# Renewable Energy Hub Optimizer



June 2023

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# 1. Introduction

This report offers an energy analysis of the building Avenue de Floréal 40, 1008 Prilly , located in the canton of Vaud , 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 building for this use case.

- QBuildings is a geographical database allowing to characterize the territory from an energy point of view. The final energy demand includes the needs for domestic electricity, domestic hot water, and in heating. This data is generated using databases (Register building and housing authority, Sonnendach, swissBUILDINGS3D 2.0) and the standards of the Swiss Society of Engineers and Architects.
- REHO is a decision support tool for the energy optimization of buildings, according to economic, environmental and energy efficiency.

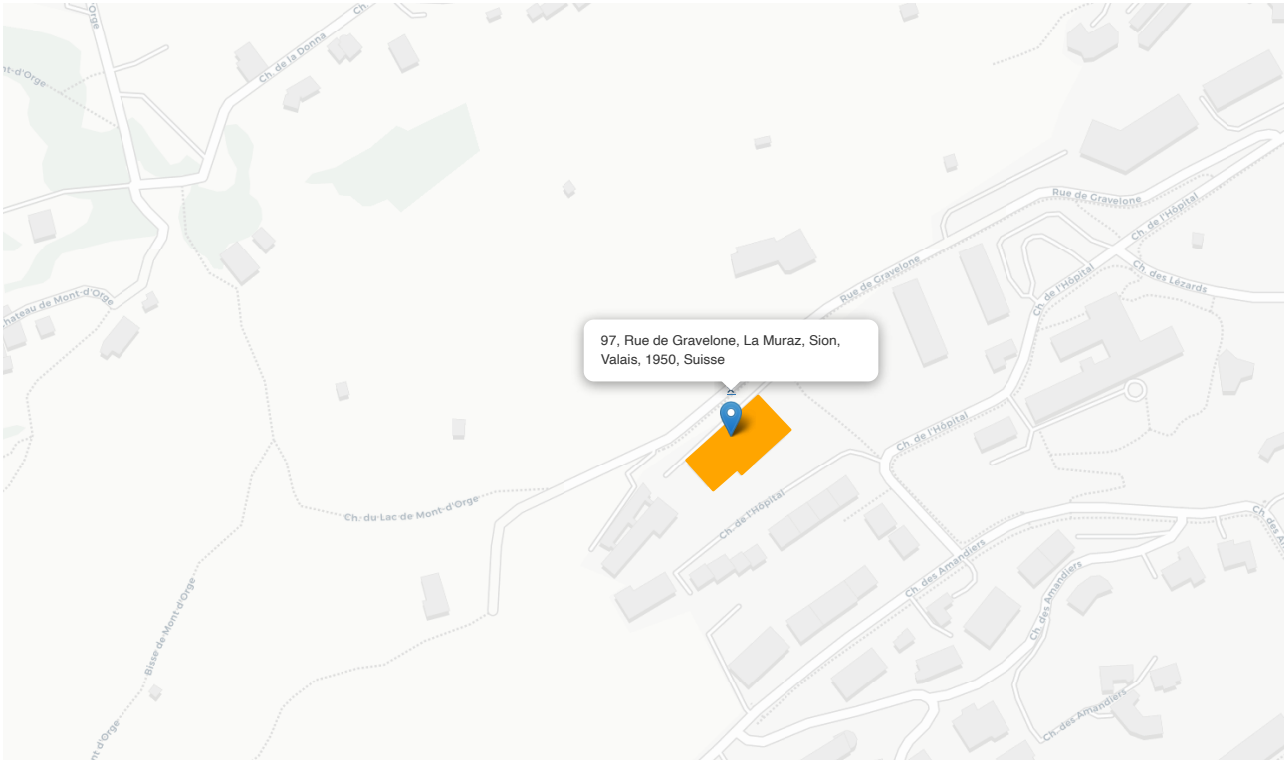


Figure: Chosen buildings for study case.

# 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_Boiler, NG_Cogeneration, WOOD_Stove, 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:

- Construction period: 1981-1990.
- 3307.0 [m2] of reference energy surface (= SRE). That corresponds to the total heated floor area all dwellings
- 264.0 residents.
- Thermal transmittance signature of 0.002 [kW/K/m2] (expressed relative to the SRE).
- Set temperature for thermal comfort: 20.0 [°C].
- Heating circuit temperatures: 65.0-50.0 [°C] for the boiler fuel oil, and TODO [°C] for air-water heat pumps or geothermal.
- The surface available on the roof for the installation of panels is 1122.0[m2].
    - This area is estimated from Sonnendach data. The roof surface of the studied building is 1122.0 [m2], of which 1122.0 [m2] with very good skill.
    - The solar irradiance received by this roof surface is 1412406.0 [MWh/year], i.e. TODO 1346 [kWh/m2/year].

## Studied scenarios

In this case study a multi-objective optimization was done

TODO

## 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) | 0.279 | 0.13 |
| Electricity (selling) | 0.164 | 0.13 |
| Fuel oil | 0.140 | 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

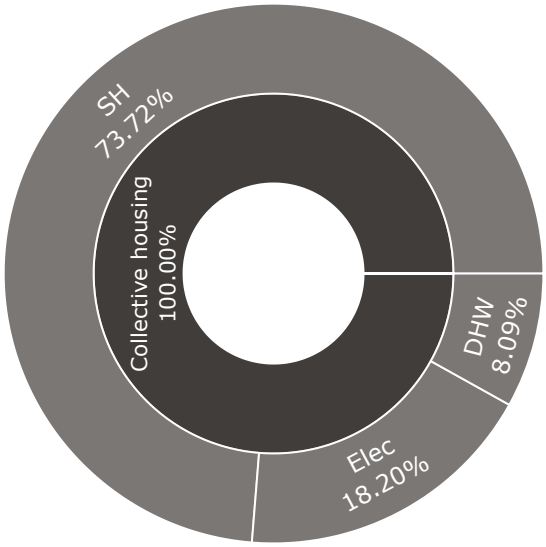


Figure: Energy demand by class of building and by use.

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

| Energy Use | Building Type | Energy demand [MWh/yr] |
|---|---|---|
| Collective housing | Total | 2558.18 |
| SH | Collective housing | 1885.83 |
| DHW | Collective housing | 206.89 |
| Elec | Collective housing | 465.46 |

## 3.2 Multi-objective optimization

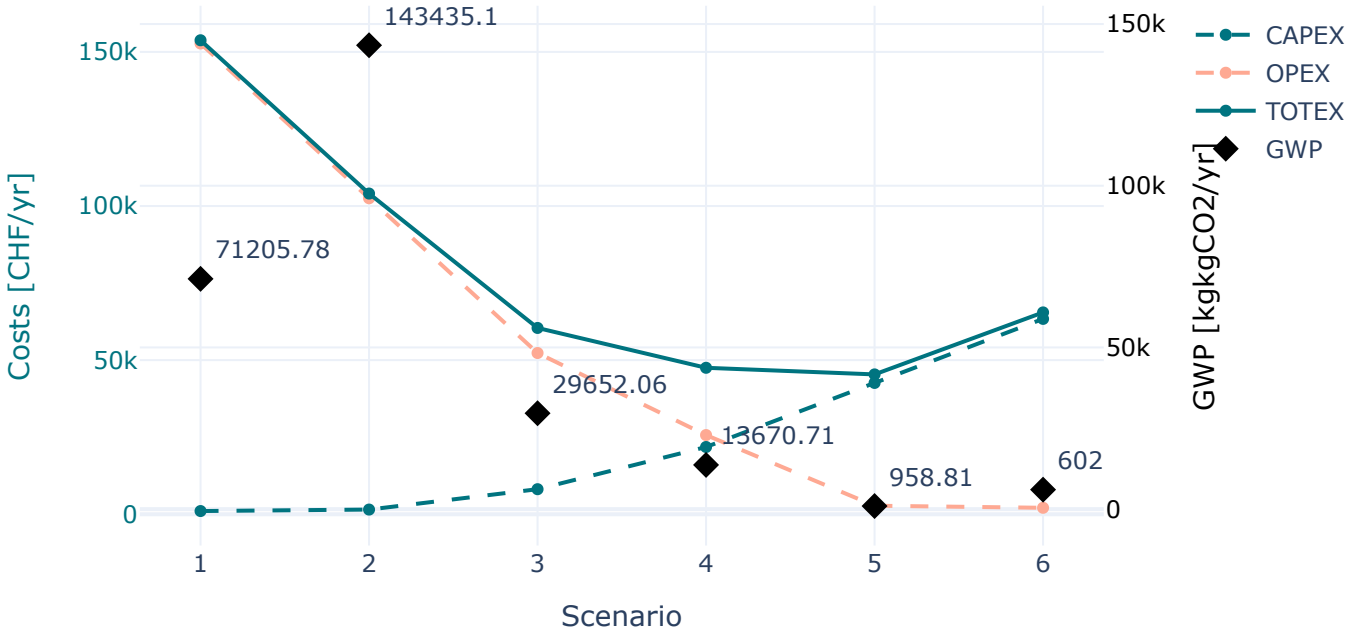


Figure: Total cost (TOTEX), capital cost (CAPEX) and the operating cost (OPEX) for each pareto point.

Table: OPEX, CAPEX and TOTEX for all pareto points.

| Scenario | CAPEX | OPEX | TOTEX | GWP |
|---|---|---|---|---|
| 1 | 1041.78 | 152739.76 | 153781.54 | 71205.78 |
| 2 | 1519.83 | 102527.12 | 104046.95 | 143435.10 |
| 3 | 8128.06 | 52314.48 | 60442.54 | 29652.06 |
| 4 | 21822.22 | 25695.06 | 47517.28 | 13670.71 |
| 5 | 42602.65 | 2768.49 | 45371.14 | 958.81 |
| 6 | 63383.08 | 2101.84 | 65484.92 | 6027.95 |

## 3.3 Economic performance

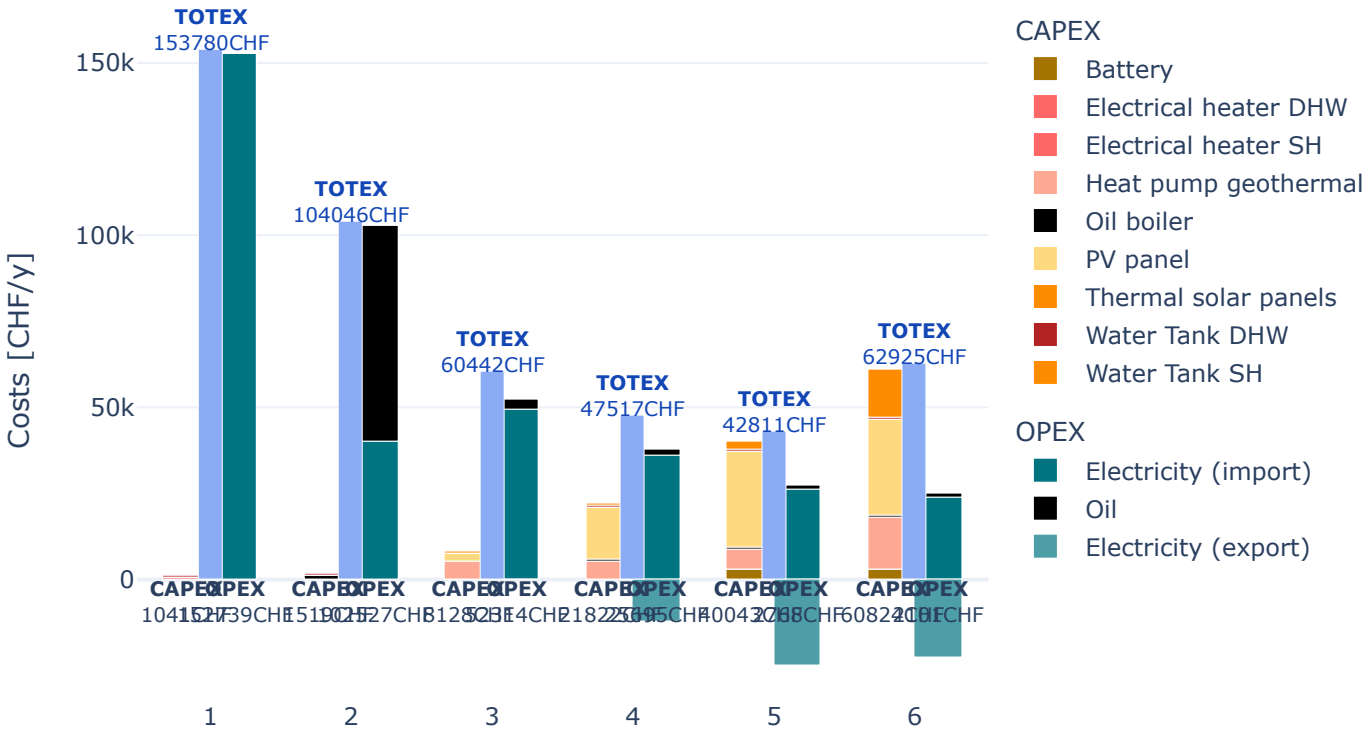


Figure: Total cost (TOTEX) distribution for all scenarios studied. The total cost is split into the capital cost (CAPEX) and the operating cost (OPEX) for each unit.

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

| Unit | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Battery | 0.00 | 0.00 | 0.00 | 0.00 | 3118.99 | 3118.99 |
| ElectricalHeater_DHW | 461.97 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| ElectricalHeater_SH | 416.50 | 189.55 | 0.00 | 0.00 | 0.00 | 0.00 |
| HeatPump_Geothermal | 0.00 | 0.00 | 5007.28 | 5162.90 | 5808.76 | 15022.75 |
| OIL_Boiler | 0.00 | 1166.96 | 444.10 | 444.10 | 451.10 | 451.32 |
| PV | 0.00 | 0.00 | 2054.70 | 15441.04 | 27752.92 | 27696.17 |
| ThermalSolar | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 299.18 |
| WaterTankDHW | 163.32 | 163.32 | 163.32 | 300.81 | 371.80 | 371.80 |
| WaterTankSH | 0.00 | 0.00 | 458.65 | 473.37 | 2540.41 | 13864.22 |

## 3.4 Environmental performance

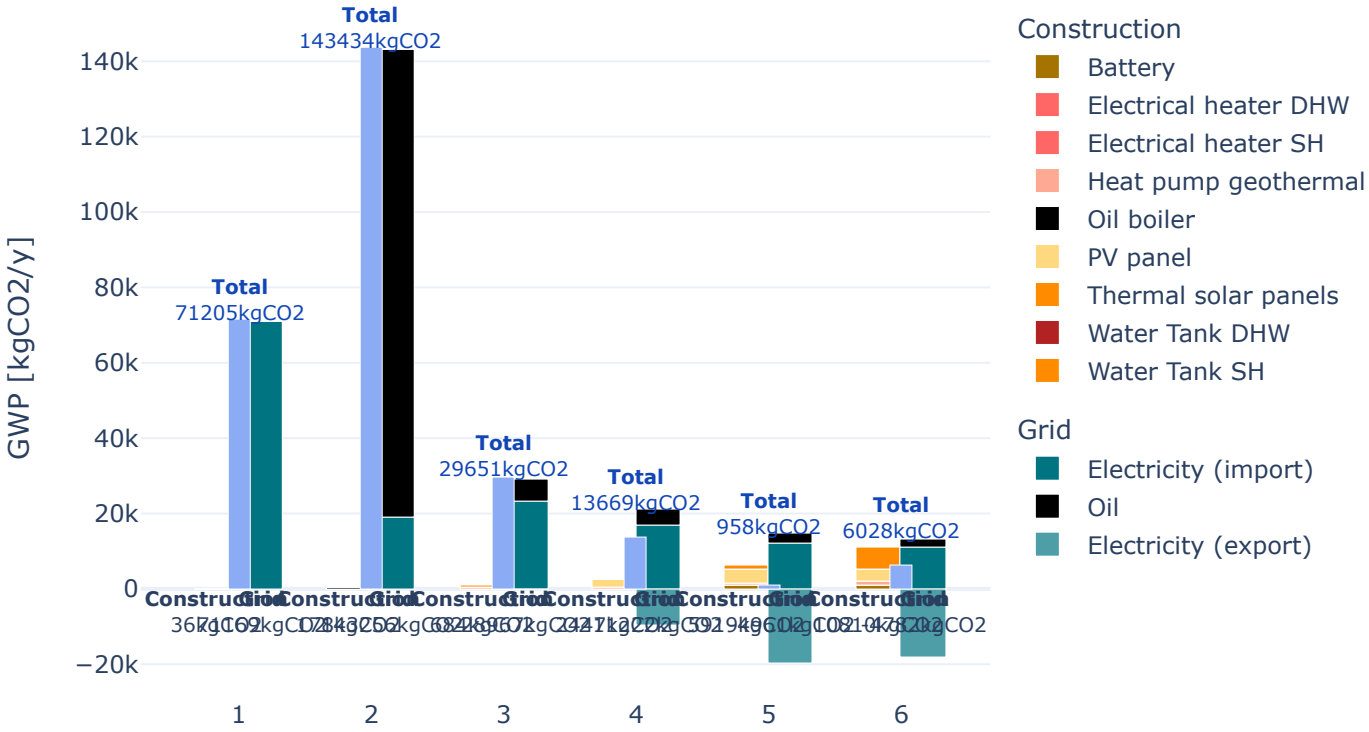


Figure: Carbon dioxide emissions distribution

Table: Carbon dioxide emissions distribution

| Unit | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Battery | 0.00 | 0.00 | 0.00 | 0.00 | 1027.80 | 1027.80 |
| ElectricalHeater_DHW | 1.57 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| ElectricalHeater_SH | 6.55 | 2.37 | 0.00 | 0.00 | 0.00 | 0.00 |
| HeatPump_Geothermal | 0.00 | 0.00 | 210.45 | 217.48 | 246.63 | 662.61 |
| OIL_Boiler | 0.00 | 147.54 | 38.65 | 38.65 | 39.71 | 39.74 |
| PV | 0.00 | 0.00 | 241.09 | 1963.99 | 3548.59 | 3541.29 |
| ThermalSolar | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 13.57 |
| WaterTankDHW | 28.60 | 28.60 | 28.60 | 55.72 | 69.73 | 69.73 |
| WaterTankSH | 0.00 | 0.00 | 166.08 | 171.89 | 987.46 | 5455.42 |

### 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.

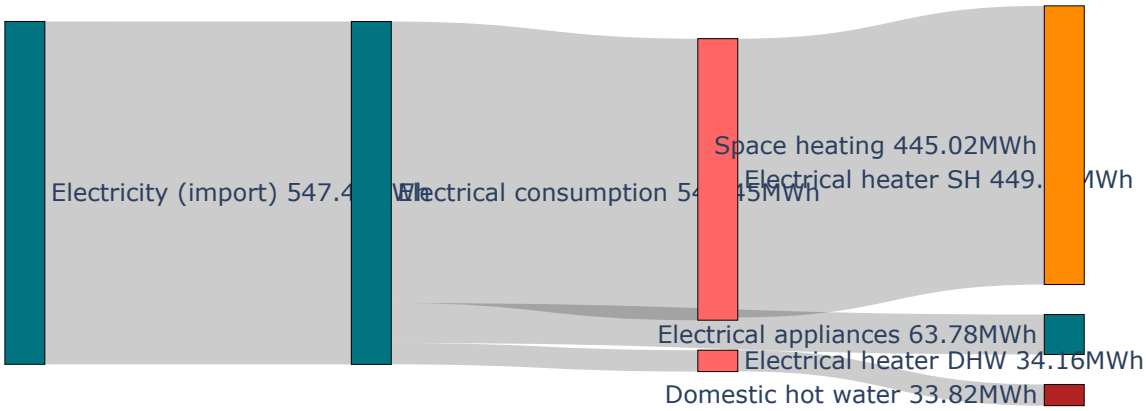


Figure: Sankey diagram of energy systems for the building for the TOTEX scenario.

Table: TOTEX scenario

| source | target | Energy demand [MWh/yr] |
|---|---|---|
| Electricity (import) | Electrical consumption | 547.45 |
| Electrical consumption | Electrical appliances | 63.78 |
| Electrical consumption | Electrical heater DHW | 34.16 |
| Electrical heater DHW | Domestic hot water | 33.82 |
| Electrical consumption | Electrical heater SH | 449.52 |
| Electrical heater SH | Space heating | 445.02 |

### 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.

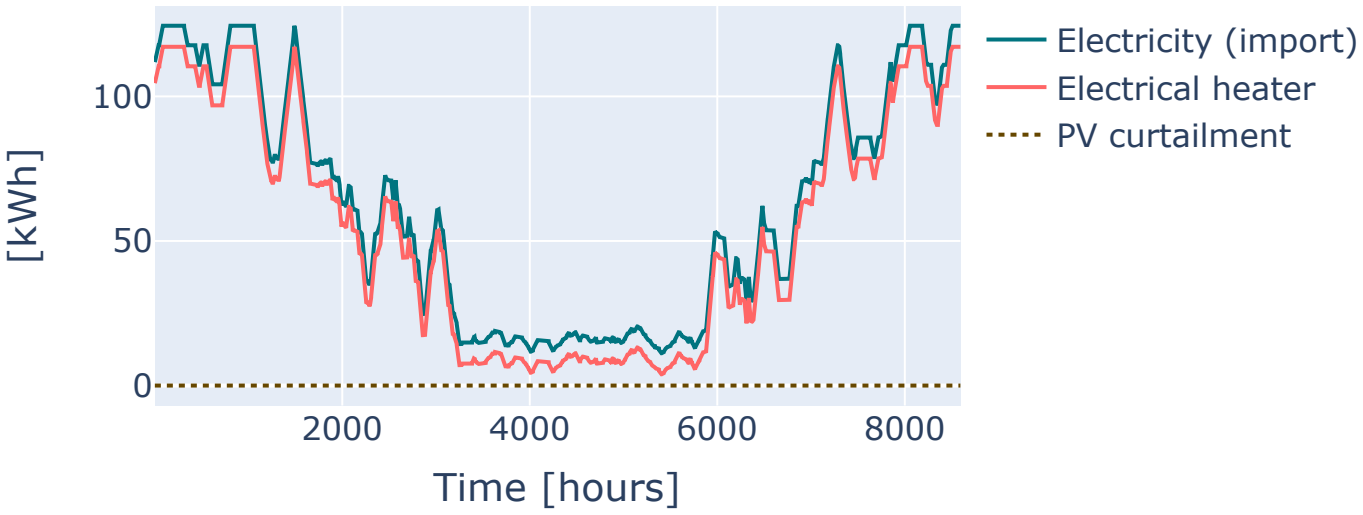


Figure: Profile plot for the building for the TOTEX scenario.

Table: TOTEX scenario