Renewable Energy Hub Optimizer

June 2023

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1. Introduction

This report offers an energy analysis of 4 buildings, using the *QBuildings* and *Renewable Energy Hub Optimizer* (REHO) tools developed within from the *Industrial Process and Energy Systems Engineering* (IPESE) laboratory at EPFL.

The figure below shows the selected buildings for this use case.

Figure: Chosen buildings for study case.

2. Methodology

In this section the two main tools to generate a building scale energy scenario, QBuildings and REHO, will be explained. Following this, the input data for the model will be presented.

2.1 Qbuildings

2.2 REHO

2.3 Data

In order to run the model, several input parameters are required.

Optimization parameters

In the present case, a building scale optimization is performed with as objective function the minimization of the total cost (TOTEX) of the energy system for the given building. For this case study, it was decided to enforce no units. In addition, it was decided to exclude NG_Cogeneration, DHN_in, DataHeat_DHW from the optimization.

As REHO makes use of typical days for its optimization a weather cluster is needed. Here, the weather cluster is used which has the following characteristics: TODO

Building

The building parameters are used to define the energy demand of the building. The following parameters are the values used for this case study:

- 15226.0 [m2] of reference energy surface (= SRE). That corresponds to the total heated floor area all dwellings
- 13305.7 [m2] of available solar area
- 1110.3 [kWh/m_2/yr] average annual solar irradiation for all the buildings
- 2628.0 [capita] estimated people living in the chosen district

Studied scenarios

The different energy configurations studied for this case study are:

1. **TOTEX:**the optimal system according to the excluded and enforced energy systems described above.
2. **Fossil:** a system based on an oil boiler.
3. **HP air:** a system based on the use of an air-water heat pump.

4. **PV + HP air:** a system based on the use of an air-water heat pump and photovoltaic (PV) panels.

Investment

The optimization is based on an investment made from a bank loan over a period of n years (which corresponds to the lifetime of the equipment) with a specified interest rate i specified. The annualization factor can therefore be expressed as :

Here is an example of a display formula:

$$\tau = i * \frac{(1+i)^n}{(1+i)^n - 1}$$

Cost of resources

A number of energy prices and specific CO_2 emissions factors are used for the optimization. They can be found in the following table:

Resource	Cost [CHF/kWh]	Carbon footprint [kgCO2-eq/kWh]
Electricity (buying)	0.2790	0.13
Electricity (selling)	0.1645	0.13
Fuel oil	0.1400	0.28

3. Results

In this section the results generated from REHO are presented.

3.1 Total Energy Demand

The total energy demand for the different services (Space heating (SH), Domestic hot water (DHW), Electricity) is proposed in the figure below

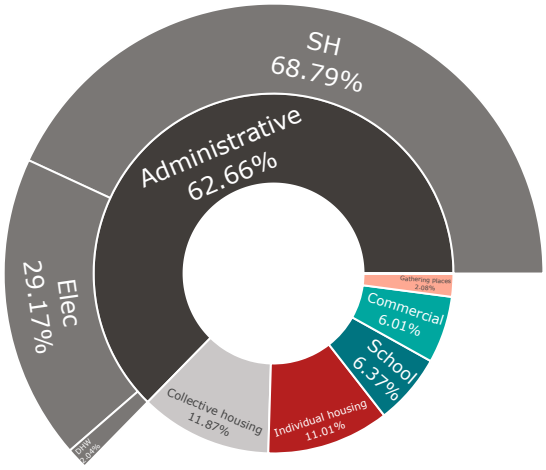

Figure: Energy demand by class of building and by use.

Table: Energy demand by class of building and by use.

Energy Use	Building Type	Energy demand [MWh/yr]
Collective housing	Total	267.71
SH	Collective housing	187.64
DHW	Collective housing	6.92
Elec	Collective housing	73.14
Individual housing	Total	248.28
SH	Individual housing	176.08

DHW	Individual housing	5.93
Elec	Individual housing	66.27
Administrative	Total	1413.31
SH	Administrative	972.19
DHW	Administrative	28.86
Elec	Administrative	412.26
School	Total	143.69
SH	School	93.28
DHW	School	1.44
Elec	School	48.97
Commercial	Total	135.59
SH	Commercial	88.02
DHW	Commercial	1.36
Elec	Commercial	46.21
Gathering places	Total	46.84
SH	Gathering places	32.66
DHW	Gathering places	1.21
Elec	Gathering places	12.97

3.2 Economic performance

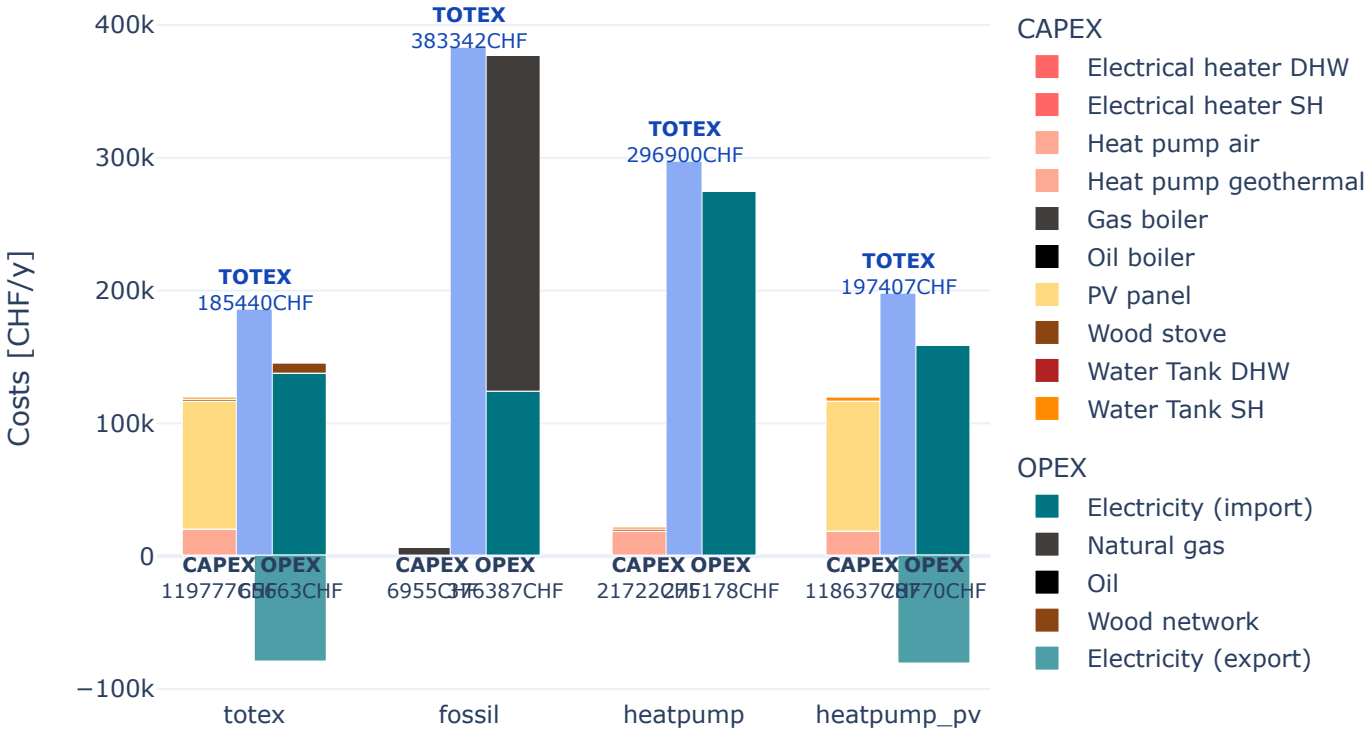

Figure: Total cost (TOTEX) distribution for all scenarios studied. The total cost is split into the capital cost (CAPEX) and the operating cost (OPEX) for each unit.

Table: Distribution of costs for each unit for all studied scenarios in CHF/yr.

Unit	fossil	heatpump	heatpump_pv	totex
ElectricalHeater_DHW	0.00	543.58	543.58	273.58
ElectricalHeater_SH	0.00	502.99	502.99	0.00
HeatPump_Air	0.00	18099.22	18046.01	596.35
HeatPump_Geothermal	0.00	0.00	0.00	18505.83
NG_Boiler	6653.66	0.00	0.00	0.00
OIL_Boiler	0.00	0.00	0.00	470.62
PV	0.00	0.00	96715.17	96715.17
WOOD_Stove	0.00	0.00	0.00	874.72
WaterTankDHW	302.02	307.74	567.76	563.88
WaterTankSH	0.00	2269.07	2262.35	1777.30

3.3 Environmental performance

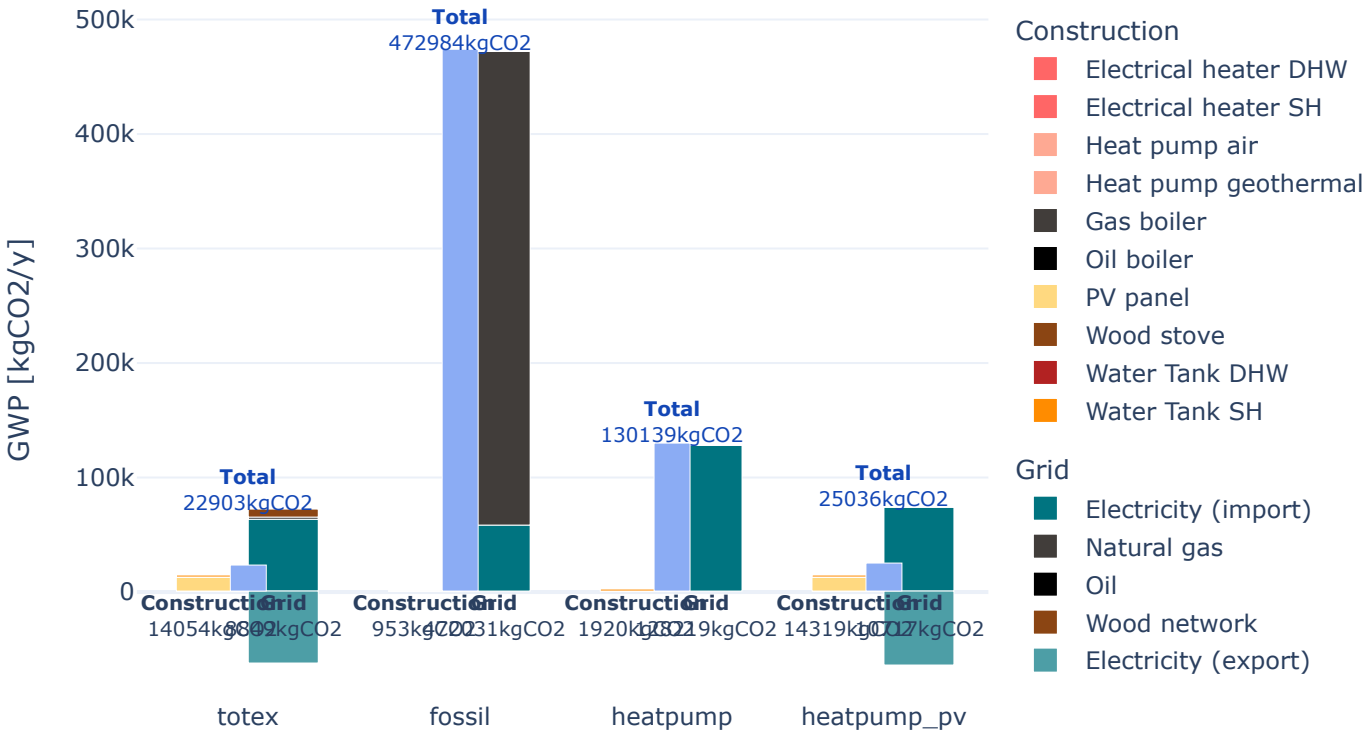

Figure: Carbon dioxide emissions distribution

Table: Carbon dioxide emissions distribution

Unit	fossil	heatpump	heatpump_pv	totex
ElectricalHeater_DHW	0.00	0.25	0.25	0.13
ElectricalHeater_SH	0.00	4.77	4.77	0.00
HeatPump_Air	0.00	1033.13	1029.93	21.81
HeatPump_Geothermal	0.00	0.00	0.00	788.64
NG_Boiler	908.89	0.00	0.00	0.00
OIL_Boiler	0.00	0.00	0.00	14.41
PV	0.00	0.00	12354.34	12354.34
WOOD_Stove	0.00	0.00	0.00	136.87
WaterTankDHW	45.10	46.23	97.53	96.77
WaterTankSH	0.00	835.73	833.08	641.69

Sankey diagrams

A Sankey diagram allows you to visualize the different flows of energy within a building:

- The building's final energy demand can be read to the right of the diagram: *Domestic Electricity*, *Heating*, *Water domestic hot*.
- Imported energy (*Oil*, *Electricity - purchase*) or produced locally (*Solar panels*) can be read on the left.
- Between these two extremes are the different conversion technologies (e.g. *Oil boiler*, *Heat pump*) and energy storage (e.g. *Hot water tank*).

The diagrams below show the annual energy balance for each of the scenarios studied.

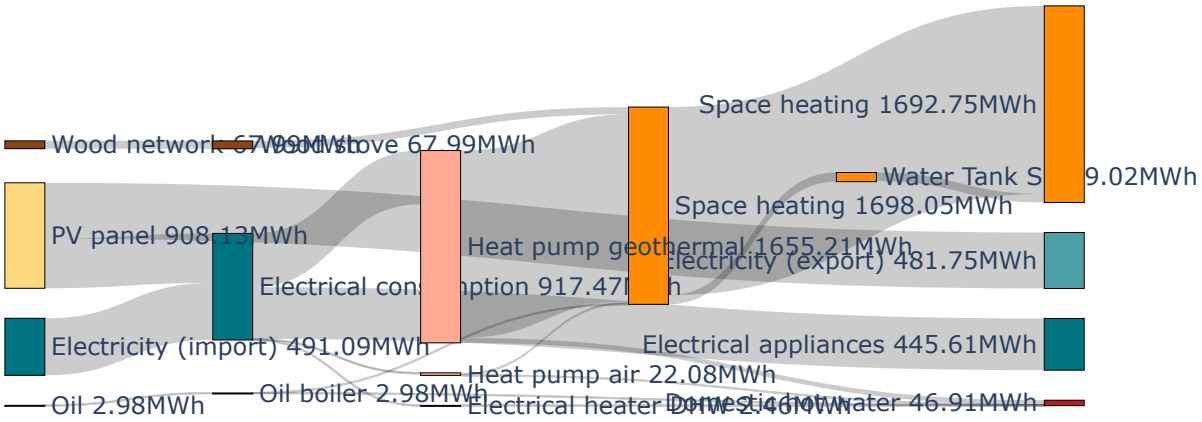

Figure: Sankey diagram of energy systems for the building for the TOTEX scenario.

Table: TOTEX scenario

source	target	Energy demand [MWh/yr]
Electricity (import)	Electrical consumption	491.09
Electrical consumption	Electrical appliances	445.61
PV panel	Electricity (export)	481.75
PV panel	Electrical consumption	426.38
Water Tank SH	Space heating	73.73
Space heating	Water Tank SH	79.02
Space heating	Space heating	1619.02
Electrical consumption	Heat pump air	6.53
Heat pump air	Domestic hot water	0.42
Heat pump air	Space heating	21.65
Oil	Oil boiler	2.98
Oil boiler	Domestic hot water	2.26
Oil boiler	Space heating	0.43
Electrical consumption	Electrical heater DHW	2.46
Electrical heater DHW	Domestic hot water	2.43
Wood network	Wood stove	67.99

Wood stove	Space heating	62.55
Electrical consumption	Heat pump geothermal	462.87
Heat pump geothermal	Domestic hot water	41.80
Heat pump geothermal	Space heating	1613.41

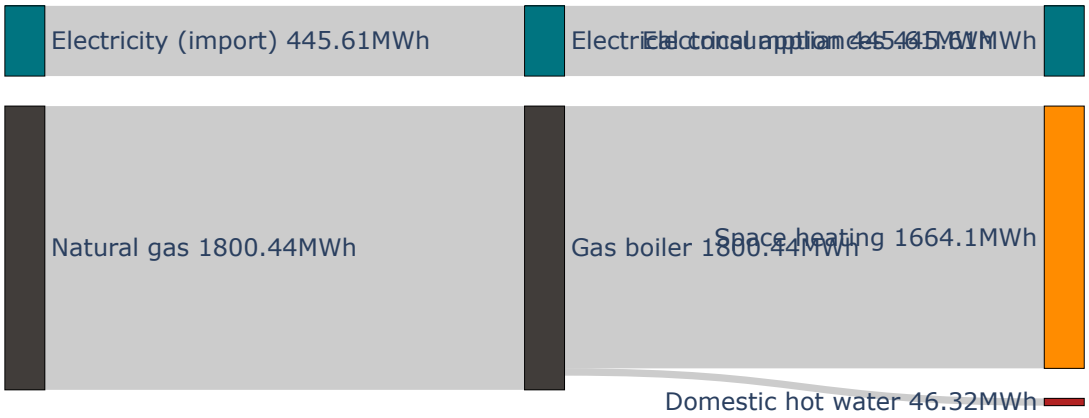

Figure: Sankey diagram of energy systems for the building for the Fossil scenario.

Table: Fossil scenario

source	target	Energy demand [MWh/yr]
Electricity (import)	Electrical consumption	445.61
Electrical consumption	Electrical appliances	445.61
Natural gas	Gas boiler	1800.44
Gas boiler	Domestic hot water	46.32
Gas boiler	Space heating	1664.10

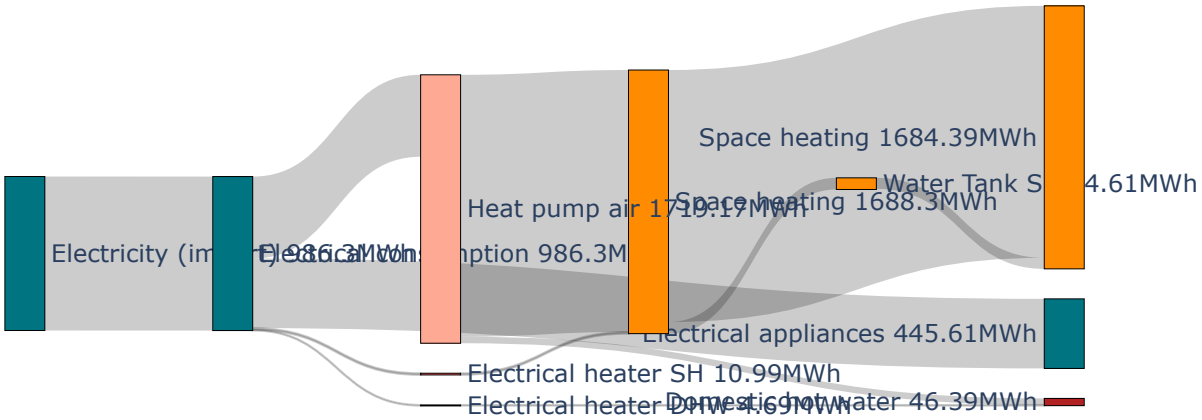

Figure: Sankey diagram of energy systems for the building for the HP air scenario.

Table: HP air scenario

source	target	Energy demand [MWh/yr]
Electricity (import)	Electrical consumption	986.30
Electrical consumption	Electrical appliances	445.61
Water Tank SH	Space heating	70.70
Space heating	Water Tank SH	74.61
Space heating	Space heating	1613.69
Electrical consumption	Heat pump air	525.01
Heat pump air	Domestic hot water	41.75
Heat pump air	Space heating	1677.42
Electrical consumption	Electrical heater DHW	4.69
Electrical heater DHW	Domestic hot water	4.64
Electrical consumption	Electrical heater SH	10.99
Electrical heater SH	Space heating	10.88

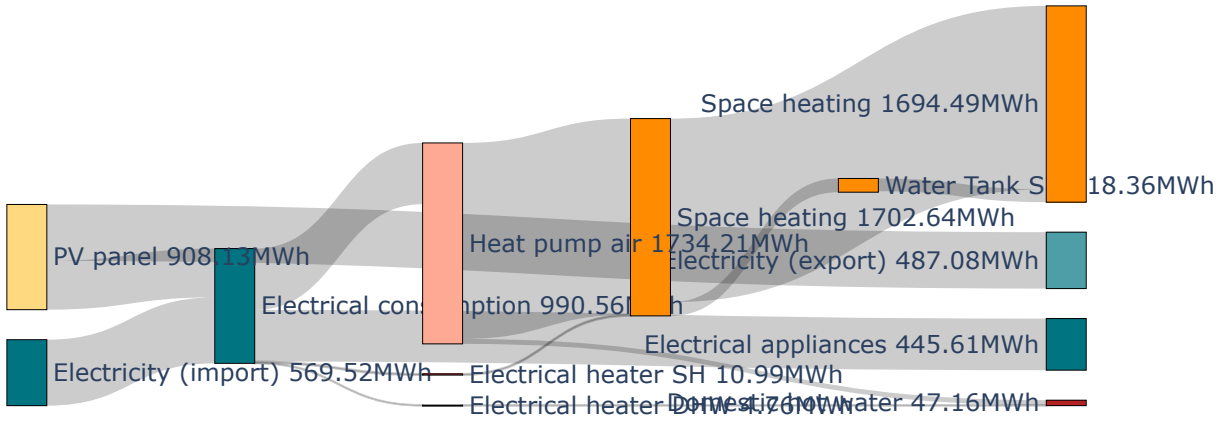

Figure: Sankey diagram of energy systems for the building for the PV + HP air scenario.

Table: PV + HP air scenario

source	target	Energy demand [MWh/yr]
Electricity (import)	Electrical consumption	569.52
Electrical consumption	Electrical appliances	445.61
PV panel	Electricity (export)	487.08
PV panel	Electrical consumption	421.05
Water Tank SH	Space heating	110.20
Space heating	Water Tank SH	118.36
Space heating	Space heating	1584.29
Electrical consumption	Heat pump air	529.20
Heat pump air	Domestic hot water	42.45
Heat pump air	Space heating	1691.77
Electrical consumption	Electrical heater DHW	4.76
Electrical heater DHW	Domestic hot water	4.72
Electrical consumption	Electrical heater SH	10.99
Electrical heater SH	Space heating	10.88

Time profiles

The graphs below show the hourly profiles (smoothed with a weekly average) of production and consumption of energy of the building for each of the studied scenarios.

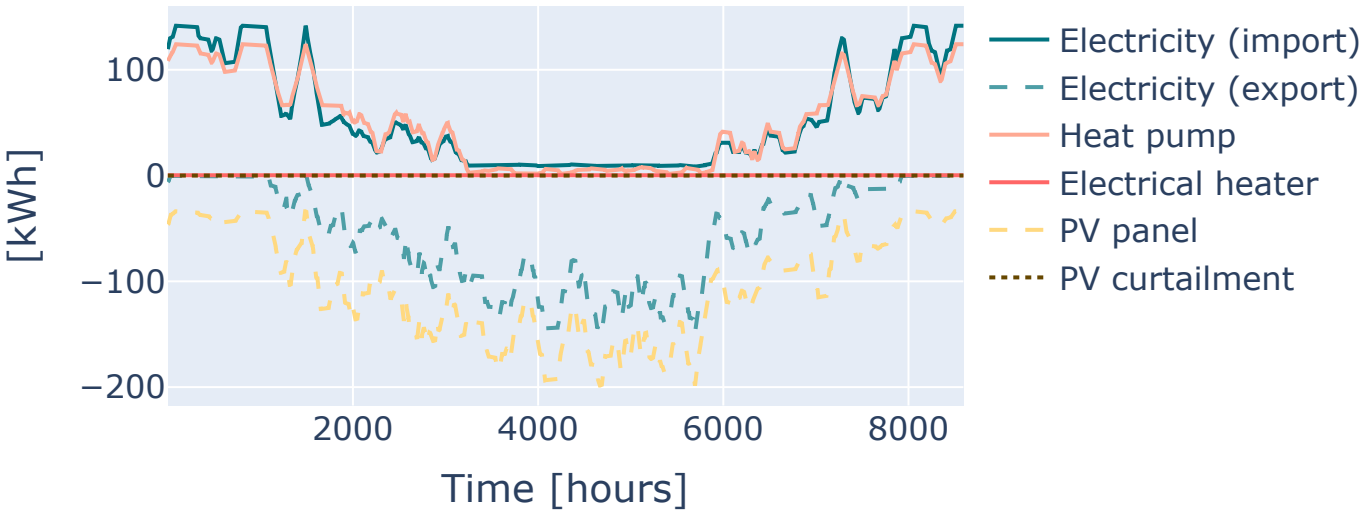

Figure: Profile plot for the building for the TOTEX scenario.

Table: TOTEX scenario

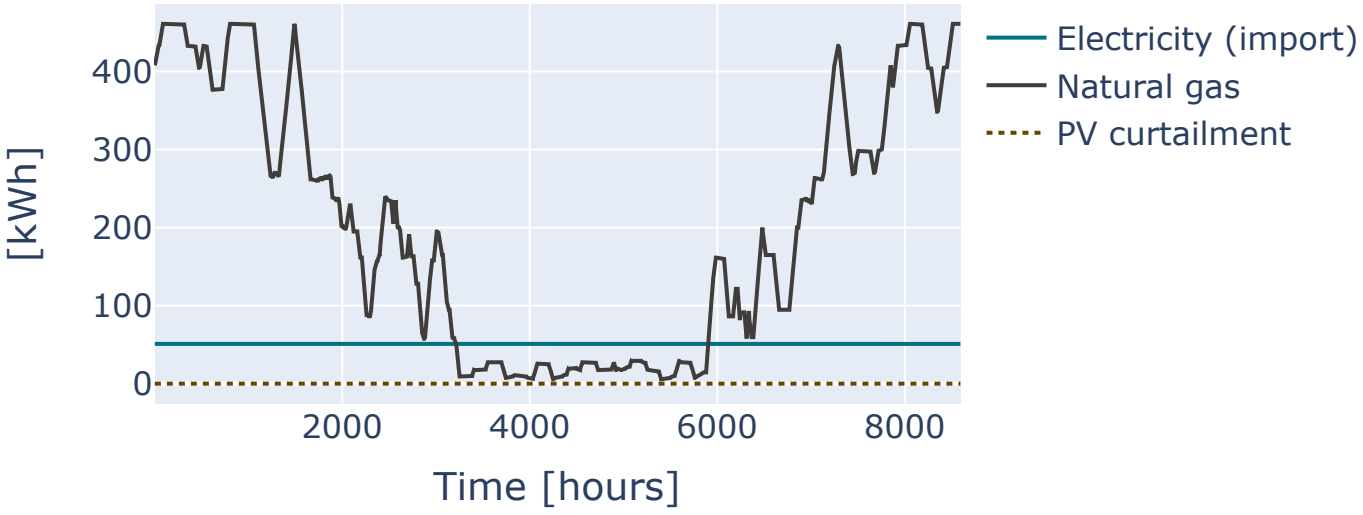

Figure: Profile plot for the building for the Fossil scenario.

Table: Fossil scenario

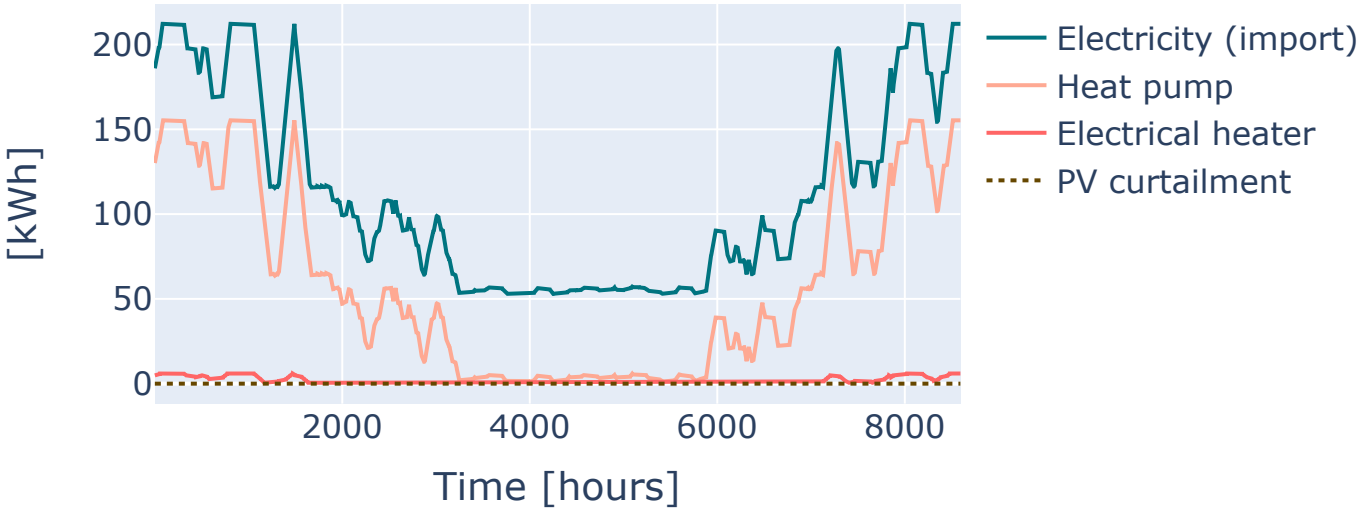

Figure: Profile plot for the building for the HP air scenario.

Table: HP air scenario

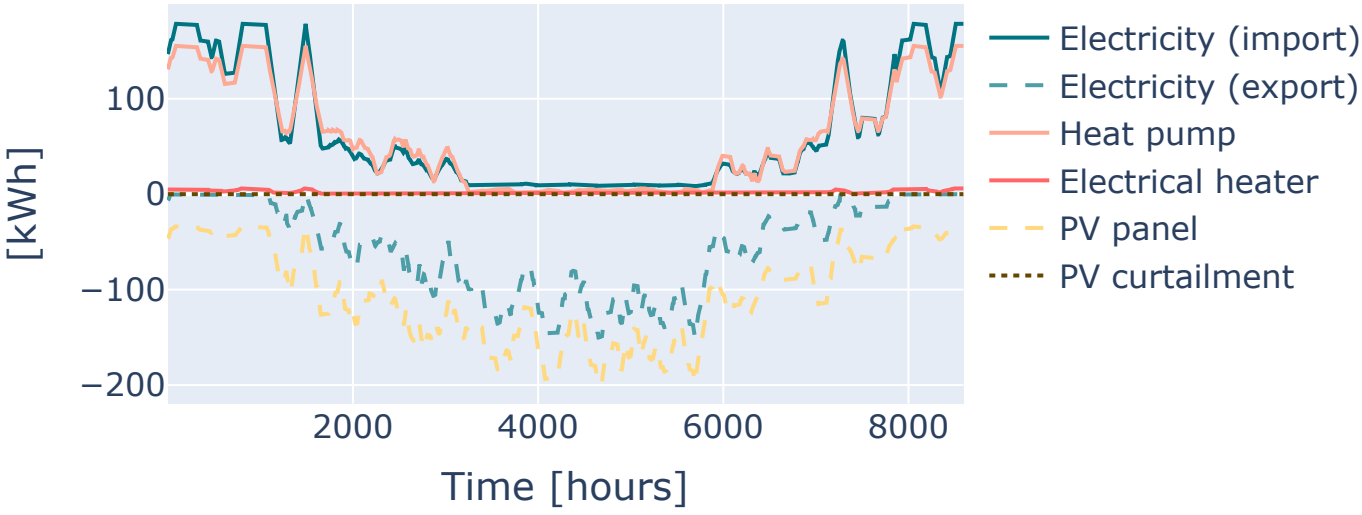

Figure: Profile plot for the building for the PV + HP air scenario.

Table: PV + HP air scenario