Heat pump and Boiler comparison

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Introduction

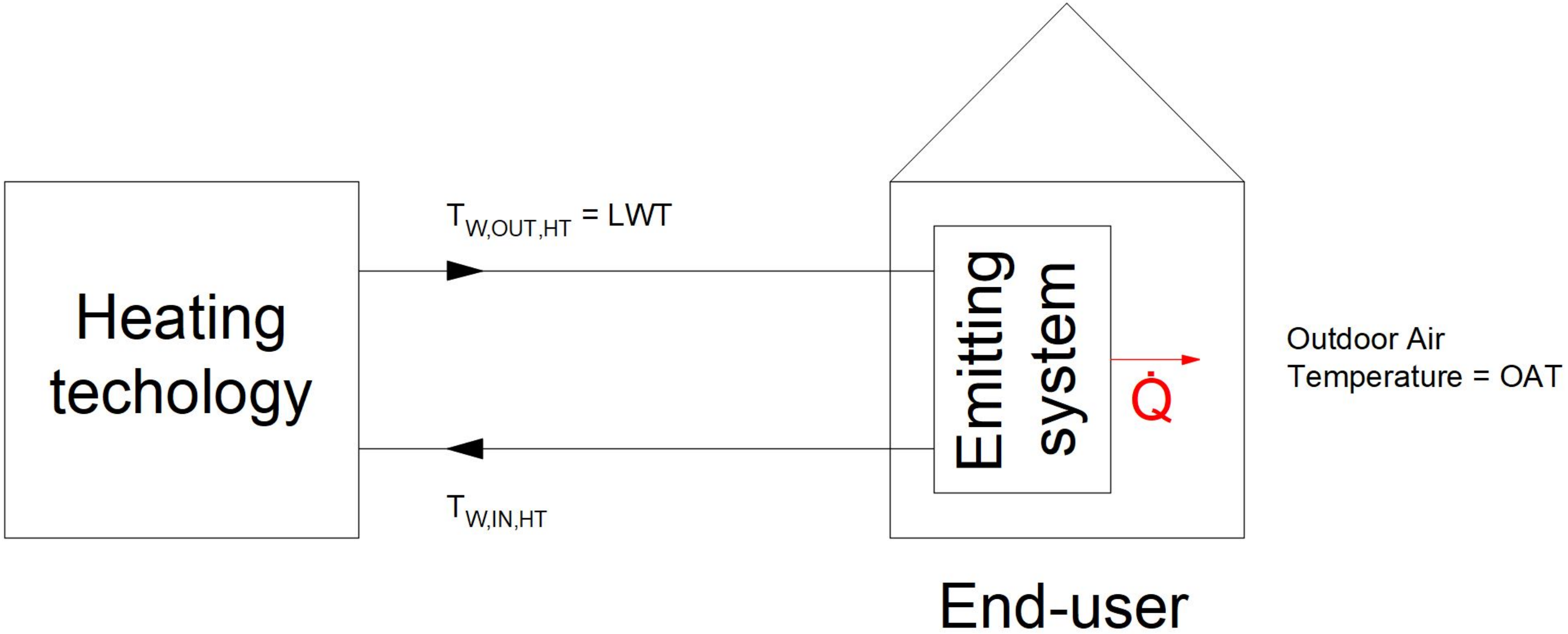


Figure 1.1: system

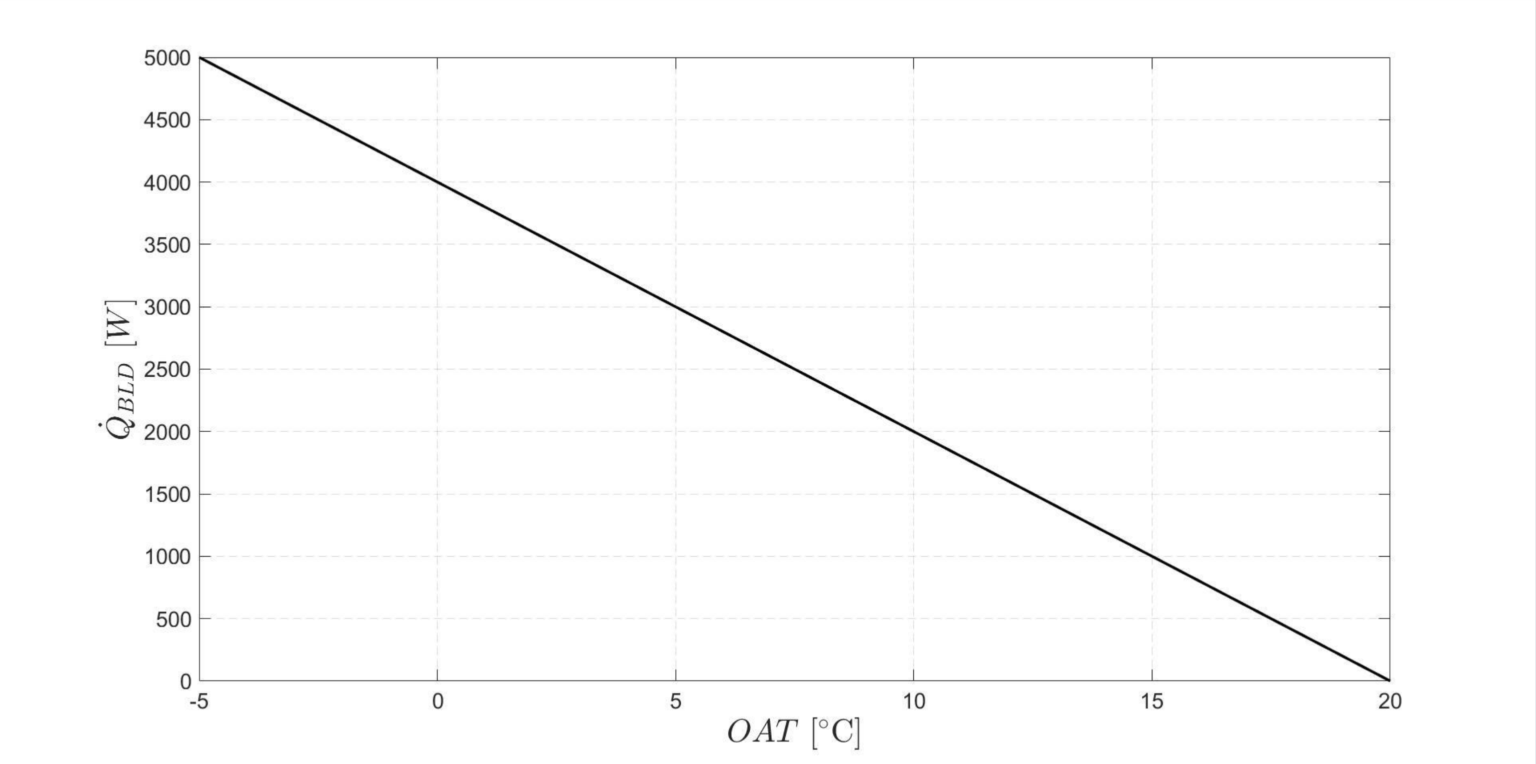


Figure1.2: Building demand by outdoor temperature

Location and weather data

→ The building is assumed to be located in Milan. Therefore, the heating season starts on 15/10 and ends on 14/04. The OAT distribution is taken from visualcrossing typical meteorological year.

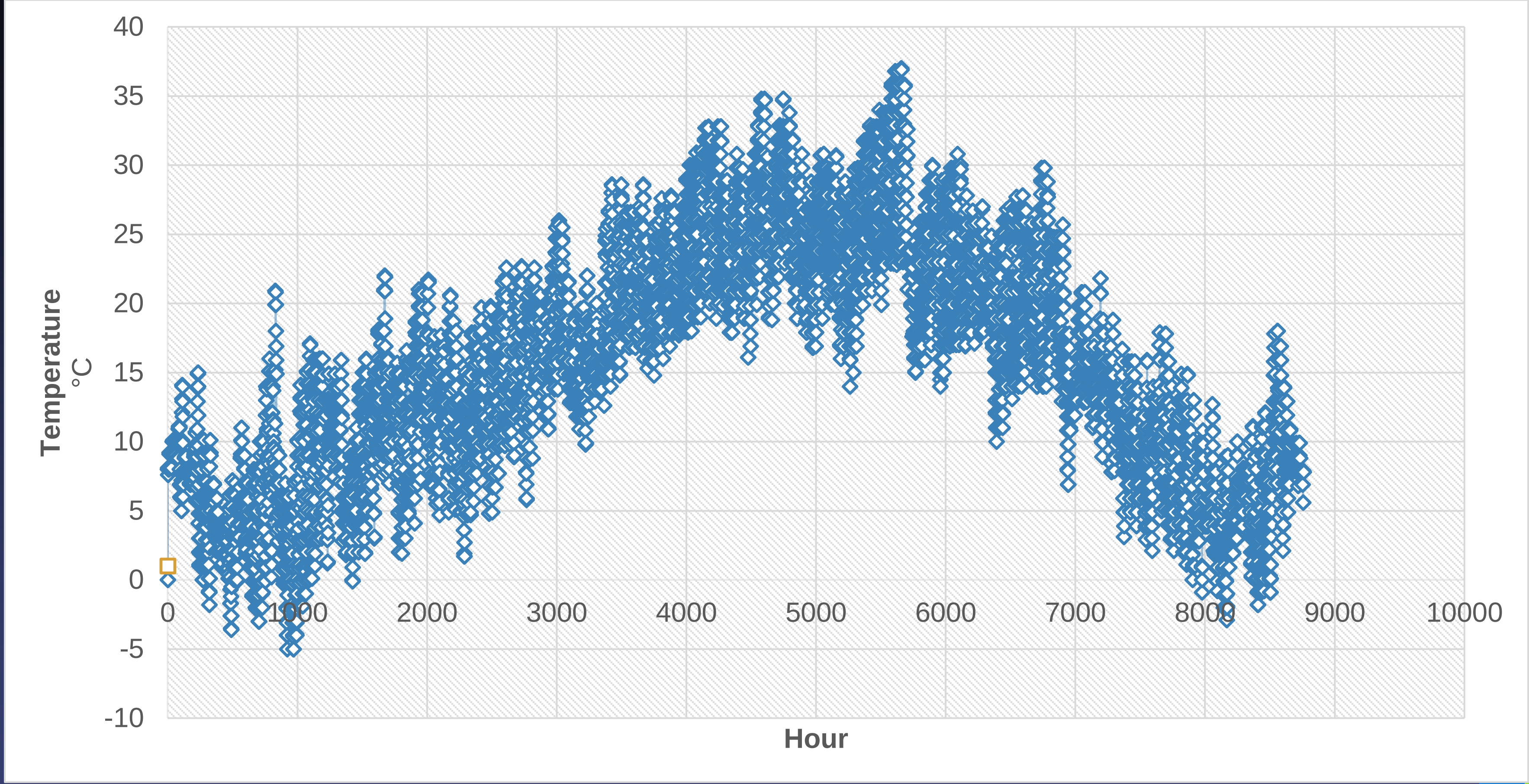


Figure1.3: Temperature for every hour of the 2023 year

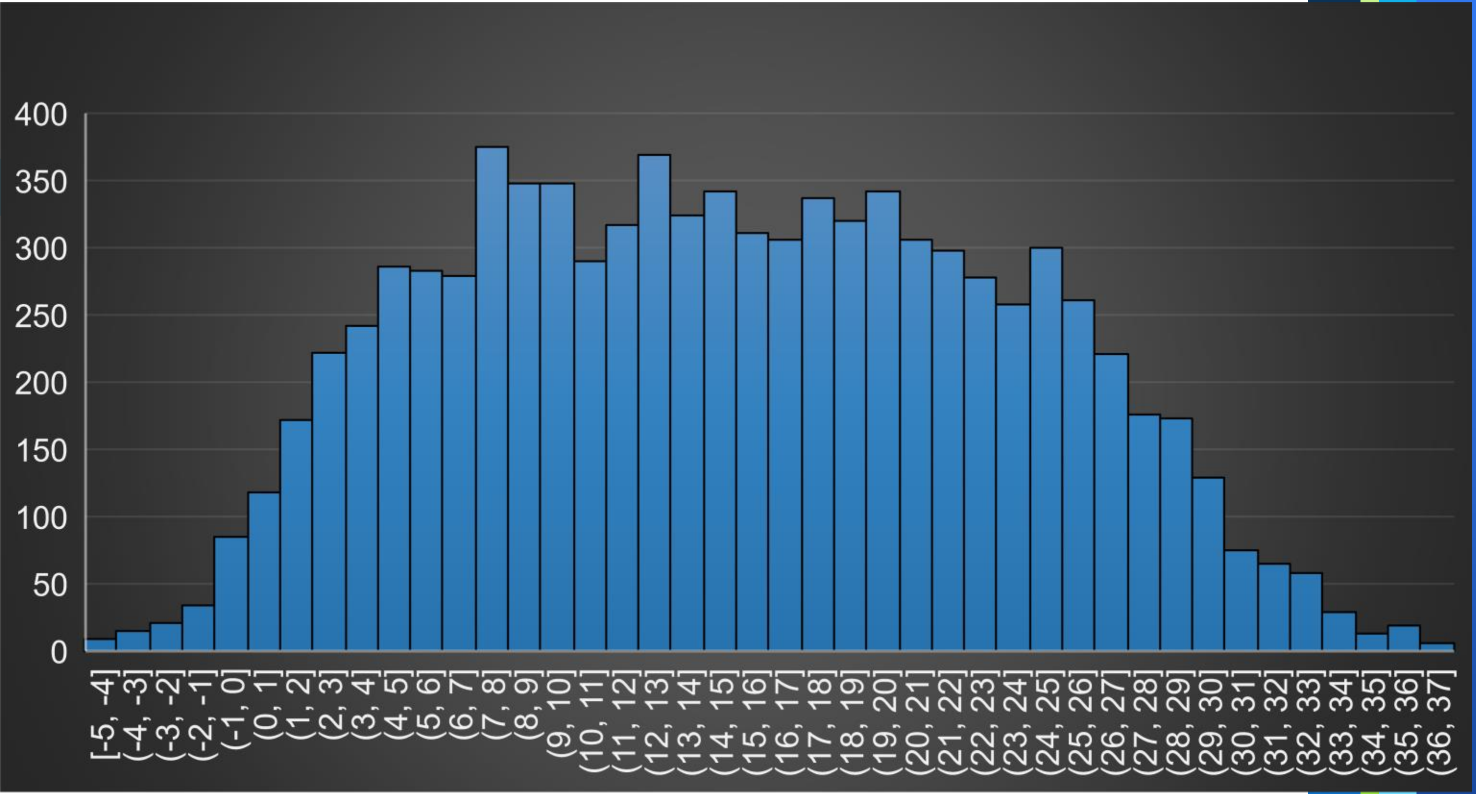


Figure1.4.: Temperature distribution for 2023 year

Scenarios

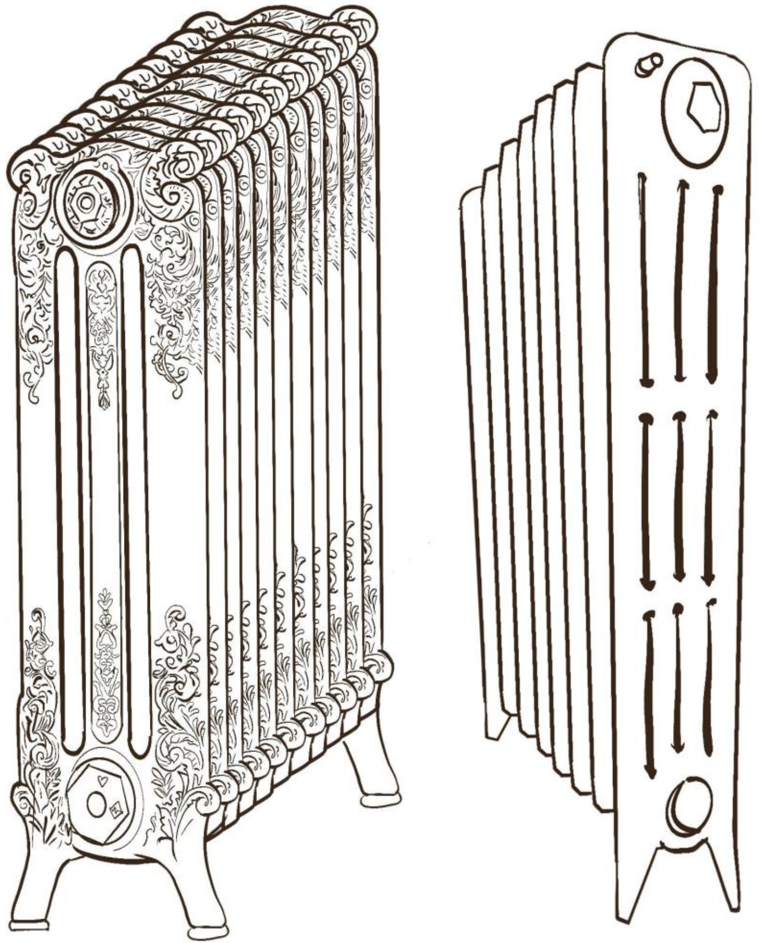
- 1.1 | Baseline heating. Heat emission system
- 1.2 | Baseline heating. Heat emission system: floor heating
- 2 | Advanced heating. Heat emission system: radiators

2

Scenarios

SCENARIO 1.1.Emitting system: radiators

- Scenario 1.1 → Baseline heating. Heat emission system: radiators (55 °C → 47 °C). Boiler: on-off, constant temperature. Heat pump: on-off (fixed speed).
- Simplifying assumption 5: there is not any heat loss in the piping system that connects the heating technology to the emitting system.



Boiler

- The boiler considered in this scenario is an "old" on-off boiler that is operated at constant temperature.
- The nominal efficiency at the nominal heating capacity (100% heating capacity or design heating capacity) is η= 90%.
- The capacity is modulated through on-off cycles → This leads to a reduction in the boiler efficiency due to the on-off energy losses

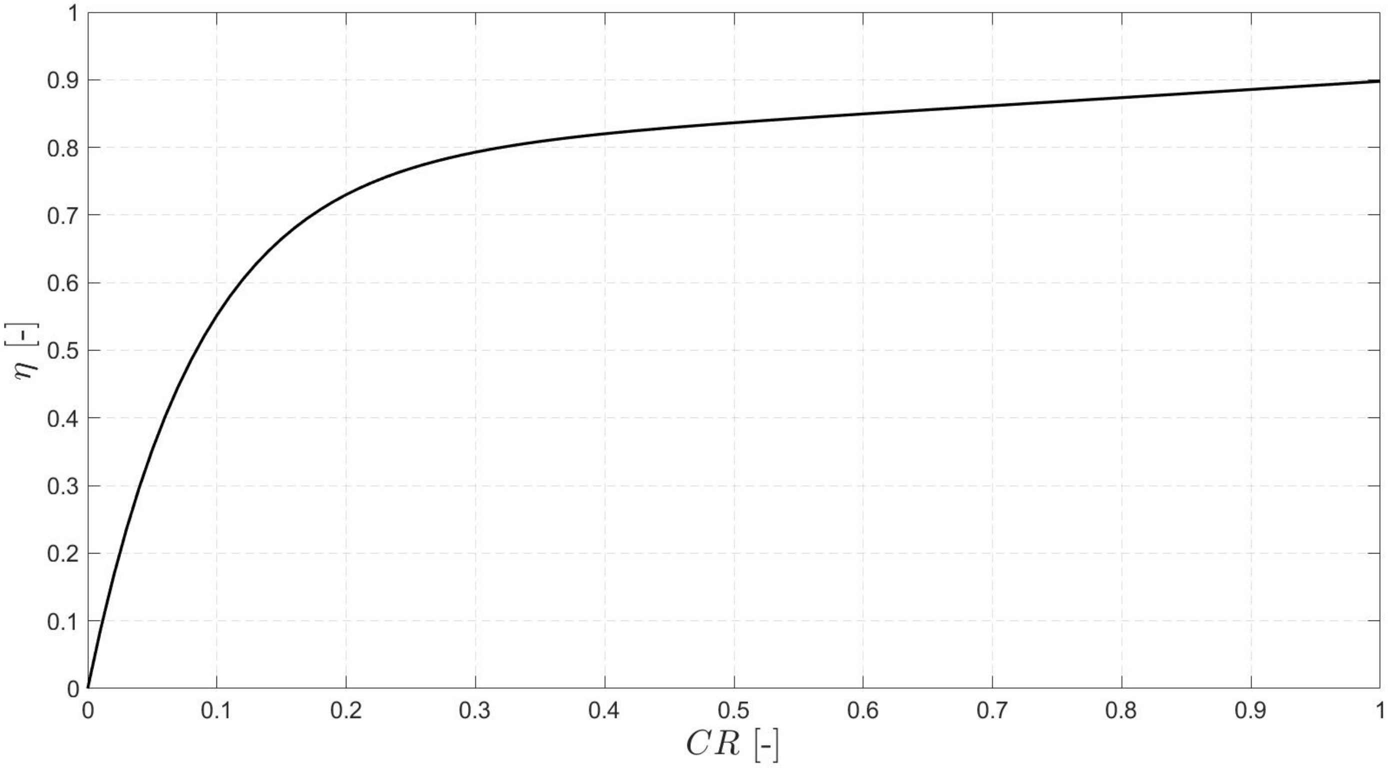


Figure 2.1: Boiler efficiency with Capacity ratio

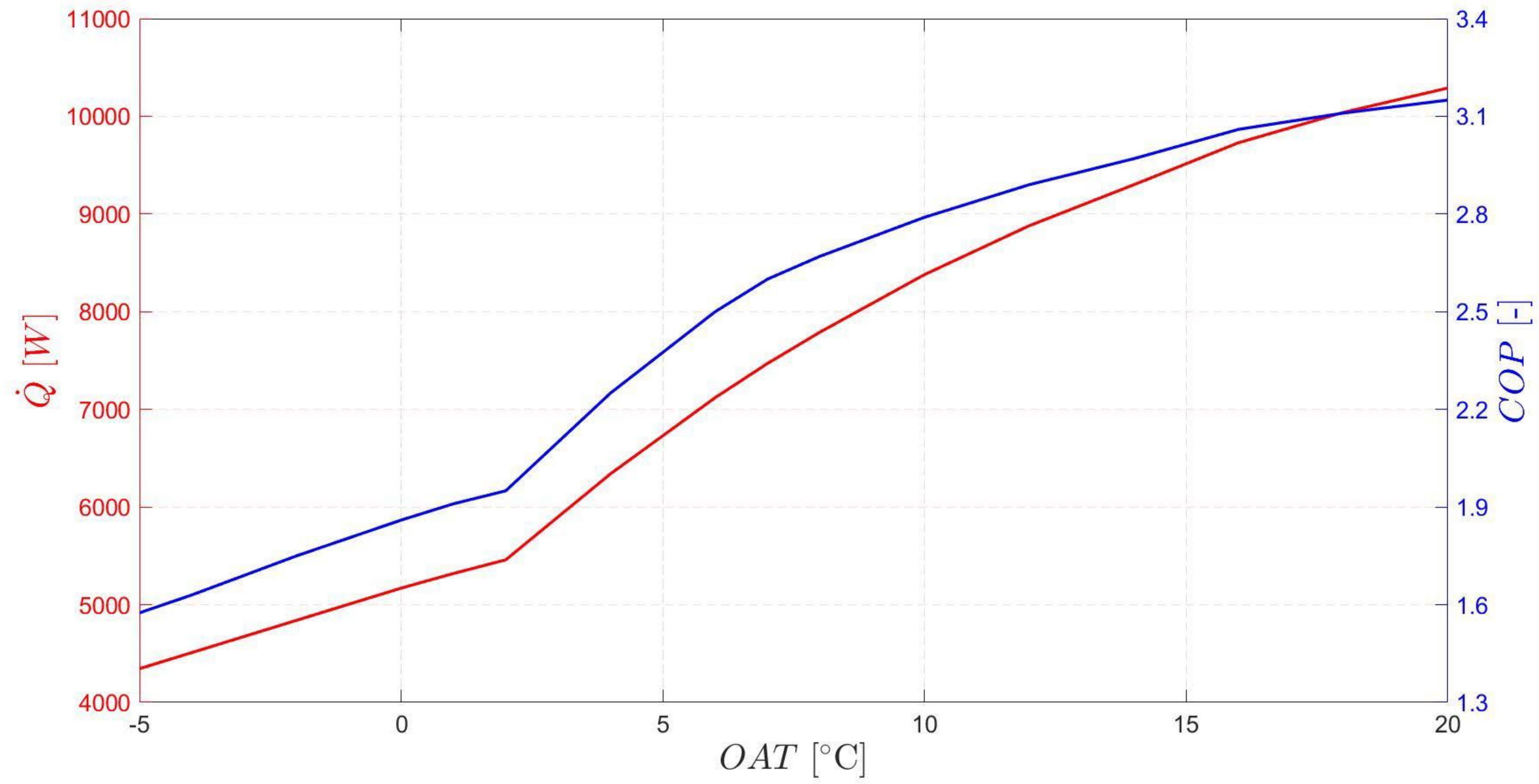


Figure 2.2: Heat pump Q and COP related to OAT

datetime	temp	Qbuilding	Qbuilding_ div_24000	CR	EFF	Qboiler [kwh]	Qboiler [J]
0	8	2400	0.1	0.1002	0.5553	4.321988	15559.16
1	7.6	2480	0.103333	0.1029	0.5631	4.404191	15855.09
2	8.1	2380	0.099167	0.1002	0.5553	4.285972	15429.5
3	8.1	2380	0.099167	0.1002	0.5553	4.285972	15429.5
4	8	2400	0.1	0.1002	0.5553	4.321988	15559.16
5	8.1	2380	0.099167	0.1002	0.5553	4.285972	15429.5
6	8	2400	0.1	0.1002	0.5553	4.321988	15559.16
7	8	2400	0.1	0.1002	0.5553	4.321988	15559.16

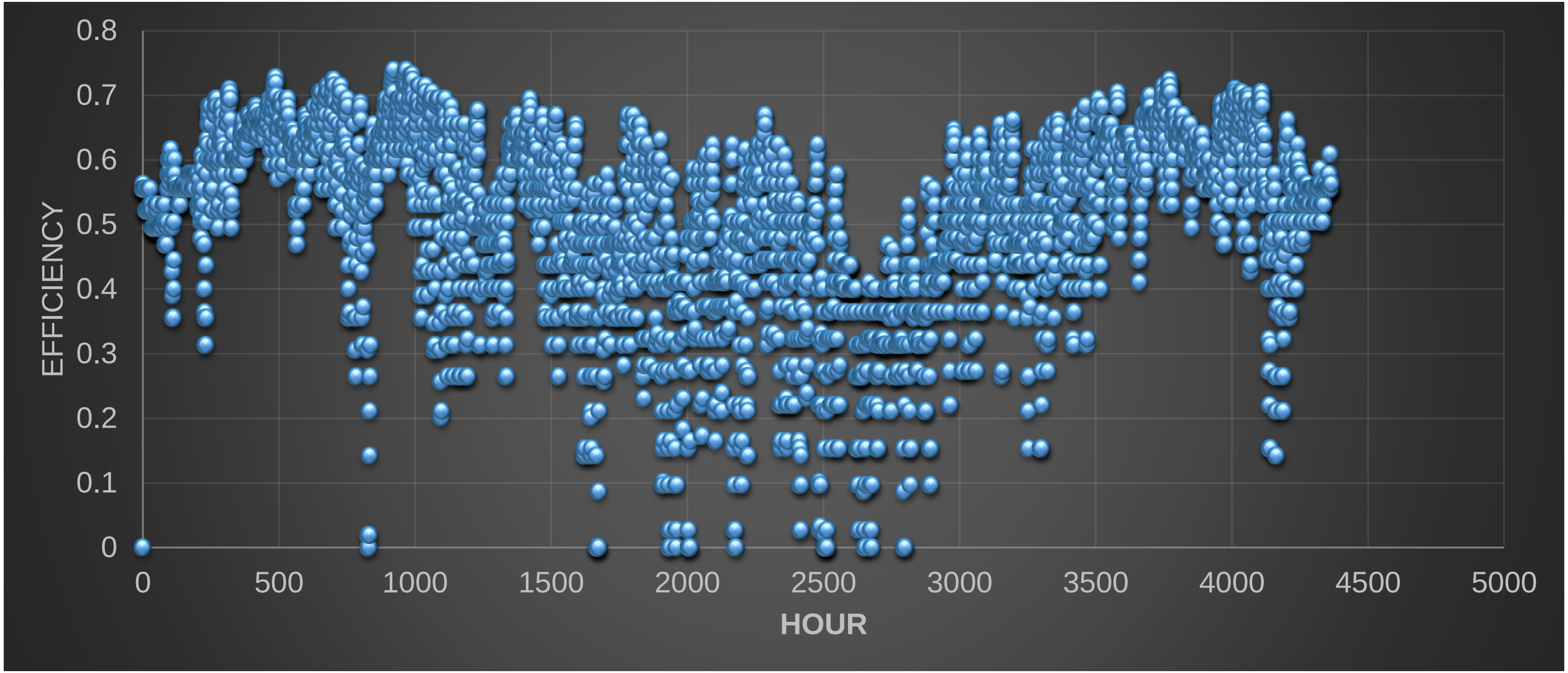


Figure 2.3: Boiler efficiency with hour

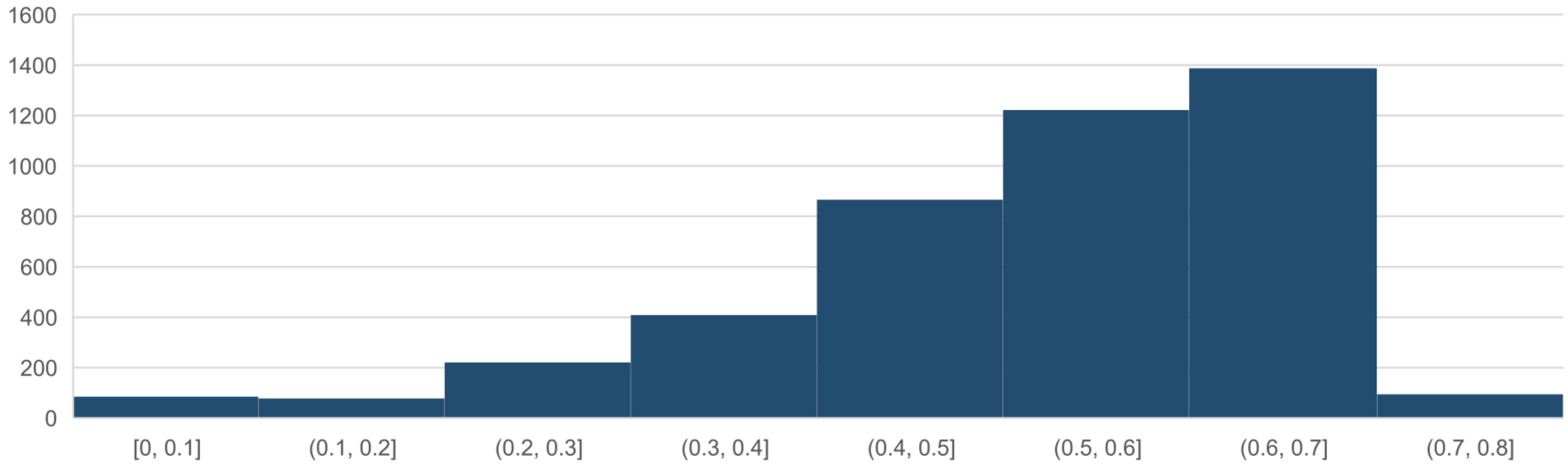


Figure 2.4: Boiler efficiency histogram

Total primary energy

18512.14553 [kWh]

Total CO2 emission
3665 kg

How calculate emission:

$$CH_4+2(O_2+3.76N_2) \longrightarrow CO_2+2H_2O+ 7.52N_2$$

Low heating value for methane is 50 MJ/kg:

$$m_{CO2}= m_{CH4}\times \frac{44}{16}$$

$$m_{CH4}\times LVH = \mathrm{PE}$$

$$m_{CH4}= 1332.86kg$$

$$m_{CO2} = 1332.86 \times \frac{44}{16}$$

$$m_{CO2} =3665.365kg$$

datetime	temp	Qbuilding	COP	COPreal	QNOM	Qbuildin [kwh]
216	9.5	2100	2.76	2.136038	8234.353	0.983129
217	8.7	2260	2.714	2.164459	7997.976	1.044141
218	5.7	2860	2.462	2.150874	6997.017	1.329692
219	5.8	2840	2.474	2.155645	7034.236	1.317471
220	6.7	2660	2.574	2.187323	7362.37	1.216098
221	8.9	2220	2.726	2.158857	8052.057	1.028322
222	7.9	2420	2.665	2.183889	7751.268	1.108115
223	9	2200	2.734	2.157247	8081.832	1.019818

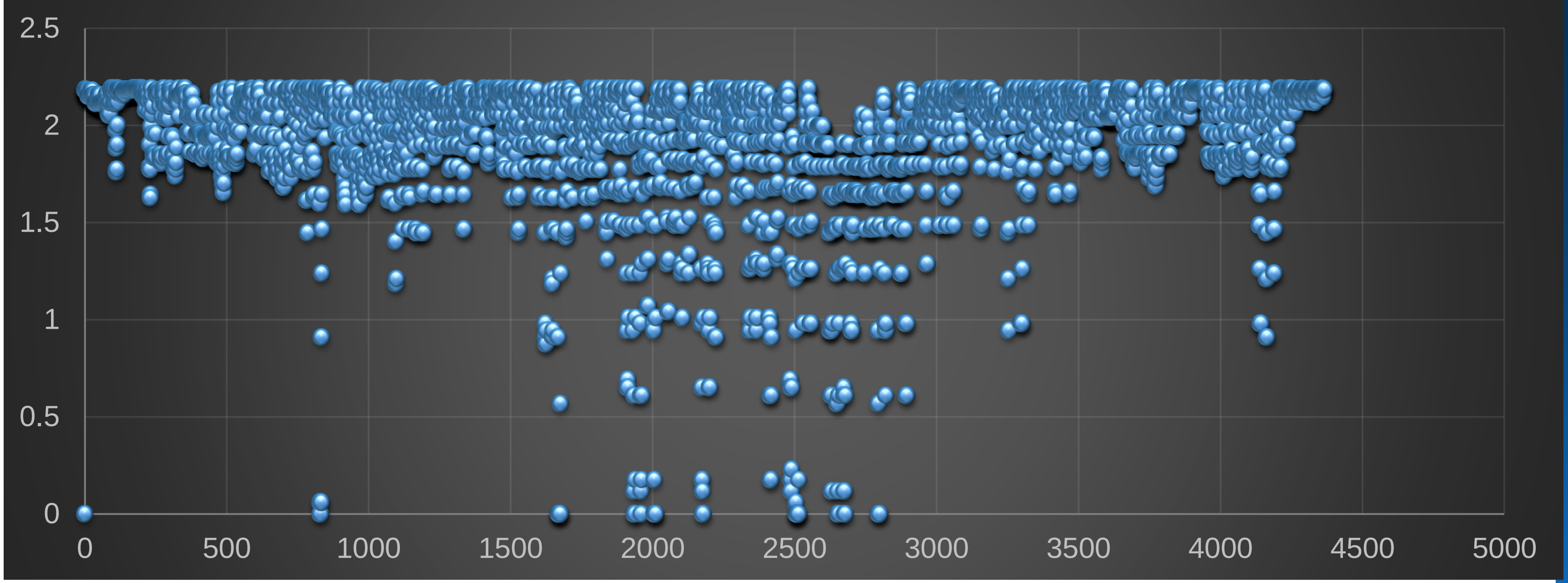


Figure 2.5: Heat pump COP with hour

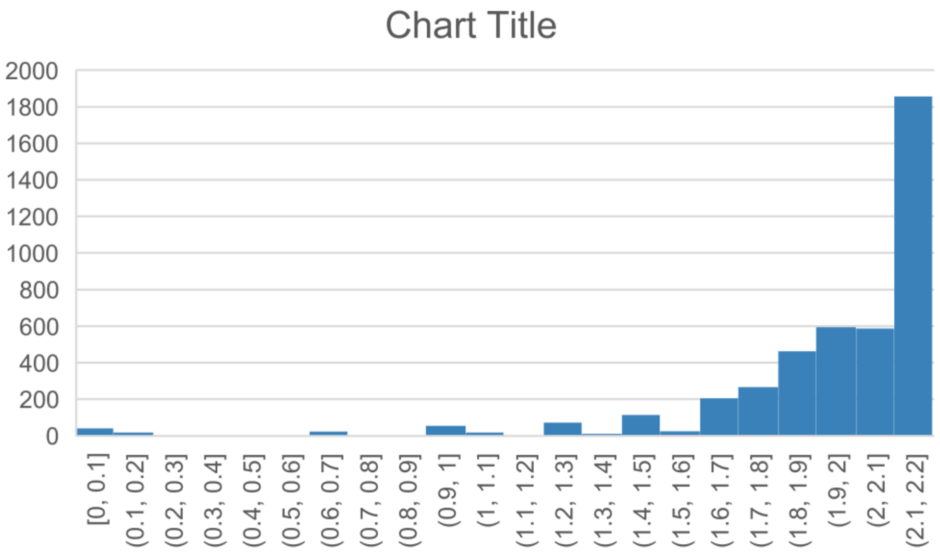


Figure 2.6: Heat pump COP histogram

Total electrical energy consumption

5033.936222 [kWh]

Total CO2 emission

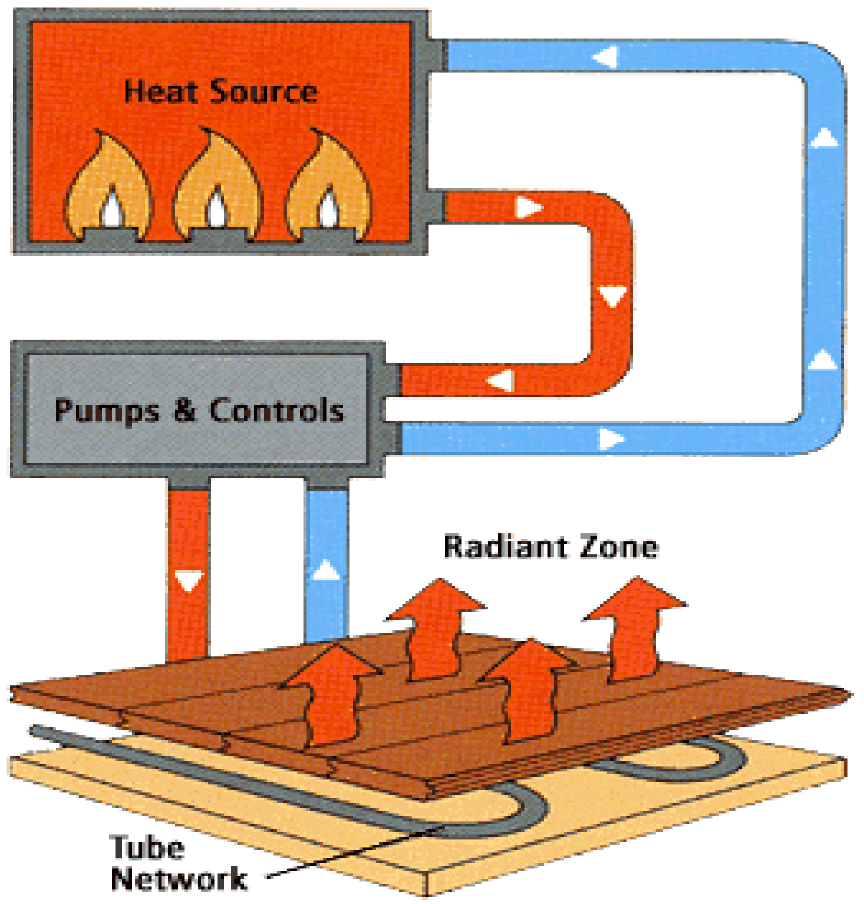
1243.37$_{kg}$

Technology	Q_{boiler} [kWH]	EE_{hp} [kWH]	$Q_{primary}$ [kWH]	Δ [%]
Boiler	18512.14553	–	18512.14553	
Heat pump	–	5033.936222	10575.6	43

Technology	CO2 emission [kg]	Δ
Boiler	3665	–
Heat pump	1243.37	66

SCENARIO 1.2. floor heating

- Scenario 1.2 floor heating (35 °C → 30 °C). Boiler: on-off, constant temperature. Heat pump: on-off (fixed speed).
- Simplifying assumption 5: there is not any heat loss in the piping system that connects the heating technology to the emitting system.



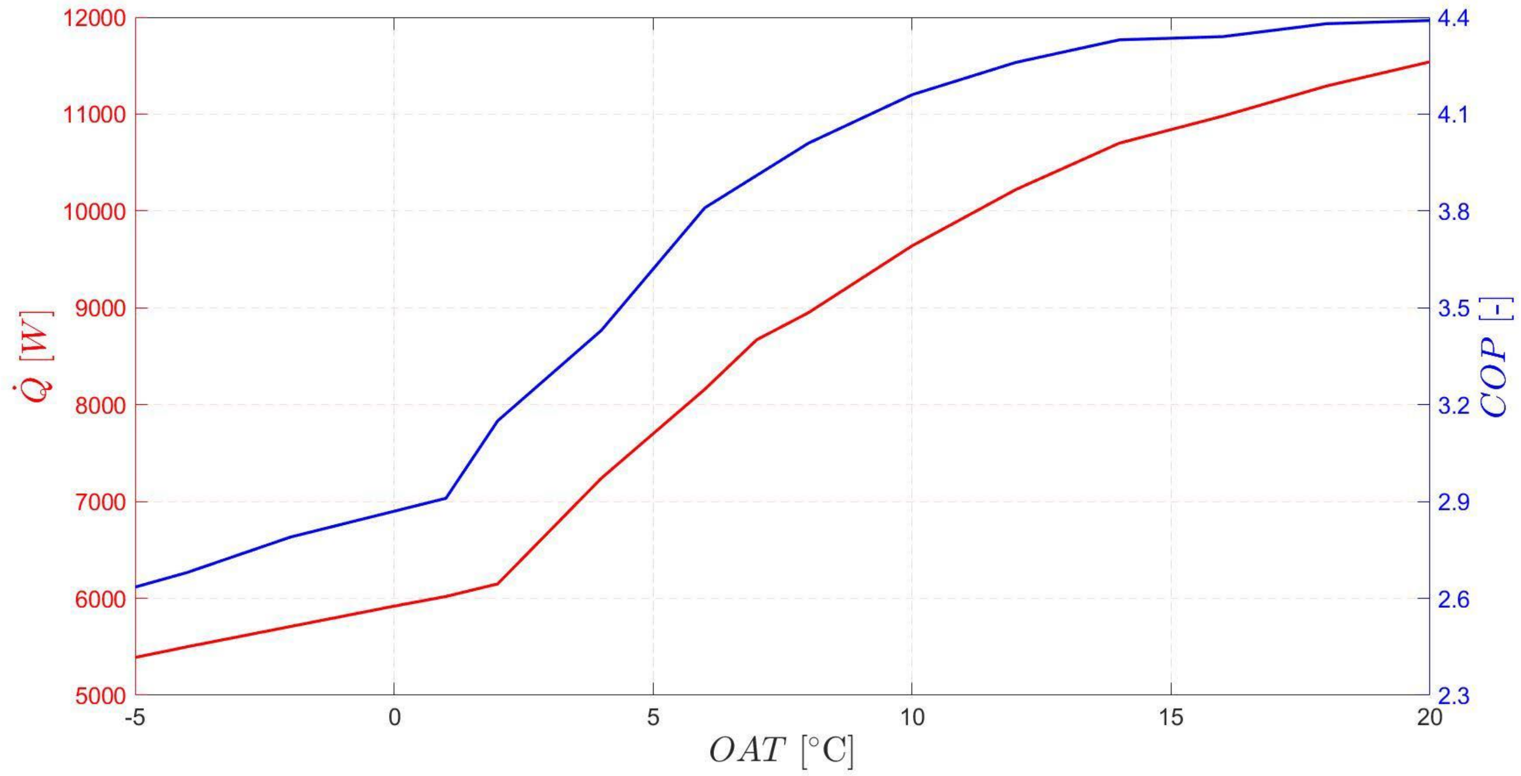


Figure 2.7: Heat pump Q and COP related to OAT

datetime	temp	Qbuilding	**COP**	COPreal	QNOM	Qbuildin [kwh]
216	9.5	2100	4.19595	2.9357	9844.619	0.6335061
217	8.7	2260	4.19095	2.9477	9815.023	0.63792
218	5.7	2860	4.13039	3.055047	9491.748	0.687386
219	5.8	2840	4.07006	3.11219	9210.969	0.7260573
220	6.7	2660	3.76736	3.1815	8037.77	0.896589
221	8.9	2220	3.78321	3.193479	8084.819	0.8893193
222	7.9	2420	3.88588	3.18322	8532.547	0.835654
223	9	2200	4.08531	3.09974	9280.785	0.716243

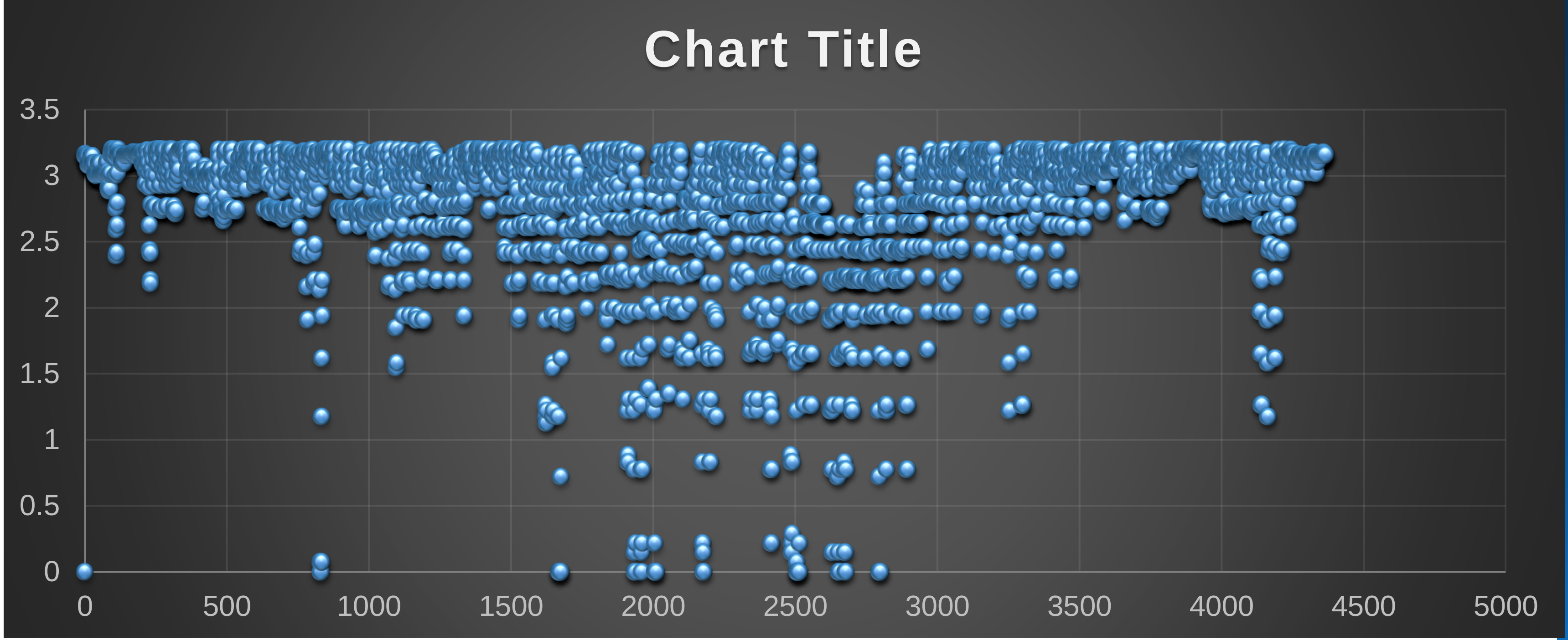


Figure 2.8: Heat pump COP with hour

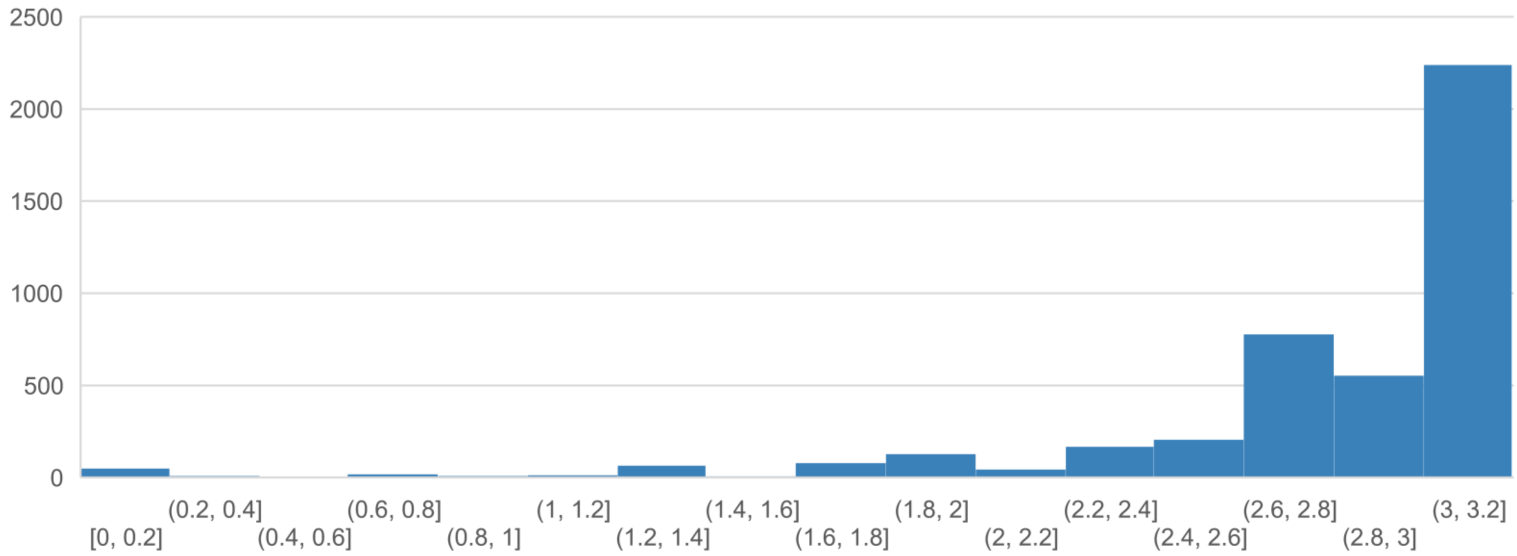


Figure 2.8: Heat pump COP histogram

Total electrical energy consumption

3445.13294 [kWh]

Total CO2 emission

851_{kg}

Technology	Q_{boiler} [kWH]	EE_{hp} [kWH]	$Q_{primary}$ [kWH]	Δ [%]
Boiler	18512.14553	–	18512.14553	
Heat pump	–	3445.13294	7208	61

Technology	CO2 emission [kg]	Δ
Boiler	3665	–
Heat pump	851	77

Scenario	Technology	Q_{boiler} [kWH]	EE_{hp} [kWH]	$Q_{primary}$ [kWH]	CO2 emission [kg]
1.1 (On-Off, LWT = 55 °C)	Boiler	18512.14553	–	18512.14553	3665
	Heat pump	–	5033.936222	10575.6	1243.37
1.2 (On-Off, LWT = 35 °C)	Boiler	18512.14553	–	18512.14553	3665
	Heat pump	–	3445.13294	7208	851

Key finding: to push the energy and environmental advantages related to the use of the heat pump to their maximum values, use the lowest possible LWT! Caveat: the temperature of the hot water is set by the end-user,this constraint has to be always fulfilled!

SCENARIO 2. Advanced heating

- Scenario 2 → Advanced heating. Heat emission system: radiators (55 °C → 47 °C). Boiler: modulating, condensing. Heat pump: inverter driven (variable speed).

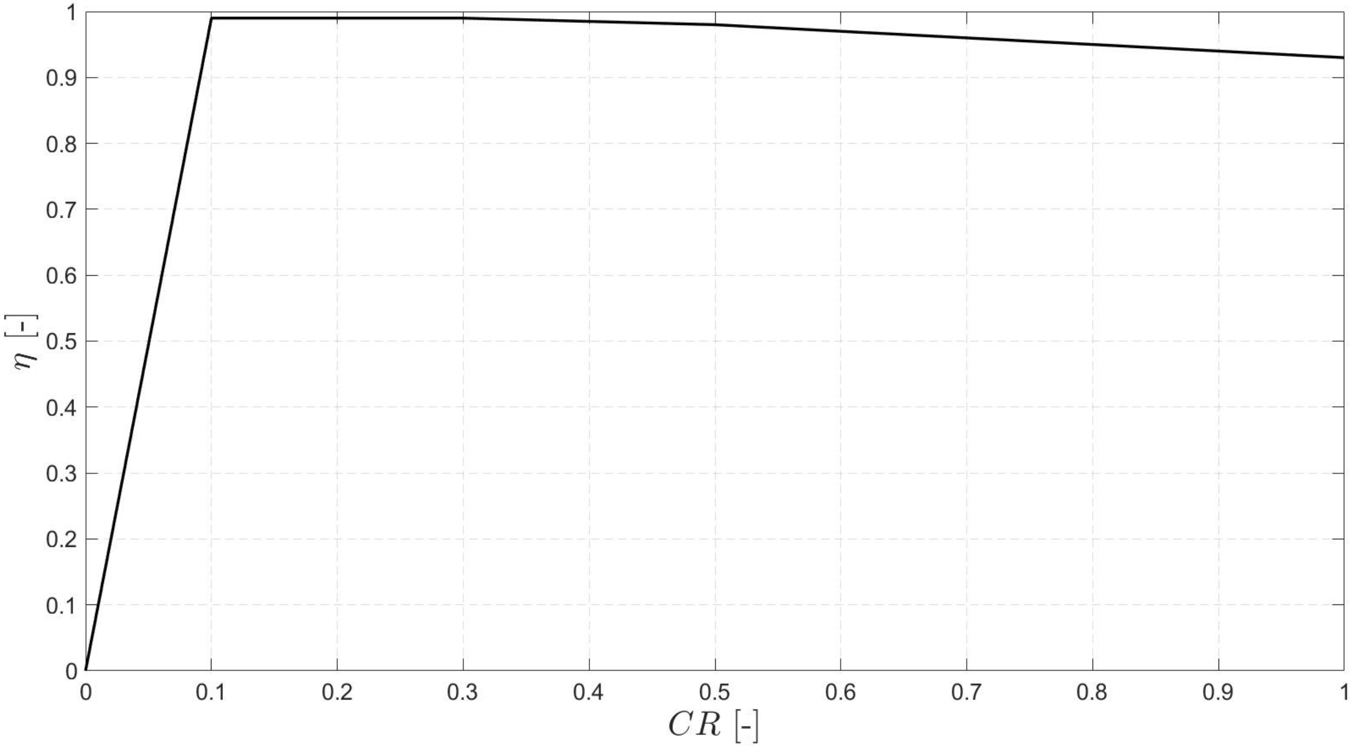


Figure 2.9: Boiler efficiency with Capacity ratio

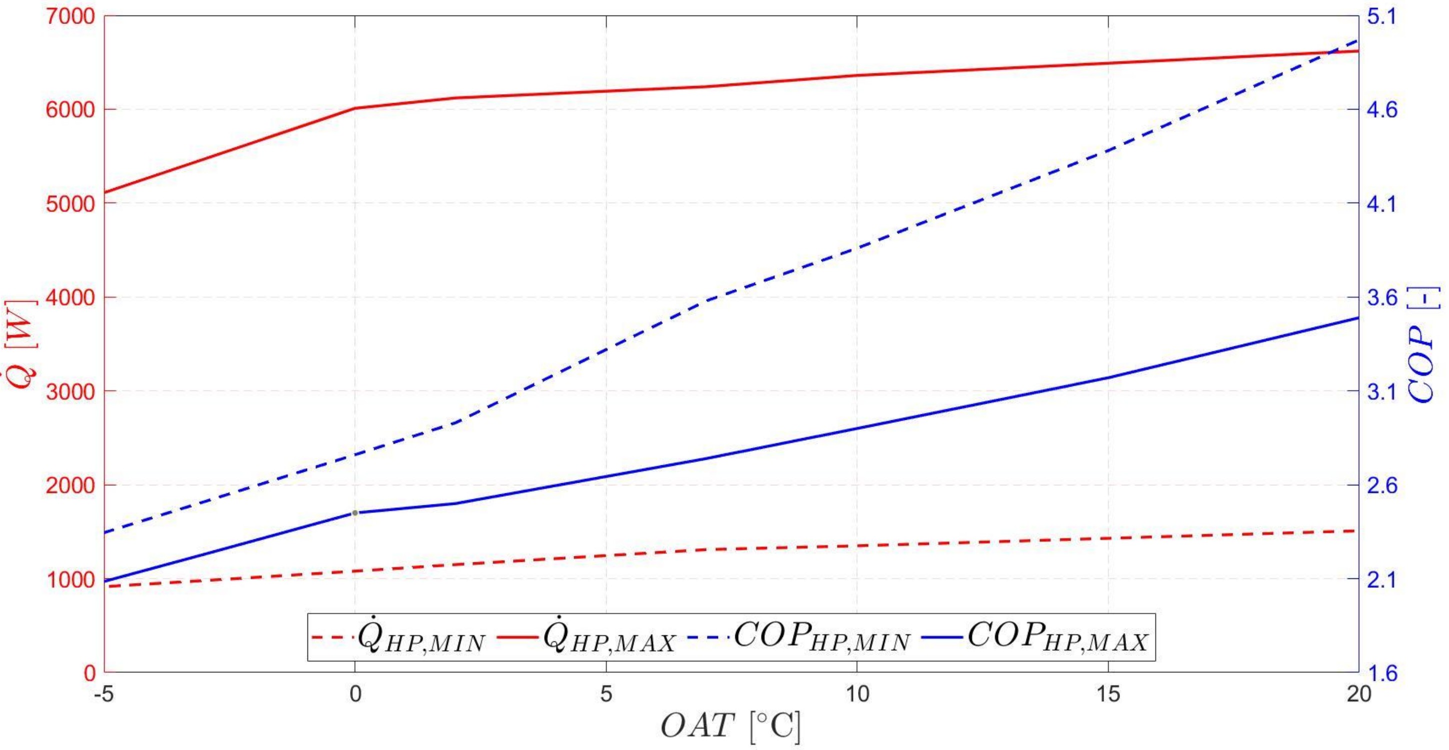


Figure 2.10: Heat pump Q and COP related to OAT

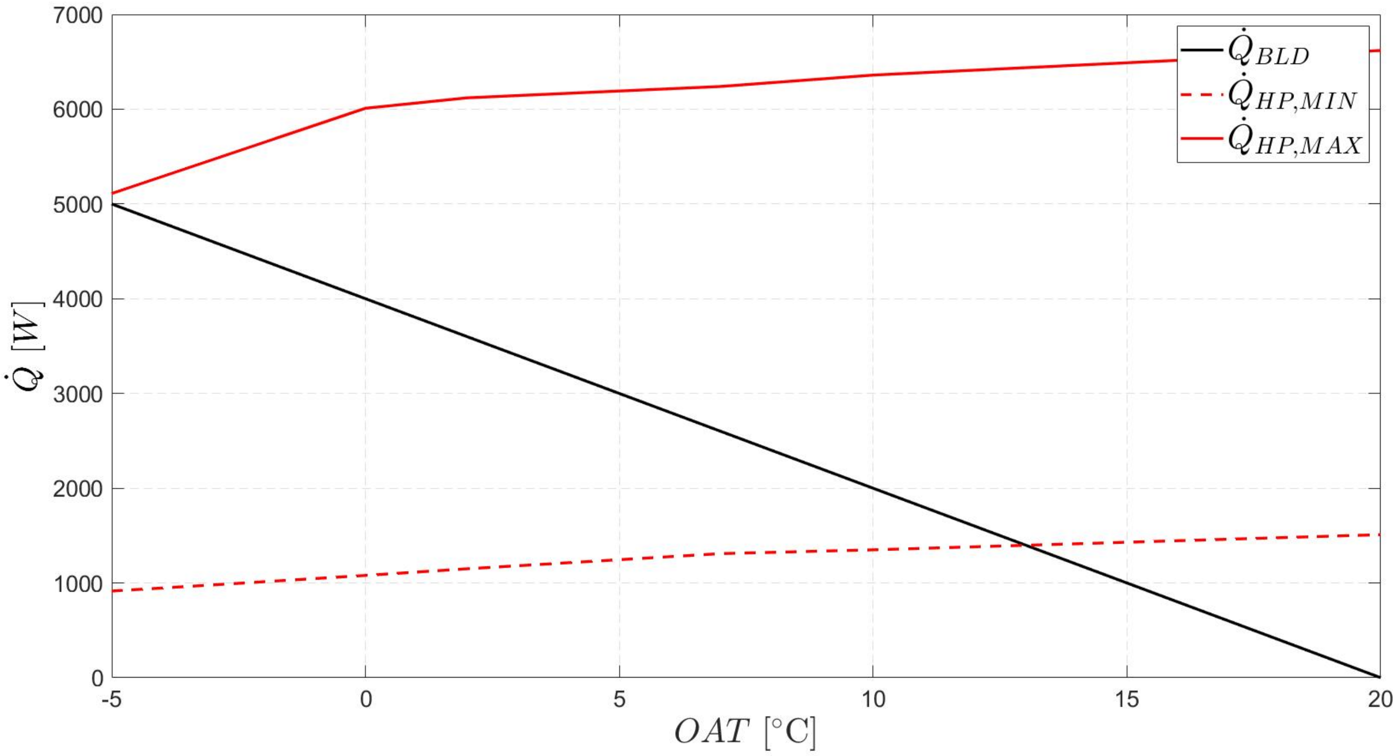


Figure 2.11: Heat pump Q and building Q

datetime	temp	Qbuilding	Qbuilding_ div_24000	CR	EFF	Qboiler [kwh]	Qboiler [J]
0	8	2400	0.1	0.1	0.96	2.5	9000
1	7.6	2480	0.1	0.1	0.97	2.47422	8907.215
2	8.1	2380	0.1	0.1	0.99	2.42424	8727.227
3	8.1	2380	0.103333	0.1	0.96	2.583333	9300
4	8	2400	0.103333	0.1	0.97	2.556701	9204.11
5	8.1	2380	0.103333	0.1	0.99	2.505050	9018.818
6	8	2400	0.099166	0.1	0.96	2.5	9000
7	8	2400	0.1	0.1	0.96	2.479166667	8925

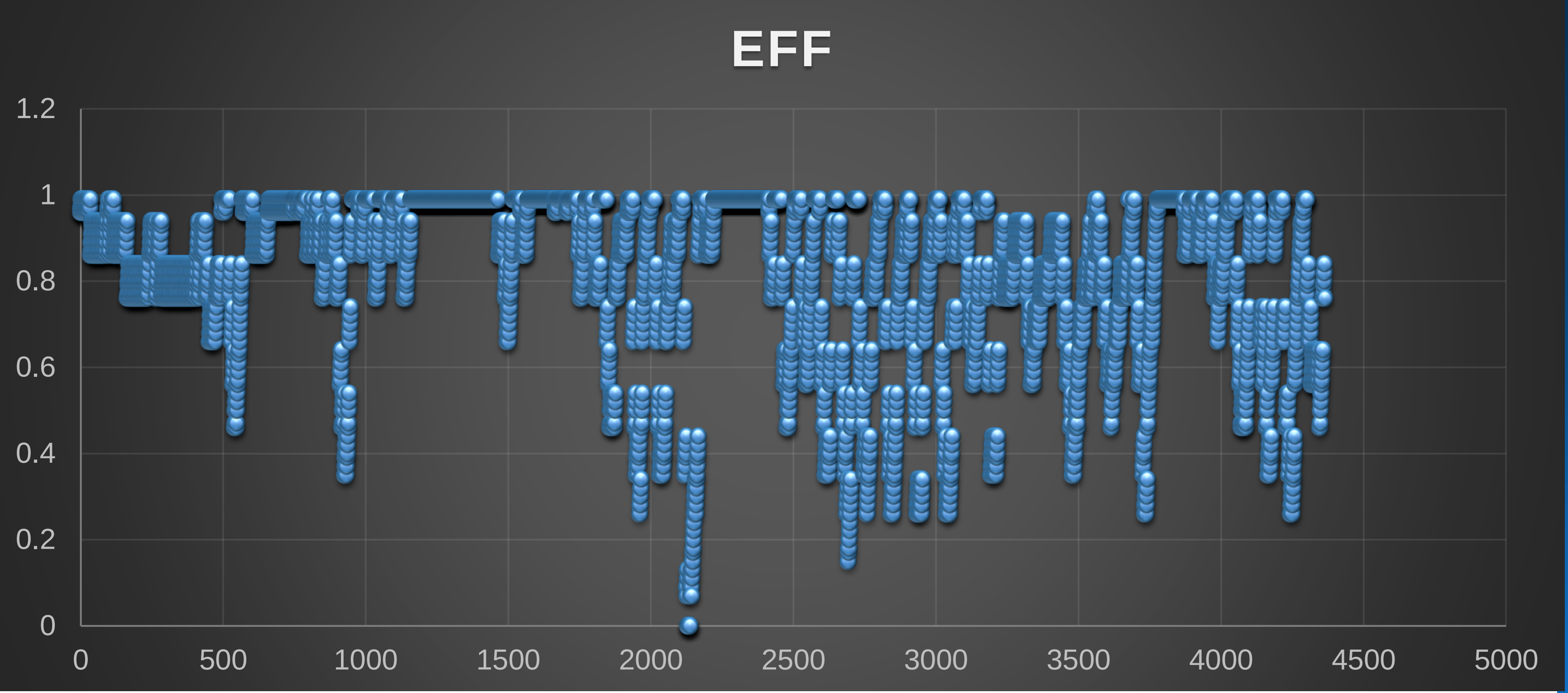


Figure 2.12: Boiler efficiency with hour

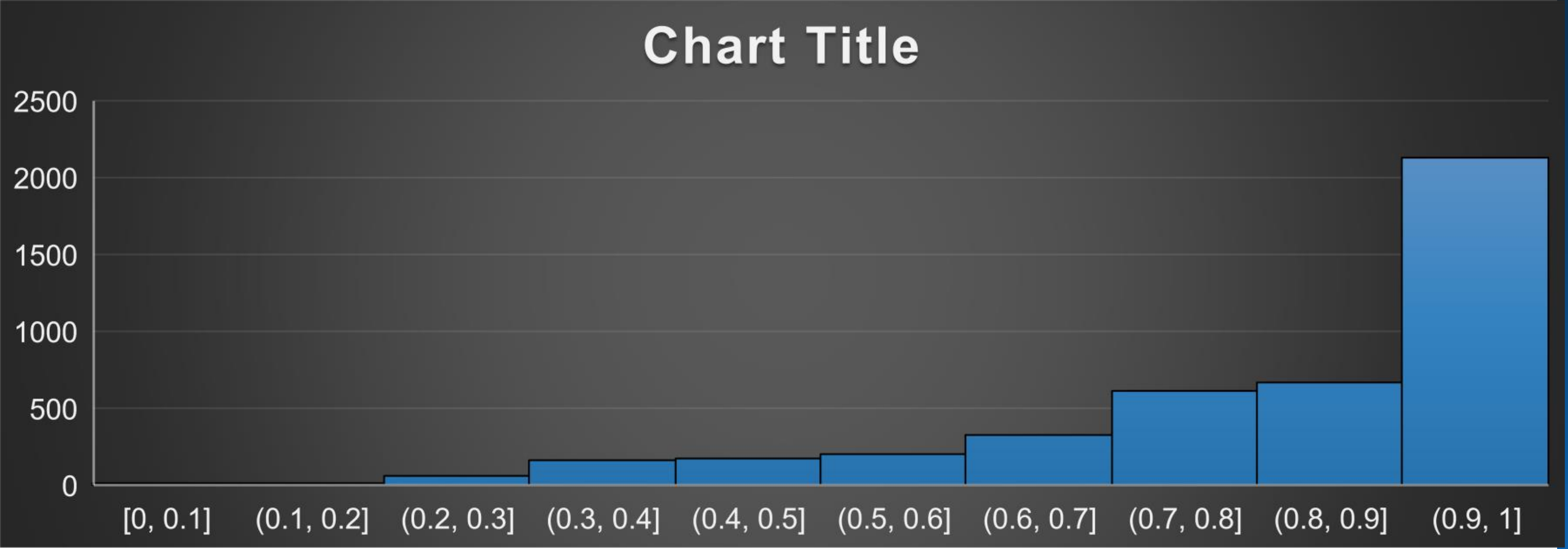


Figure 2.13: Boiler efficiency histogram

Total primary energy

11780.46539
[kWh]

Total CO2 emission
2334.75 kg

How calculate emission:

$$CH_4+2(O_2+3.76N_2) \longrightarrow CO_2+2H_2O+7.52N_2$$

Low heating value for methane is 50 MJ/kg:

$$m_{CO2}= m_{CH4}\times \frac{44}{16}$$

$$m_{CH4}\times LVH = \mathrm{PE}$$

$$m_{CH4}= 849kg$$

$$m_{CO2} = 1332.86 \times \frac{44}{16}$$

$$m_{CO2} =2334.75kg$$

Procedure heat pump

→ The only difference is related to the capacity ratio. Indeed:

→ a. If $\dot{Q}_{BUILDING} < \dot{Q}_{MIN}$, the heating capacity supplied by the heating technology at its minimum modulation is larger than the building load → control through on-off cycling (see scenario 1.1 and 1.2).

→ b. If $\dot{Q}_{MIN}, < \dot{Q}_{BUILDING} < \dot{Q}_{MAX}$, the heating technology is modulated to supply exactly the building load → the capacity ratio of the boiler and the rotational frequency of the compressor shaft are found through linear interpolation. In this case the heating technology operates continuously with time and there is not any degradation coefficient.

datetime	temp	Qbuilding	HZ	COPreal	QNOM	Qbuildin [kwh]
216	9.5	2100	30hz	3.675714	2100	0.5718
217	8.7	2260	40hz	3.48	2260	0.6494
218	5.7	2860	40hz	3.097143	2860	0.9232
219	5.8	2840	40hz	3.097143	2840	0.9174
220	6.7	2660	40hz	3.305714	2660	0.8067
221	8.9	2220	30hz	3.628571	2220	0.6111
222	7.9	2420	30hz	3.411429	2420	0.708
223	9	2200	30hz	3.637143	2200	0.60487

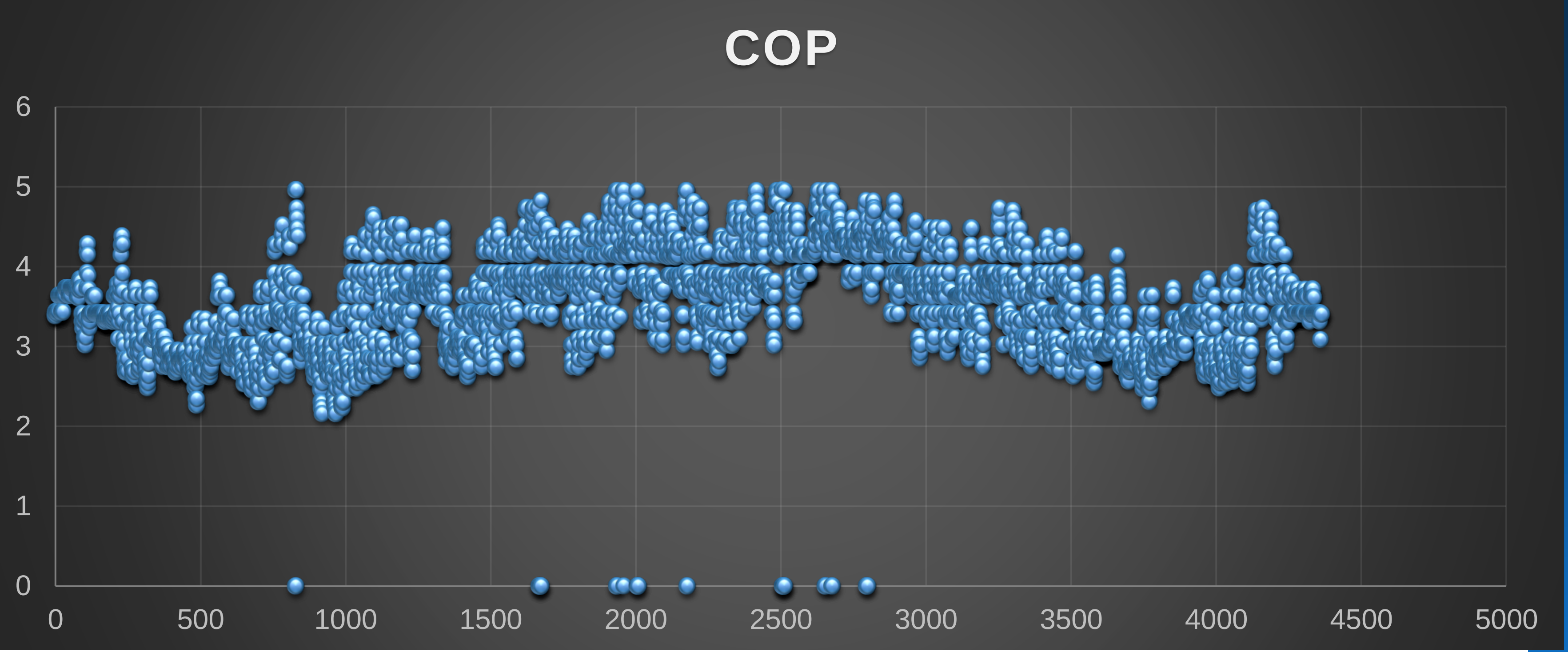


Figure 2.5: Heat pump COP with hour

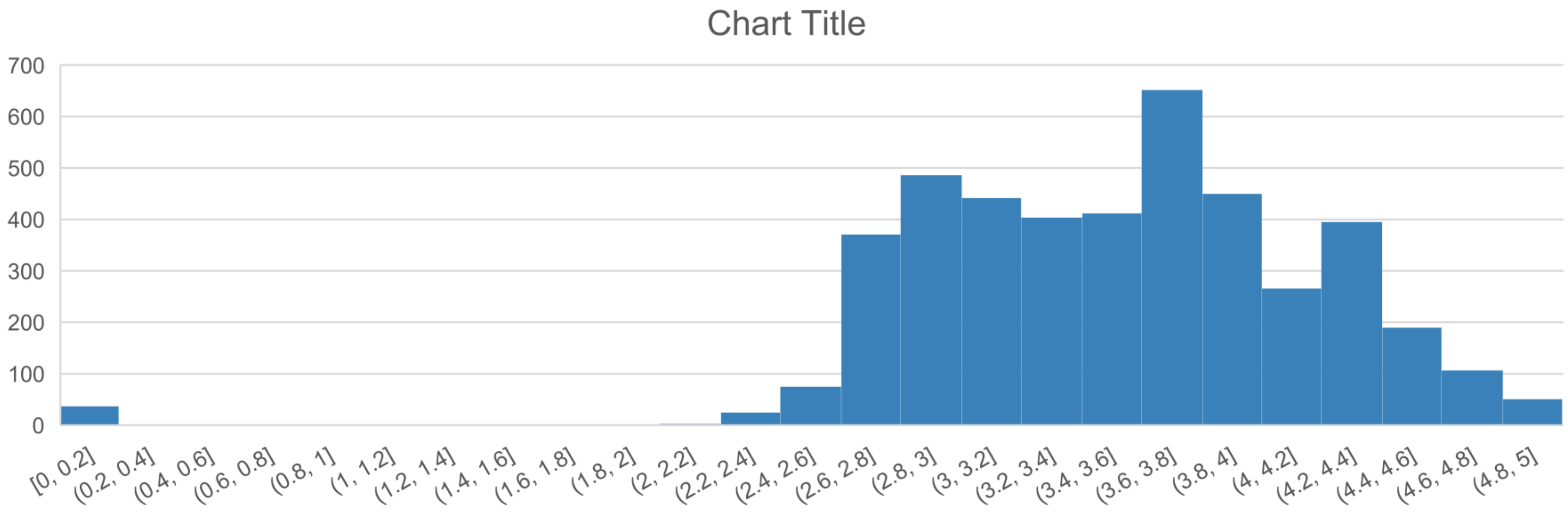


Figure 2.6: Heat pump COP histogram

Total electrical energy consumption

$$\left(\begin{array}{c} 3113.90068 \\ [\mathrm{kWh}] \end{array} \right)$$

Total CO2 emission

1243.37$_{\text{kg}}$

Technology	Q_{boiler} [kWH]	EE_{hp} [kWH]	$Q_{primary}$ [kWH]	Δ [%]
Boiler	11780.46539	–	11780.46539	
Heat pump	–	3113.9	6541.8	44

Technology	CO_2 emission [kg]	Δ
Boiler	2334.75	–
Heat pump	769.1	67

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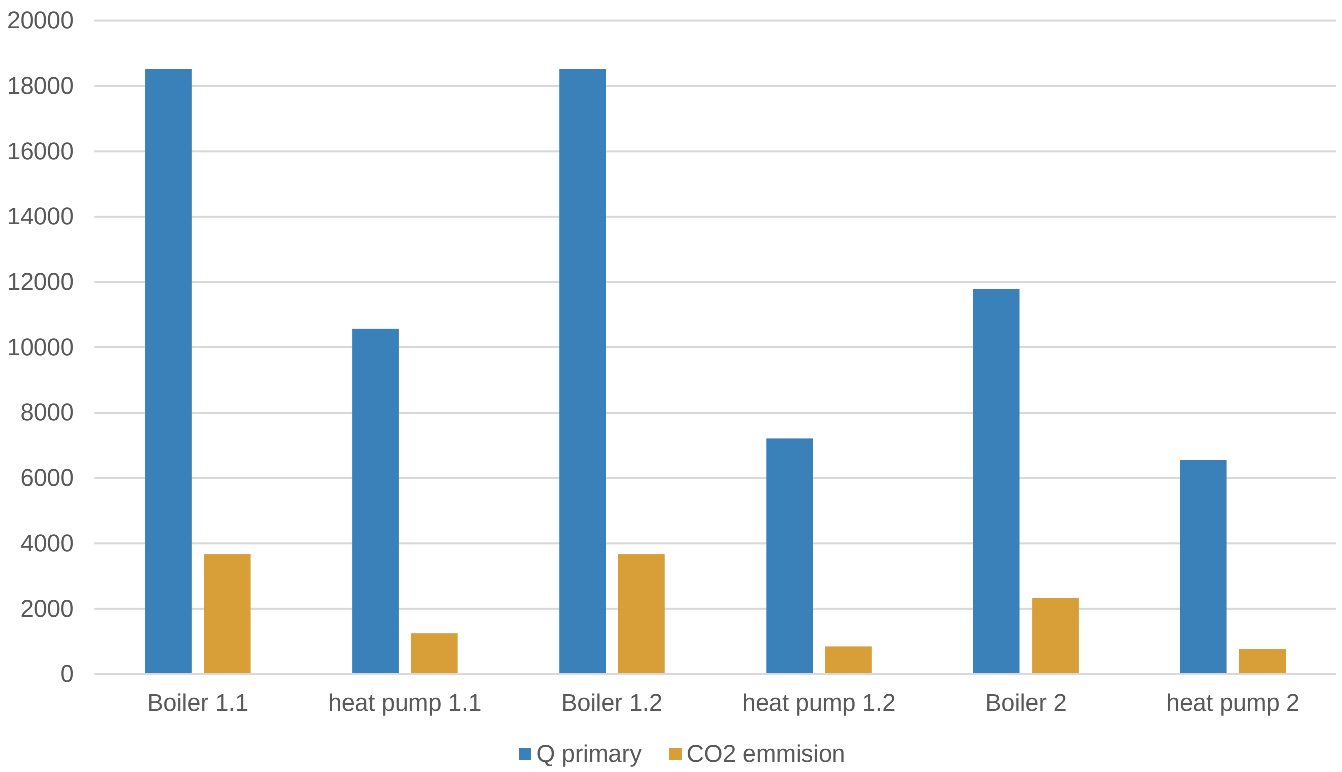
Conclusion

Scenario	Technology	Q_{boiler} [kWH]	EE_{hp} [kWH]	$Q_{primary}$ [kWH]	CO2 emission [kg]
1.1 (On-Off, LWT = 55 °C)	Boiler	18512.14553	–	18512.14553	3665
	Heat pump	–	5033.936222	10575.6	1243.37
1.2 (On-Off, LWT = 35 °C)	Boiler	18512.14553	–	18512.14553	3665
	Heat pump	–	3445.13294	7208	851
2 (Modulating, LWT = 55 °C)	Boiler	11780.46539	–	11780.46539	2334.75
	Heat pump	–	3113.9	6541.8	769.1


20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Boiler 1.1
heat pump 1.1
Boiler 1.2
heat pump 1.2
Boiler 2
heat pump 2
Q primary
CO2 emmision

4

References

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Thanks!

Any questions?