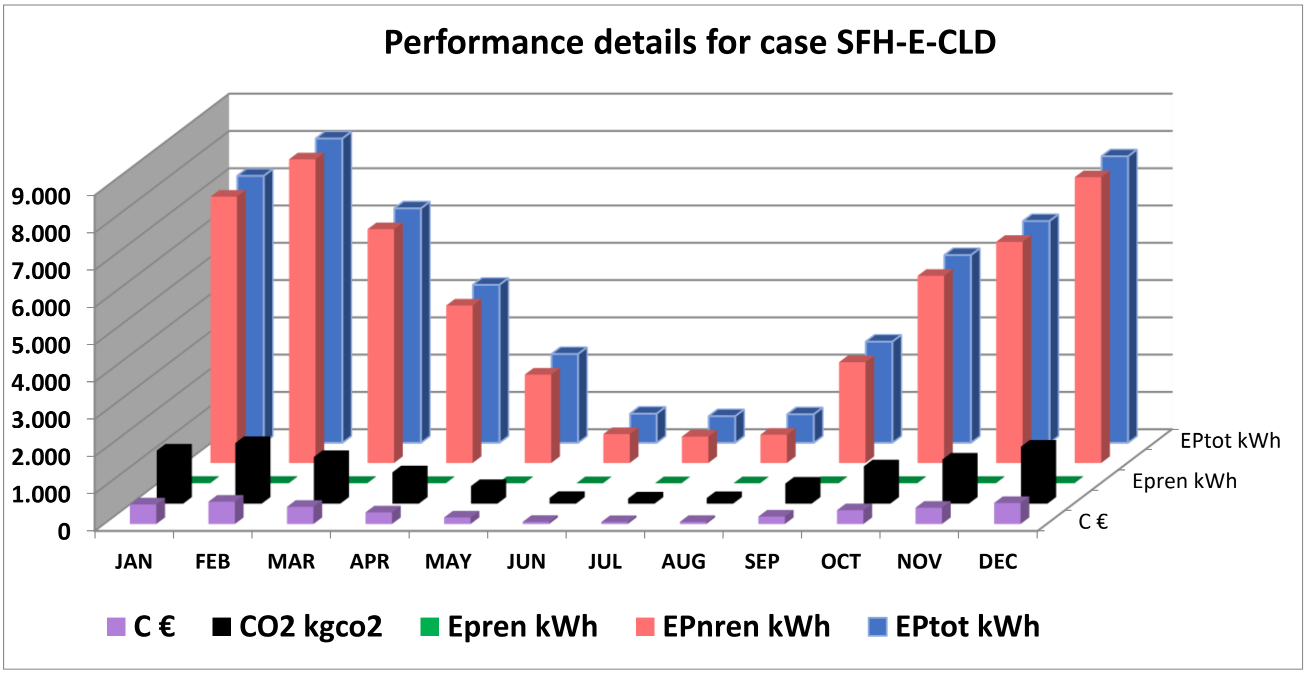
Case and variant ID : SFH-E-CLD								
Building	***Type***	***Climate***	***Heating***	***DHW***	***Cooling***	***Ventilation***	***PV***	***Kexp***
SFH	Existing	Cold	Radiators Boiler	Boiler	None	Natural	None	1,0

Building and technical systems are the same as for the base case, see details in clause 6.2.2.1, except for:

- the U values are adapted, according to table 1
- domestic hot water needs are the same in term of volume at the tap (205,5 liters/day @ 42 °C) but they increase in term of energy because of the colder domestic water: 3.124 kWh/yr or 22,0kWh/m^2 yr (+ 16 % compared to average climate)

6.2.3.2 Calculation results

PERFORMANCE SUMMARY FOR CASE SFH-E-CLD						
Non renewable primary energy	E_{Pnren}	*kWh/m² yr*	**364,2**	*kWh/yr*	**51.715**
Renewable primary energy	E_{Pren}	*kWh/m² yr*	**0,8**	*kWh/yr*	**116**
Total primary energy	E_{Ptot}	*kWh/m² yr*	**365,0**	*kWh/yr*	**51.831**
CO2 emission	CO_2	*kg/m² yr*	**72,7**	*kg/yr*	**10.320**
Cost	C	*€/m² yr*	**26,82**	*€/yr*	**3.809**
Reference area	A_{ref}	m²	142		



6.2.3.3 Discussion

As expected, energy use and performance are increased with respect to average climate.

6.2.4 Variant for thermal solar on cold climate

6.2.4.1 Description

Case and variant ID : SFH-E-CLD-TS								
Building	***Type***	***Climate***	***Heating***	***DHW***	***Cooling***	***Ventilation***	***PV***	***Kexp***
SFH	Existing	Cold	Radiators Boiler	Boiler	None	Natural	None	1,0

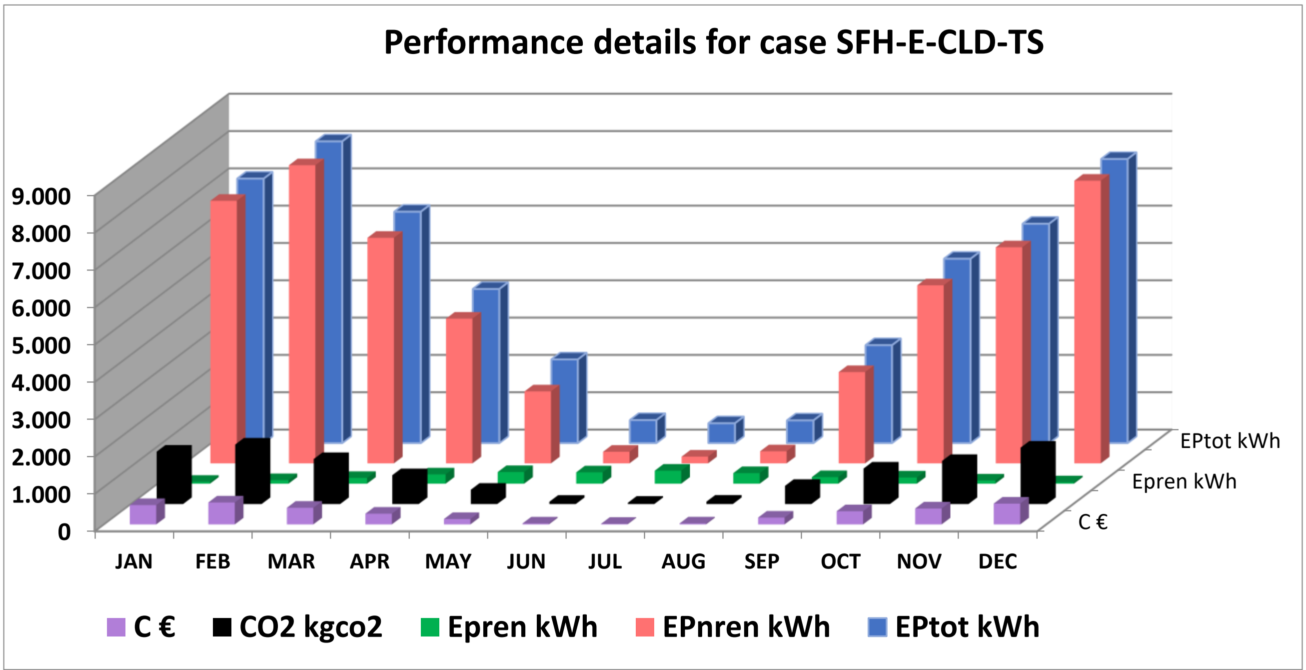
Building and technical systems are the same as for the variant for cold climate, see details in clause 6.2.3.1, except for the addition of a thermal solar system for domestic hot water production with the following characteristics:

- Collector module reference area — 2,51 m^2
- Number of collector modules installed — 2
- Peak collector efficiency, η_0 — 0,741
- First order heat loss coefficient a_1 — 3,491 W/m^{2}K
- Second order heat loss coefficient a_2 — 0,015 W/m^{2}K^2
- Hemispherical incidence angle modifier IAM — 0,94
- Tilt angle of the collector — 45°
- Azimuth angle of the collector — 0° (south)

Additionally, the size of the domestic hot water storage is increased to 300 liters.

6.2.4.2 Calculation results

PERFORMANCE SUMMARY FOR CASE SFH-E-CLD-TS					
Non renewable primary energy	E_{Pnren}	kWh/m² yr	340,0	kWh/yr	48.277
Renewable primary energy	E_{Pren}	kWh/m² yr	15,9	kWh/yr	2.263
Total primary energy	E_{Ptot}	kWh/m² yr	355,9	kWh/yr	50.539
CO2 emission	CO_2	kg/m² yr	67,8	kg/yr	9.629
Cost	C	€/m² yr	25,11	€/yr	3.566
Reference area	A_{ref}	m²	142		



6.2.4.3 Discussion

Thermal solar do contribute but it is a limited change due to the dominance of heating.

6.2.5 Variant for warm climate

6.2.5.1 Description

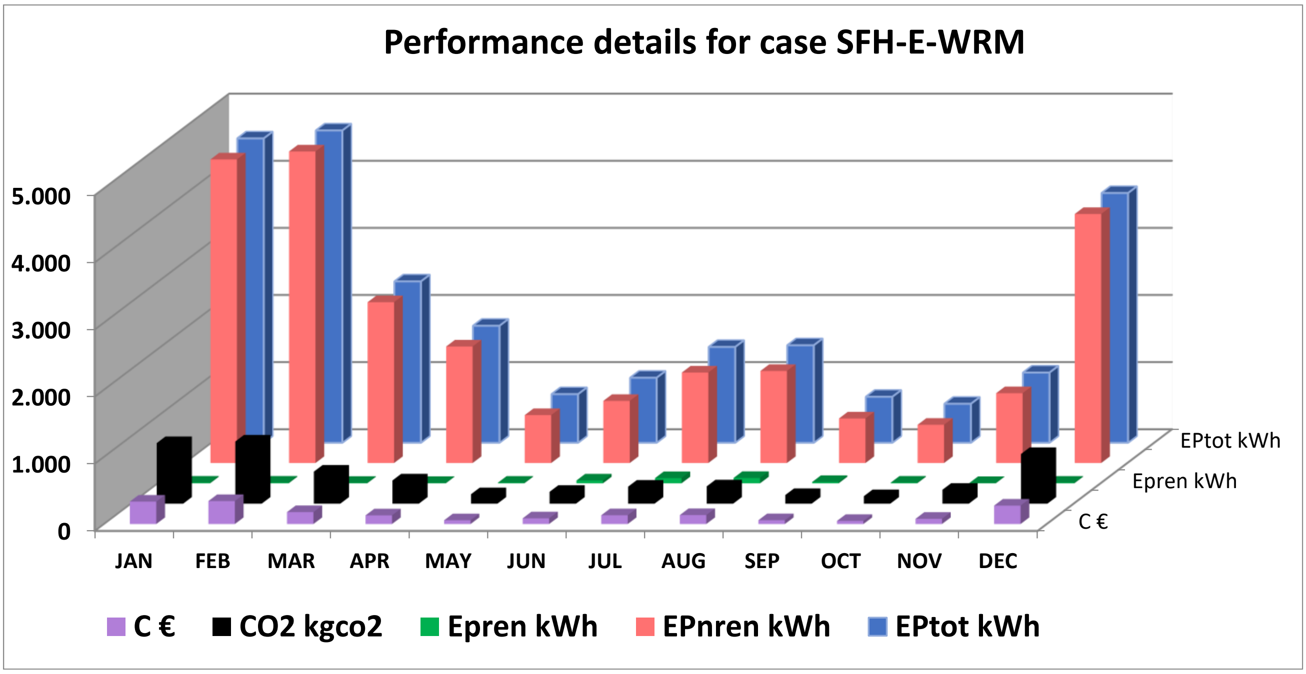
Case and variant ID : SFH-E-WRM								
Building	***Type***	***Climate***	***Heating***	***DHW***	***Cooling***	***Ventilation***	***PV***	***Kexp***
SFH	Existing	Warm	Radiators Boiler	Boiler	Air Split	Natural	None	1,0

Building and technical systems are the same as for the base case, see details in clause 6.2.2.1, except for:

- the U values are adapted, according to table 1
- domestic hot water needs are the same in term of volume at the tap (205,5 liters/day @ 42 °C) but they decrease in term of energy (with respect to average climate) because of the warmer domestic water: 2.106 kWh/yr or 14,8 kWh/m² yr (- 21,5 % compared to average climate)
- cooling is guaranteed by a multi-split air conditioner, with installed power 5 kW.

6.2.5.2 Calculation results

PERFORMANCE SUMMARY FOR CASE SFH-E-WRM					
Non renewable primary energy	E_{Pnren}	*kWh/m² yr*	**166,5**	*kWh/yr*	**23.642**
Renewable primary energy	E_{Pren}	*kWh/m² yr*	**2,0**	*kWh/yr*	**288**
Total primary energy	E_{Ptot}	*kWh/m² yr*	**168,5**	*kWh/yr*	**23.931**
CO2 emission	CO_2	*kg/m² yr*	**32,9**	*kg/yr*	**4.671**
Cost	C	*€/m² yr*	**12,95**	*€/yr*	**1.839**
Reference area	A_{ref}	m²	142		



6.2.5.3 Discussion

The cooling is obviously responsible for the peak in energy use during summer.

The reduction in heating energy use starts to be partly compensated by an increase in cooling energy use.

6.2.6 Variants for thermal solar on warm climate

6.2.6.1 Description

Case and variant ID : SFH-E-WRM-TS								
Building	***Type***	***Climate***	***Heating***	***DHW***	***Cooling***	***Ventilation***	***PV***	***Kexp***
SFH	Existing	Warm	Radiators Boiler	Boiler Solar	Air Split	Natural	None	1,0

Building and technical systems are the same as for the variant for warm climate, see details in clause 6.2.6.1, except for the addition of a thermal solar system for domestic hot water production with the following characteristics:

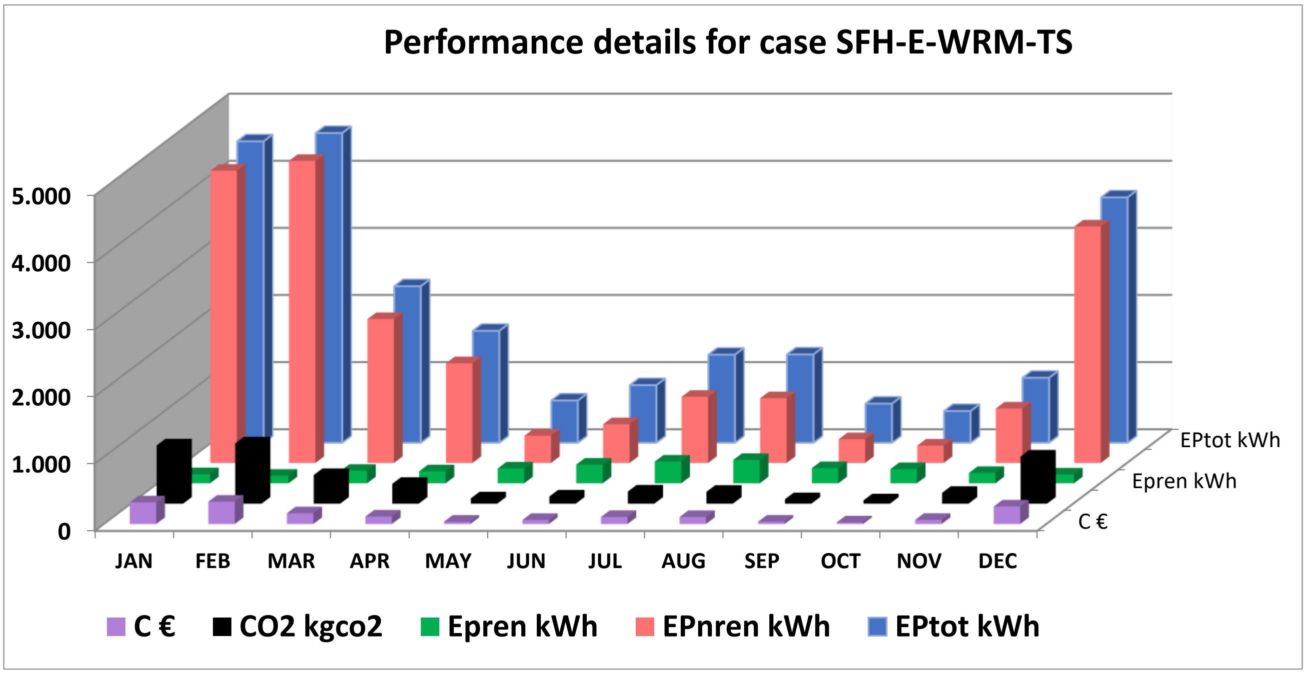
- Collector module reference area 2,51 m²
- **Number of collector modules installed 1**

- Peak collector efficiency, η_0 0,741
- First order heat loss coefficient a_1 3,491 W/m²K
- Second order heat loss coefficient a_2 0,015 W/m²K²
- Hemispherical incidence angle modifier IAM 0,94
- Tilt angle of the collector 45°
- Azimuth angle of the collector 0° (south)

Additionally, the size of the domestic hot water storage is increased to 300 litres.

6.2.6.2 Calculation results

PERFORMANCE SUMMARY FOR CASE SFH-E-WRM-TS					
Non renewable primary energy	E_{Pnren}	*kWh/m² yr*	**143,5**	*kWh/yr*	**20.376**
Renewable primary energy	E_{Pren}	*kWh/m² yr*	**17,7**	*kWh/yr*	**2.512**
Total primary energy	E_{Ptot}	*kWh/m² yr*	**161,2**	*kWh/yr*	**22.888**
CO2 emission	CO_2	*kg/m² yr*	**28,3**	*kg/yr*	**4.013**
Cost	C	*€/m² yr*	**11,34**	*€/yr*	**1.610**
Reference area	A_{ref}	m²	142		



6.2.6.3 Discussion

The hourly calculation demonstrated that 2 solar collectors are no use in this climate for the assumed domestic hot water needs. Despite the presence of only 1 collector:

- the collector loop supplies 2.200 kWh to the domestic hot water storage;
- the boiler supplies only 990 kWh to the domestic hot water storage

If two collector were installed, the stagnation would occur repeatedly with no significant benefit on renewable energy production. This important information cannot be extracted from a monthly method. Experience shows that:

- the oversizing of solar collectors with respect to the needs;
- the under sizing of the domestic hot water storage with respect to the installed collector surfaces;

are two common mistakes when using solar collectors.

6.2.7 Variant for PV on warm climate

6.2.7.1 Description

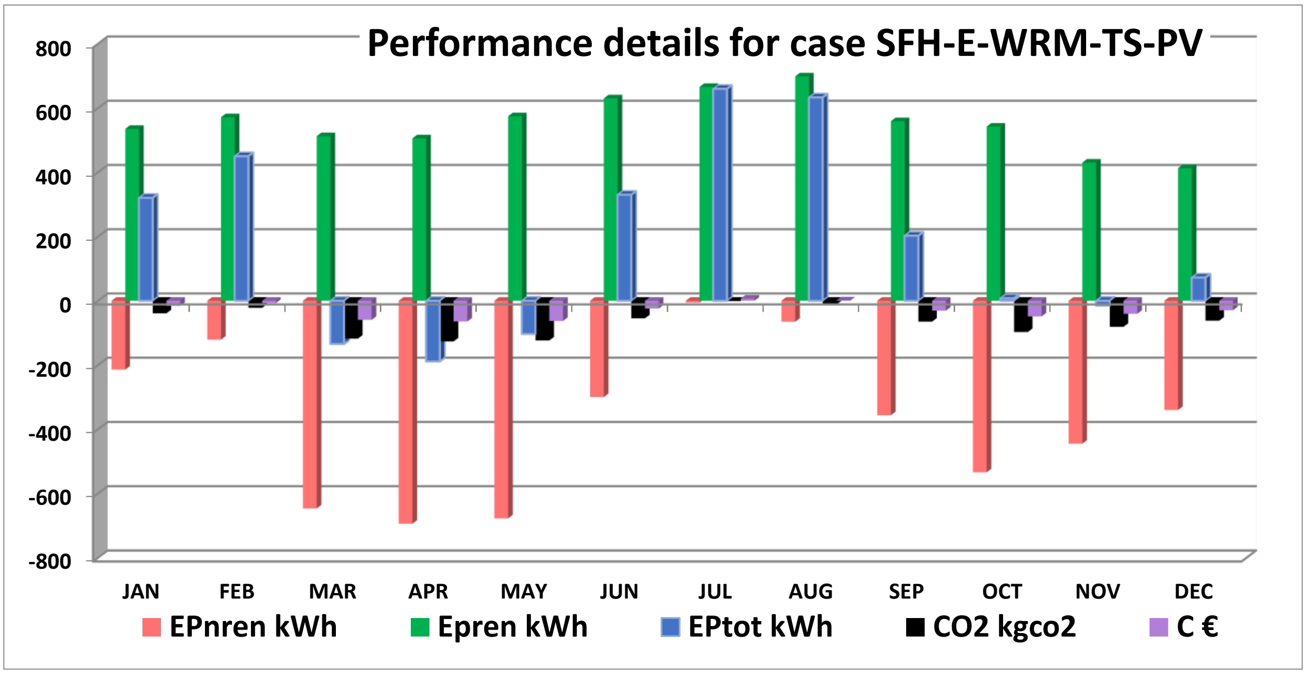
Case and variant ID : SFH-E-WRM-TS-PV								
Building	***Type***	***Climate***	***Heating***	***DHW***	***Cooling***	***Ventilation***	***PV***	***Kexp***
SFH	Existing	Warm	Radiators Boiler	Boiler Solar	Air Split	Natural	3 kW	1,0

Building and technical systems are the same as for the variant for warm climate with the thermal solar, see details in clause 6.2.7.1, and as a second step of improvement, PV panels are installed, with the following properties:

- peak power 3 kW
- Tilt angle of the collector 45°
- Azimuth angle of the collector 0° (south)

6.2.7.2 Calculation results

PERFORMANCE SUMMARY FOR CASE SFH-E-WRM-TS-PV					
Non renewable primary energy	E_{Pnren}	*kWh/m² yr*	**-31,0**	*kWh/yr*	**-4.402**
Renewable primary energy	E_{Pren}	*kWh/m² yr*	**46,7**	*kWh/yr*	**6.636**
Total primary energy	E_{Ptot}	*kWh/m² yr*	**15,7**	*kWh/yr*	**2.234**
CO2 emission	CO_2	*kg/m² yr*	**-5,7**	*kg/yr*	**-804**
Cost	C	*€/m² yr*	**-2,66**	*€/yr*	**-378**
Reference area	A_{ref}	m²	142		



6.2.7.3 Discussion

The energy performance becomes negative because the exported electricity is accounted into the energy performance in the building (k_{exp} = 1) and it exceeds the building energy use.

Note: the building is still heated by natural gas.

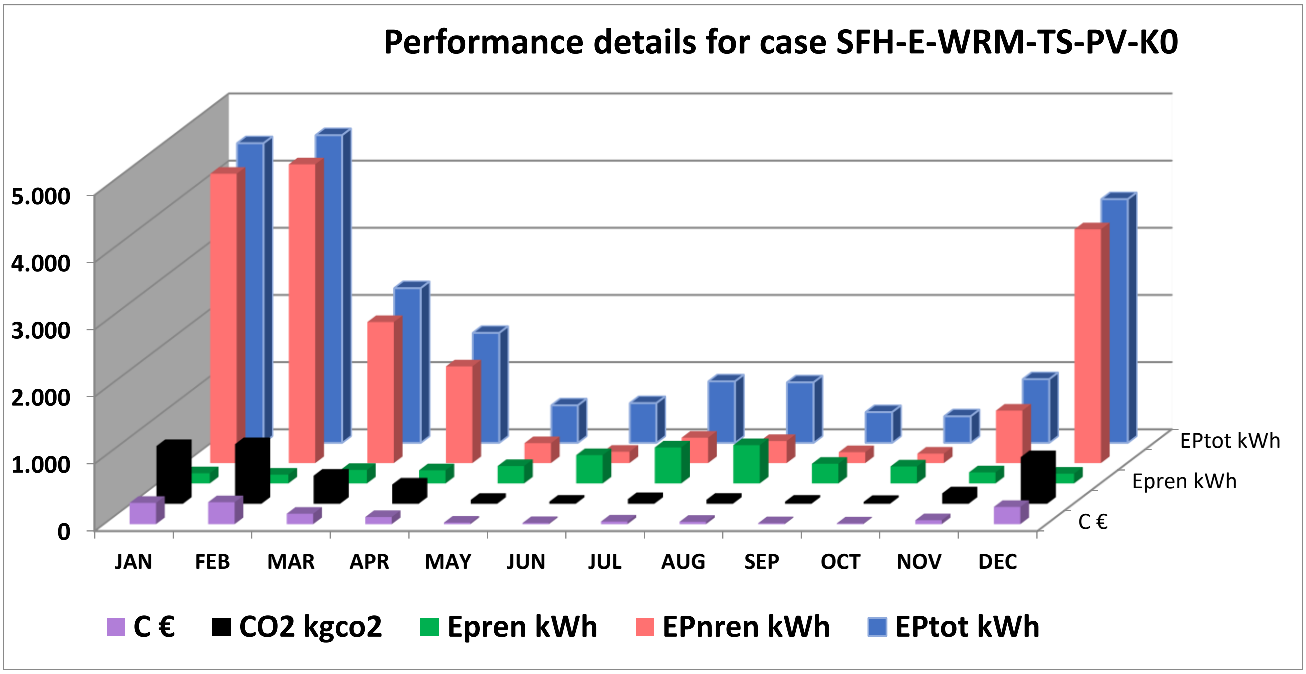
6.2.8 Variant for k_{exp}=0

6.2.8.1 Description

Case and variant ID : SFH-E-WRM-TS-PV-K0								
Building	***Type***	***Climate***	***Heating***	***DHW***	***Cooling***	***Ventilation***	***PV***	***Kexp***
SFH	Existing	Average	Radiators Boiler	Boiler Solar	Air Split	Natural	3 kW	0,0

6.2.8.2 Calculation results

PERFORMANCE SUMMARY FOR CASE SFH-E-WRM-TS-PV-K0					
Non renewable primary energy	E_{Pnren}	*kWh/m² yr*	**127,0**	*kWh/yr*	**18.037**
Renewable primary energy	E_{Pren}	*kWh/m² yr*	**23,4**	*kWh/yr*	**3.325**
Total primary energy	E_{Ptot}	*kWh/m² yr*	**150,4**	*kWh/yr*	**21.362**
CO2 emission	CO_2	*kg/m² yr*	**25,3**	*kg/yr*	**3.586**
Cost	C	*€/m² yr*	**9,55**	*€/yr*	**1.356**
Reference area	A_{ref}	m²	142		



6.2.8.3 Discussion

If k_{exp} is set equal to 0, then the PV electricity can only contribute to cooling and auxiliaries.

6.3 Case 2: New building

6.3.1 Base case for average climate

6.3.1.1 Description

Case and variant ID : SFH-N-AVG								
Building	***Type***	***Climate***	***Heating***	***DHW***	***Cooling***	***Ventilation***	***PV***	***Kexp***
SFH	New	Average	Floor HP	HP	Floor HP	Mech. Heat rec.	None	1,0

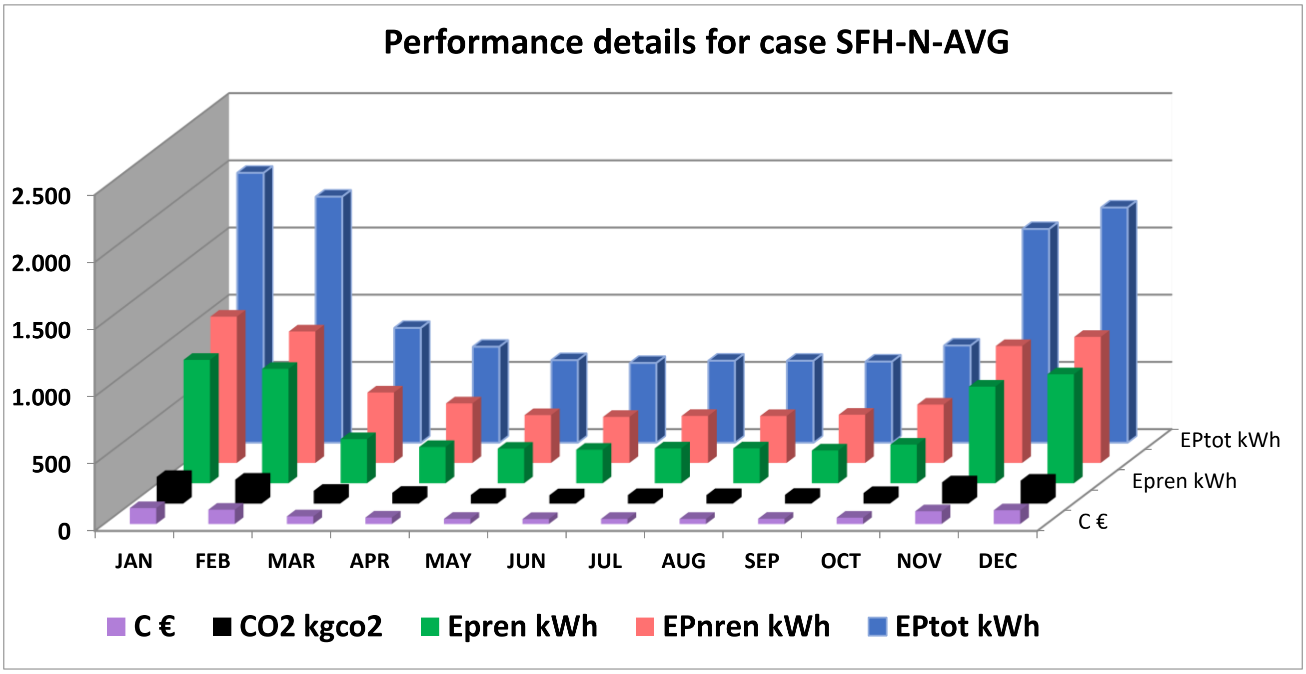
Calculation assumptions:

- Climate: average
- Conditions of use: according to EN 16798-1 annex B, single family house, detached, comfort category II.
- Building properties: U values according to table 2
- domestic hot water needs according to EN 12831-3, net floor area 142 m^2, table B.5 (average value for single family house)
    - water volume 205,5 liters/day @ 42 °C
    - tapping profile XL
    - domestic hot water needs: 2.680 kWh/yr or 18,9 kWh/m^2 yr
- System configuration:
    - Heating: floor heating, room thermostats, internal distribution, heat pump with independent flow rate
    - Domestic hot water: domestic hot water storage 120 liters, heated by the heat pump
    - Ventilation: mechanical ventilation, air exchange rate 0,60 h^{-1}.

- Floor cooling for average and warm climate
- Humidification and dehumidification: none

6.3.1.2 Calculation results

PERFORMANCE SUMMARY FOR CASE SFH-N-AVG					
Non renewable primary energy	E_{Pnren}	*kWh/m² yr*	**49,5**	*kWh/yr*	**7.034**
Renewable primary energy	E_{Pren}	*kWh/m² yr*	**38,4**	*kWh/yr*	**5.459**
Total primary energy	E_{Ptot}	*kWh/m² yr*	**88,0**	*kWh/yr*	**12.492**
CO2 emission	CO_2	*kg/m² yr*	**9,0**	*kg/yr*	**1.284**
Cost	C	*€/m² yr*	**5,38**	*€/yr*	**765**
Reference area	A_{ref}	m²	142		



6.3.1.3 Discussion

The renewable energy is the contribution by the heat pump and (marginally) the grid electricity.

In summer, the base renewable energy use is linked to domestic hot water. When cooling with the heat pump there is no renewable energy contribution because of the interaction with the sink.

6.3.2 Variant for photovoltaic on average climate

6.3.2.1 Description

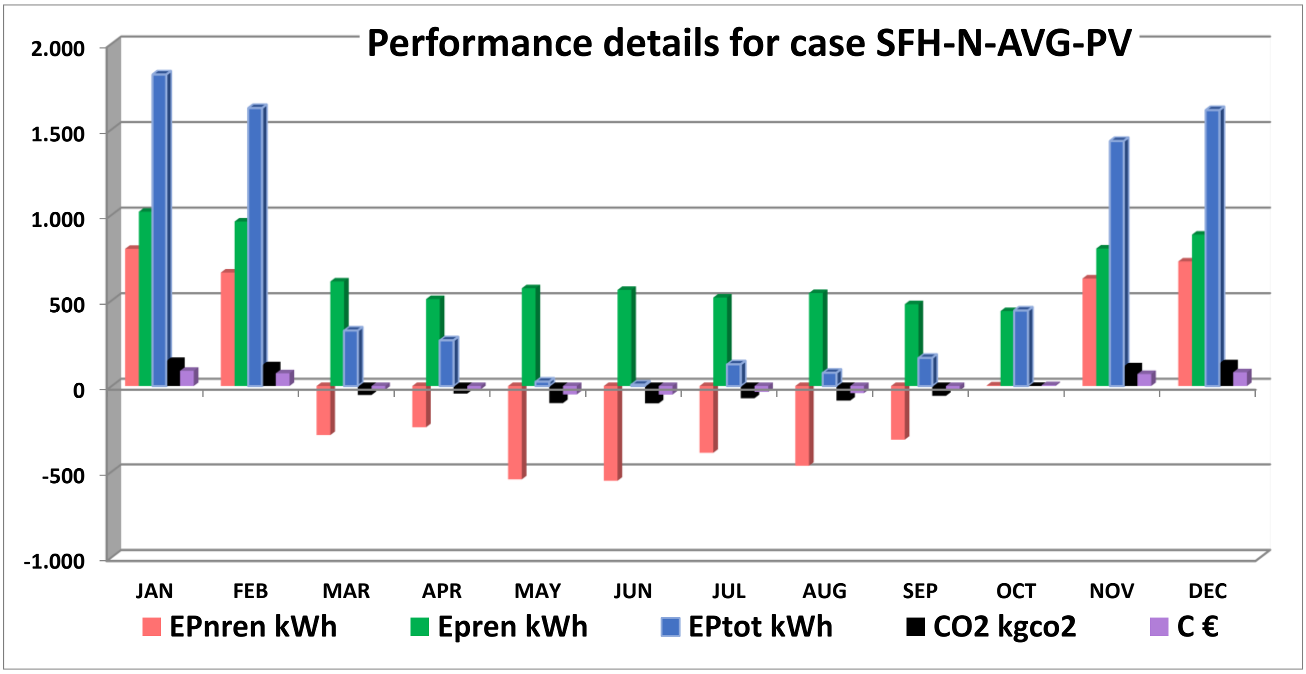
Case and variant ID : SFH-N-AVG-PV								
Building	***Type***	***Climate***	***Heating***	***DHW***	***Cooling***	***Ventilation***	***PV***	***Kexp***
SFH	New	Average	Floor HP	HP	Floor HP	Mech. Heat rec.	3 kW	1,0

Building and technical systems are the same as for the base case, see details in clause 6.3.1.1, except for the addition of PV panels on the roof, with the following properties:

- peak power 3 kW
- Tilt angle of the collector 45°
- Azimuth angle of the collector 0° (south)

6.3.2.2 Calculation results

PERFORMANCE SUMMARY FOR CASE SFH-N-AVG-PV					
Non renewable primary energy	E_{Pnren}	*kWh/m² yr*	**0,2**	*kWh/yr*	**29**
Renewable primary energy	E_{Pren}	*kWh/m² yr*	**55,6**	*kWh/yr*	**7.895**
Total primary energy	E_{Ptot}	*kWh/m² yr*	**55,8**	*kWh/yr*	**7.924**
CO2 emission	CO_2	*kg/m² yr*	**0,0**	*kg/yr*	**5**
Cost	C	*€/m² yr*	**0,55**	*€/yr*	**78**
Reference area	A_{ref}	m²	142		



6.3.2.3 Discussion

Over a full year, the total PV production matches the uses for EPB purpose.

If k_{exp} is set equal to 0, then the PV electricity can only contribute when it is simultaneous with the EPB use.

The comparison of the results without PV, with PV and with PV and k_{exp} = 0 is given in the following table.

CASE ID#	E_{Pnren} kWh/m² yr	E_{Pren} kWh/m² yr	E_{Ptot} kWh/m² yr	CO_2 kg/m² yr	C €/m² yr
SFH-N-AVG	49,5	38,4	88,0	9,0	5,38
SFH-N-AVG-PV	0,2	55,6	55,8	0,0	0,55
SFH-N-AVG-PV-K0	40,4	41,6	82,0	7,4	4,39

6.3.3 Variant for cold climate

6.3.3.1 Description

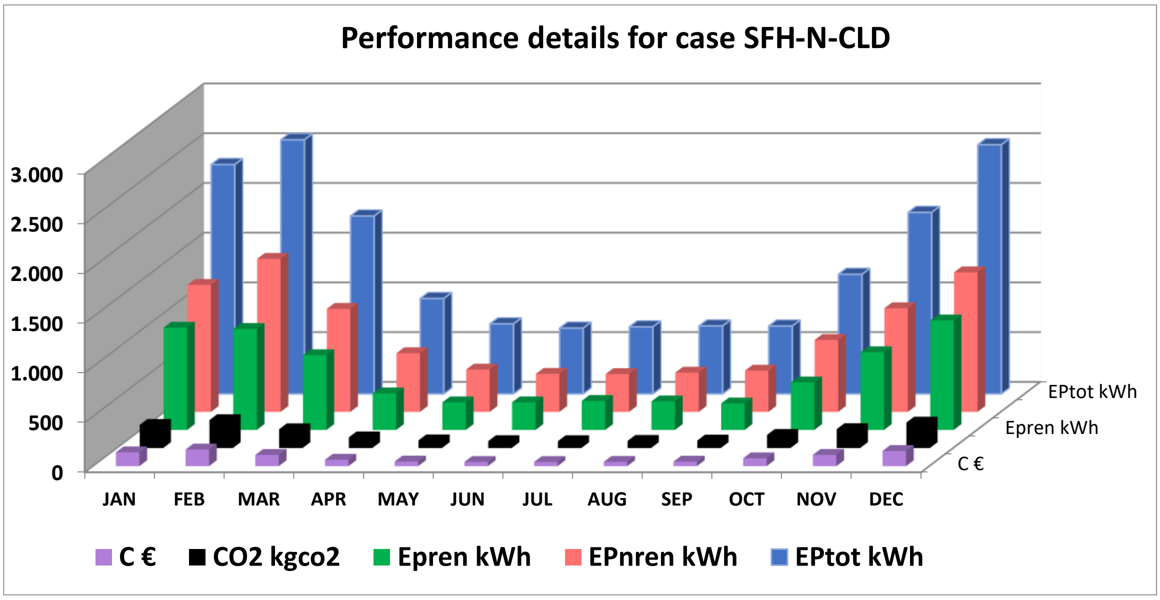
Case and variant ID : SFH-N-CLD								
Building	***Type***	***Climate***	***Heating***	***DHW***	***Cooling***	***Ventilation***	***PV***	***Kexp***
SFH	New	Cold	Floor HP	HP	None	Mech. Heat rec.	None	1,0

Building and technical systems are the same as for the new building base case described in clause 6.3.1.1, except for:

- the U values are adapted, according to table 2
- domestic hot water needs are the same in term of volume at the tap (205,5 liters/day @ 42 °C) but they increase in term of energy because of the colder domestic water: 3.124 kWh/yr or 22,0kWh/m^2 yr (+ 16 % compared to average climate)
- No cooling is foreseen with cold climate

6.3.3.2 Calculation results

PERFORMANCE SUMMARY FOR CASE SFH-N-CLD					
Non renewable primary energy	E_{Pnren}	kWh/m² yr	67,7	kWh/yr	9.609
Renewable primary energy	E_{Pren}	kWh/m² yr	48,8	kWh/yr	6.927
Total primary energy	E_{Ptot}	kWh/m² yr	116,5	kWh/yr	16.536
CO2 emission	CO_2	kg/m² yr	12,4	kg/yr	1.755
Cost	C	€/m² yr	7,36	€/yr	1.044
Reference area	A_{ref}	m²	142		



6.3.3.3 Discussion

The continuous use of energy in summer is also related to mechanical ventilation (fans).

6.3.4 Variant for photovoltaic on cold climate

6.3.4.1 Description

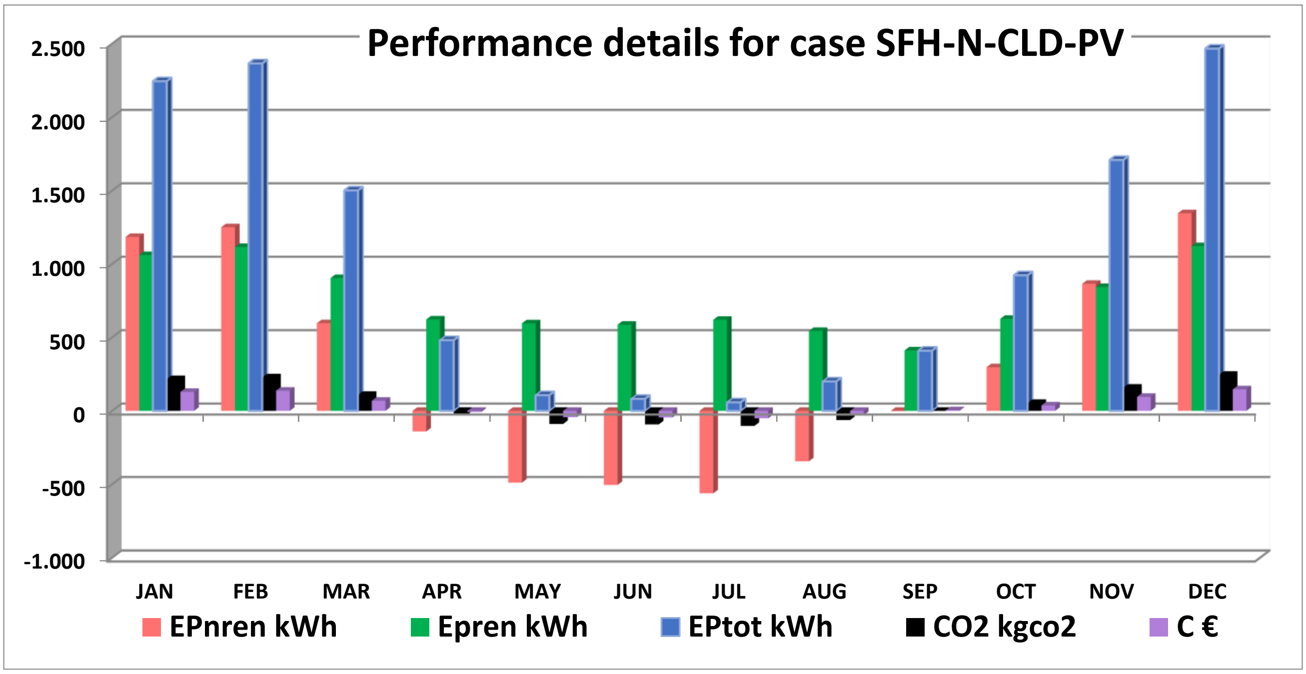
Case and variant ID : SFH-N-CLD-PV								
Building	***Type***	***Climate***	***Heating***	***DHW***	***Cooling***	***Ventilation***	***PV***	***Kexp***
SFH	New	Cold	Floor HP	HP	None	Mech. Heat rec.	3 kW	1,0

Building and technical systems are the same as for the variant for cold climate, see details in clause 6.3.3.1, except for the addition of PV panels on the roof, with the following properties:

- peak power 3 kW
- Tilt angle of the collector 45°
- Azimuth angle of the collector 0° (south)

6.3.4.2 Calculation results

PERFORMANCE SUMMARY FOR CASE SFH-N-CLD-PV					
Non renewable primary energy	E_{Pnren}	*kWh/m² yr*	**24,6**	*kWh/yr*	**3.498**
Renewable primary energy	E_{Pren}	*kWh/m² yr*	**63,8**	*kWh/yr*	**9.053**
Total primary energy	E_{Ptot}	*kWh/m² yr*	**88,4**	*kWh/yr*	**12.550**
CO2 emission	CO_2	*kg/m² yr*	**4,5**	*kg/yr*	**639**
Cost	C	*€/m² yr*	**3,11**	*€/yr*	**442**
Reference area	A_{ref}	m²	142		



6.3.4.3 Discussion

Over a full year, the total PV compensates most of the uses for EPB purpose.

If k_{exp} is set equal to 0, then the PV electricity can only contribute when it is simultaneous with the EPB use. The comparison of the results without PV, with PV and with PV and k_{exp} = 0 is given in the following table.

CASE ID#	E_{Pnren} kWh/m² yr	E_{Pren} kWh/m² yr	E_{Ptot} kWh/m² yr	CO_2 kg/m² yr	C €/m² yr
SFH-N-CLD	67,7	48,8	116,5	12,4	7,36
SFH-N-CLD-PV	24,6	63,8	88,4	4,5	3,11
SFH-N-CLD-PV-K0	58,0	52,2	110,1	10,6	6,30

6.3.5 Variant for warm climate

6.3.5.1 Description

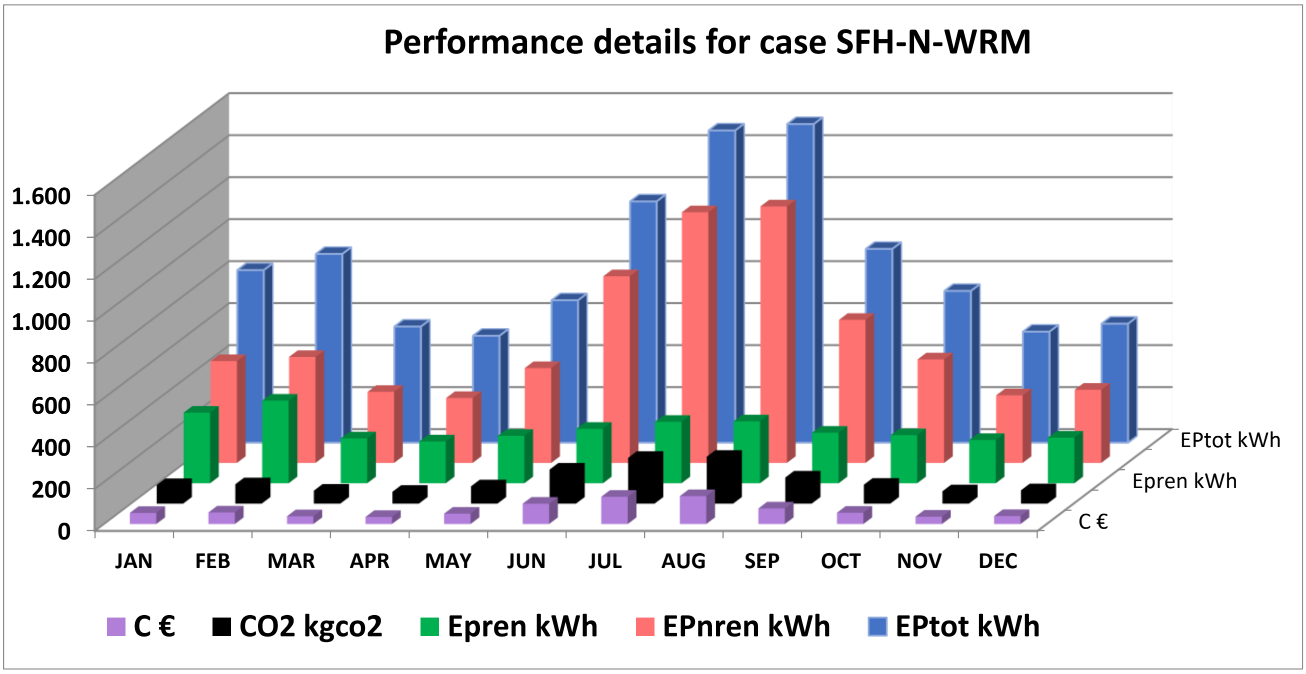
Case and variant ID : SFH-N-WRM								
Building	***Type***	***Climate***	***Heating***	***DHW***	***Cooling***	***Ventilation***	***PV***	***Kexp***
SFH	New	Warm	Floor HP	HP	Floor HP	Mech. Heat rec.	None	1,0

Building and technical systems are the same as for the base case for the new building described in clause 6.3.1.1, except for:

- the U values are adapted, according to table 1
- domestic hot water needs are the same in term of volume at the tap (205,5 liters/day @ 42 °C) but they decrease in term of energy (with respect to average climate) because of the warmer domestic water: 2.106 kWh/yr or 14,8 kWh/m² yr (- 21,5 % compared to average climate)

6.3.5.2 Calculation results

PERFORMANCE SUMMARY FOR CASE SFH-N-WRM					
Non renewable primary energy	E_{Pnren}	*kWh/m² yr*	**51,0**	*kWh/yr*	**7.240**
Renewable primary energy	E_{Pren}	*kWh/m² yr*	**21,9**	*kWh/yr*	**3.111**
Total primary energy	E_{Ptot}	*kWh/m² yr*	**72,9**	*kWh/yr*	**10.350**
CO2 emission	CO_2	*kg/m² yr*	**9,3**	*kg/yr*	**1.322**
Cost	C	*€/m² yr*	**5,54**	*€/yr*	**787**
Reference area	A_{ref}	m²	142		



6.3.5.3 Discussion

With the well-insulated building, the cooling needs exceed by far the heating needs.

The cooling needs may be controlled by:

- appropriate shadings, to limit solar gains;
- ventilative cooling, as far as possible.

These techniques are taken into account by the set of EPB standards, see specific case studies on this topic.

6.3.6 Variant for photovoltaic on warm climate

6.3.6.1 Description

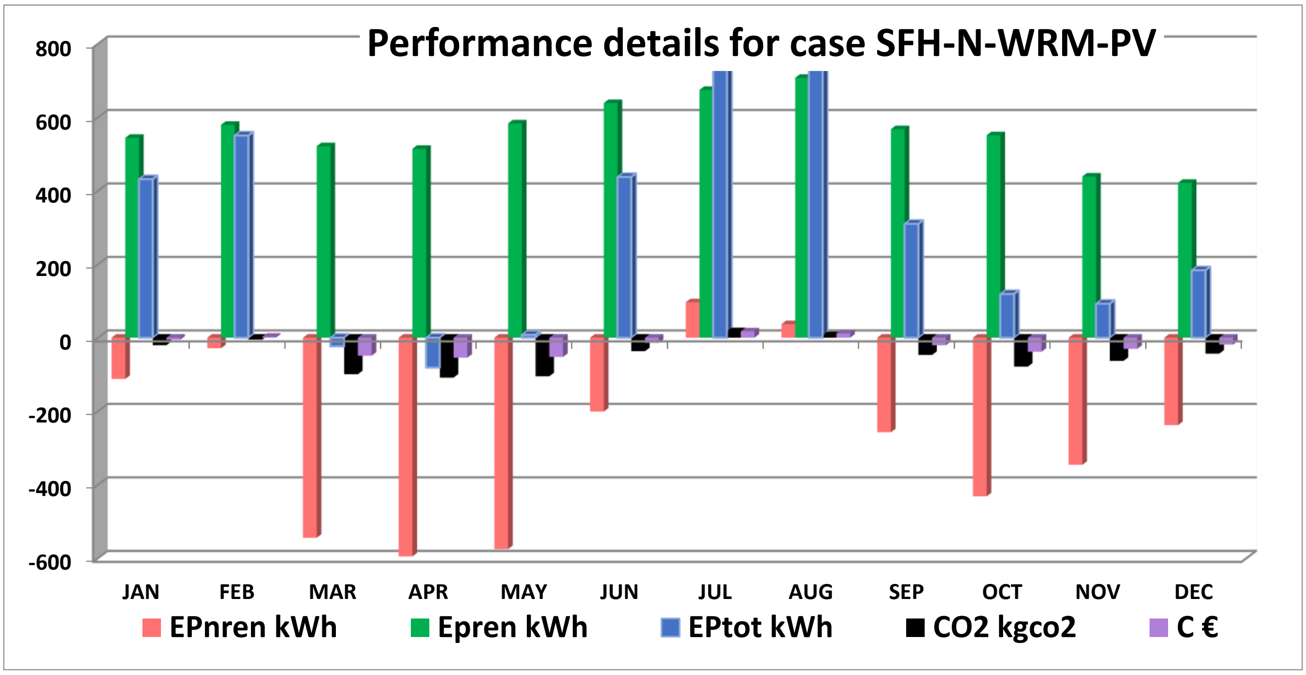
Case and variant ID : SFH-N-WRM-PV								
Building	***Type***	***Climate***	***Heating***	***DHW***	***Cooling***	***Ventilation***	***PV***	***Kexp***
SFH	New	Warm	Floor HP	HP	Floor HP	Mech. Heat rec.	3 kW	1,0

Building and technical systems are the same as for the variant for warm climate, see details in clause 6.2.6.1, except for the addition of PV panels on the roof, with the following properties:

- peak power 3 kW
- Tilt angle of the collector 45°
- Azimuth angle of the collector 0° (south)

6.3.6.2 Calculation results

PERFORMANCE SUMMARY FOR CASE SFH-N-WRM-PV						
Non renewable primary energy	E_{Pnren}	*kWh/m² yr*	**-22,5**	*kWh/yr*	**-3.198**
Renewable primary energy	E_{Pren}	*kWh/m² yr*	**47,5**	*kWh/yr*	**6.741**
Total primary energy	E_{Ptot}	*kWh/m² yr*	**25,0**	*kWh/yr*	**3.543**
CO2 emission	CO_2	*kg/m² yr*	**-4,1**	*kg/yr*	**-584**
Cost	C	*€/m² yr*	**-1,78**	*€/yr*	**-253**
Reference area	A_{ref}	m²	142		



6.3.6.3 Discussion

Over a full year, the total PV exceeds by far the uses for EPB purpose.

If k_{exp} is set equal to 0, then the PV electricity can only contribute when it is simultaneous with the EPB use. The comparison of the results without PV, with PV and with PV and k_{exp} = 0 is given in the following table.

CASE ID#	E_{Pnren} kWh/m² yr	E_{Pren} kWh/m² yr	E_{Ptot} kWh/m² yr	CO_2 kg/m² yr	C €/m² yr
SFH-N-WRM	51,0	21,9	72,9	9,3	5,54
SFH-N-WRM-PV	-22,5	47,5	25,0	-4,1	-1,78
SFH-N-WRM-PV-K0	28,5	29,7	58,2	5,2	3,10

7 Analysis

7.1 Completeness

The case study demonstrates that the set of (EN and EN ISO) EPB standards allows a calculation of the building energy performance:

- starting from building elements and product properties, new and existing;
- taking into account climatic data;
- taking into account operation schedules and control strategies;
- covering heating, cooling, ventilation, air conditioning, domestic hot water, lighting (not shown in the case study but available)
- taking into account the interactions with supply grids and networks, also leveraging features allowed by an hourly calculation method
- taking into account several possible weighting criteria (e.g. primary energy, GHG emissions).

Only few special technologies are not covered (e.g. battery, heat pumps for simultaneous heating and cooling) but inclusion should be easy thanks to the modular structure.

7.2 Functionality

The set of EPB standards provides all the information needed to generate adequate indicators to highlight the features of the building (including systems); including indicators that have not been, but could have been extracted from the calculated values, such as needs per service and systems efficiencies

The set of EPB standards can cover virtually any building and technical systems configuration.

7.3 Sensitivity

The set of EPB standards reacts correctly to all expected parameters.

The changes in overall results are consistent with the assumed changes between cases and variants.

See the specific case studies for an analysis of the sensitivity to situations and characteristics evaluated in the individual modules (such as characteristics of incorporated technologies).

7.4 Usability

The set of EPB standards is generally easy to use as a whole, thanks to the detailed and consistent specification of the inputs and outputs of each module.

The case studies could be performed with a full hourly calculation using exclusively the demo spreadsheets.

8 Conclusions and recommendations

Specific recommendations are given in the case studies dedicated to individual modules.

Concerning the overall set, some more guidance and further specifications are needed about handling the connection between modules when dealing with complex systems.

The spreadsheet tools used for the case studies are primarily intended to validate and demonstrate the individual standards in a transparent way: in the spreadsheet, each step in the calculation can be followed. As a result, they are not suited (but also not intended) for use in daily practice. On the other hand, the spreadsheet programs are very suitable for software developers to check the calculation algorithms in their programs. For daily practice of an EPB assessment, a software tool will be needed, with user-friendly interface and connecting the successive modules needed for the overall EPB calculation and evaluation. Consequently, guidance will also be needed to ensure the quality of these software tools.

Annex A

List of calculation files

A.1 Folders

The set of calculation files for each variant in the case study are grouped in a separate folder named with the code of the variant. For small changes, only specific changing files are included.

The names of the folders are built in the following way:

SFH-X-CLI-OTH

where

- **SFH** means single family house
- **X** can be:
  - **E** for existing building
  - **N** for new building
- **CLI** is the climate code
  - **AVG** for average climate
  - **CLD** for cold climate
  - **WRM** for warm climate
- **OTH** indicates other information
  - **TS** for thermal solar
  - **PV** for photovoltaic

The resulting folder list is:

- SFH-E-AVG
- SFH-E-AVG-TS
- SFH-E-CLD
- SFH-E-CLD-TS
- SFH-E-WRM
- SFH-E-WRM-TS
- SFH-E-WRM-TS-PV
- SFH-N-AVG
- SFH-N-AVG-PV
- SFH-N-CLD
- SFH-N-CLD-PV
- SFH-N-WRM
- SFH-N-WRM-PV

A.2 File name coding

The file names are constructed in the following way.

NNa - STANDARD_BBB_X_CLI_C_OP__OTH.

where

- **NNa** is
  - a progressive number **NN** identifying the calculation order
  - an optional letter **a** to identify the files related to cases and variants
- **STANDARD** is the standard code
  - EN_12831-3 domestic hot water needs
  - EN_16798-1 Use profiles
  - ISO_52016-1 building description and heating needs calculation
  - ...
- **BBB** is the building type
  - **SFH** for Single Family house
  - **MFH** for Multi Family house
  - **OFF** for office
- **X** can be:
  - **E** for existing building
  - **N** for new building
- **CLI** is the climate code
  - **AVG** for average climate
  - **CLD** for cold climate
  - **WRM** for warm climate
- **C** indicates the comfort category
  - **I / II / III**
- **OP** indicates operation type of heating
  - **CNT** for continuous
  - **INT** for intermittent (night set back)
- **OTH** indicates other information
  - **TS** for thermal solar
  - **PV** for photovoltaic

A.3 File list

A.3.1 General

One file list is given here for the new and the existing building.

The basic lists of files for different climates is the same with few obvious exceptions, such as the additional file for cooling generation for the warm climate.

A.3.2 List of files for an existing building (AVG, CLD and WRM)

- 00 - ISO_52010-1_TMY_Athens_8_planes.xlsx
- 10 - EN 12831-3 - SFH-X-WRM - DHW_needs.xlsx
- 12 - EN_16798-1_SFH-X-WRM-II-CNT_HUDU-DHW.xlsm
- 15 - EN_16798-1_SFH-X-WRM-II-CNT_HUDU.xlsm
- 20 - ISO_52016-1_SFH_E_WRM-II-CNT_DESC.xlsx
- 21 - ISO_52016-1_SFH_E-WRM-II-CNT-CALC - DT_em.xlsm
- 21 - ISO_52016-1_SFH_E-WRM-II-CNT-CALC - Test free indoor summer temp.xlsm
- 21 - ISO_52016-1_SFH_E-WRM-II-CNT-CALC.xlsm
- 30 - EN_15316-1_SFH-E-WRM-II-CNT-RAD.xlsm
- 35 - EN 15316_5_SFH-X_WRM.xlsm
- 40 - EN_15316-4-1_SFH-E-WRM-II-CNT-RAD.xlsm
- 50 - EN16798-13_A_SFH-X-_WRM.xlsm
- 60 - EN15316-4-3-PV_SFH-X-_AVG.xlsm
- 90 - EN_ISO_52000-1_SFH-E-WRM-II-CNT-RAD.xlsm

A.3.3 List of files for an existing building with thermal solar and PV (AVG, CLD and WRM)

- 00 - ISO_52010-1_TMY_Athens_8_planes.xlsx
- 10 - EN 12831-3 - SFH-X-WRM - DHW_needs.xlsx
- 12 - EN_16798-1_SFH-X-WRM-II-CNT_HUDU-DHW.xlsm
- 15 - EN_16798-1_SFH-X-WRM-II-CNT_HUDU.xlsm
- 20 - ISO_52016-1_SFH_E_WRM-II-CNT_DESC.xlsx
- 21 - ISO_52016-1_SFH_E-WRM-II-CNT-CALC - DT_em.xlsm
- 21 - ISO_52016-1_SFH_E-WRM-II-CNT-CALC - Test free indoor summer temp.xlsm
- 21 - ISO_52016-1_SFH_E-WRM-II-CNT-CALC.xlsm
- 35 - EN 15316_5_SFH-X_WRM-1-TS.xlsm
- 36 - EN 15316-4-3_SFH-X_WRM-1-TS.xlsm
- 37 - Multi_SOL-STO_SFH-X_WRM-1-TS.xlsm
- 40 - EN_15316-4-1_SFH-E-WRM-II-CNT-RAD-TS.xlsm
- 50 - EN16798-13_A_SFH-X-_WRM.xlsm
- 60 - EN15316-4-3-PV_SFH-X-_AVG.xlsm
- 90 - EN_ISO_52000-1_SFH-E-WRM-II-CNT-RAD-TS.xlsm
- 90 - EN_ISO_52000-1_SFH-E-WRM-II-CNT-RAD-TS-PV-K0.xlsm
- 90 - EN_ISO_52000-1_SFH-E-WRM-II-CNT-RAD-TS-PV-K1.xlsm

A.3.4 List of files for a new building (AVG, CLD and WRM)

- 00 - ISO_52010-1_TMY_Strasbourg_8_planes.xlsx
- 10 - EN 12831-3 - SFH-X-AVG - DHW_needs.xlsx
- 12 - EN_16798-1_SFH-X-AVG-II-CNT_HUDU-DHW.xlsm
- 15 - EN_16798-1_SFH-X-AVG-II-CNT_HUDU.xlsm
- 20 - ISO_52016-1_SFH_N_AVG-II-CNT_DESC.xlsx
- 21 - ISO_52016-1_SFH_N-AVG-II-CNT-CALC.xlsm

- 25 - EN_16798-5-1_SFH_N-AVG-II-CNT.xlsm
- 30 - EN_15316-1_SFH-N-AVG-II-CNT-FLR.xlsm
- 35 - EN 15316_5_SFH-X_AVG.xlsm
- 40 - EN_15316-4-2_SFH-N-AVG-II-CNT-FLR.xlsm
- 90 - EN_ISO_52000-1_SFH-N-AVG-II-CNT-K1.xlsm
- 90 - EN_ISO_52000-1_SFH-N-AVG-II-CNT-RAD-TS.xlsm
- 90 - EN_ISO_52000-1_SFH-N-AVG-II-CNT-RAD-TS-PV-K0.xlsm
- 90 - EN_ISO_52000-1_SFH-N-AVG-II-CNT-RAD-TS-PV-K1.xlsm

Bibliography

[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 15316-4-2, Heat pumps October 31, 2021

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

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

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

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

[10] ENERC32017-437-SI2-785.185, Case study on EN 16798-7 and EN 16798-5-1, Mechanical ventilation 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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