Comparison of RES-systems for domestic hot water, space heating and space cooling in selected European cities

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EXECUTIVE SUMMARY

The final energy consumption and CO_2- emissions of four renewable energy heating systems, which are air-source heat pump, solar thermal, biomass and geothermal heat pump, are compared with one conventional heating system.

Eight reference buildings are defined, which differ in size (single family, multi family) building standard (new built, refurbished) and location (southern Europe, northern Europe). The building types are in line with the 2015 energy requirements for “nearly zero energy buildings” and for “buildings undertaking major renovations”. The calculation is done for five European cities, which are Stockholm, Vienna, Würzburg, Madrid and Athens.

Reference systems for domestic hot water, space heating and space cooling are defined and simulated with the simulation software Polysun (Vela Solaris, Version 8.0.12.21302). As a result of the simulation, the energy demand, the consumed energy and the according CO_2-emissions are summarised in figures for each city. The final energy needed to cover the energy demand varies according to the efficiency of the heating system, which mainly depends on the energy source.

Biomass heating systems have the lowest CO_2- emissions, as biomass in the European region is considered as carbon neutral.

The CO_2- emission of a conventional oil heating system in the reference new built single family house in Vienna is 2.917 kg CO_2/a. By the use of an air-source heat pump the emissions can be reduced to 862 kg CO_2/a. With a geothermal heat pump a reduction to 513 kg CO_2/a can be reached and a biomass boiler can minimise the emissions to 20 kg CO_2/a

An air source heat pump consumes 25.464 kWh/a electrical energy to cover the heat energy demand of the reference refurbished multi family house in Würzburg. By the use of a high efficient geothermal heat pump the electrical energy need can be reduced to 20.703 kWh/a.

Because of the high solar irradiation in the southern European regions, high solar fractions can be reached. In Madrid 80,6 % of the total heating energy demand of the reference new built single family house can be covered with 12 m² solar thermal absorber area. For the reference new built multi family house in Athens, a solar fraction of 69,5 % can be reached by a solar thermal system with 64 m² absorber area.

The reference new built multi family house in Madrid has a cooling energy demand of 2.485 kWh/a, a heating energy demand of 6.278 kWh/a including domestic hot water. A Reversible heat pump can cover the total energy demand with 2480 kWh/a of electrical energy.

1. Method

As part of the project "FROnT Fair RHC Options & Trade" a comparison of the performance data of four different renewable energy systems (RES) technologies under similar conditions is done. Therefore a reference system supplied with a conventional energy source is defined for each of the five target cities and the average energy demand for domestic hot water production, space heating and space cooling in different building types is estimated. For the comparison of the performance data the following renewable energy sources are taken into account:

- Air-source heat pumps
- Solar thermal energy
- Biomass
- Geothermal heat pumps

Within the consortium five locations respectively cities, two in the South, two in central Europe and one in the North of Europe are defined for the simulation of the performance data which are:

- Madrid
- Stockholm
- Vienna
- Würzburg
- Athens

The building types are in line with the 2015 energy requirements for "nearly zero energy buildings" and for "buildings undertaking major renovations". Every country has different requirements to reach the European building standards, which is why the following building types are defined for southern and northern European cities:

- New built single family house (NBSFH)
- Refurbished single family house (RSFH)
- New built multi family house (NBMFH)
- Refurbished multi family house (RMFH)

Differences between buildings in northern Europe (Stockholm, Vienna and Würzburg) and south Europe (Madrid, Athens) are taken into account by a reduction of south orientated window area, a reduction of internal heat sources and a raise of heat capacity of the building.

Building parameters for north European cities are listed in Table 1, parameters for south European buildings are listed in Table 2.

Table 1: Building parameters for north European cities (Stockholm, Vienna and Würzburg).

	NBSFH	RSFH	NBMFH	RMFH
Building width / depth [m]	8 / 6,5	8 / 6,5	16,3 / 7,6	16,3 / 7,6
Heated area per floor [m²]	52	52	123	123
Number of floors	2	2	5	5
Number of dwellings per floor			2	2
Floor height [m]	2,5	2,5	2,5	2,5
Shading	Internal blinds	Internal blinds	Internal blinds	Internal blinds
Ventilation	natural	natural	natural	natural
Overall U-value [W/K/m²]	0.24	0.3	0.24	0.3
Window to wall area south [%]	25	25	25	25
Window to wall area north [%]	13	13	13	13
Window to wall area east [%]	25	25	25	25
Window to wall area west [%]	6	6	6	6
Air change [1/h]	0.3	0.4	0.3	0.4
Air infiltration [1/h]	0.3	0.4	0.3	0.4
Internal heat gain equipment [W/m²]	240	240	240	240
Internal heat gain people [W/m²]	2	2	2	2
Heat capacity of the building [kJ/K/m²]	750	750	750	750
g-Value window [-]	0.52	0.52	0.52	0.52

Table 2: Building parameters for south European cities (Madrid and Athens).

	NBSFH	RSFH	NBMFH	RMFH
Building width / depth [m]	8 / 6,5	8 / 6,5	16,3 / 7,6	16,3 / 7,6
Heated area per floor [m²]	52	52	123	123
Number of floors	2	2	5	5
Number of dwellings per floor			2	2
Floor height [m]	2,5	2,5	2,5	2,5
Shading	Internal blinds	Internal blinds	Internal blinds	Internal blinds
Ventilation	natural	natural	natural	natural
Overall U-value [W/K/m²]	0.24	0.3	0.24	0.3
Window to wall area south [%]	6	6	6	6
Window to wall area north [%]	13	13	13	13
Window to wall area east [%]	25	25	25	25
Window to wall area west [%]	6	6	6	6
Air change [1/h]	0.3	0.4	0.3	0.4
Air infiltration [1/h]	0.1	0.2	0.1	0.2
Internal heat gain equipment [W/m²]	0	0	0	0
Internal heat gain people [W/m²]	2	2	2	2
Heat capacity of the building [kJ/K/m²]	1000	1000	1000	1000
g-Value window [-]	0.52	0.52	0.52	0.52

Simulation variations are summarised in Table 3. The variations are bundled in different climate zones, which mean that all possible options are calculated for each climate zone but not for every city. In addition to the domestic hot water and space heating demand the space cooling demand is calculated only for south European cities. Functionalities and control systems are described in chapter 2.

Table 3: Overview of the calculated options.

		Stockholm	Vienna	Würzburg	Madrid	Athens
Heating systems	Domestic hot water*	X	X	X	X	X
	Domestic hot water and heating	X	X	X		
	Domestic hot water, heating and cooling				X	X
Building type	New built single family house	X	X		X	
	Refurbished single family house	X		X	X	
	New built multi family house	X	X			X
	Refurbished multi family house	X		X		X
Five different heat sources		X	X	X	X	X
Climate Zone		North	Central		South	

*Domestic hot water demand is calculated for single and multi family houses in all five locations.
X… calculated

The different options are simulated with the simulation software Polysun (Vela Solaris, Version 8.0.12.21302). The calculation of heat- and cool energy demand is aligned to the German EnEV (DIN V 4701) and the climate simulation is based on the Meteonorm database. According to the Vela Solaris software developers, the simulation tool Polysun has difficulties to calculate cooling simulations for several store building. It is recommended to simulate one-store buildings with equivalent floor area, which is done in this report. Detailed information on the simulation software can be found at http://www.velasolaris.com/files/tutorial_en.pdf and http://www.velasolaris.com/files/help_en.pdf.

All different systems are analysed according to their energy demands (domestic hot water, space heating and space cooling) and their energy consumptions (heating oil, electricity, pellets and heating gas). To enable an economical comparison, the CO_2-emissions are calculated by multiplying the final energy demand with the according European LCA CO_2-emissions factor (Appendix B).

Simulation results are summarized in figures for the observed cities.

2. System description

The calculation is based on three main heating types, “domestic hot water (DHW)”, “domestic hot water and space heating (SH)” and “domestic hot water, space heating and space cooling (SC)”. In this chapter the operating principles and the used calculation parameters are described. Efficiency values are regarded to the lower heating value.

2.1 Domestic hot water

The domestic hot water demand is calculated with the values shown in Table 4.

Table 4: Configuration parameters for the domestic hot water demand.

	Stockholm	Vienna	Würzburg	Madrid	Athens
Number of inhabitants single family house [Persons]	4	3	3	4	4
Hot water demand single family house [l/day]	170	150	150	210	210
Number of inhabitants multi family house [Persons]	21	21	21	21	21
Hot water demand single family house [l/day]	900	1050	1050	1100	1100
Hot water temperature [°C]	50	50	50	50	50

Figure 1 shows the hydraulic scheme for domestic hot water preparation. A Boiler (1) charges a storage tank (2) to 55 °C. The possibility of over temperature at the hot water valve (3) is excluded by the use of a mixing valve (4). In case that the temperature in temperature level T1 is lower than 50 °C the heating control system (a) sets the boiler status and the integrated pump status to “ON”. When the temperature in temperature level T2 reaches 55 °C the storage is fully charged and the boiler is turned off again.
The mixing valve control system (b) varies the mass flow of T3 and T4 to reach the set hot water temperature (T5). The hot water tank has to be overheated continuously to ensure hygienic operation with no legionella bacteria. The energy demand for this procedure is not considered in the calculation.

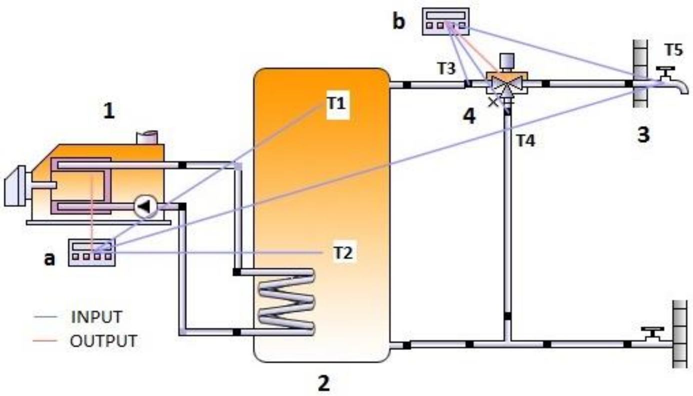

Figure 1: Hydraulic diagram with control system for domestic hot water preparation.

Because of the poor availability of boilers with low nominal heating power, the simulated boilers might be oversized. Sanitary hot water tank volumes in single family houses are considered to be as high as the daily hot water consumption. In multi family houses volumes are lower because of the unsimultaneously energy demand.

2.1.1 DHW Reference system

The technical parameters for the reference system are listed in Table 5. Commonly used fossil heat generators are defined for the observed cities.

Table 5: Configuration parameters for domestic hot water preparation with reference heating systems.

		Stockholm	Vienna	Würzburg	Madrid	Athens
Single family house-	Reference heat generator	Electric	Oil	Oil	Gas	Gas
	Power [kW]	4	5	5	5	5
	Efficiency value [%]	95	85	85	90	90
	Sanitary hot water tank [l]	150	150	150	150	150
Multi family house-	Central reference heat generator	Electric	Oil	Oil	Gas	Gas
	Power [kW]	6	5	5	5	5
	Efficiency value [%]	95	85	85	90	90
	Sanitary hot water tank [l]	800	800	800	800	800

Control system and functionality is explained in chapter 2.1.

2.1.2 DHW Air- source heat pump

In Table 6 the design parameters for the domestic hot water preparation with air- source heat pumps are listed. On the assumption that compact hot water heat pump is located indoors, a constantly high evaporation temperature is reached and by that a high annual coefficient of performance (COP). The indoor air temperature is assumed to be constant at a level of 18 °C.

Table 6: Configuration parameters for domestic hot water preparation with air-source heat pumps.

		Stockholm	Vienna	Würzburg	Madrid	Athens
Single family house-	Heat source	Indoor air	Indoor air	Indoor air	Indoor air	Indoor air
	Heating power(1) [kW] at A2/W35	4	4	4	4	4
	Operating mode	Monovalent	Monovalent	Monovalent	Monovalent	Monovalent
	Annual COP [-]	4,1	4,1	4,1	4,1	4
	Sanitary hot water tank [l]	150	150	200	150	150
Multi family house-	Heat source	Indoor air	Indoor air	Indoor air	Indoor air	Indoor air
	Heating power(1) [kW] at A2/W35	4	4	4	4	4
	Operating mode	Monovalent	Monovalent	Monovalent	Monovalent	Monovalent
	Annual COP [-]	4,2	4,2	4,3	4,2	4,2
	Sanitary hot water tank [l]	800	800	800	800	800

(1) Operating point: Air temperature 2 °C; Water temperature 35 °C (A2/W35)

The control system of the air-source heat pump systems is slightly different to the one explained in chapter 2.1.

To ensure that the heat pump is operating efficiently, high evaporating temperatures and low condensing temperatures are necessary. The control system, which can be seen in Figure 2, is optimized in order to decrease the condensing temperature.

Whenever the temperature in tank level T1 is lower than 45 °C the heat pump (1) starts to operate and in case that the temperature in tank level T2 is higher than 50 °C it stops.

The average storage temperature is 5 °C lower than the average storage temperature of the reference system. The hot water tank has to be overheated continuously to ensure hygienic operation with no legionella bacteria. The energy demand for this procedure is not considered in the calculation.

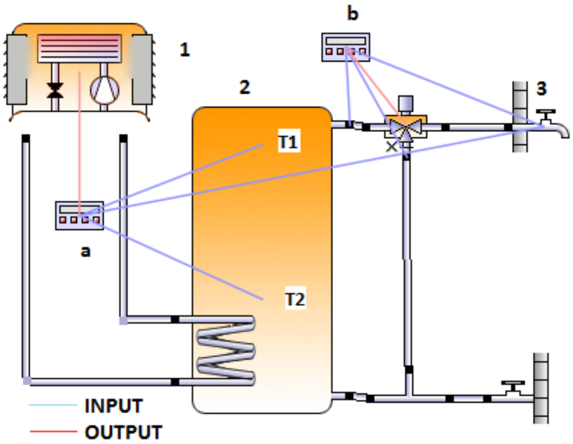

Figure 2: Hydraulic diagram with control system for domestic hot water preparation with an air-source heat pump.

2.1.3 DHW Solar thermal

Domestic hot water is heated by a solar thermal heating system with flat plate collectors and a back-up boiler. The ratio of energy covered by the solar thermal system and the total energy demand is called solar fraction. The considered solar fractions vary according to the location and are shown in Table 7. The water tank volume is optimized to the collector area. The back-up boiler must be able to cover the full energy needs without the solar system.

Table 7: Configuration parameters for domestic hot water preparation with solar thermal systems.

		Stockholm	Vienna	Würzburg	Madrid	Athens
Single family house	Collector type	Flat plate	Flat plate	Flat plate	Flat plate	Flat plate
	Solar fraction [%]	64,5	67,2	65,1	78,2	76,8
	Sanitary hot water tank [l]	300	300	300	300	300
	Collector area [m²]	6	6	6	4	4
Multi family house	Collector type	Flat plate	Flat plate	Flat plate	Flat plate	Flat plate
	Solar fraction [%]	51,1	53,8	52,3	81,8	78,9
	Sanitary hot water tank [l]	1000	1000	1000	1000	1000
	Collector area [m²]	20	20	20	20	20

Collector efficiency: Eta0: 0,75 / A1: 3,5 / A2: 0,02

The heating and control systems described in chapter 2.1 can be complemented with a solar thermal heating system.

For the domestic hot water preparation with solar thermal support, the flat plate collector (1) and the extra heat exchanger embedded in the sanitary hot water tank (3) are connected via a solar loop that includes a circulating pump (2), as shown in Figure 3.

With the incidence of solar radiation on the flat plate collectors, the fluid temperature T1 increases. Whenever the collector exit temperature T1 is 8 °C higher than the measured temperature in storage layer T2, the pump (2) circulates with a specific flow rate of 40 l/h/m² and transfers the heat to the storage tank.

When the temperature difference of T1 and T2 is lower than 3 °C, the solar pump (2) stop.

If the temperature in the storage level T3 is lower than 49,5 °C the back-up boiler starts and heats the level to 55,5 °C.
To avoid parallel operation of the back-up boiler and the solar thermal system, an operating time frame for the back-up boiler is implemented. In time from 5pm to 8am low irradiation is expected and the back-up boiler is enabled to run.

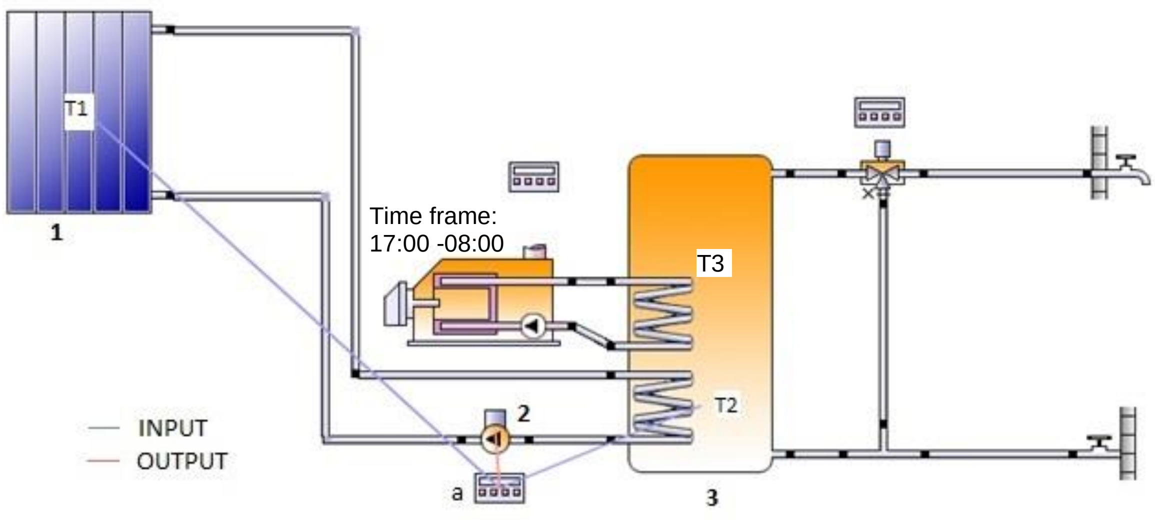

Figure 3: Hydraulic diagram for domestic hot water preparation with solar thermal support.

2.1.4 DHW Biomass

The domestic hot water preparation for single family houses with biomass boilers is not common in Europe. In this project the domestic hot water preparation with biomass boilers is exclusively considered for multi family houses. Chosen design values are shown in Table 8.

Table 8: Configuration parameters for domestic hot water preparation with biomass systems.

		Stockholm	**Vienna**	**Würzburg**	**Madrid**	**Athens**
Multi family house	Biomass	Pellet	Pellet	Pellet	Pellet	Pellet
	Power [kW]	5	5	5	5	5
	Efficiency value [%]	82	82	82	82	82
	Sanitary hot water tank [l]	800	800	800	800	800

Control system and functionality is explained in chapter 2.1.

2.1.5 DHW Geothermal heat pump

Geothermal heat pumps are commonly not used for exclusive domestic hot water preparation in single family houses as the energy demand is far too low to justify the high installation costs. In this project the domestic hot water preparation with geothermal heat pumps is exclusively considered for multi family houses. Design parameters are shown in Table 9.

Table 9: Configuration parameters for domestic hot water preparation with geothermal heat pump systems.

		Stockholm	**Vienna**	**Würzburg**	**Madrid**	**Athens**
Multi family house	Heating power [kW] at B0/W35	5,6	5,6	5,6	5,6	5,6
	Operating mode	Monovalent	Monovalent	Monovalent	Monovalent	Monovalent
	Annual COP [-]	4,0	4,2	4,1	4,2	4,2
	Sanitary hot water tank [l]	800	800	800	800	150
Boreholes		1x 40mm double U	1x 40mm double U	1x 40mm double U	1x 40mm double U	1x 40mm double U
Borehole heat exchanger length [m]		200	200	200	200	200
*Earth layer 1 [Cat.Nr. - depth]		2 - 50	2 - 50	2 - 50	2 - 50	2 - 50
*Earth layer 2 [Cat.Nr. - depth]		27 - 150	27 - 150	27 - 150	27 - 150	27 - 150

* Earth layer types available in the software Polysun can be seen in Appendix A

The control system and functionality is equal to the one described in chapter 2.1.2. An additional pump for the geothermal circuit can be seen in Figure 4.

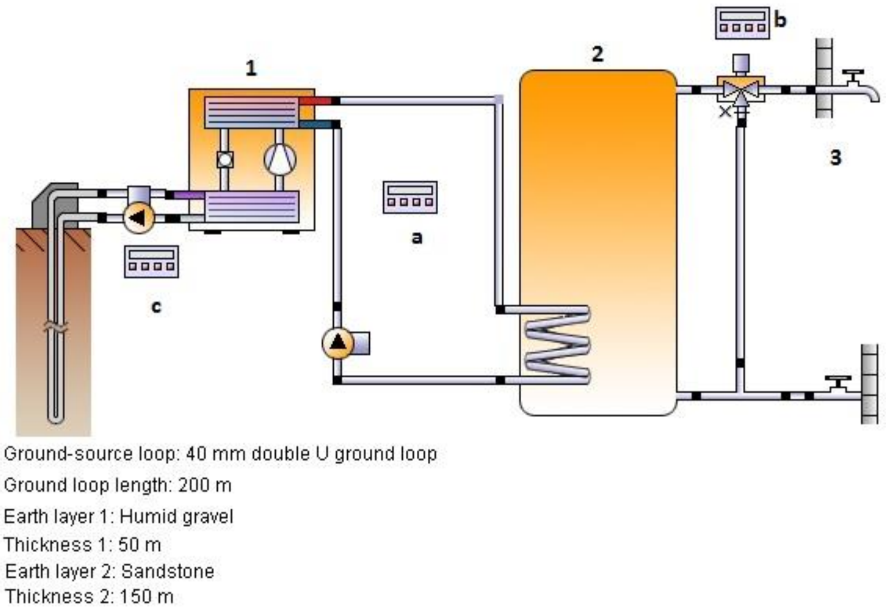

Figure 4: Hydraulic diagram for domestic hot water preparation with geothermal heat pump systems.

2.2 Domestic hot water and space heating

In addition to the domestic hot water demand described in chapter 2.1, the heating demand of new and refurbished buildings for single- and multi family houses are considered. Heating systems of single family houses are different to the heating systems of multi family houses. Aside from the sizes of the components also the domestic hot water preparation changes from a tank in tank system to an instantaneous water heater as it is displayed in Figure 5 and Figure 6.

The following description of heating systems is valid for all building types, as the building types have no impact on the control systems or its functionalities.

Depending on the position of the three-way valves (2, 3), weather the hot water-volume or the heating-volume of the buffer storage (4) is charged by the boiler (1). The mixing valves (5, 6) ensure that the set temperature level for hot water (8) and heating emitters (9) are not exceeded. In order to heat the building (10), the pump (7) circulates and transfers the heat to the radiators (9). As the buildings are renovated or even new, low temperature radiators are chosen. The radiator inlet temperature is 40 °C and the return temperature is 30 °C. The heating set point temperature is 22 °C.

The heating control system (a) differentiates two operating modes, “domestic hot water” and “space heating”.

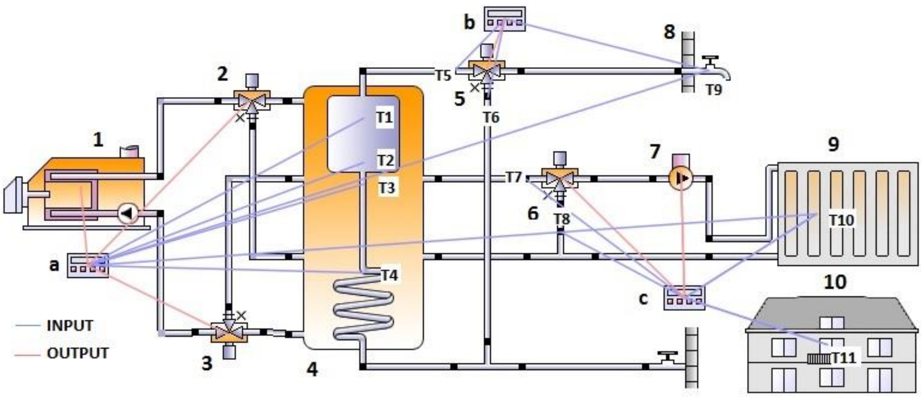

Figure 5: Hydraulic diagram with control system for heating and domestic hot water preparation.

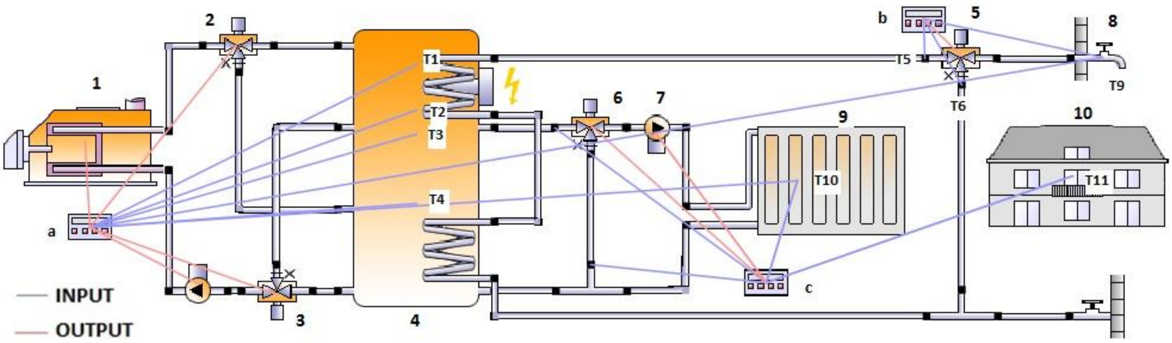

Figure 6: Hydraulic diagram with control system for heating and domestic hot water preparation.

Operating mode "domestic hot water"

If the temperature in temperature level T1 is under 50 °C the boiler with the integrated pump (1) starts. As shown in Figure 7, the position of the three-way valves (2, 3) are set in a way that exclusively the upper third of the storage is loaded.
When the measured temperature in level T2 has reached 50 °C, the boiler and the pump is turned off.

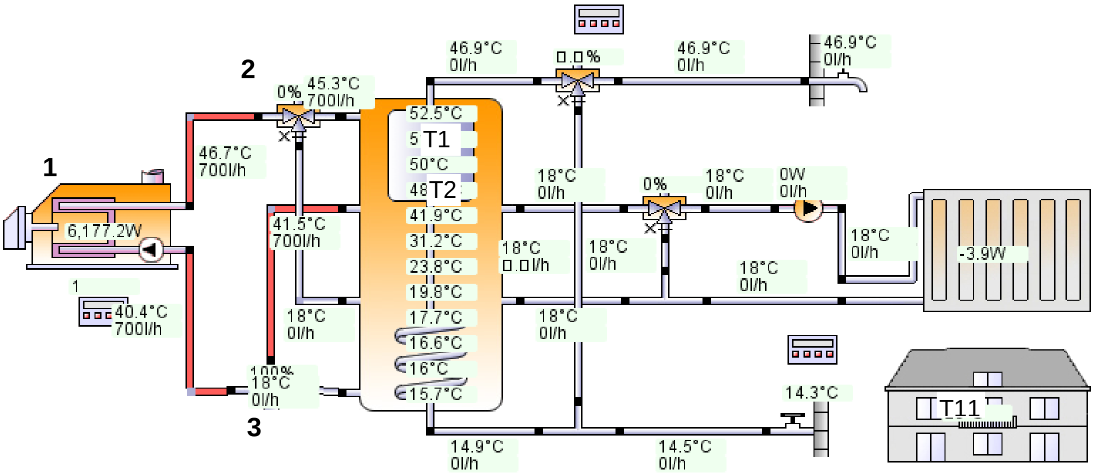

Figure 7: Operation mode domestic hot water.

Operating mode "space heating"

In case that the room temperature T11 is lower than the heating set point temperature of 22 °C, the heating pump (7) starts and heats up the radiators. Due to that the storage temperature decreases. If the storage temperature in level T3 is lower than the convector supply temperature of 40 °C (T10) and the control system is not in "domestic hot water" mode, the boiler with the integrated pump (1) starts. Figure 8 shows the position of the three-way valves (2, 3) when the system is operating in "space heating" mode.
The boiler with integrated pump (1) stops when the storage temperature in level T4 has reached the convector supply temperature T10.

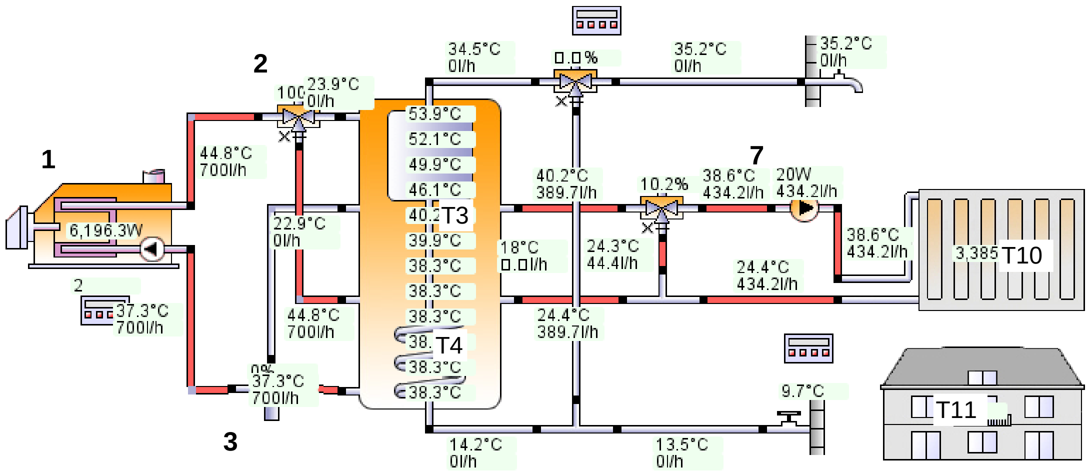

Figure 8: Operation mode space heating.

2.2.1 DHW and SH reference system

Typical conventional heating energy sources are defined for every city. The boiler power is chosen according to the calculated heat power demand. The sizes of the main heating circuit components are listed in Table 10.

Table 10: Configuration parameters of the reference system for domestic hot water and heating.

		Stockholm	Vienna	Würzburg
Single family houses	Reference heat generator	Electric	Oil	Oil
	Power [kW]	8	7,5	7,5
	Efficiency value [%] Regard to lower heating value	95	85	85
	Buffer tank / embedded sanitary hot water tank[l]	600 / 200	600 / 200	600 / 200
Multi family houses	Reference heat generator	Electric	Oil	Oil
	Power [kW]	30	20	30
	Efficiency value [%] Regard to lower heating value	95	85	85
	Buffer tank volume [l]	1000	1000	1000

Control system and functionality is explained in chapter 2.2.

2.2.2 DHW and SH Air-source heat pump

Heat pumps of this size range need an outdoor installed evaporator. The heat pumps work monovalent, which means without an additional boiler to cover the heat demand. In case that the outdoor temperatures are too low to run the heat pump, the integrated heating element covers the energy demand. Key points of the heating system are listed in Table 11.

Table 11: Configuration parameters of the air-source heat pump system for domestic hot water and heating.

		Stockholm	Vienna	Würzburg
Single family house-	Heat source	Ambient air	Ambient air	Ambient air
	Heating power [kW] at A2/W35	10	10	10
	Operating mode	Monovalent	Monovalent	Monovalent
	Annual COP [-]	2,4	2,7	2,5
	Buffer tank / embedded sanitary hot water tank[l]	600 / 200	600 / 200	600 / 200
Multi family house-	Heat source	Ambient air	Ambient air	Ambient air
	Heating power [kW] at A2/W35	36,8	20,8	30,4
	Operating mode	Monovalent	Monovalent	Monovalent
	Annual COP [-]	2,8	3,1	3,1
	Buffer tank volume [l]	1000	1000	1000

Control system and functionality is explained in chapter 2.2.

2.2.3 DHW and SH Solar thermal

Solar thermal heat is used to support the boiler. Values of solar fraction are chosen for an economical operation. Multi family houses have lower solar fraction, as the roof space is limited. Considered components are listed in Table 12.

Table 12: Configuration parameters of the solar thermal system for domestic hot water and heating.

		Stockholm	Vienna	Würzburg
Single family house	Collector type	Flat plate	Flat plate	Flat plate
	Solar fraction new built house/ refurbished house [%]	27,6 / 21,6	35,8 / -	- / 24,4
	Buffer tank / embedded sanitary hot water tank[l]	600 / 200	600 / 200	600 / 200
	Collector area [m²]	12	12	12
Multi family house	Collector type	Flat plate	Flat plate	Flat plate
	Solar fraction new built house/ refurbished house [%]	17,3 / 13,2	23,9 / -	- / 15,1
	Buffer tank volume [l]	1000	1000	1000
	Collector area [m²]	64	64	64

Collector efficiency: Eta0: 0,75 / A1: 3,5 / A2: 0,02

An additional solar thermal support of the reference system is shown in Figure 9. The control system of the solar thermal cycle is equal to the one described in chapter 2.1.3. The control system of the boiler has the following functionality:
The boiler with integrated pump (4) starts when the temperature in storage level T3 is lower than the set hot water temperature T4. Whenever the bottom temperature layer in the embedded sanitary hot water tank (T3) is 10 °C higher than the set hot water temperature T4 the boiler stops. No operating timeframe is set to the boiler.

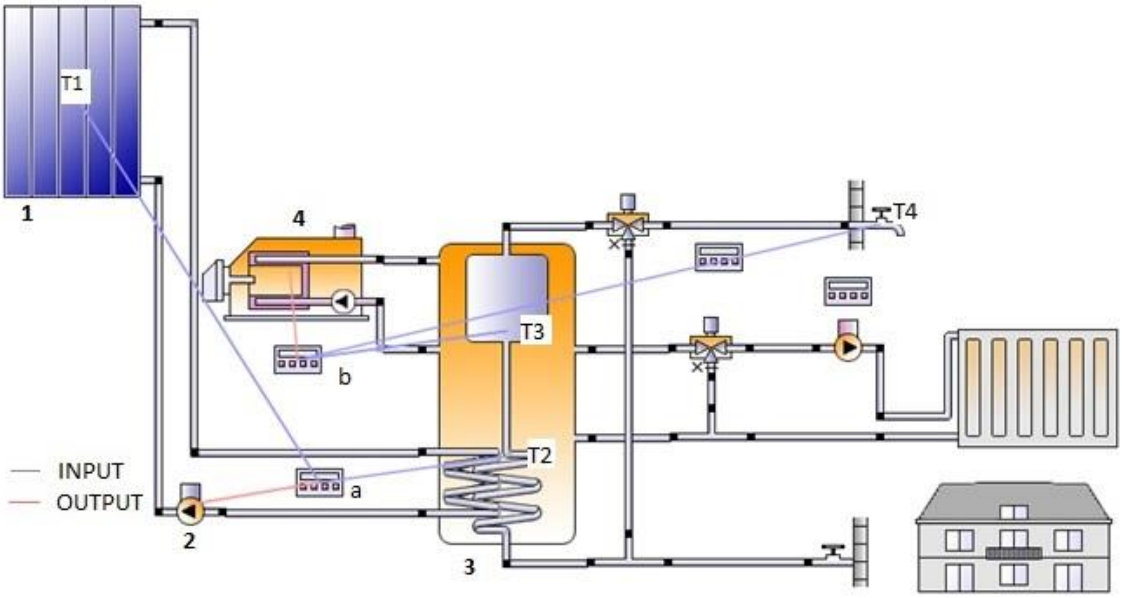

Figure 9: Hydraulic diagram for domestic hot water and heating preparation with solar thermal support.

2.2.4 DHW and SH Biomass

The boiler of the reference system is exchanged with a pellets boiler. Design parameters can be seen in Table 13.

Table 13: Configuration parameters of the biomass system for domestic hot water and heating.

		Stockholm	Vienna	Würzburg
Single family house	Biomass	Pellet	Pellet	Pellet
	Power [kW]	7,5	7,5	7,5
	Efficiency value [%]	82	82	82
	Buffer tank / embedded sanitary hot water tank[l]	600 / 200	600 / 200	600 / 200
Multi family house	Biomass	Pellet	Pellet	Pellet
	Power [kW]	35	20	30
	Efficiency value [%]	82	82	82
	Buffer tank volume [l]	1000	1000	1000

Control system and functionality is explained in chapter 2.2.

2.2.5 DHW and SH Geothermal heat pump

Considered design values of the geothermal heat pump are shown in Table 14. The heating power and the needed boreholes are designed according to the different energy demands.

Table 14: Configuration parameters of the solar thermal system for domestic hot water and heating.

		Stockholm	Vienna	Würzburg
Single family house	Heating power [kW] at B0/W35	8,9	8,9	8,9
	Operating mode	Monovalent	Monovalent	Monovalent
	Annual COP [-]	4,0	4,4	4,0
	Buffer tank / embedded sanitary hot water tank[l]	600 / 200	600 / 200	600 / 200
	Boreholes	1x 40mm double U	1x 40mm double U	1x 40mm double U
	*Total borehole heat exchanger length [m]	160	120	140
Multi family house	Heating power [kW] at B0/W35	38,1	18,7	28,7
	Operating mode	Monovalent	Monovalent	Monovalent
	Annual COP [-]	3,7	3,7	3,8
	Buffer tank volume [l]	1000	1000	1000
	Boreholes	2x2 40mm double U	2x 40mm double U	3x 40mm double U
	*Total borehole heat exchanger length [m]	800	340	600
	**Earth layer 1 [Cat.Nr. - depth]	2 - 50	2 - 50	2 - 50
	**Earth layer 2 [Cat.Nr. - depth]	27 - 150	27 - 150	27 - 150

* BHE-length calculated by EGEC using EED software (Appendix C)

** Earth layer types available in the software Polysun can be seen in Appendix A

2.3 Domestic hot water, space heating and space cooling

Heating systems for domestic hot water and space heating are defined in chapter 2.1 and 2.2. For the south European cities a cooling system is implemented. The cooling energy demand is dynamically calculated with the simulation software Polysun. In Figure 10 the hydraulic diagram and the control system with input and output data lines are shown.

The functionality can be described as follows:
Pump number 5 circulates a cooling fluid between the condenser of the compression refrigeration machine (2) and the outstanding recooler (1). Pump number 4 circulates a cooling fluid from the evaporator of the compression refrigeration machine to a fan coil (3).
The control system (a) sets the compression refrigeration machine status “ON” in case that the building temperature T1 is lower than the cooling set point temperature of 24 °C and it sets the compression refrigeration machine status “OFF” if the building temperature reached 23 °C.

For systems with a compression refrigeration machines, a recooler is necessary.
The only enabled recooler in the simulation software Polysun is a wet-recooler with a cooling capacity of at least 30 kW. This leads to low source temperatures for the cooling machine and by that to a very high COP.

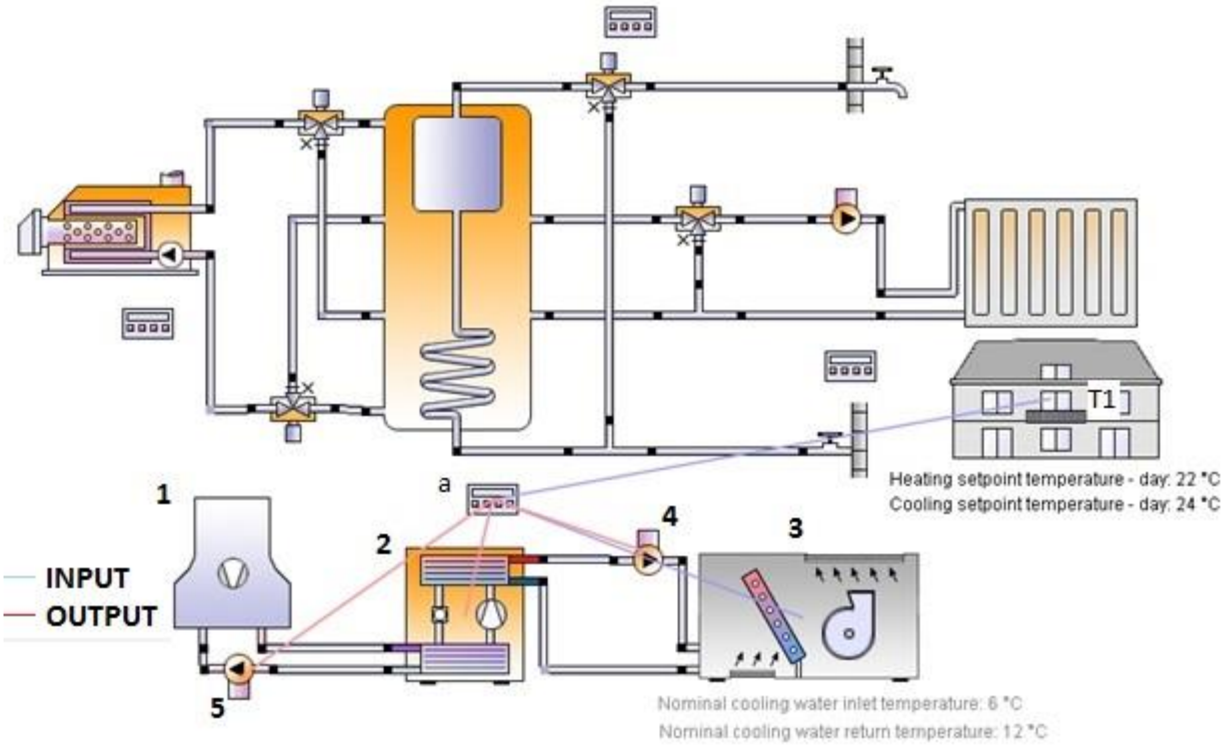

Figure 10: Hydraulic diagram with control system for domestic hot water, space heating and space cooling.

2.3.1 DHW, SH and SC reference system

Functionality and control system for domestic hot water and space heating are described in chapter 2.2.1. The cooling principle and hydraulic scheme is shown in Figure 10. The design parameters are listed in Table 15. The hybrid system consists of a compression refrigeration machine for cooling and a gas boiler for heating.

Table 15: Configuration parameters of the reference system for domestic hot water, space heating and space cooling.

		Madrid	Athens
Single family houses	Reference heat generator	Gas	-
	Power [kW]	10	-
	Efficiency value [%] Regard to lower heating value	90	-
	Buffer tank / embedded sanitary hot water tank[l]	600 / 200	-
	compression refrigeration machine Power [kW] at W24/W5	7,53	-
	Annual cooling performance factor	4,37	-
Multi family houses	Reference heat generator	-	Gas
	Power [kW]	-	20
	Efficiency value [%] Regard to lower heating value	-	90
	Buffer tank volume [l]	-	1000
	compression refrigeration machine Power [kW] at W24/W5	-	7,03
	Annual cooling performance factor	-	4,1

It would be good to mention somewhere that it is a hybrid system with two different technologies, as the system described is not a biomass installation doing cooling but a biomass boiler + a heat pump.

2.3.2 DHW, SH and SC Air-source heat pump

Functionality and control system for domestic hot water and space heating are described in chapter 2.2.2. The cooling principle and hydraulic scheme is shown in Figure 10. The design parameters are listed in Table 16.

Table 16: Configuration parameters of the air-source heat pump system for domestic hot water, space heating and space cooling.

		Madrid	Athens
Single family house-	Heat source	Ambient air	-
	Heating power [kW] at A2/W35	10	-
	Operating mode	Monovalent	-
	Annual COP [-]	3,2	-
	Buffer tank / embedded sanitary hot water tank[l]	600 / 200	-
	compression refrigeration machine Power [kW] at W24/W5	7,03	-
	Annual cooling performance factor	4,37	-
Multi family house-	Heat source	-	Ambient air
	Heating power [kW] at A2/W35	-	20,8
	Operating mode	-	Monovalent
	Annual COP [-]	-	3,75
	Buffer tank volume [l]	-	1000
	compression refrigeration machine Power [kW] at W24/W5	-	7,03
	Annual cooling performance factor	-	4,1

2.3.3 DHW, SH and SC Solar thermal

Functionality and control system for domestic hot water and space heating are described in chapter 2.2.3. The cooling principle and hydraulic scheme is shown in Figure 10. The design parameters are listed in Table 17. The hybrid system consists of a compression refrigeration machine for cooling and solar collectors with a gas back up boiler for heating.

Table 17: Configuration parameters of the solar thermal system for domestic hot water, space heating and space cooling.

		Madrid	**Athens**
Single family house	Collector type	Flat plate	-
	Solar fraction new built / refurbished building [%]	80,6 / 67,5	-
	Buffer tank / embedded sanitary hot water tank[l]	600 / 200	-
	Collector area [m²]	12	-
	compression refrigeration machine Power [kW] at W24/W5	7,03	-
	Annual cooling performance factor	4,33	-
Multi family house	Collector type	-	Flat plate
	Solar fraction new built / refurbished building [%]	-	69,5 / 55,7
	Buffer tank volume [l]	-	1000
	Collector area [m²]	-	64
	compression refrigeration machine Power [kW] at W24/W5	-	7,03
	Annual cooling performance factor	-	4,1

Collector efficiency: Eta0: 0,75 / A1: 3,5 / A2: 0,02

2.3.4 DHW, SH and SC Biomass

Functionality and control system for domestic hot water and space heating are described in chapter 2.2.4. The cooling principle and hydraulic scheme is shown in Figure 10. The design parameters are listed in Table 18. The hybrid system consists of a compression refrigeration machine for cooling and biomass boiler for heating.

Table 18: Configuration parameters of the biomass system for domestic hot water, space heating and space cooling.

		Madrid	**Athens**
Single family house	Biomass	Pellet	-
	Power [kW]	7,5	-
	Efficiency value [%]	82	-
	Buffer tank / embedded sanitary hot water tank[l]	600 / 200	-
	compression refrigeration machine Power [kW] at W24/W5	7,03	-
	Annual cooling performance factor	4,37	-
Multi family house	Biomass	-	Pellet
	Power [kW]	-	20
	Efficiency value [%]	-	82
	Buffer tank volume [l]	-	1000
	compression refrigeration machine Power [kW] at W24/W5	-	7,03
	Annual cooling performance factor	-	4,1

2.3.5 DHW, SH and SC Geothermal heat pump

Functionality and control system for domestic hot water and space heating are described in chapter 2.2.5. The hydraulic scheme is shown in Figure 11. The heat pump is operating reverse (cooling mode) when it is not working in any other mode and the building temperature is higher than 24 °C. It stops in case that the building temperature reaches 23,8 °C. The design parameters are listed in Table 19.

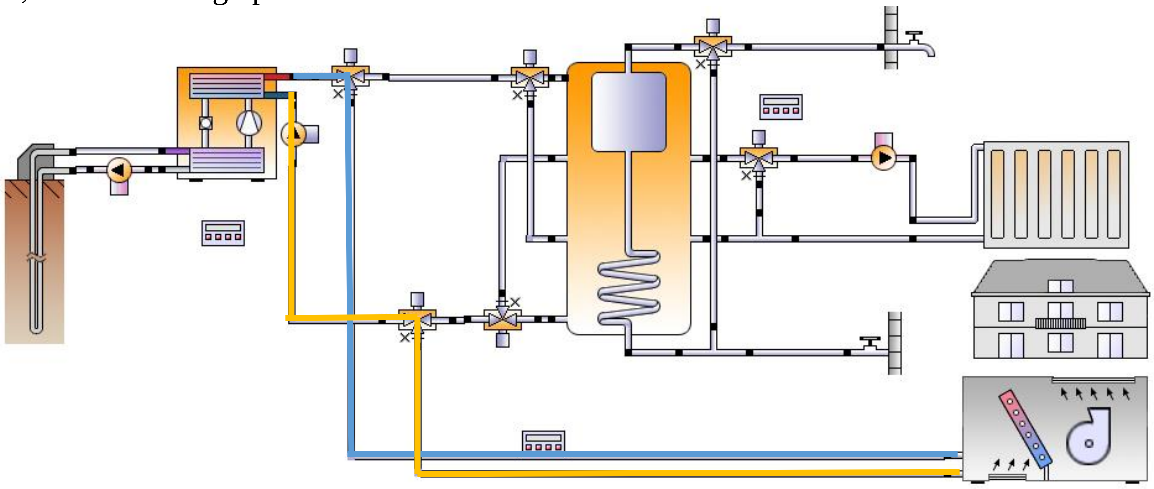

Figure 11: Hydraulic diagram for domestic hot water, space heating and space cooling with a reverse working ground source heat pump.

Table 19: Configuration parameters of the solar thermal system for domestic hot water, space heating and space cooling.

		Madrid	Athens
Single family house	Heating power [kW] at W2/W38	11,8	-
	Operating mode	Monovalent	-
	Annual COP [-]	3,9	-
	Buffer tank / embedded sanitary hot water tank[l]	600 / 200	-
	Boreholes	3x 40mm double U	-
	Cooling power[kW] at W24/W5	11,6	-
	Total borehole heat exchanger length [m]	300	
Multi family house	Heating power [kW] at W2/W38	-	15,1
	Operating mode	-	Monovalent
	Annual COP [-]	-	4,4
	Buffer tank volume [l]	-	1000
	Boreholes	-	10x 40mm double U
	Cooling power[kW] at W24/W5	-	15,6
	Total borehole heat exchanger length [m]	-	1000
*Earth layer 1 [Cat.Nr. - depth]		2 - 50	2 - 50
*Earth layer 2 [Cat.Nr. - depth]		27 - 150	27 - 150

* BHE-length calculated by EGEC using EED software (Appendix C)

** Earth layer types available in the software Polysun can be seen in Appendix A

3. Stockholm

The energy demand for domestic hot water and space heating is summarized in Table 20. Used building parameters are shown in Table 1

Table 20: Energy demand for domestic hot water and space heating for the reference buildings in Stockholm.

	Domestic hot water demand (DHW)			Space heating	
Reference building type	Inhabitants (Persons)	Hot water demand (l/d)	**DHW (kWh/a)**	Heated Area (m^2)	**Space heating demand (kWh/a)**
New built SFH	4	170	**3.057**	104	**6.948**
Refurbished SFH					**10.884**
New built MFH	21	900	**16.214**	619	**49.327**
Refurbished MFH					**73.327**

In the following chapters primary energy consumptions and the CO_2-emissions of the five different heating systems are calculated for each of the four reference building types.

3.1 DHW Stockholm

Heating concepts and the according control systems are described in chapter 2.1.

3.1.1 DHW in single family houses

Figure 12 shows the domestic hot water energy demand, the final energy consumption and the CO_2-emissions of all calculated heating systems for the reference single family house described in chapter 2.1.

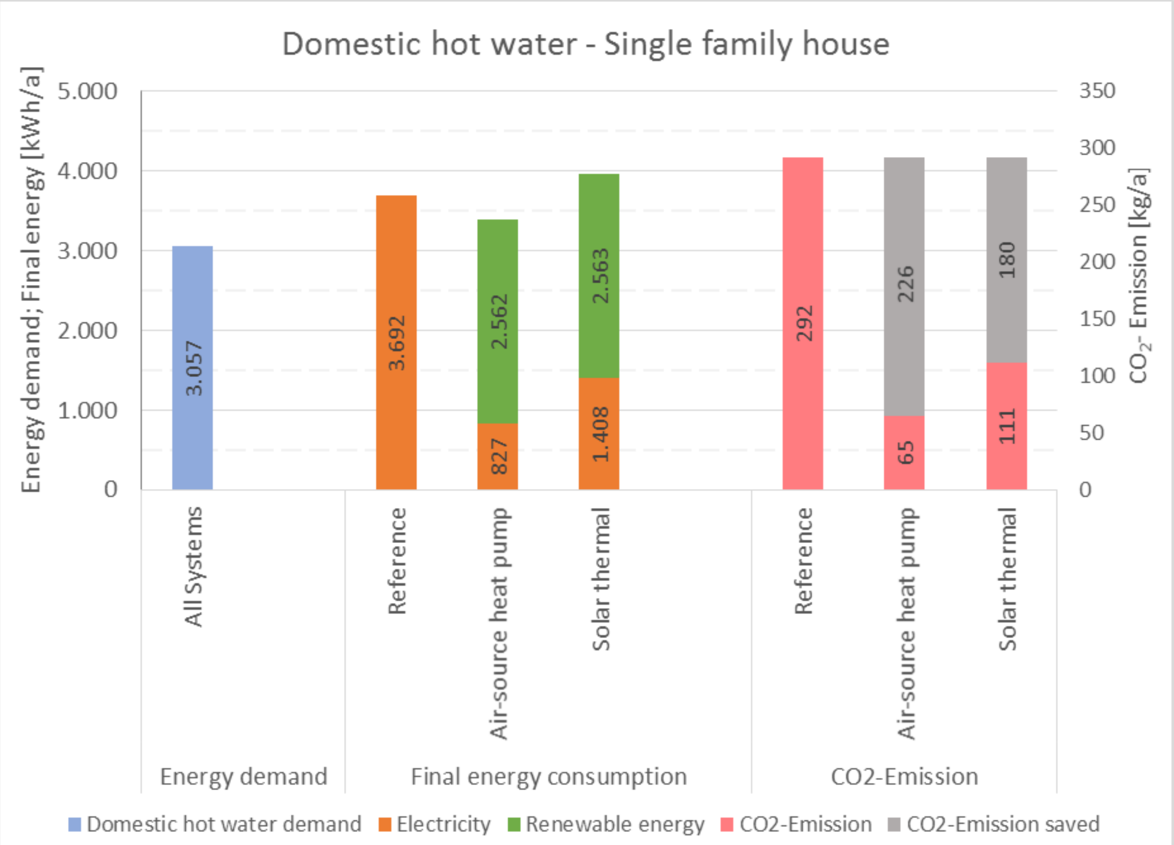

Figure 12: Comparison of all observed heating systems for domestic hot water preparation in single family houses in Stockholm.

CO_2-emission factor electricity Sweden: 0,079 t CO_2/MWh (Appendix B)

3.1.2 DHW in multi family houses

A comparison of heating systems with focus on domestic hot water energy demand, final energy consumption and CO_2- emission is shown in Figure 13. The calculation is based on the reference multi family house described in chapter 2.1.

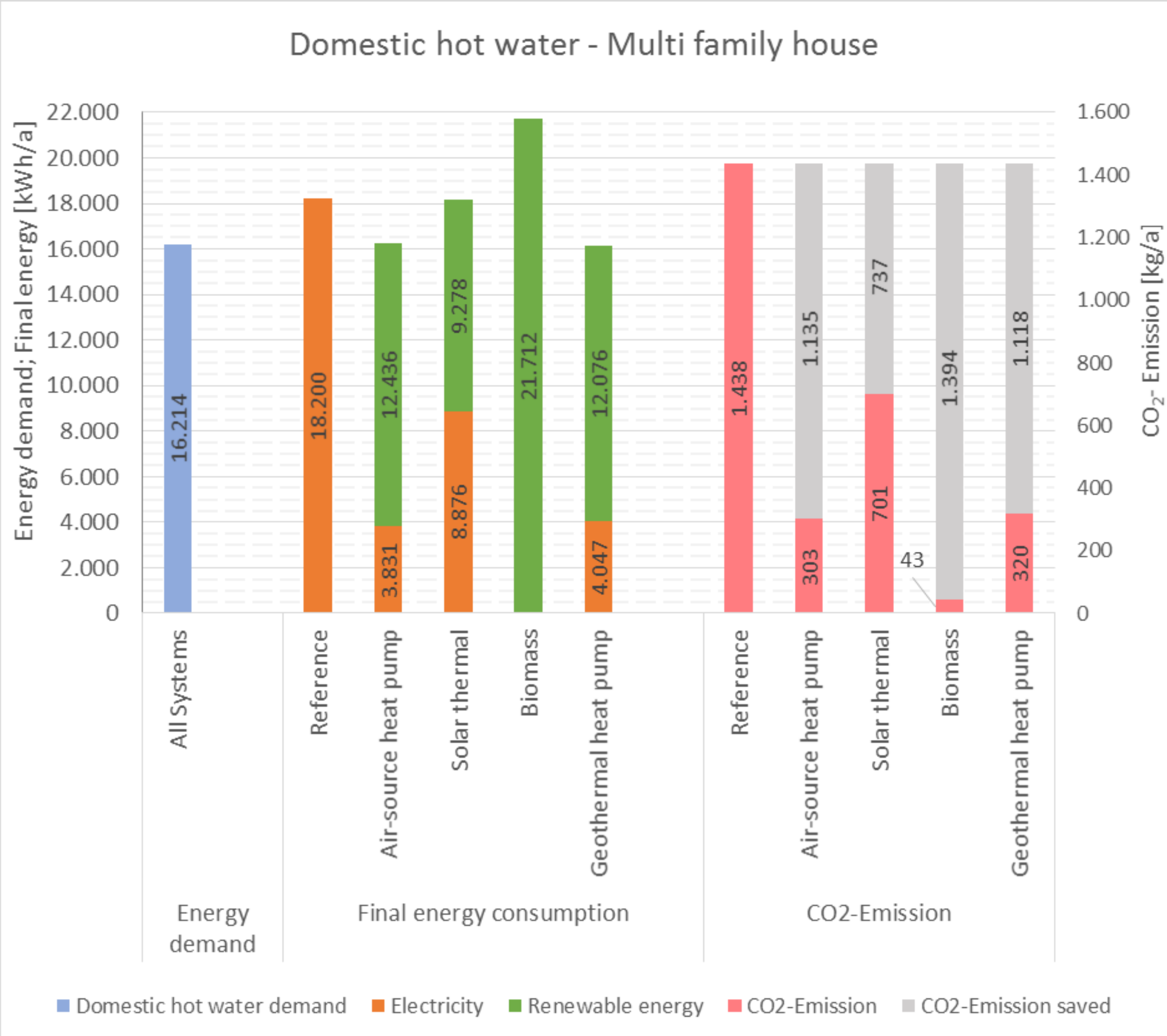

Figure 13: Comparison of all observed heating systems for domestic hot water preparation in multi family houses in Stockholm.

CO_2-emission factor electricity Sweden: 0,079 t CO2/MWh (Appendix B)
CO_2-emission factor biomass: 0,002 t CO2/MWh (Appendix B)

The electrical energy demand of the air source heat pump is very low because the source temperature is considered to be a constant level of 18 °C (indoor air).

3.2 DHW and SH in Stockholm

Heating concepts and the according control systems are described in chapter 2.2.

3.2.1 DHW and SH in new built single family houses

The domestic hot water energy demand of 3.058 kWh and the space heating energy demand of 6.948 kWh are dynamically calculated for the reference new built single family house described in chapter 1. In Figure 14, the primary energy needed to cover the energy demand and the resulting CO_2- emissions of the calculated heating systems are shown.

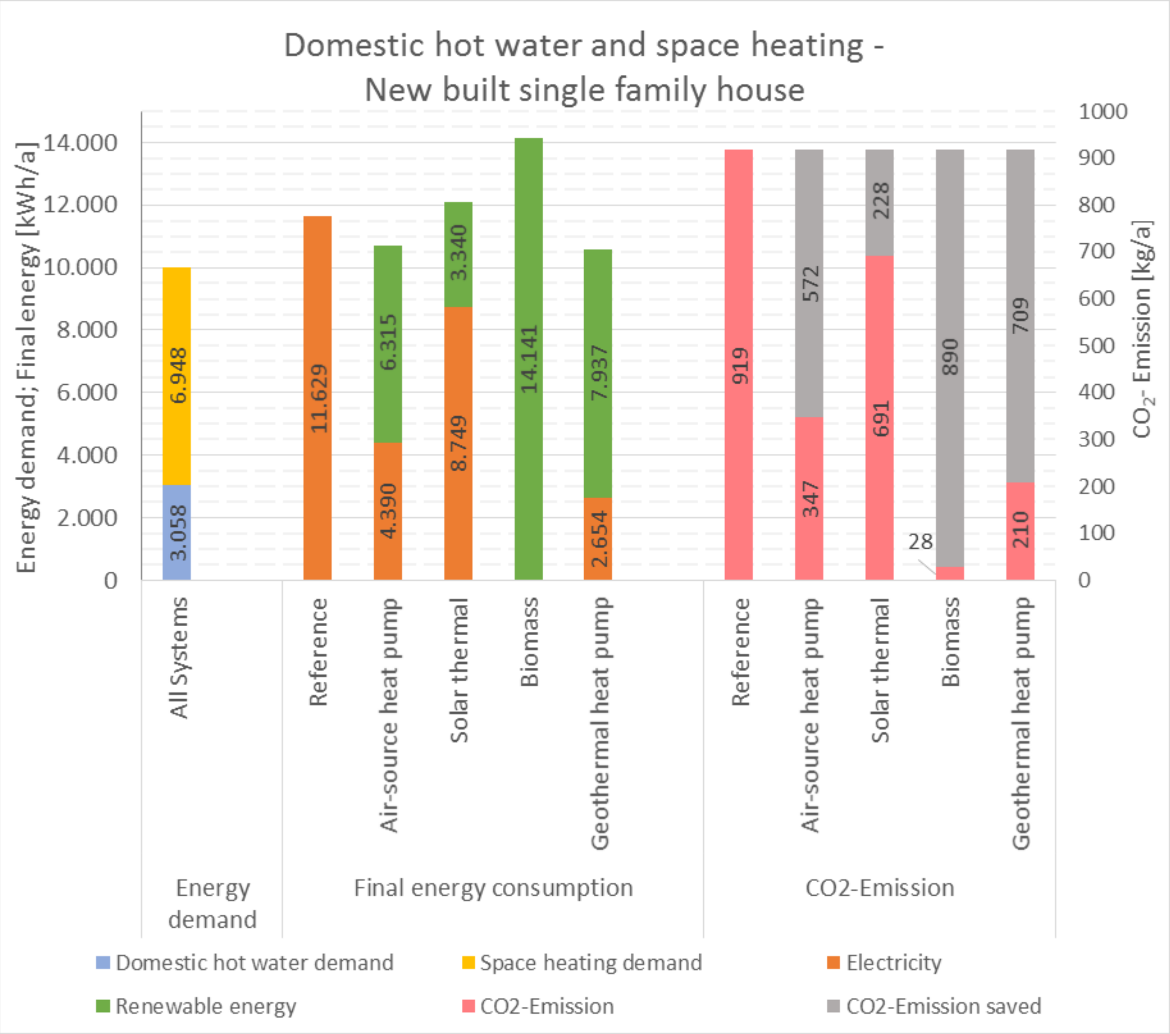

Figure 14: Comparison of all observed heating systems for domestic hot water and space heating preparation in new built single family houses in Stockholm.

CO_2-emission factor electricity Sweden: 0,079 t CO2/MWh (Appendix B)
CO_2-emission factor biomass: 0,002 t CO2/MWh (Appendix B)

3.2.2 DHW and SH in refurbished single family houses

The domestic hot water energy demand of 3.058 kWh and the space heating energy demand of 10.884 kWh are dynamically calculated for the reference refurbished single family house described in chapter 1. In Figure 15, the primary energy needed to cover the energy demand and the resulting CO_2- emissions of the observed heating systems are shown.

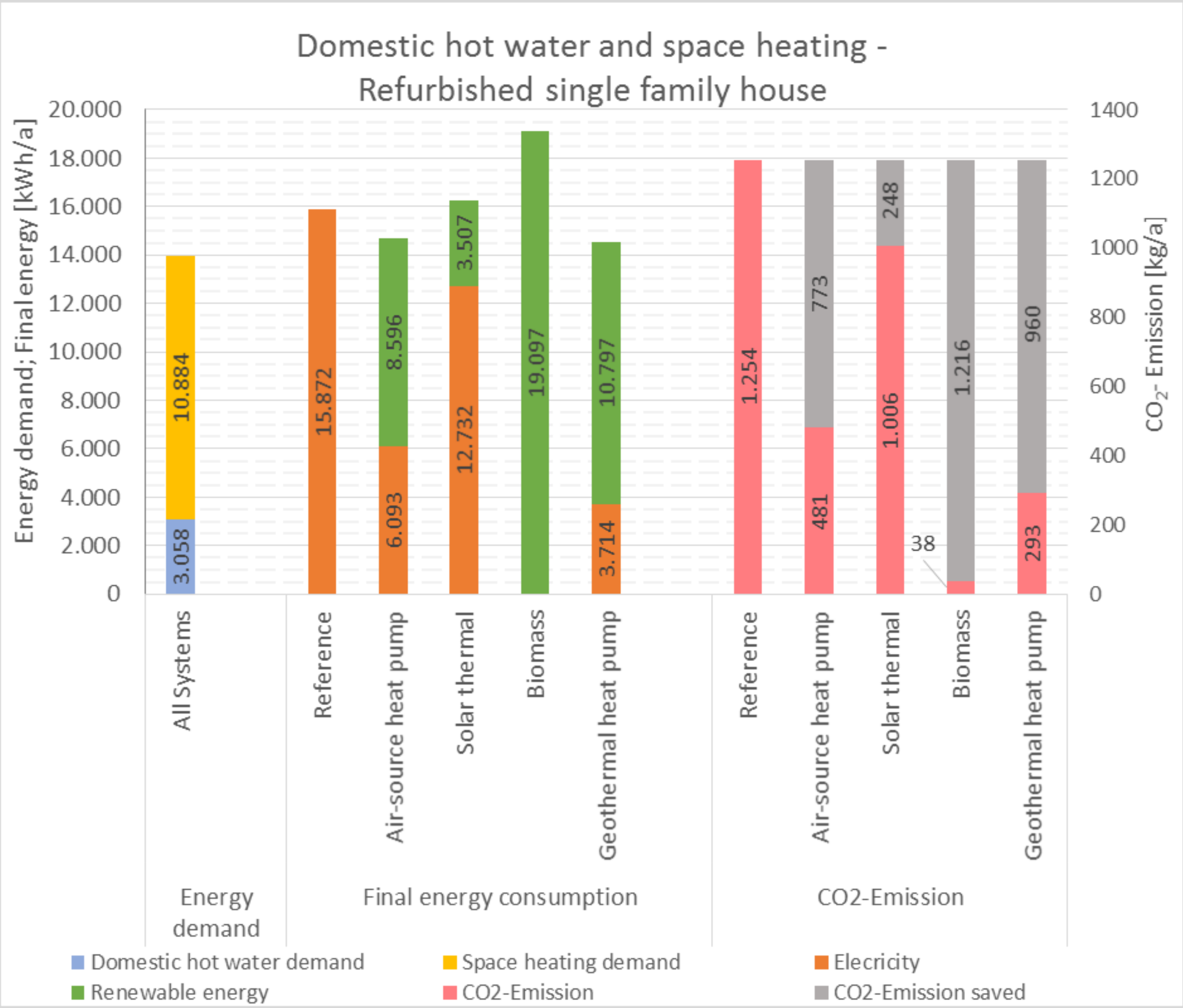

Figure 15: Comparison of all observed heating systems for domestic hot water and space heating preparation in refurbished single family houses in Stockholm.

CO_2-emission factor electricity Sweden: 0,079 t CO2/MWh (Appendix B)
CO_2-emission factor biomass: 0,002 t CO2/MWh (Appendix B)

3.2.3 DHW and SH in new built multi family houses

The domestic hot water energy demand of 16.214 kWh and the space heating energy demand of 49.327 kWh are dynamically calculated for the reference new built multi family house described in chapter 1. In Figure 16, the primary energy needed to cover the energy demand and the resulting CO_2- emissions of the observed heating systems are shown.

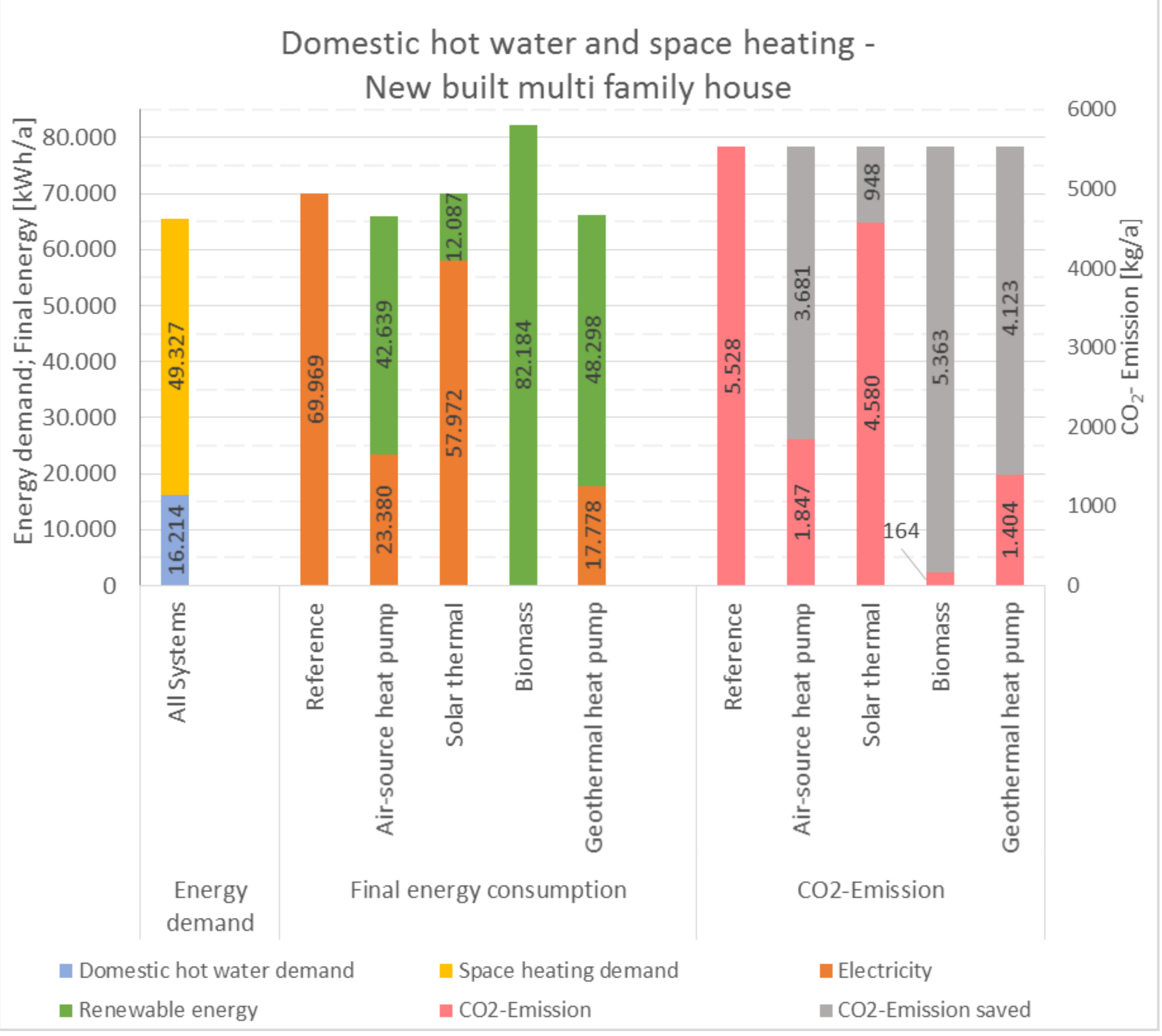

Figure 16: Comparison of all observed heating systems for domestic hot water and space heating preparation in new built multi family houses in Stockholm.

CO_2-emission factor electricity Sweden: 0,079 t CO2/MWh (Appendix B)
CO_2-emission factor biomass: 0,002 t CO2/MWh (Appendix B)

3.2.4 DHW and SH in refurbished multi family houses

The domestic hot water energy demand of 16.214 kWh and the space heating energy demand of 73.327 kWh are dynamically calculated for the reference refurbished multi family house described in chapter 1. In Figure 17, the primary energy needed to cover the energy demand and the resulting CO_2- emissions of the observed heating systems are shown.

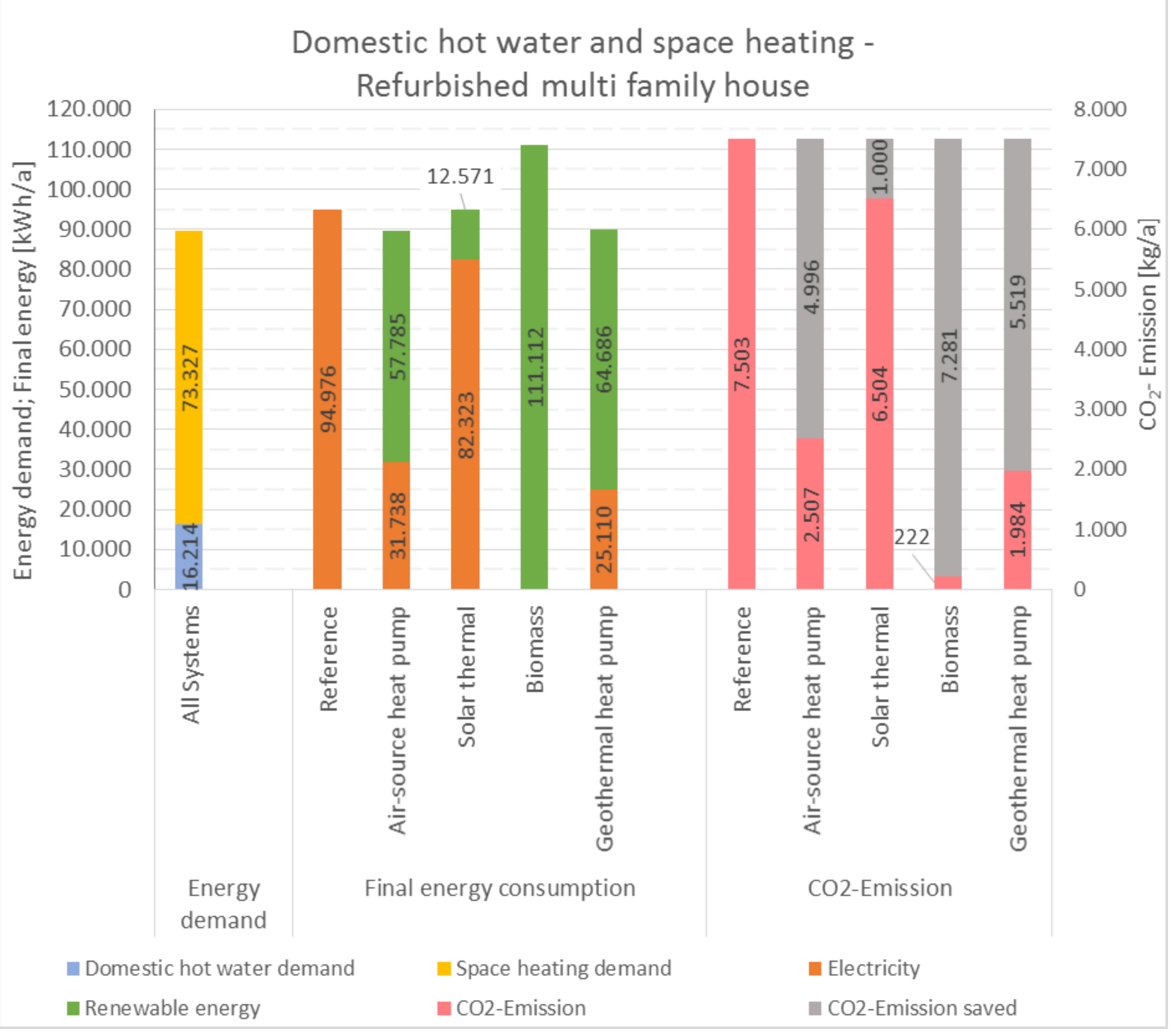

Figure 17: Comparison of all observed heating systems for domestic hot water and space heating preparation in refurbished multi family houses in Stockholm.

CO_2-emission factor electricity Sweden: 0,079 t CO2/MWh (Appendix B)
CO_2-emission factor biomass: 0,002 t CO2/MWh (Appendix B)

4. Vienna

The energy demand for domestic hot water and space heating is summarized in Table 21. Used building parameters are shown in Table 1

Table 21: Energy demand of the reference buildings in Vienna for domestic hot water and space heating.

	Domestic hot water demand (DHW)			Space heating	
Reference building type	Inhabitants (Persons)	Hot water demand (l/d)	**DHW (kWh/a)**	Heated Area (m^2)	**Space heating demand (kWh/a)**
New built SFH	3	150	**2.437**	104	**4.071**
New built MFH	21	1.050	**17.062**	619	**30.882**

In the following chapters primary energy consumptions and the CO_2-emissions of the five different heating systems are calculated for new built single- and multi family houses.

4.1 DHW Vienna

Heating concepts and the according control systems are described in chapter 2.1.

4.1.1 DHW in single family houses

Figure 18 shows the domestic hot water energy demand, final energy consumption and the CO_2-emissions of all calculated heating systems for the reference single family house described in chapter 2.1.

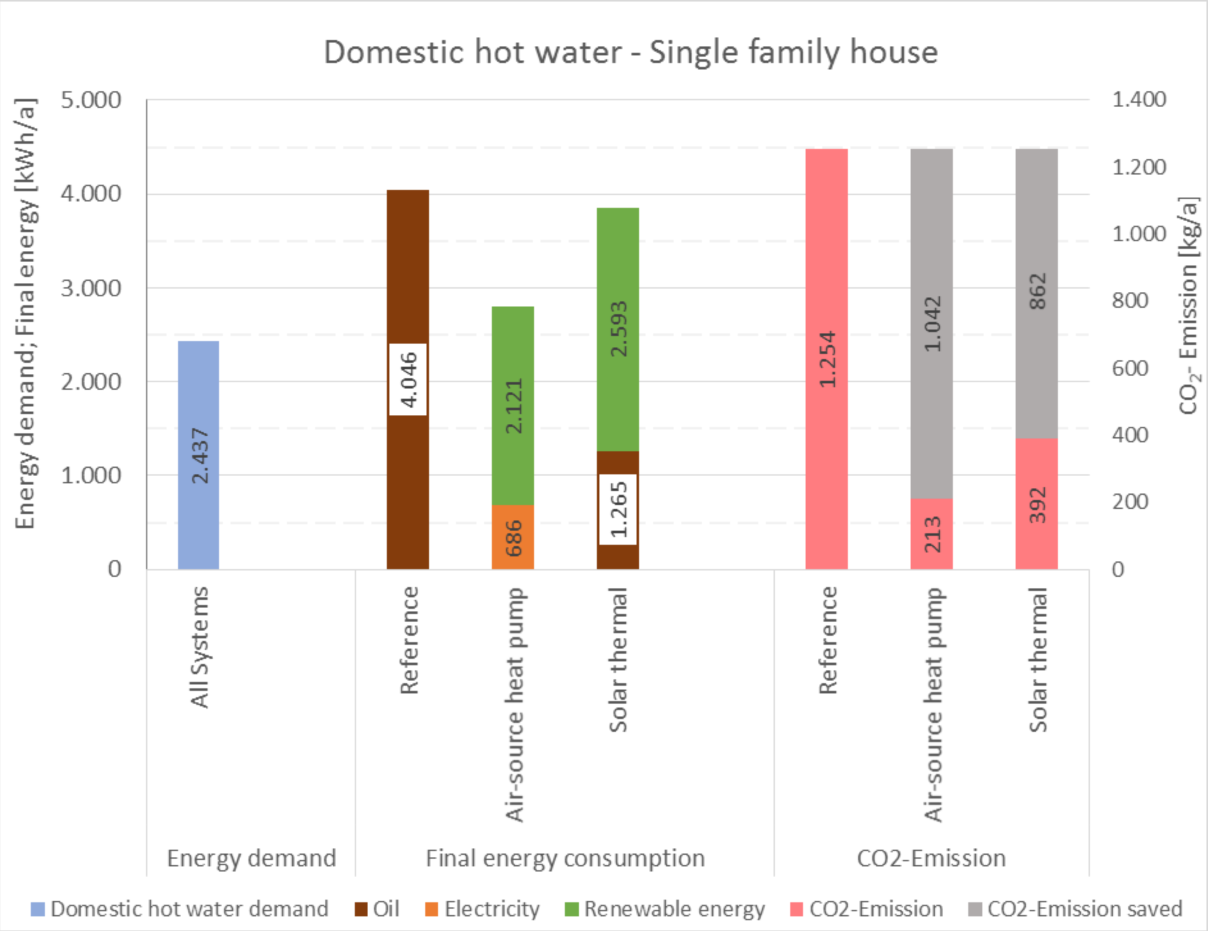

Figure 18: Comparison of all observed heating systems for domestic hot water preparation in single family houses in Vienna.

CO_2-emission factor electricity Austria: 0,310 t CO_2/MWh (Appendix B)
CO_2-emission factor fuel oil: 0,310t CO_2/MWh (Appendix B)

4.1.2 DHW in multi family houses

A comparison of heating systems with focus on domestic hot water energy demand, final energy consumption and CO_2- emission is shown in Figure 19. The calculation is based on the reference multi family house described in chapter 2.1.

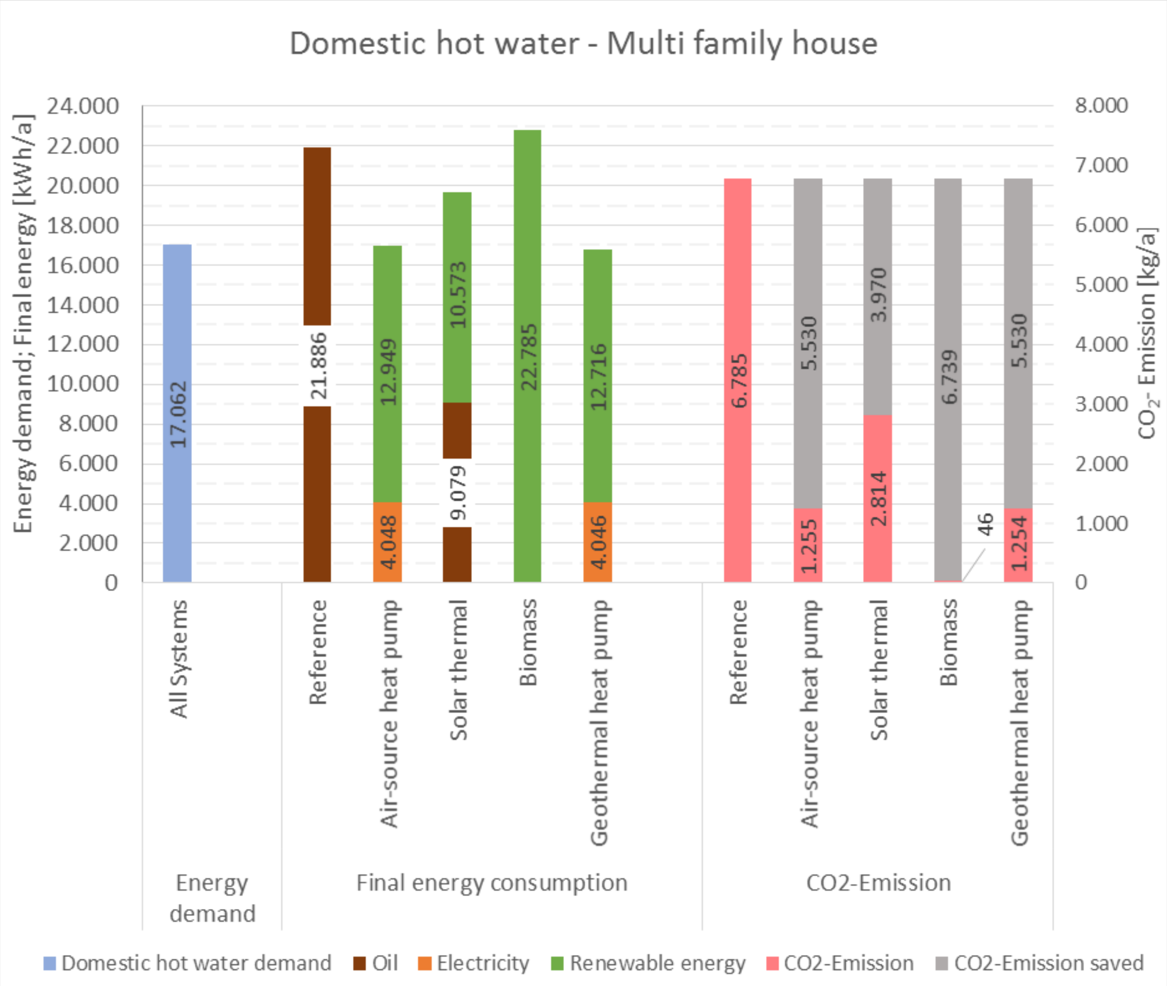

Figure 19: Comparison of all observed heating systems for domestic hot water preparation in multi family houses in Vienna.

CO_2-emission factor electricity Austria: 0,310 t CO_2/MWh (Appendix B)
CO_2-emission factor fuel oil: 0,310t CO_2/MWh (Appendix B)
CO_2-emission factor biomass: 0,002 t CO_2/MWh (Appendix B)

4.2 DHW and SH Vienna

Heating concepts and the according control systems are described in chapter 2.2.

4.2.1 DHW and SH in new built single family houses

The domestic hot water energy demand of 2.437 kWh and the space heating energy demand of 4.071 kWh are dynamically calculated for the reference new built single family house described in chapter 1. In Figure 20, the primary energy needed to cover the energy demand and the resulting CO_2- emissions of the calculated heating systems are shown.

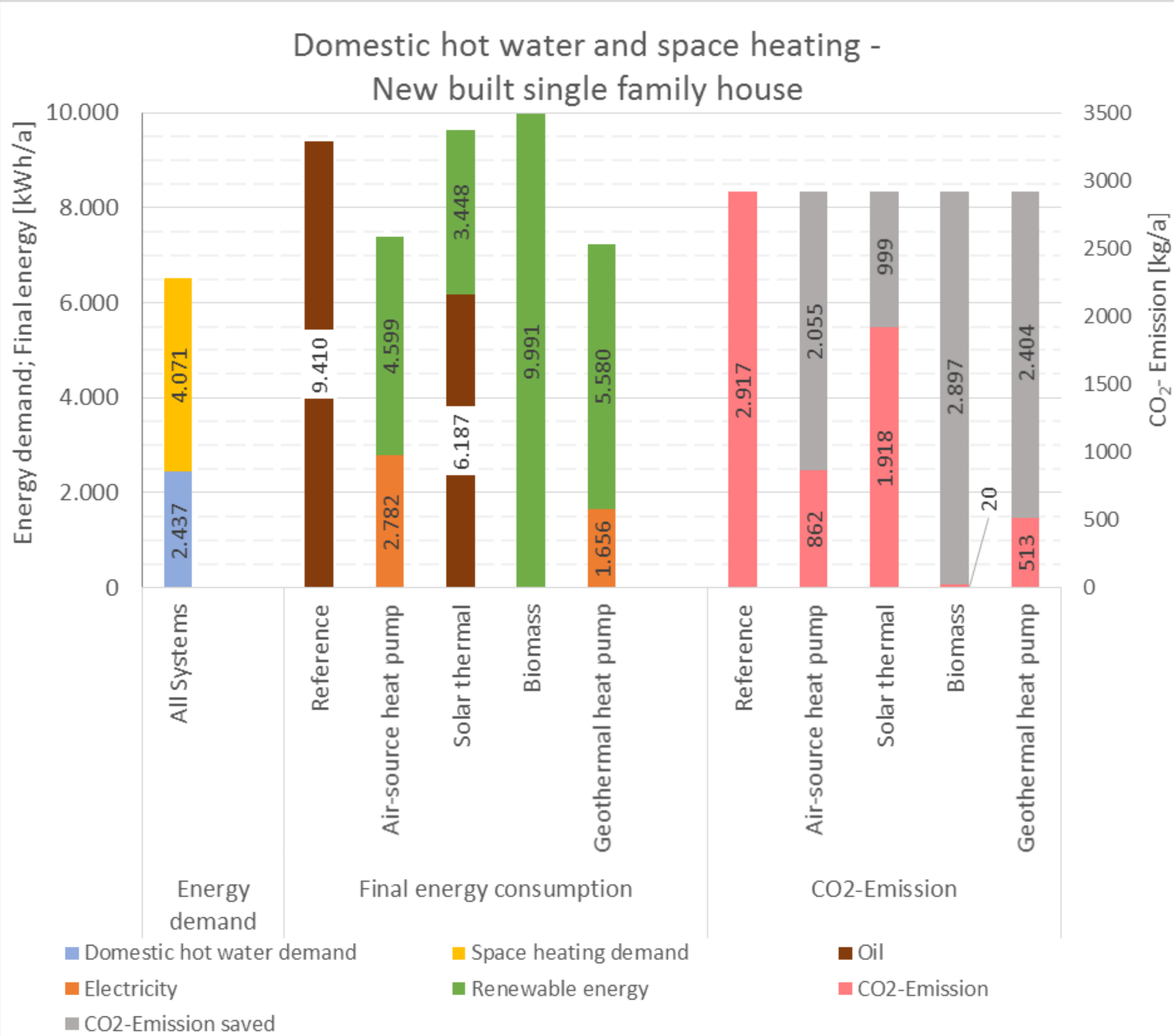

Figure 20: Comparison of all observed heating systems for domestic hot water and space heating preparation in new built single family houses in Vienna.

CO_2-emission factor electricity Austria: 0,310 t CO_2/MWh (Appendix B)
CO_2-emission factor fuel oil: 0,310t CO_2/MWh (Appendix B)
CO_2-emission factor biomass: 0,002 t CO_2/MWh (Appendix B)

4.2.2 DHW and SH in new built multi family houses

The domestic hot water energy demand of 17.062 kWh and the space heating energy demand of 30.882 kWh are dynamically calculated for the reference new built multi family house described in chapter 1. In Figure 21, the primary energy needed to cover the energy demand and the resulting CO_2- emissions of the observed heating systems are shown.

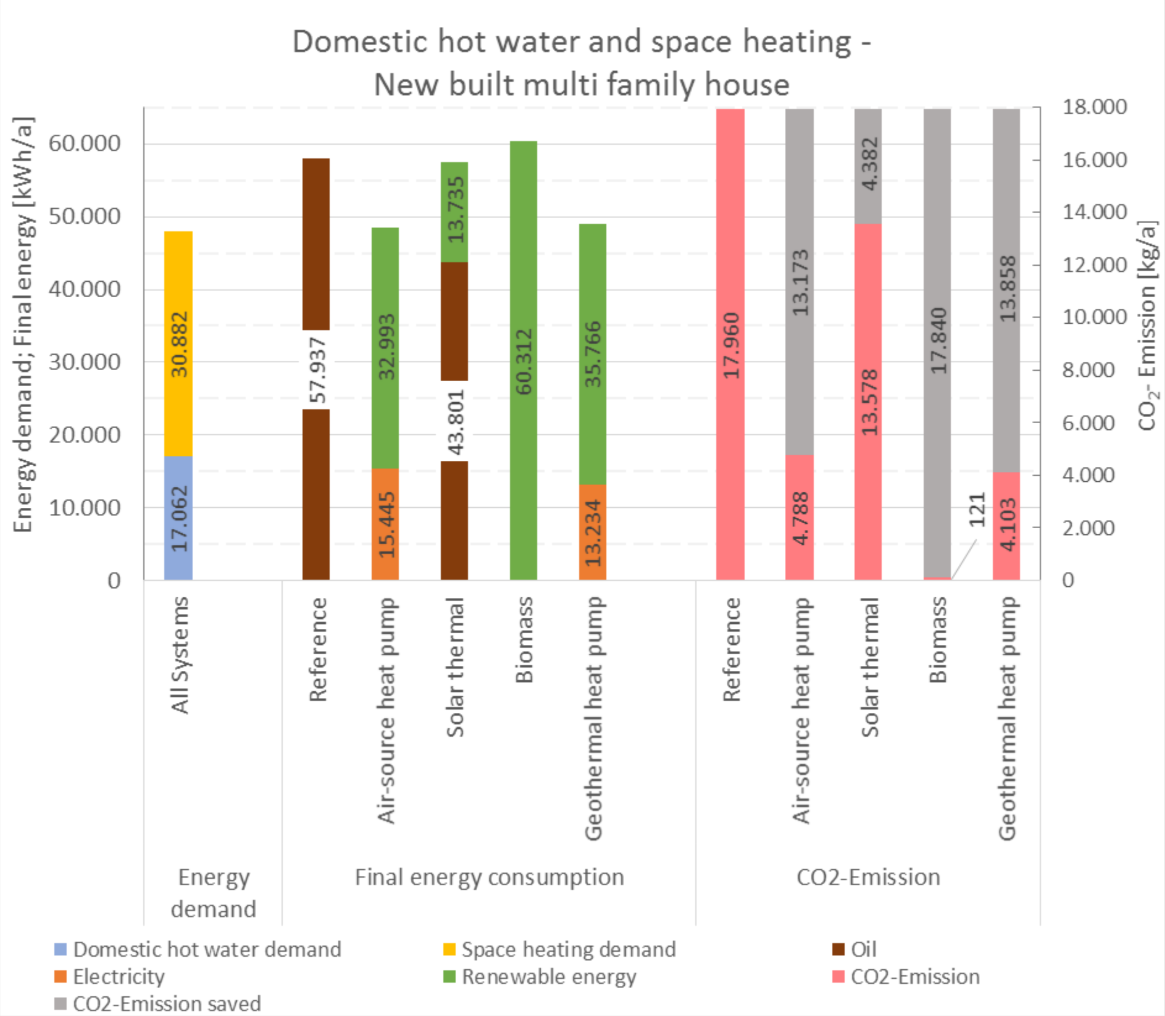

Figure 21: Comparison of all observed heating systems for domestic hot water and space heating preparation in new built multi family houses in Vienna.

CO_2-emission factor electricity Austria: 0,310 t CO_2/MWh (Appendix B)
CO_2-emission factor fuel oil: 0,310t CO_2/MWh (Appendix B)
CO_2-emission factor biomass: 0,002 t CO_2/MWh (Appendix B)

5. Würzburg

The energy demand for domestic hot water and space heating is summarized in Table 2. Used building parameters are shown in Table 1

Table 22: Energy demand of the reference buildings in Würzburg for domestic hot water and space heating.

	Domestic hot water demand (DHW)			**Space heating**	
Reference building type	Inhabitants (Persons)	Hot water demand (l/d)	**DHW (kWh/a)**	Heated Area (m²)	**Space heating demand (kWh/a)**
Refurbished SFH	3	150	**2.600**	104	**8.483**
Refurbished MFH	21	1.050	**18.206**	619	**59.146**

In the following chapters primary energy consumptions and the CO_2-emissions of the five different heating systems are calculated for new built single- and multi family houses.

5.1 DHW Würzburg

Heating concepts and the according control systems are described in chapter 2.1.

5.1.1 DHW in single family houses

Figure 22 shows the domestic hot water energy demand, final energy consumption and the CO_2-emissions of all calculated heating systems for the reference single family house described in chapter 2.1.

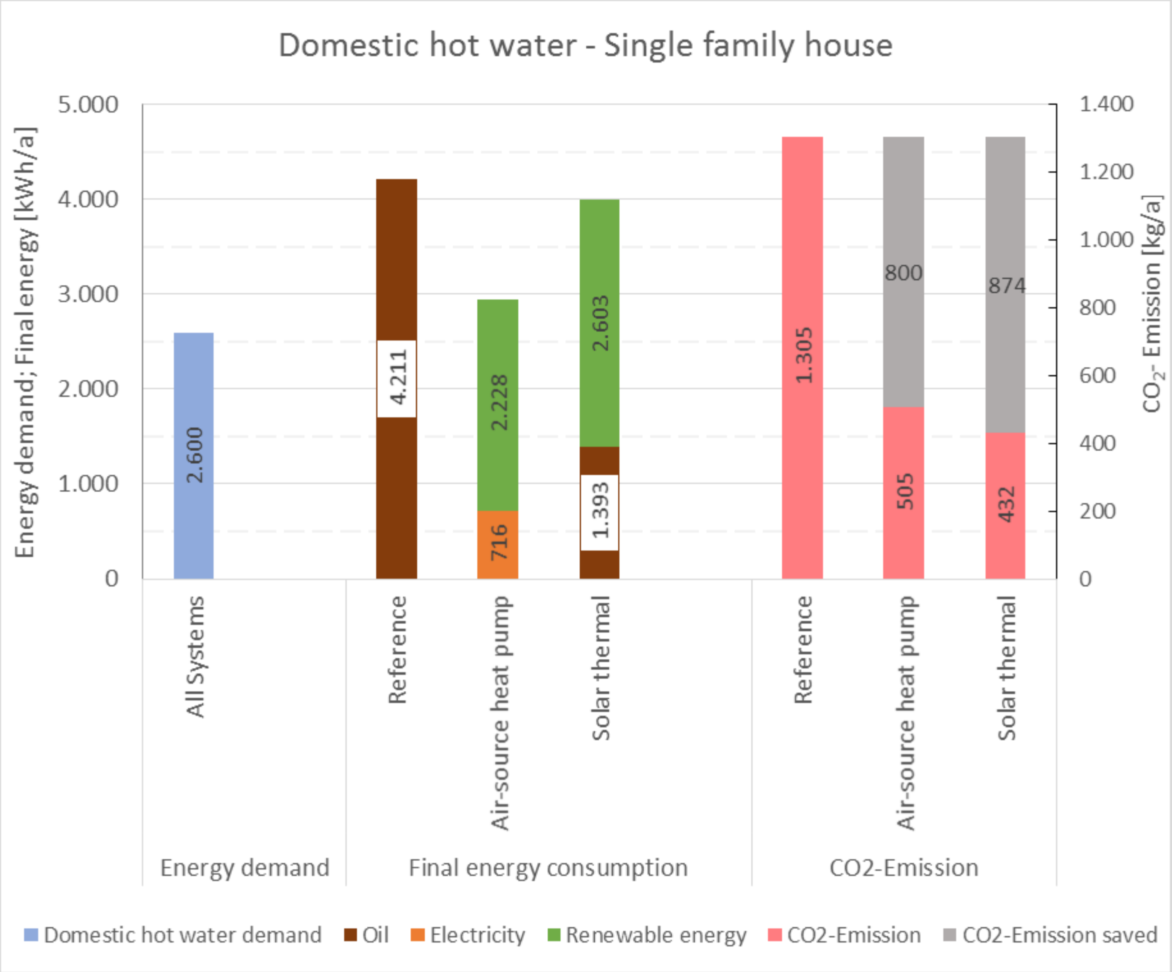

Figure 22: Comparison of all observed heating systems for domestic hot water preparation in single family houses in Würzburg.

CO_2-emission factor electricity Germany: 0,706 t CO_2/MWh (Appendix B)
CO_2-emission factor fuel oil: 0,310 t CO_2/MWh (Appendix B)

5.1.2 DHW in multi family houses

A comparison of heating systems with focus on domestic hot water energy demand, final energy consumption and CO_2- emission is shown in Figure 23. The calculation is based on the reference multi family house described in chapter 2.1.

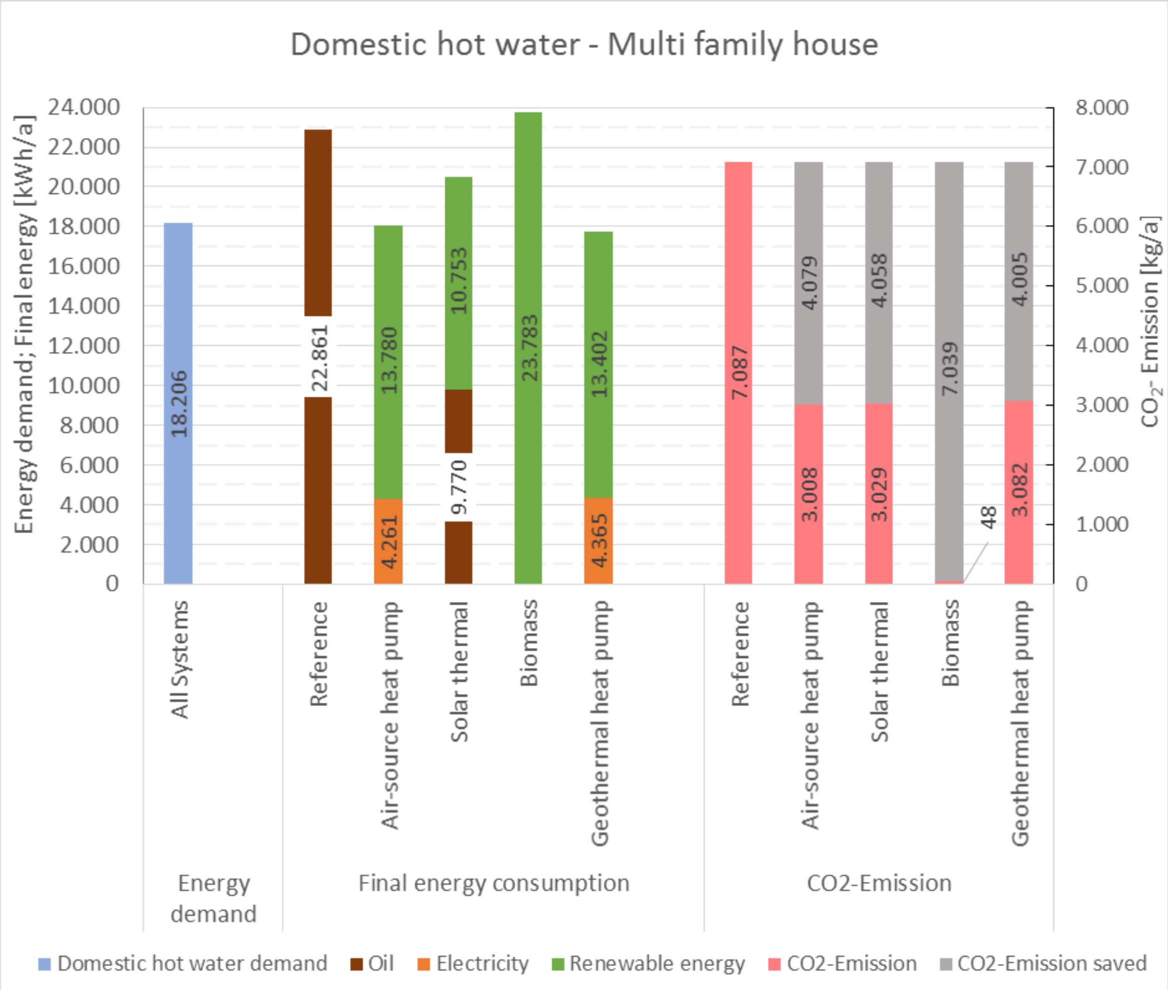

Figure 23: Comparison of all observed heating systems for domestic hot water preparation in multi family houses in Würzburg.

CO2-emission factor electricity Germany: 0,706 t CO_2/MWh (Appendix B)
CO2-emission factor fuel oil: 0,310 t CO_2/MWh (Appendix B)
CO2-emission factor biomass: 0,002 t CO_2/MWh (Appendix B)

5.2 DHW and SH Würzburg

Heating concepts and the according control systems are described in chapter 2.2.

5.2.1 DHW and SH in refurbished single family houses

The domestic hot water energy demand of 2.600 kWh and the space heating energy demand of 8.483 kWh are dynamically calculated for the reference refurbished single family house described in chapter 1. In Figure 24, the primary energy needed to cover the energy demand and the resulting CO_2- emissions of the calculated heating systems are shown.

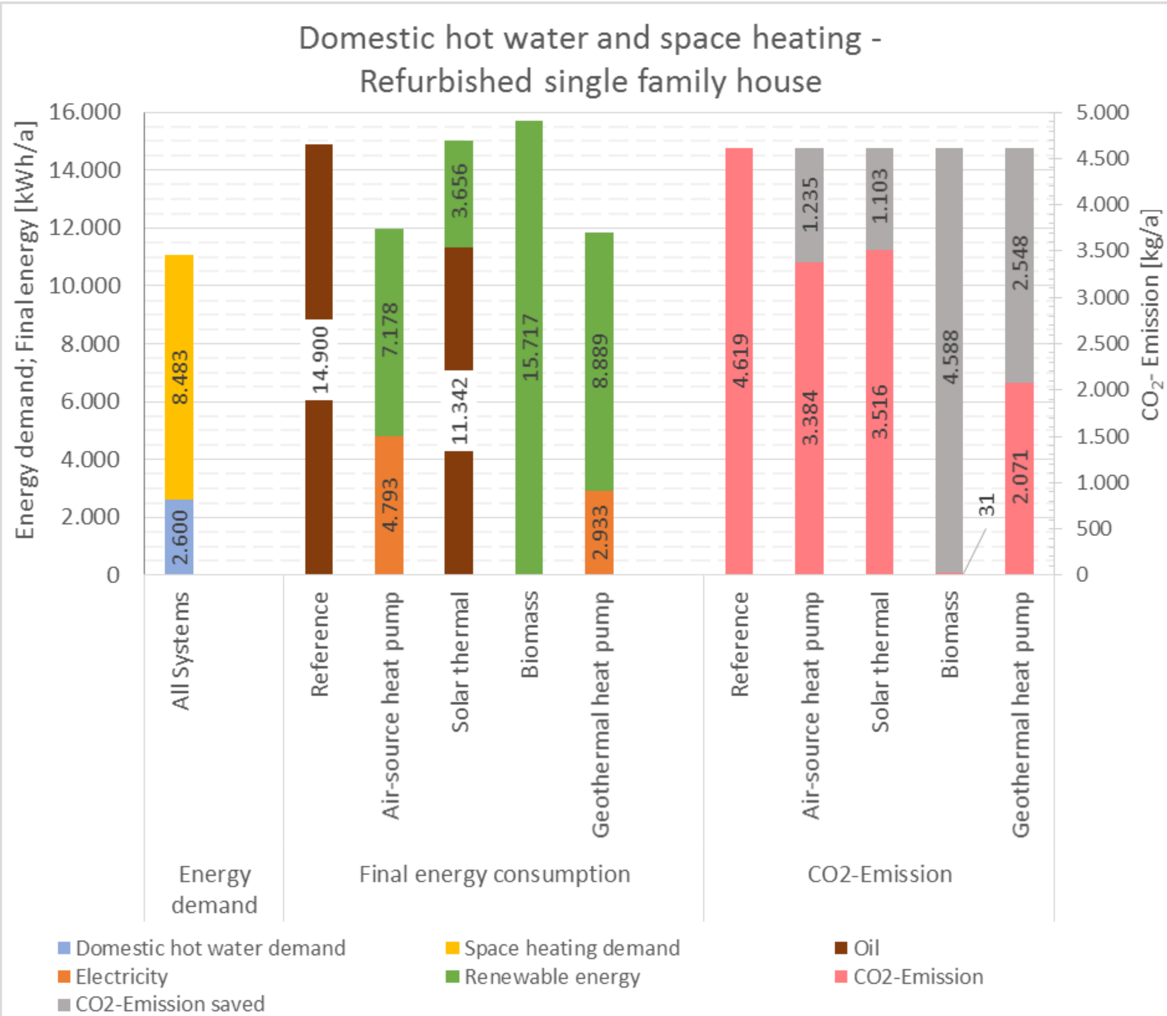

Figure 24: Comparison of all observed heating systems for domestic hot water and space heating preparation in refurbished single family houses in Würzburg.

CO2-emission factor electricity Germany: 0,706 t CO_2/MWh (Appendix B)
CO2-emission factor fuel oil: 0,310 t CO_2/MWh (Appendix B)
CO2-emission factor biomass: 0,002 t CO_2/MWh (Appendix B)

5.2.2 DHW and SH in refurbished multi family houses

The domestic hot water energy demand of 18.206 kWh and the space heating energy demand of 59.146 kWh are dynamically calculated for the reference refurbished multi family house described in chapter 1. In Figure 25, the primary energy needed to cover the energy demand and the resulting CO_2- emissions of the observed heating systems are shown.

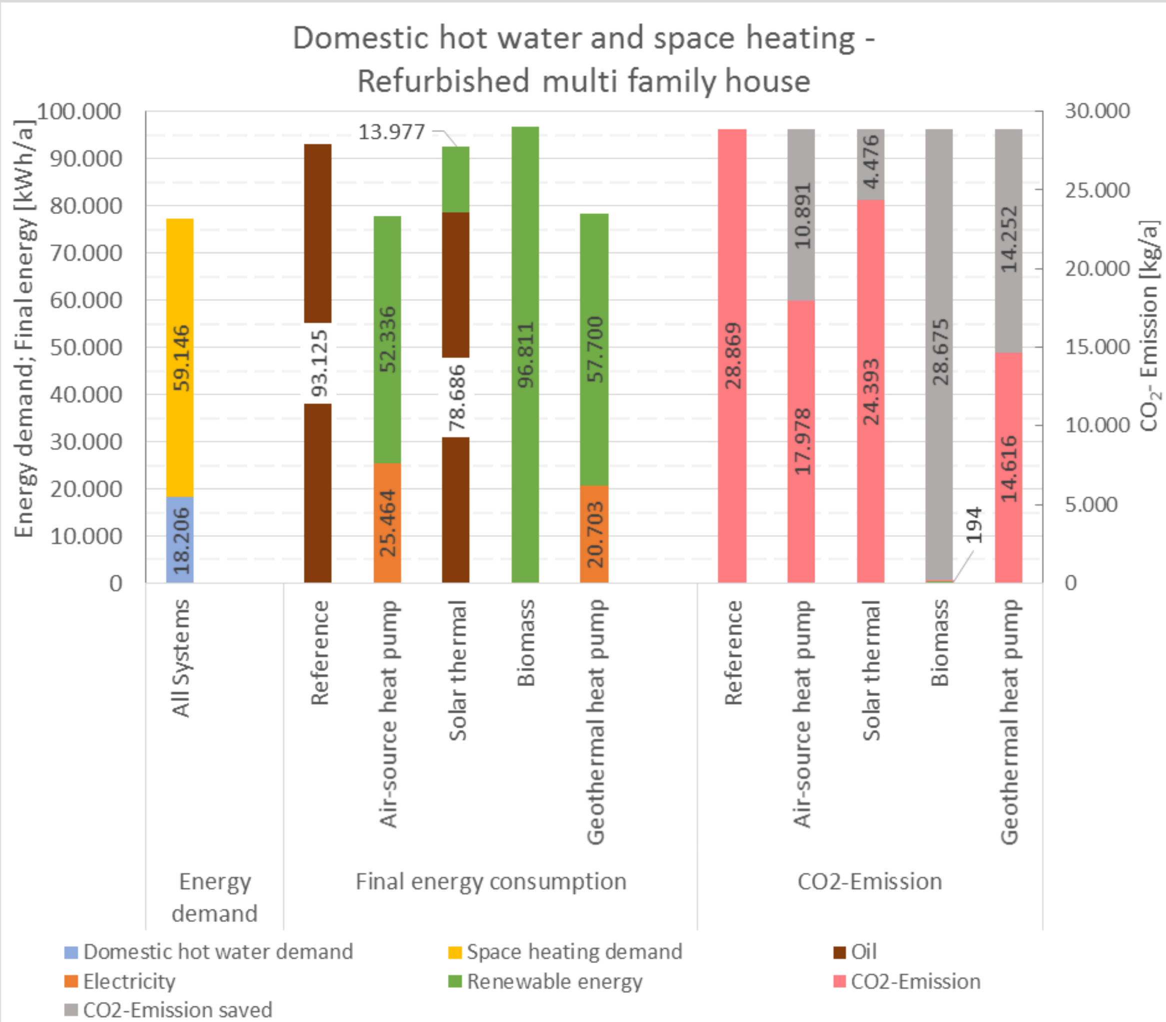

Figure 25: Comparison of all observed heating systems for domestic hot water and space heating preparation in refurbished multi family houses in Würzburg.

CO2-emission factor electricity Germany: 0,706 t CO_2/MWh (Appendix B)
CO2-emission factor fuel oil: 0,310 t CO_2/MWh (Appendix B)
CO2-emission factor biomass: 0,002 t CO_2/MWh (Appendix B)

6. Madrid

The energy demand for domestic hot water, space heating and space cooling is summarized in Table 23. Used building parameters are shown in Table 2

Table 23: Energy demand of the reference buildings in Madrid for domestic hot water, space heating and space cooling

	Domestic hot water demand (DHW)			Space heating / cooling		
Reference building type	Inhabitants (Persons)	Hot water demand (l/d)	**DHW (kWh/a)**	Heated Area (m^2)	**Space heating demand (kWh/a)**	**Space cooling demand (kWh/a)**
New built SFH	4	210	**3.067**	104	**3.211**	**2.485**
Refurbished SFH	4	210	**3.067**	104	**5.379**	**2.594**
MFH	21	1.100	**16.066**			

In the following chapters primary energy consumptions and the CO_2-emissions of the five different heating systems are calculated for new built- and refurbished single family houses.

6.1 DHW Madrid

Heating and cooling concepts and the according control systems are described in chapter 2.1.

6.1.1 DHW in single family houses

Figure 26 shows the domestic hot water energy demand, final energy consumption and the CO_2-emissions of all calculated heating systems for the reference single family house described in chapter 2.1.

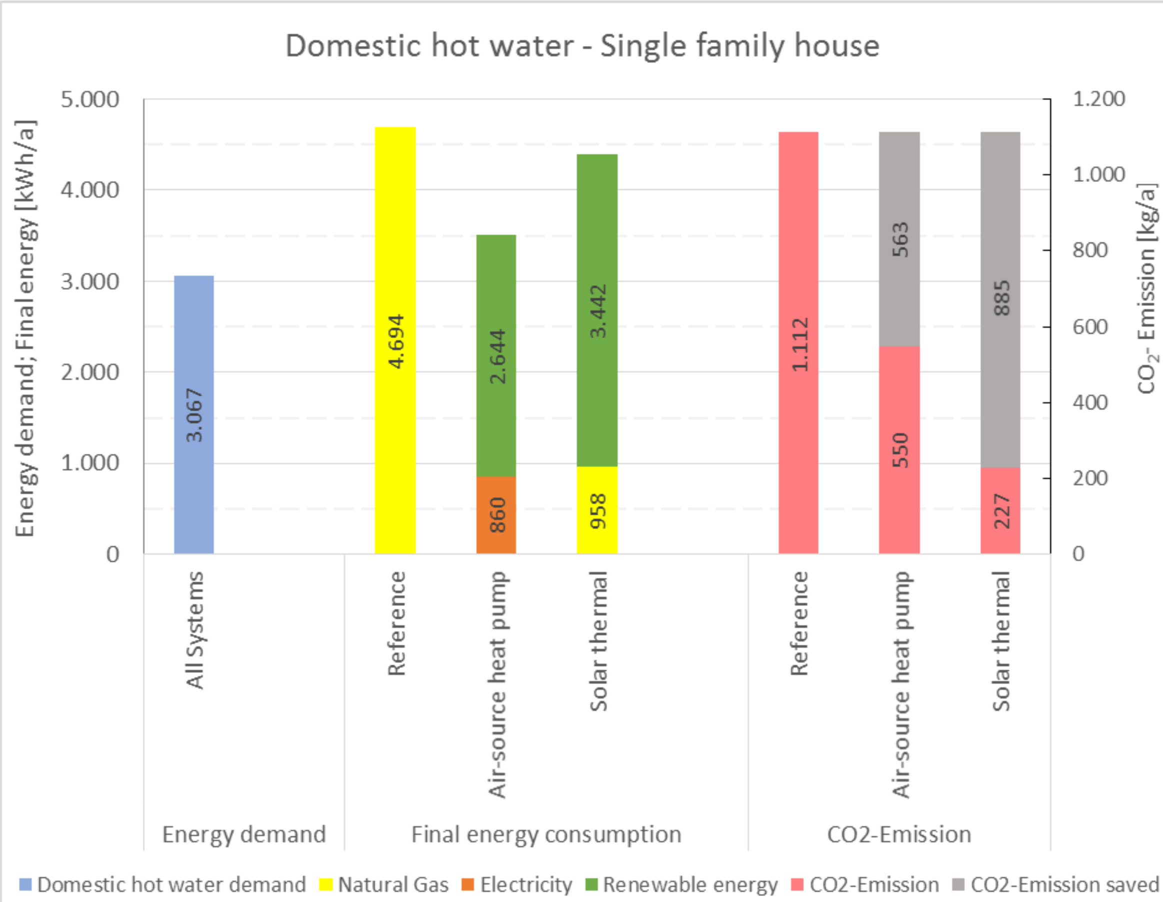

Figure 26: Comparison of all observed heating systems for domestic hot water preparation in single family houses in Madrid.

CO_2-emission factor electricity Spain: 0,639 t CO_2/MWh (Appendix B)
CO_2-emission factor natural gas: 0,237 t CO_2/MWh (Appendix B)

6.1.2 DHW in multi family houses

A comparison of heating systems with focus on domestic hot water energy demand, final energy consumption and CO_2- emission is shown in Figure 27. The calculation is based on the reference multi family house described in chapter 2.1.

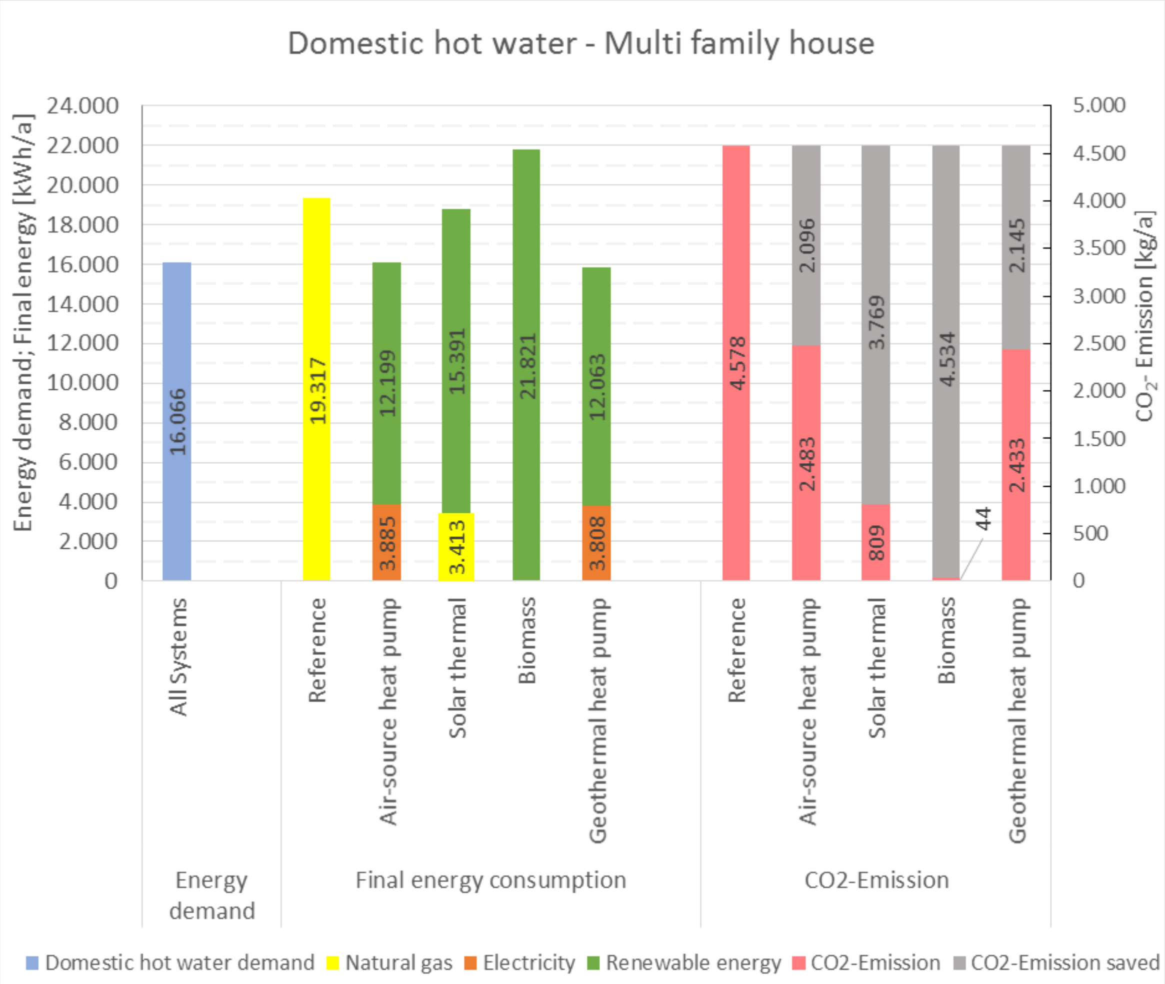

Figure 27: Comparison of all observed heating systems for domestic hot water preparation in multi family houses in Madrid.

CO_2-emission factor electricity Spain: 0,639 t CO_2/MWh (Appendix B)
CO_2-emission factor natural gas: 0,237 t CO_2/MWh (Appendix B)
CO_2-emission factor biomass: 0,002 t CO_2/MWh (Appendix B)

6.2 DHW, SH and SC Madrid

Heating and cooling concepts are described in chapter 2.3.

6.2.1 DHW, SH and SC in new built single family houses

The domestic hot water energy demand of 3.067 kWh, the space heating energy demand of 3.211 kWh and the space cooling energy demand of 2.485 kWh are dynamically calculated for the reference new built single family house in southern Europe described in chapter 1. In Figure 28 the primary energy needed to cover the energy demand and the resulting CO2- emissions of the calculated heating systems are shown. The consumed final energy for heating includes domestic hot water and space heating.

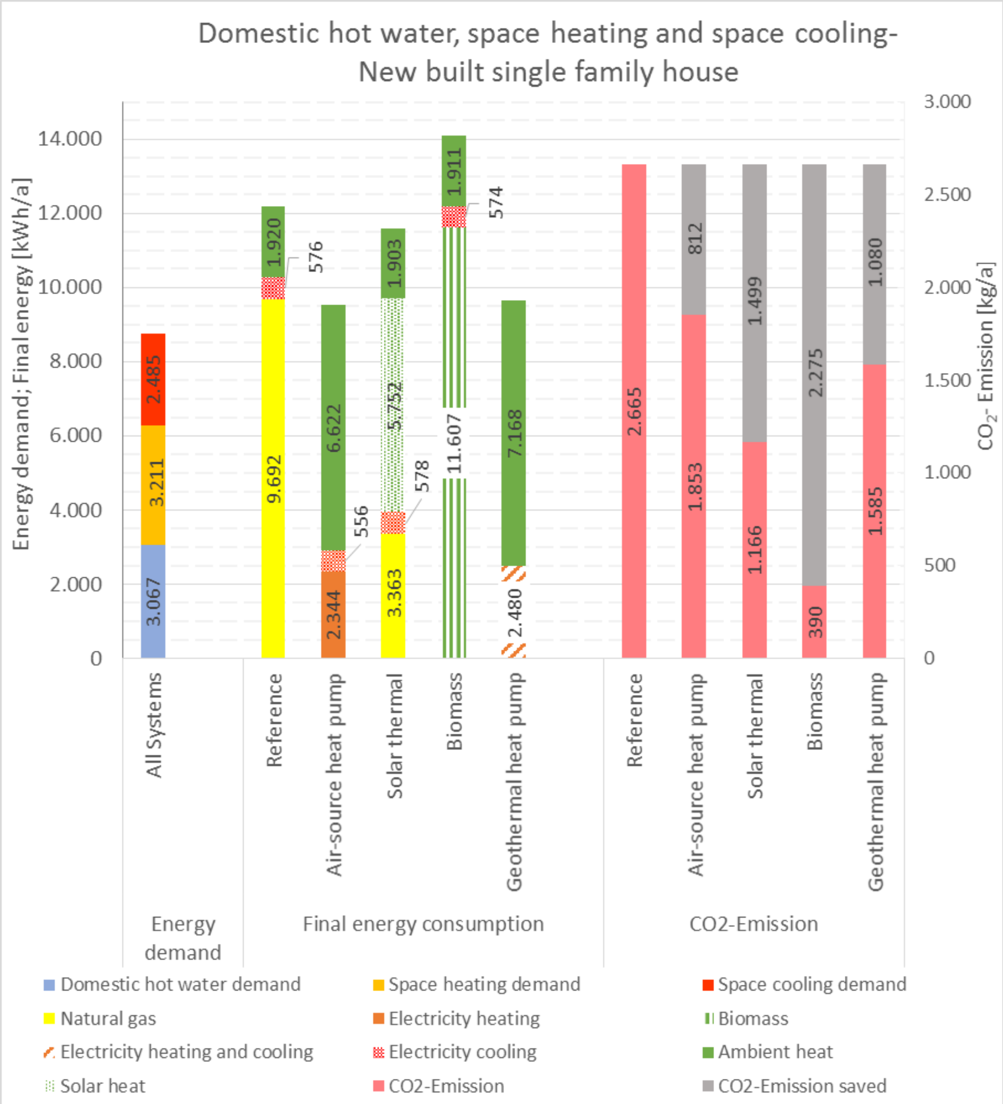

Figure 28: Comparison of all observed heating systems for domestic hot water, space heating and space cooling in new built single family houses in Madrid.

CO_2-emission factor electricity Spain: 0,639 t CO_2/MWh (Appendix B)
CO_2-emission factor natural gas: 0,237 t CO_2/MWh (Appendix B)
CO_2-emission factor biomass: 0,002 t CO_2/MWh (Appendix B)

6.2.2 DHW, SH and SC in refurbished single family houses

The domestic hot water energy demand of 3.067 kWh, the space heating energy demand of 5.379 kWh and the space cooling energy demand of 2.594 kWh are dynamically calculated for the refurbished single family house in southern Europe described in chapter 1. In Figure 29 the primary energy needed to cover the energy demand and the resulting CO2-emissions of the observed heating systems are shown. The consumed final energy for heating includes domestic hot water and space heating.

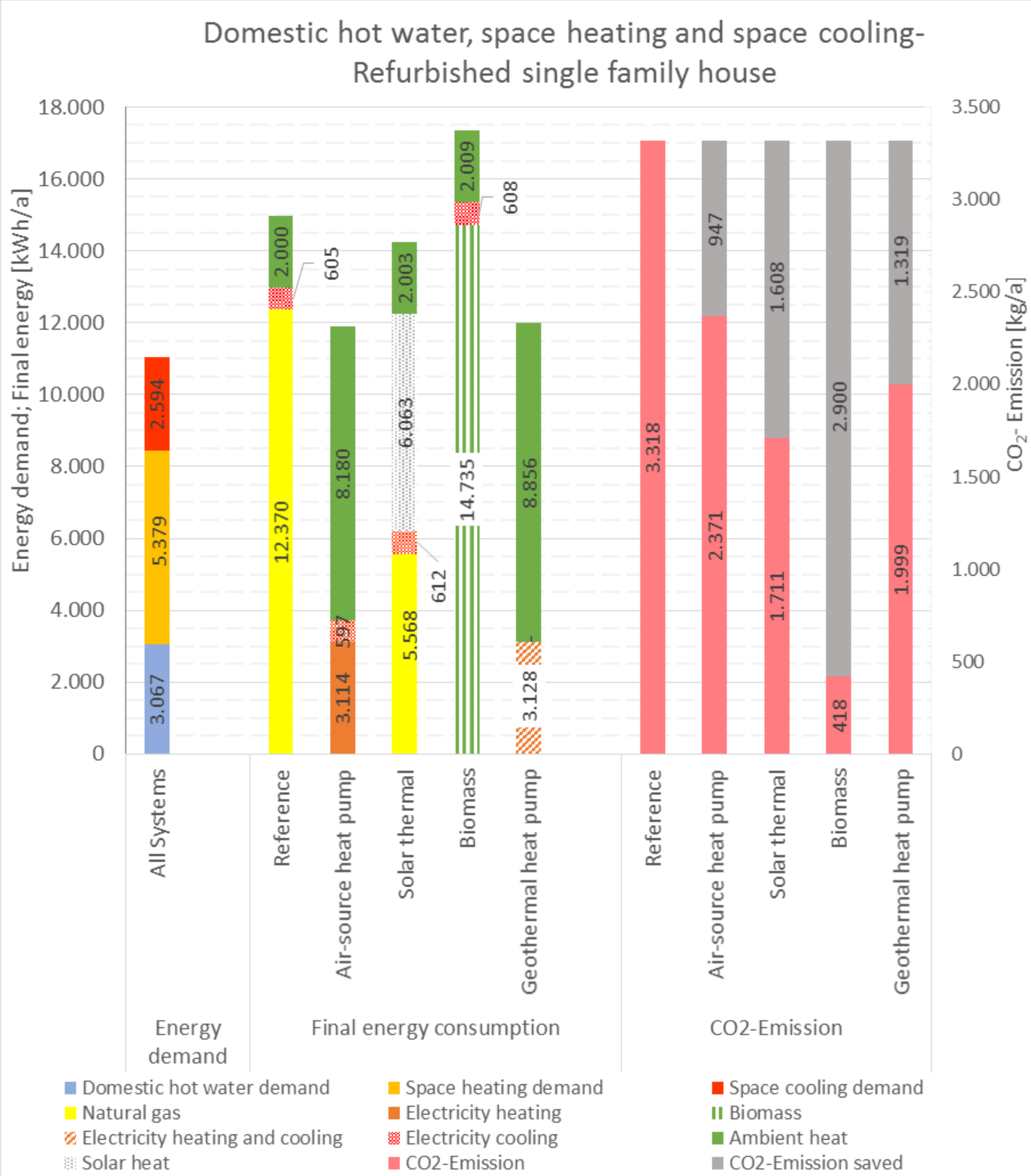

Figure 29: Comparison of all observed heating systems for domestic hot water, space heating and space cooling in refurbished single family houses in Madrid.

CO_2-emission factor electricity Spain: 0,639 t CO_2/MWh (Appendix B)
CO_2-emission factor natural gas: 0,237 t CO_2/MWh (Appendix B)
CO_2-emission factor biomass: 0,002 t CO_2/MWh (Appendix B)

7. Athens

The energy demand for domestic hot water, space heating and space cooling is summarized in Table 24. Used building parameters are shown in Table 2

Table 24: Energy demand of the reference buildings in Athens for domestic hot water, space heating and space cooling.

	Domestic hot water demand (DHW)			**Space heating / cooling**		
Reference building type	Inhabitants (Persons)	Hot water demand (l/d)	**DHW (kWh/a)**	Heated Area (m²)	**Space heating demand (kWh/a)**	**Space cooling demand (kWh/a)**
New built MFH	21	1.100	**14.911**	619	**14.279**	**11.118**
Refurbished MFH	21	1.100	**14.911**	619	**22.983**	**12.290**
SFH	4	210	**2.847**			

In the following chapters primary energy consumptions and the CO_2-emissions of the five different heating systems are calculated for new built- and refurbished multi family houses.

7.1 DHW Athens

Heating concepts and the according control systems are described in chapter 2.1.

7.1.1 DHW in single family houses

Figure 30 shows the domestic hot water energy demand, final energy consumption and the CO_2-emissions of all calculated heating systems for the reference single family house described in chapter 2.1.

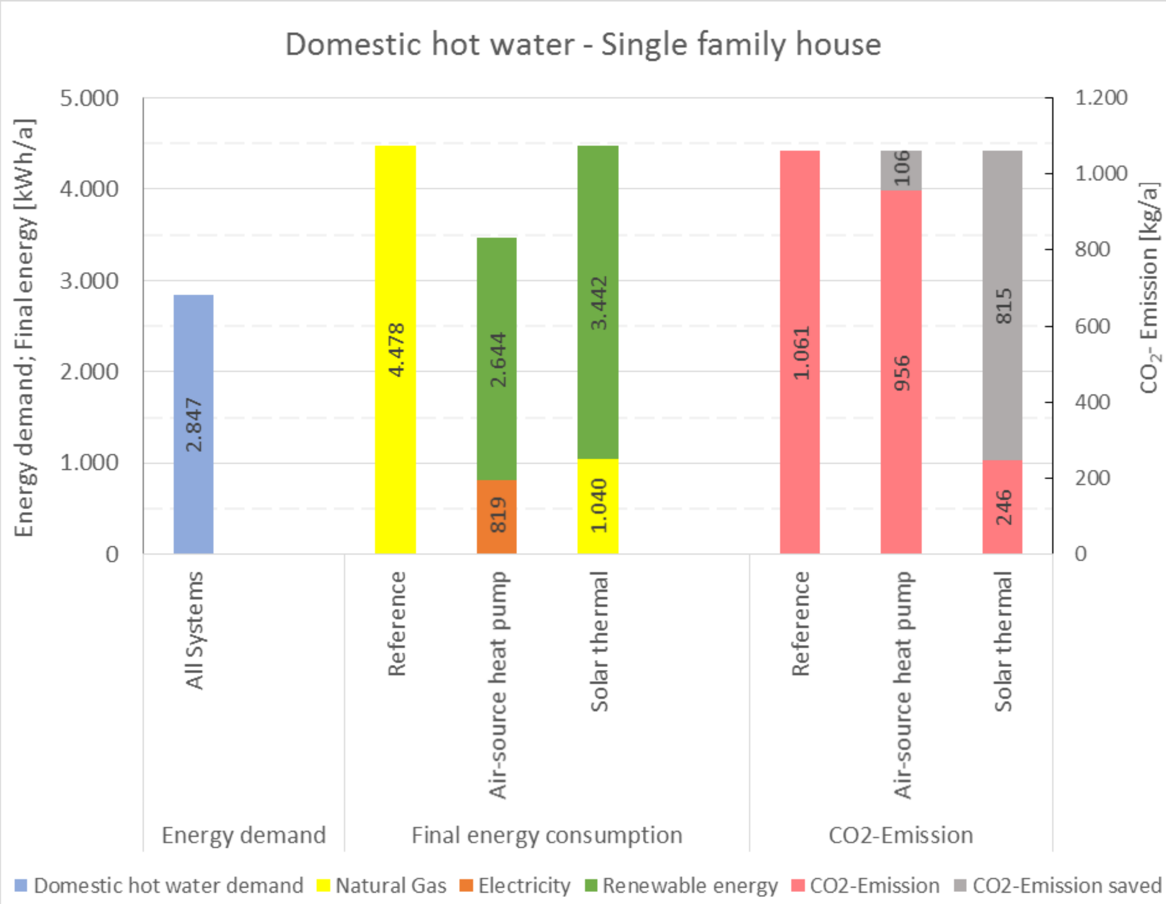

Figure 30: Comparison of all observed heating systems for domestic hot water preparation in single family houses in Athens.

CO_2-emission factor electricity Greece: 1,167 t CO_2/MWh (Appendix B)
CO_2-emission factor natural gas: 0,237 t CO_2/MWh (Appendix B)

7.1.2 DHW in multi family house

A comparison of heating systems with focus on domestic hot water energy demand, final energy consumption and CO_2- emission is shown in Figure 31. The calculation is based on the reference multi family house described in chapter 2.1.

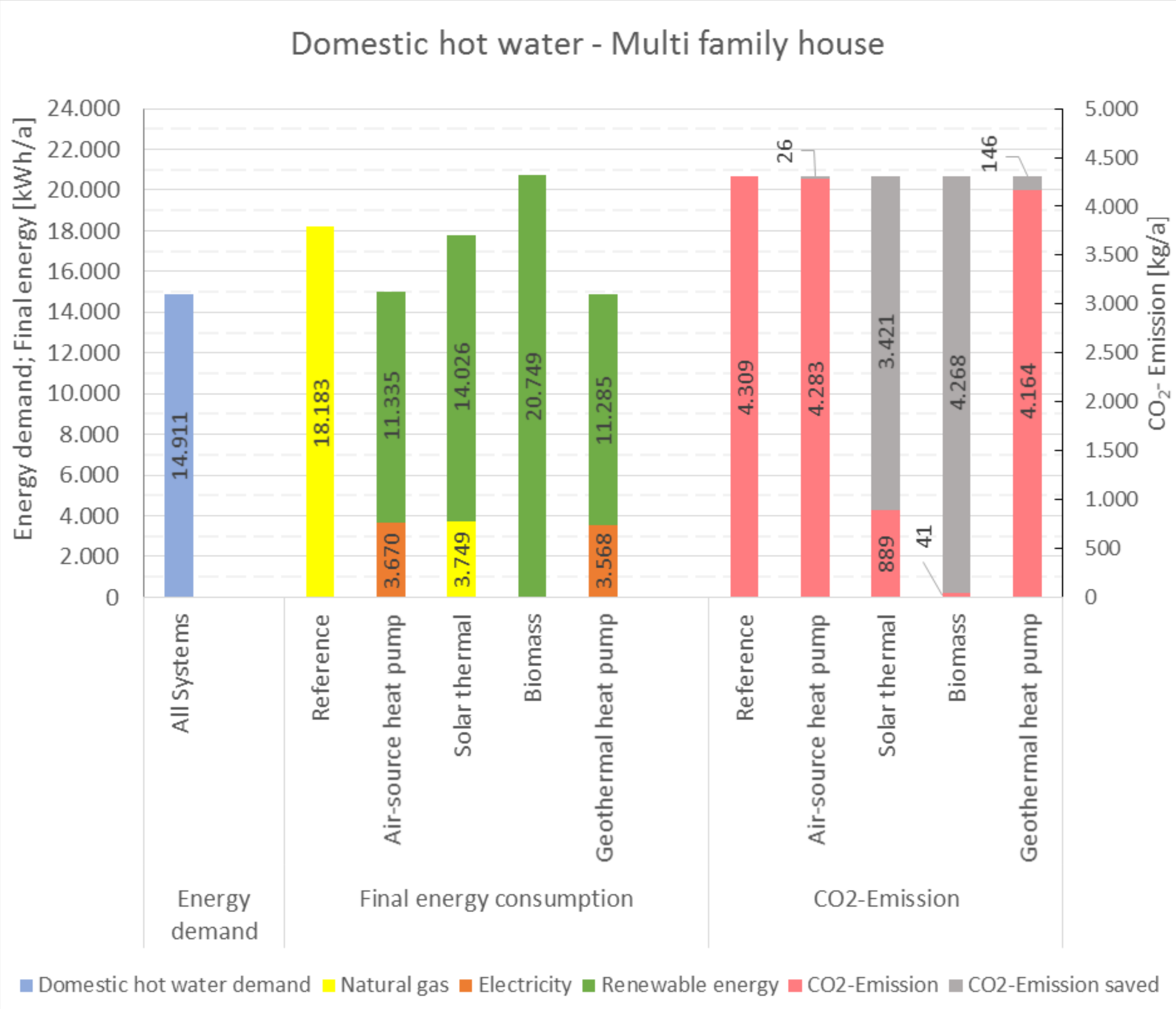

Figure 31: Comparison of all observed heating systems for domestic hot water preparation in multi family houses in Athens.

CO_2-emission factor electricity Greece: 1,167 t CO_2/MWh (Appendix B)
CO_2-emission factor natural gas: 0,237 t CO_2/MWh (Appendix B)
CO_2-emission factor biomass: 0,002 t CO_2/MWh (Appendix B)

The electrical energy demand of the air source heat pump is very low because the source temperature is considered to be a constant level of 18 °C (indoor air).

7.2 DHW, SH and SC Athens

Heating and cooling concepts are described in chapter 2.3.

7.2.1 DHW, SH and SC in new built multi family houses

The domestic hot water energy demand of 14.911 kWh, the space heating energy demand of 14.279 kWh and the space cooling energy demand of 11.118 kWh are dynamically calculated for the reference new built multi family house in southern Europe described in chapter 1. In Figure 32 the primary energy needed to cover the energy demand and the resulting CO2- emissions of the calculated heating systems are shown. The consumed final energy for heating includes domestic hot water and space heating.

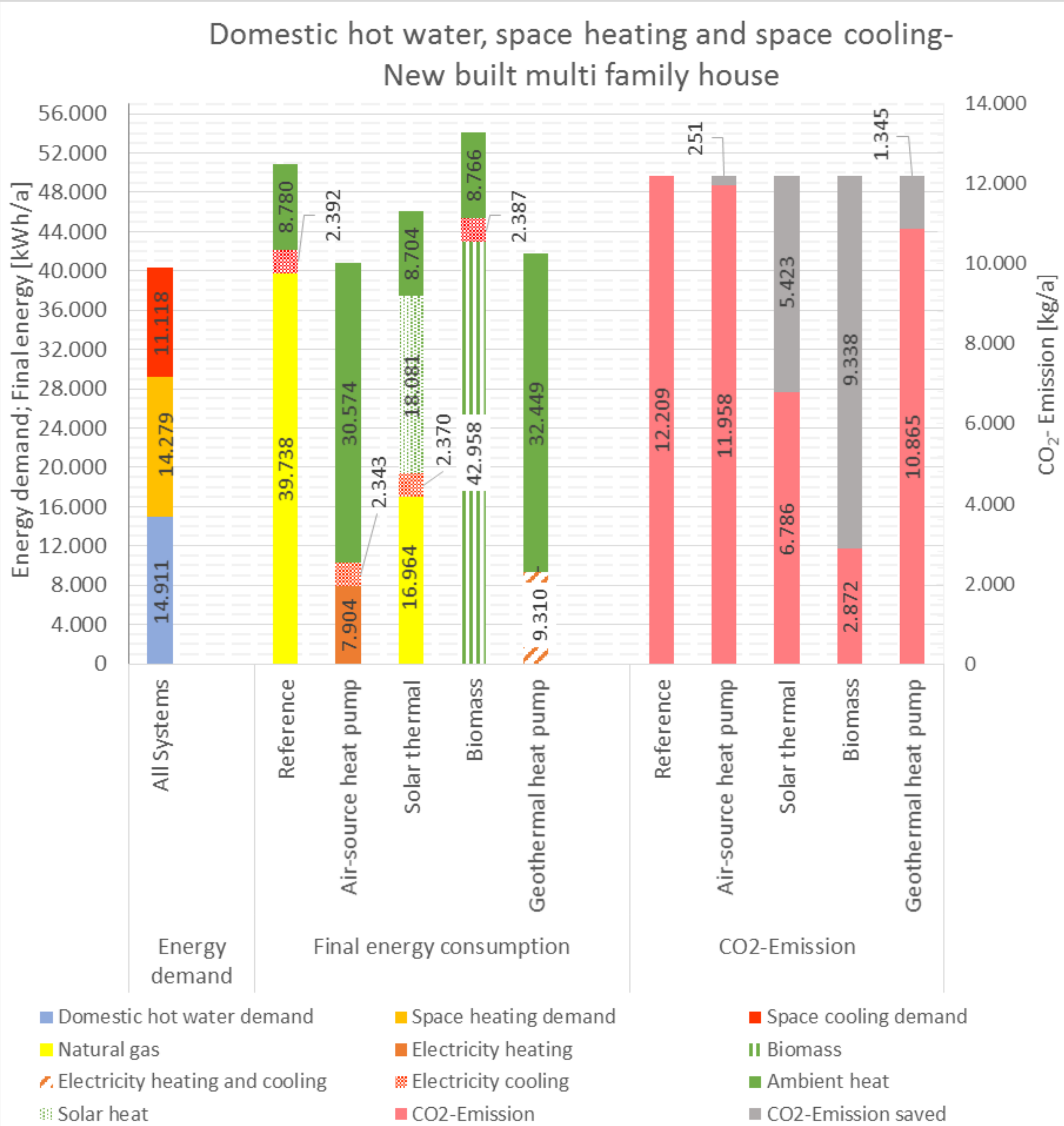

Figure 32: Comparison of all observed heating systems for domestic hot water, space heating and space cooling in new built multi family houses in Athens.

CO_2-emission factor electricity Greece: 1,167 t CO_2/MWh (Appendix B)
CO_2-emission factor natural gas: 0,237 t CO_2/MWh (Appendix B)
CO_2-emission factor biomass: 0,002 t CO_2/MWh (Appendix B)

7.2.2 DHW, SH and SC in refurbished multi family houses

The domestic hot water energy demand of 14.911 kWh, the space heating energy demand of 22.983 kWh and the space cooling energy demand of 12.290 kWh are dynamically calculated for the refurbished multi family house in southern Europe described in chapter 1. In Figure 33 the primary energy needed to cover the energy demand and the resulting CO2- emissions of the observed heating systems are shown. The consumed final energy for heating includes domestic hot water and space heating.

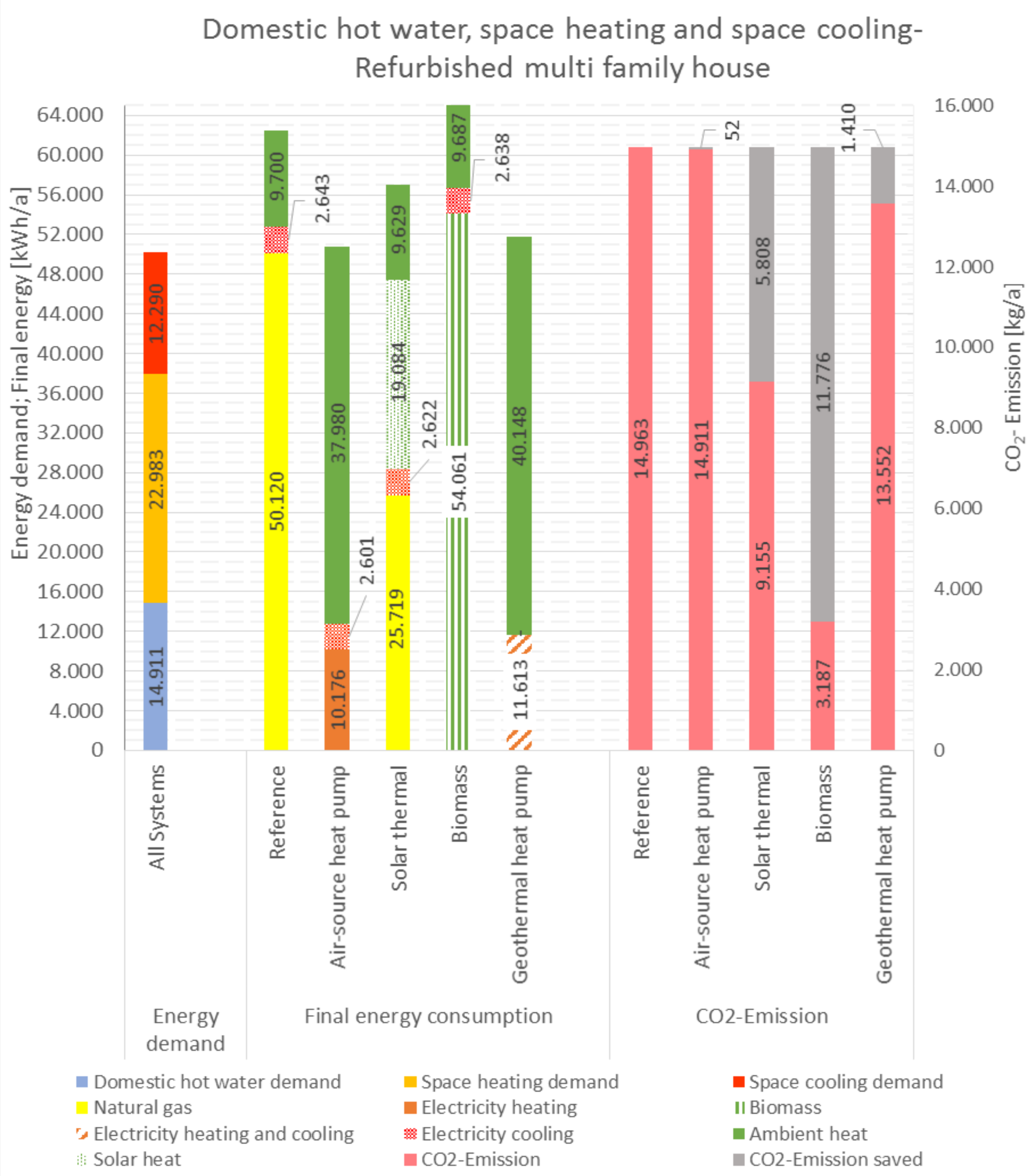

Figure 33: Comparison of all observed heating systems for domestic hot water, space heating and space cooling in refurbished multi family houses in Athens.

CO_2-emission factor electricity Greece: 1,167 t CO_2/MWh (Appendix B)
CO_2-emission factor natural gas: 0,237 t CO_2/MWh (Appendix B)
CO_2-emission factor biomass: 0,002 t CO_2/MWh (Appendix B)

CONCLUSIONS

Domestic hot water demand, heat energy demand, cool energy demand, the according final energy consumptions and CO_2-emissions are calculated for five different heating systems, in five different European cities.

All simulated variants are calculated with the simulation software Polysun. The simulation software takes all heat losses into account. Due to that, the energy demand and final energy consumption of the same buildings in the same locations can vary slightly according to the different efficiencies of the various heating systems and the different control mechanisms.

Calculations in this report are done under the following simplifications:

- Heat energy demands are calculated for the reference buildings defined in Table 1 and Table 2. The location and weather data is chosen according to the simulated city.
- The hot water tank has to be overheated continuously to ensure hygienic operation with no legionella bacteria. The energy demand for this procedure is not considered in the calculation.
- Air source heat pumps for exclusive domestic hot water preparation are located indoors. The source temperature is assumed to be constantly 18°C. Energy extracted from the indoor air is excluded in the calculation.
- As a wet recooler is the only enabled recooler type in Polysun, it is used for cooling systems with compression refrigeration machines, which results in very high COP.

Energy demands shown in the following tables are calculated for reference buildings with reference heating systems. Final energy needed to cover the energy demands and the according CO_2-Emissions are shown in the figures 12 to 33.

Table 25: Summery of the domestic hot water demands.

		Domestic hot water demand				
		Stockholm	**Vienna**	**Würzburg**	**Madrid**	**Athens**
Single family house	Inhabitants (Persons)	4	3	3	4	4
	Hot water demand (l/d)	170	150	150	210	210
	Energy demand (kWh/a)	3.057	2.437	2.600	3.067	2.847
Multi family house	Inhabitants (Persons)	21	21	21	21	21
	Hot water demand (l/d)	900	1.050	1.050	1.100	1.100
	Energy demand (kWh/a)	16.214	17.062	18.206	16.066	14.911

Table 26: Summery of the space heating demands.

		Space heating demand				
		Stockholm	**Vienna**	**Würzburg**	**Madrid**	**Athens**
Single family house	Heated area (m²)	104	104	104	104	104
	Specific energy demand new building (kWh/m²/a)	67	39	-	31	-
	Specific energy demand Refurbished building (kWh/m²/a)	105	-	82	52	-
Multi family house	Heated area (m²)	619	619	619	619	619
	Specific energy demand new building (kWh/m²/a)	80	50	-	-	23
	Specific energy demand Refurbished building (kWh/m²/a)	118	-	96	-	37

Table 27: Summery of the space cooling demands.

		Space cooling demand	
		Madrid	**Athens**
Single family house	Cooled area (m²)	104	-
	Specific energy demand new building (kWh/m²/a)	24	-
	Specific energy demand Refurbished building (kWh/m²/a)	25	-
Multi family house	Heated area (m²)		619
	Specific energy demand new building (kWh/m²/a)	-	18
	Specific energy demand Refurbished building (kWh/m²/a)	-	20

Appendix A: Earth layer catalog

Available earth layer types in simulation software Polysun
(The required borehole length was calculated using software EED, which has similar values for ground type, but a larger list; more info in Appendix C)

Cat.Nr.	Earth layer	Density [kg/m³]	Specific heat capacity [J/kg/K]	Thermal conductivity [W/m/K]
1	Dry gravel	2,000	700	0.4
2	Humid gravel	2,100	1,095	1.7
3	Moraine	2,200	900	1.6
4	Humid clay	2,100	1,150	1.4
5	Siltstone UFM	2,550	825	2.3
6	Siltstone UMM	2,550	825	2.7
7	Siltstone LFM	2,550	825	2.4
8	Fine sandstone UFM	2,550	825	2.3
9	Fine sandstone UMM	2,550	825	2.9
10	Fine sandstone LFM	2,550	825	2.5
11	Medium sandstone UFM	2,550	825	2.6
12	Medium sandstone UMM	2,550	825	2.8
13	Medium sandstone LFM	2,550	825	2.9
14	Coarse sandstone and conglomerate UFM	2,550	825	2.6
15	Coarse sandstone and conglomerate UMM	2,550	825	2.7
16	Coarse sandstone and conglomerate LFM	2,550	825	2.4
17	Limestone	2,550	863	2.8
18	Dolomite	2,500	1,200	3.4
19	Granite	2,600	1,400	3.2
20	Gneiss	2,550	784	2.6
21	Dry clay	1,900	750	0.6
22	Dry sand	2,000	700	0.5
23	Humid sand	2,100	1,143	2.3
24	Moraine, firmly deposited	2,200	909	1.8
25	Peat	650	2,462	0.4
26	Claystone	2,500	880	1.9
27	Sandstone	2,450	857	2.3
28	Conglomerate/breccia	2,450	857	2.6
29	Marlstone	2,450	898	2.1
30	Granite	2,700	888	2.8
31	Diorite	2,950	915	2.3
32	Gabbro	2,950	881	2
33	Slate	2,550	901	1.9
34	Marble	2,650	755	1.9
35	Quartzite	2,650	793	5.3
36	Schist	2,550	902	2
37	Amphibolite	2,750	764	2.6
38	Claystone - Siltstone UFM	2,550	825	2.3
39	Claystone - Siltstone UMM	2,550	825	2.7
40	Claystone - Siltstone LFM	2,550	825	2.3
41	User-defined from Polysun Online	2,550	980.4	2.5
42	Soil	2,500	800	2

Appendix B: Technical annex to the SEAP template Instructions document: THE EMISSION FACTORS

National and European emission factors for consumed electricity

Country	Standard emission factor (t CO_2/MWh_e)	LCA emission factor (t CO_2-eq/MWh_e)
Austria	0.209	0.310
Belgium	0.285	0.402
Germany	0.624	0.706
Denmark	0.461	0.760
Spain	0.440	0.639
Finland	0.216	0.418
France	0.056	0.146
United Kingdom	0.543	0.658
Greece	1.149	1.167
Ireland	0.732	0.870
Italy	0.483	0.708
Netherlands	0.435	0.716
Portugal	0.369	0.750
Sweden	0.023	0.079
Bulgaria	0.819	0.906
Cyprus	0.874	1.019
Czech Republic	0.950	0.802
Estonia	0.908	1.593
Hungary	0.566	0.678
Lithuania	0.153	0.174
Latvia	0.109	0.563
Poland	1.191	1.185
Romania	0.701	1.084
Slovenia	0.557	0.602
Slovakia	0.252	0.353
EU-27	**0.460**	**0.578**

Standard CO2 emission factors (from IPCC, 2006) and CO2-equivalent LCA emission factors (from ELCD) for most common fuel types

Type	Standard emission factor [t CO_2/MWh]	LCA emission factor [t CO_2-eq/MWh]
Motor Gasoline	0.249	0.299
Gas oil, diesel	0.267	0.305
Residual Fuel Oil	0.279	0.310
Anthracite	0.354	0.393
Other Bituminous Coal	0.341	0.380
Sub-Bituminous Coal	0.346	0.385
Lignite	0.364	0.375
Natural Gas	0.202	0.237
Municipal Wastes (non-biomass fraction)	0.330	0.330
Wood [a]	0 – 0.403	0.002[b] – 0.405

[a] Lower value if wood is harvested in a sustainable manner, higher if harvesting is unsustainable.
[b] The figure reflects the production and local/regional transport of wood, representative for Germany, assuming: spruce log with bark; reforested managed forest; production mix entry to saw mill, at plant; and 44% water content. The local authority using this emission factor is recommended to check that it is representative for the local circumstances and to develop an own emission factor if the circumstances are different.

Appendix C: Calculations borehole heat exchanger length

Calculations for required length of borehole heat exchangers (BHE) for geothermal heat pumps in the sample buildings were carried out, applying the widely used software EED (Earth Energy Designer). The calculations are based on the energy needs of the individual buildings as to chapters 3 to 7.

Summary of values for DHW and SH, with additional optimization for DHW, SH and SC where appropriate:

Building location and type	Number of BHE	Depth of BHE	Total BHE length
Athens, new-built MFH Optimized for cooling	6 10	200 m 100 m	1200 m 1000 m
Madrid, new-built SFH Optimized for cooling	3 2	170 m 100 m	340 m 300 m
Vienna, new-built SFH	1	120 m	120 m
Vienna, new-built MFH	2	170 m	340 m
Würzburg, refurbished SFH	1	140 m	140 m
Würzburg, refurbished MFH	3	200 m	600 m
Stockholm, new-built SFH	1	160 m	160 m
Stockholm, new-built MFH	4	200 m	800 m

Earth Energy Designer (EED) is a software developed since the 1990 at the University of Lund, Sweden [1,2]. It is considered as a standard design tool for BHE in Europe, with design guidelines e.g. in UK (MIS 3005 – MCS 022, 2008) or Germany (VDI 4640-2, revision draft 2015) based upon values from EED-calculations. EED was updated continuously and is now in version 3.21, which was used for the calculations related to the FROnT study. EED has been validated several times against monitoring data from realised geothermal heat pump projects, a recent dates from 2013 [3].

Additional information, input parameters and full EED results can be found in the respective working document prepared by EGEC for the FROnT WP 3.5.

[1] Hellström, G. & Sanner, B. (1994): Software for dimensioning of deep boreholes for heat extraction. - Proc. CALORSTOCK 94, pp. 195-202, Espoo/Helsinki

[2] Hellström, G. Sanner, B., Klugescheid, M., Gonka, T. & Mårtensson, S. (1997): Experiences with the borehole heat exchanger software EED. - Proc. MEGASTOCK 97, pp. 247-252, Sapporo

[3] Bohne, D., Wohlfahrt, M., Harhausen, G., Sanner, B., Mands, E., Sauer, M. & Grundmann, E. (2013): Results and lessons learned from geothermal monitoring of eight non-residential buildings with heat and cold production in Germany. - Proc. EGC 2013, paper SG2-06, 8 p., Pisa

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