Zero Emission and Positive Energy Districts: Energy Strategy Report

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1. ***Describe the problem and the chosen energy solutions***

The aim of the project is to design a zero-emission positive energy district, situated in Crescenzago, Milan; 45”30.2’ North, 9”14.8’ East. MATLAB is used to run simulations to evaluate district energy needs, HVAC choice and sizing, renewable energy integration, energy system design and optimization, life cycle assessment (LCA), and resilience to climate change – considering 2050 predicted weather data.

The case study, “Green Between – Tessiture Urbane” involves eight buildings to be analyzed, with ground floors used for commercial reasons and upper floors for residential use, in an area of 1.5 hectares. “Tower” and “block” buildings, the former of 12 or 13 floors, the latter of 6 or 7, comprise the district: 4 of each type. The building footprint of the former is 824 meters squared, the latter 1186, for a total footprint of 2010 m^2. Each type is paired adjacently, with tower buildings typically 42 meters tall and the latter around 20 meters. Surrounding buildings are also present just outside the area, which causes shading on the buildings investigated. Building data is shown in Tables 1 and 2, with heights above ground in meters.

The district energy demand calculator was used, with weather data provided for Milan Linate. The use of sky models determines solar irradiance over surfaces, for each hour and period.

Weather data is plotted for each hour of the year, shown in Figure 2. The curve of temperature shows a mean of around 0 to 10 degrees in winter, and 20 to 25 degrees in summer. Solar irradiance follows a similar trend, with highs of around 900 and lows of 100 W/m^2. Summer shows greater humidity, whilst winter is drier. Wind speeds are more variable, with greater winds in spring.

Figure 1: Geoplot of the District

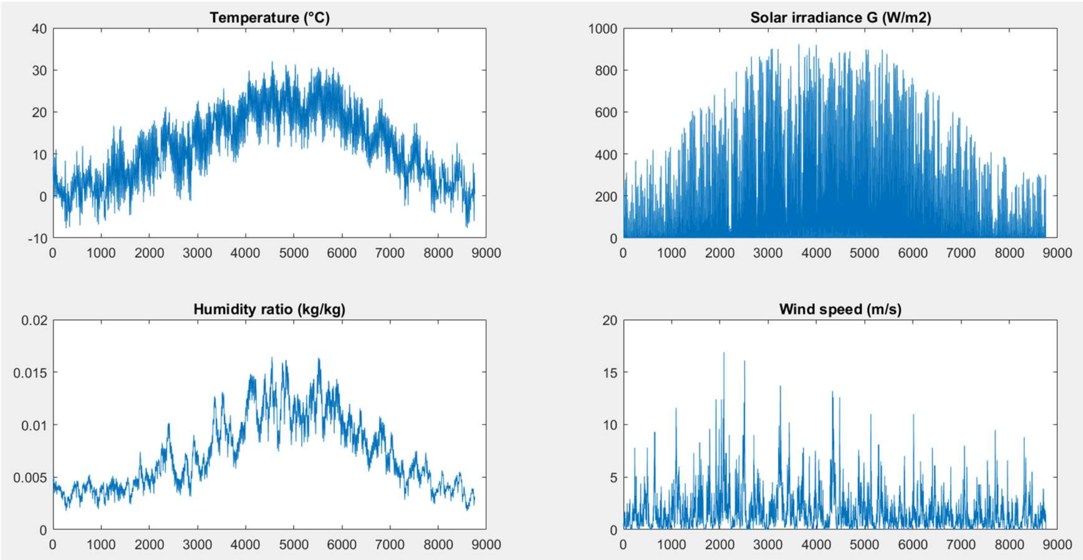

Figure 2: Weather Plots for each hour of the year

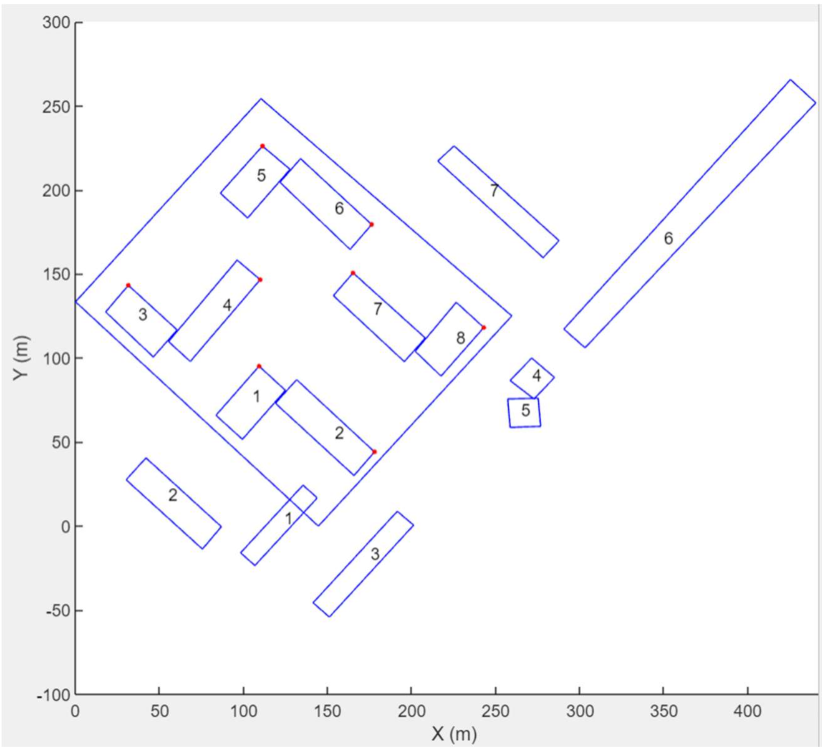

Figure 3: District Footprint

Figure 3 represents the eight buildings in the district, shown within the rectangle, as well as seven surrounding buildings, responsible for shading effects on the district.

Table 1: District Buildings

ID	Name	Height	Floors
1	Bld_1	42.1200	13
2	Bld_2	22.6800	7
3	Bld_3	42.1200	13
4	Bld_4	22.6800	7
5	Bld_5	42.1200	13
6	Bld_6	19.4400	6
7	Bld_7	19.4400	6
8	Bld_8	38.3800	12

Table 2: Neighboring Buildings

ID	Name	Height
1	Bld_1	9
2	Bld_2	18
3	Bld_3	9
4	Bld_4	27
5	Bld_5	27
6	Bld_6	6
7	Bld_7	24

<u>Envelope</u>

Theoretical energy needs – the thermal and electrical loads – of each building were evaluated to provide the basis for HVAC selection. Schedules for occupation, domestic hot water, and appliances were defined based on intended use of each space. Calculations also required information regarding building geometry and weather data. Building geometry involved shape, height, orientation, number of surfaces, areas, and window surfaces and areas. The stratigraphy of each surface was also required, providing information on material properties composing layers of surfaces. The code's output includes data regarding sensible and latent loads for heating and cooling, electrical appliance load, and domestic hot water load (DHW), on an hourly basis. These are shown in Figures 4 to 7, on an hourly basis, over a year.

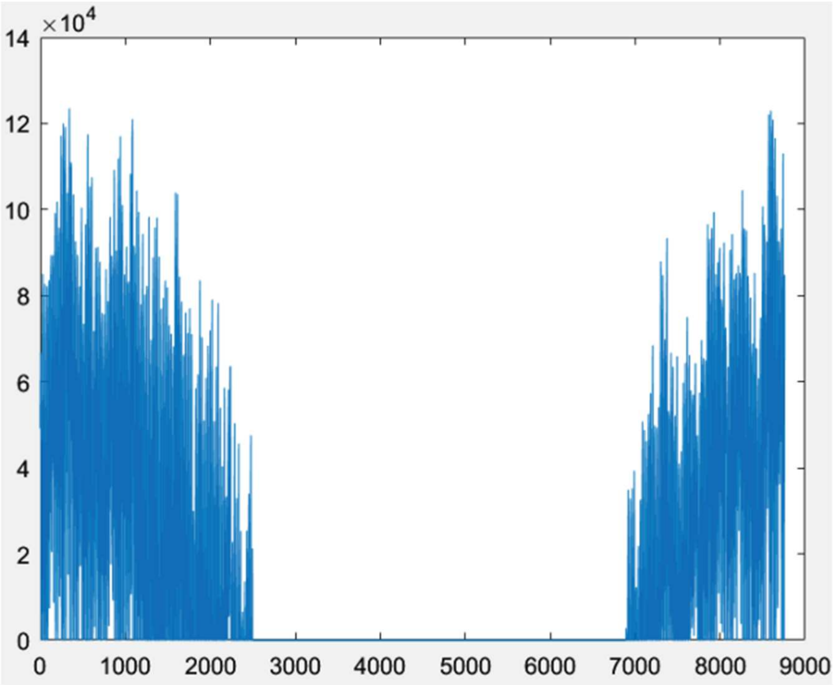

Figure 4: Sensible Heating Load [W]

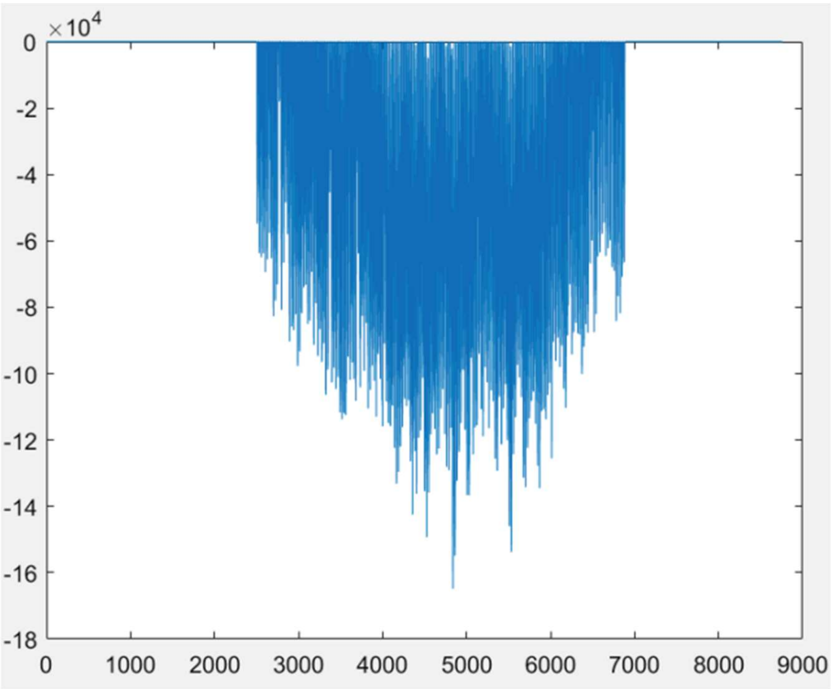

Figure 5: Sensible Cooling Load [W]

Heating is required only in the winter months and is thus zero in summer. The peak load is around 120 kW. Cooling load is represented as negative, as heat must be extracted from buildings, this is required in summer. The peak is around -160 kW.

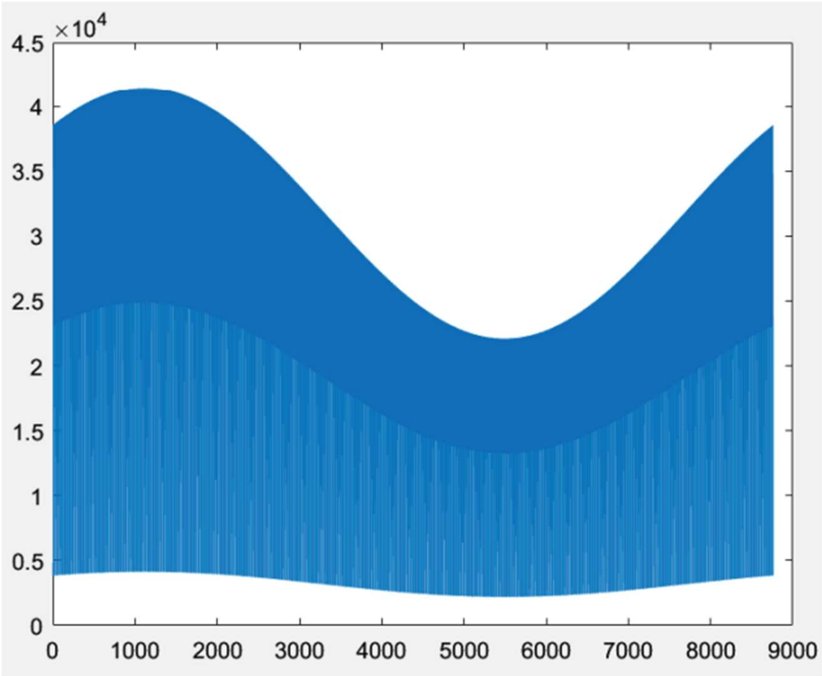

Figure 6: Domestic Hot Water Load [W]

DHW requirement is greater in the colder months, although it is a necessity throughout the year. Load rarely falls below 5 kW, with peaks above 400 kW.

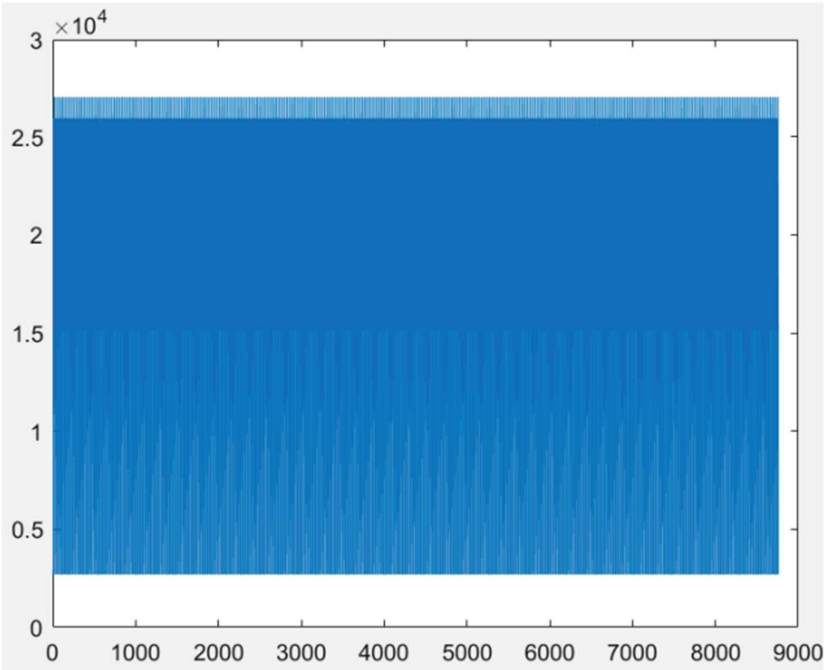

Figure 7: Electric Appliances Load [W]

Electric appliances have almost constant use throughout the year, usually within the range of 15 to 25 kW.

Net-Zero Energy Buildings require adherence to national and regional regulations. For Milan, the building envelope must respect imposed limits on average heat transfer coefficient, depending on surface-to-volume ratio of the building, summarized in Table 3.

Table 3: Surface-to-volume ratio and corresponding Heat Transfer Coefficient Limits

S/V	$H'_{T,lim}$
≥ 0.7	0.50
≥ 0.4 *and* ≤ 0.7	0.55
≤ 0.4	0.75

HVAC System

Where the initial evaluation of building subsystem energy needs gave an estimate, a further analysis considers the energy that must be supplied to the distribution subsystem. This includes losses due to parasitic power. Various types of distribution subsystems are listed, which were applied to the various buildings and sub-buildings:

Table 4: Subsystem Types

Type	Distribution
1	Fan-coils + Natural Ventilation
2	Fan-coils + Mechanical Ventilation
3	Primary Air AHU + Fan-coils
4	Primary Air AHU + Radiant Floors
5	All Air AHU
6	DEC system + Radiant Floors

Modification of input parameters sizes the HVAC and the DHW systems, in terms of power installed, tank volume, and heater capacity. For the first two cases humidity is not regulated, which reduces energy needs but may cause discomfort. Type 2 performs better than type 1 due to heat recovery in the crossflow heat exchanger, thus outweighing the negatives of parasitic energy consumption due to mechanical ventilation. Type 1 is not considered in the analysis, natural ventilation requires manual intervention (someone deciding to open a window, for example). It is thus subjective, leading to energy losses, ventilation would not be optimized. In the third case a reheat is present in the dehumidifier, thus there is a heating energy requirement associated with cooling. The use of a reheat is for comfort reasons, to move away from the saturation curve: equating to the point of 100% relative humidity, where one may feel discomfort due to sweating. Parasitic consumption is higher than in the previous case. Type 4 uses radiant floors, with the disadvantage of temperature limits on these; in summer a floor that is too cool risks condensation, and in winter a floor that is too hot may be uncomfortable. Radiant floors are avoided due to insufficiency regarding comfort levels. The fifth option has very high energy needs due to high air volume change per hour. It is suited for commercial use as high loads can be covered. In designing a residential district in this report, type 5 is not considered. Type 6 is not considered due to radiant floor use, although Dessicant Evaporative Cooling (DEC) is a good technology, showing lower heating and cooling energy use compared to air handling units.

The selected type for the analysis is type 2, implementing fan-coils as well as mechanical ventilation, applied to all the buildings. Use of heat recovery in the heat exchanger makes it a good choice, and unlike types 3 and 4 there is no consumption due to reheating. In designing a "green" district limitation of parasitic consumption is favorable, both to reduce environmental impact and wasted heat. A cooling potential is lost in the reheat, although it may prove more comfortable. Fan-coils provide heating, cooling, with ventilation provided mechanically, although dehumidification is not regulated. Comfort levels may be slightly lower than for type 3, thus there is a trade-off between limiting wasted heat and comfort levels. However, fan-coils are a water-based distribution system, which is inherently more efficient than air (e.g. type 3). Air is less dense than water, requiring larger ducts, thus greater capital costs. Parasitic power is higher compared to water, and air leakages are an inherent and significant problem. Thus, type 2 is selected.

Thermal Micro-grid Energy Center and Substation

Substations' heat pumps and District Hot Water storage are sized in this section. Daily profiles are thus obtained. The following analyzes the subsystem case 2, fan coil plus mechanical ventilation. Chiller heat pump is sized based on maximum value between space cooling and DHW, to satisfy energy needs. Thus, the smallest energy efficiency ratio ("EER3") is taken, to consider worst case scenario, so that the pump can meet requirements. It is better to have an oversized heat pump rather than an undersized one. Heat pump sizing also considers worst case scenario, minimum COP, and only space heating is considered since the heat pump is not used for DHW. 16 substations are designed, with fan-coils plus mechanical ventilation.

The optimization is made considering 8 different temperatures of the network (6 to 34 °C) and 12 periods (from the 15th to the 14th of each month), resulting in daily profiles of the power flowing in the single substation. Heating, cooling, and DHW curves are shown below.

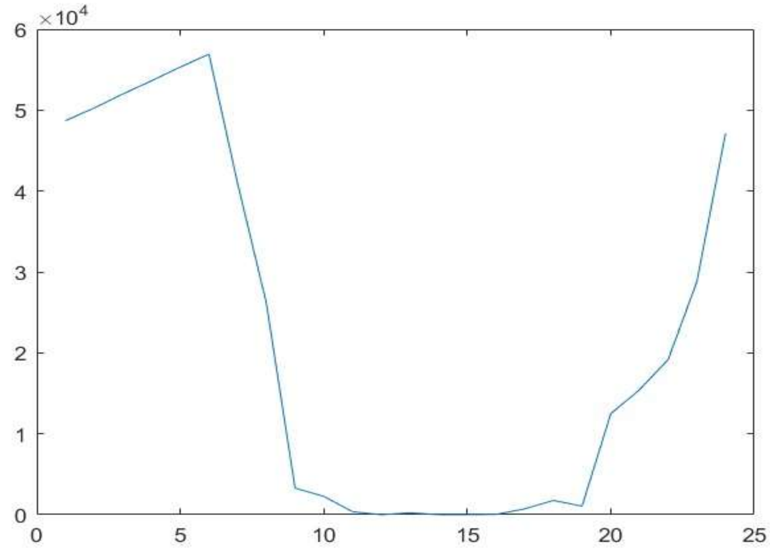

Figure 8: Heat Production of Heat Pump-1st period, 1st typical day

Figure 8 shows heat production of the heat pump, for a typical January day. Heat production is in the morning and evening, with almost no production in the afternoon.

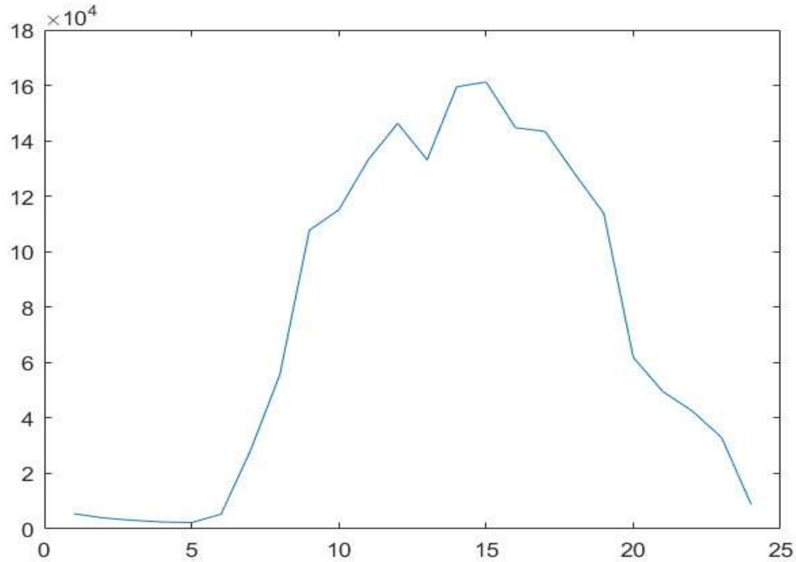

Figure 9: Cooling Production-7th period, 1st typical day

Cooling production in July is focused around the afternoon, with very little production at night. DHW production peaks around mealtimes, with the greatest peaks in the morning and evening.

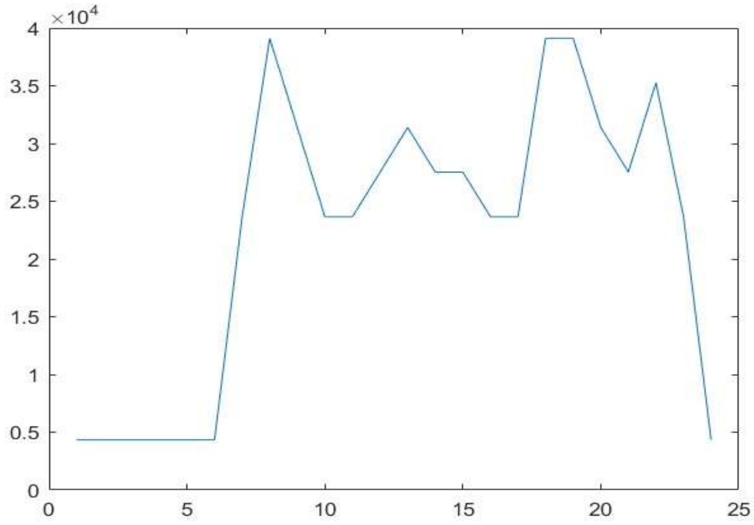

Figure 10: Heating of Domestic Hot Water-1st period, 1st typical day

Furthermore, the sizing of the central heat pump, balancing unit, and chiller (groundwater heat exchanger and pump) are performed. Power inputs of both pumps are defined, as well as maximum mass flowrate from groundwater wells, and balancing unit volume. This is achieved through the following steps. The first comprises aggregation of all substations, for all the periods. Then, balancing unit volume is computed; the highest demands for heating and cooling for two separate periods are defined, the volume is derived from an energy balance. The maximum volume between the two cases is selected as that of the balancing unit. Next, considering the central heat pump to operate at full load for 20 hours per day, its heating capacity at full load can be computed. The lowest Coefficient of Performance is taken, to evaluate the worst-case scenario, in calculating power input. To compute maximum mass flowrate, energy balances are performed at evaporator for heating, and chiller for cooling, the maximum between the two being the mass flowrate defined. This leads to the following step, computation of groundwater pump electric power, being the power required for groundwater extraction.

In the case of heating, where the heat pump evaporator extracts heat from groundwater, the balancing unit is heated by the rejected heat from the condenser. The heat exiting the balancing unit is exactly that which is injected in the energy center, as internal energy variation is set to zero. In the case of cooling, heat from the balancing unit is used in the heat exchanger where the groundwater now acts as cooling water. Due to no internal energy variation, the heat leaving the balancing unit must be extracted from the energy center.

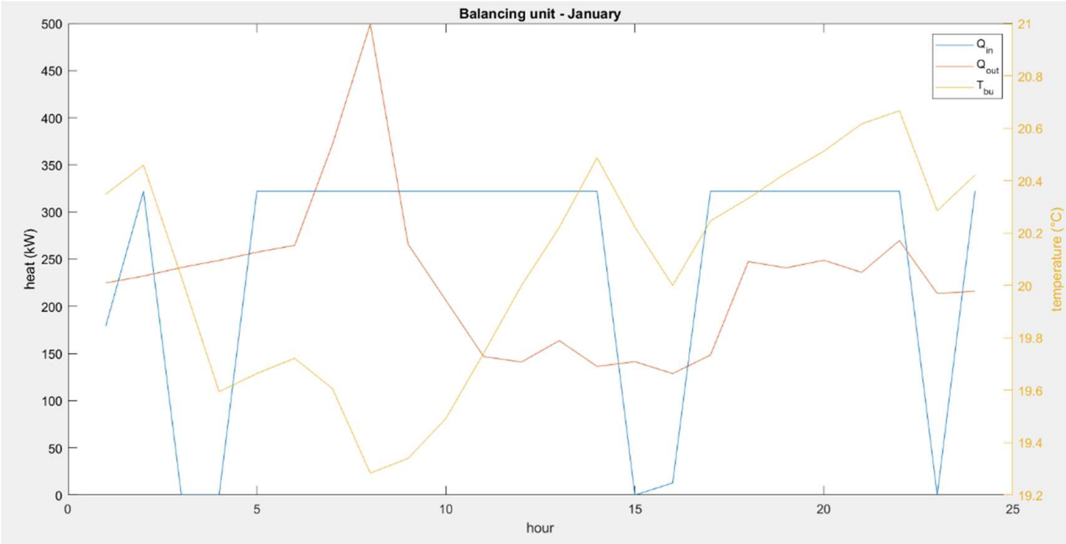

Figure 11: Balancing Unit, January

Figure 11 is for the case of heating. The Q_{out} curve follows heating demand, with Q_{in} the required heat input from groundwater. Balancing unit temperature increases when heating demand is lower, as the heat extracted from the ground is still present.

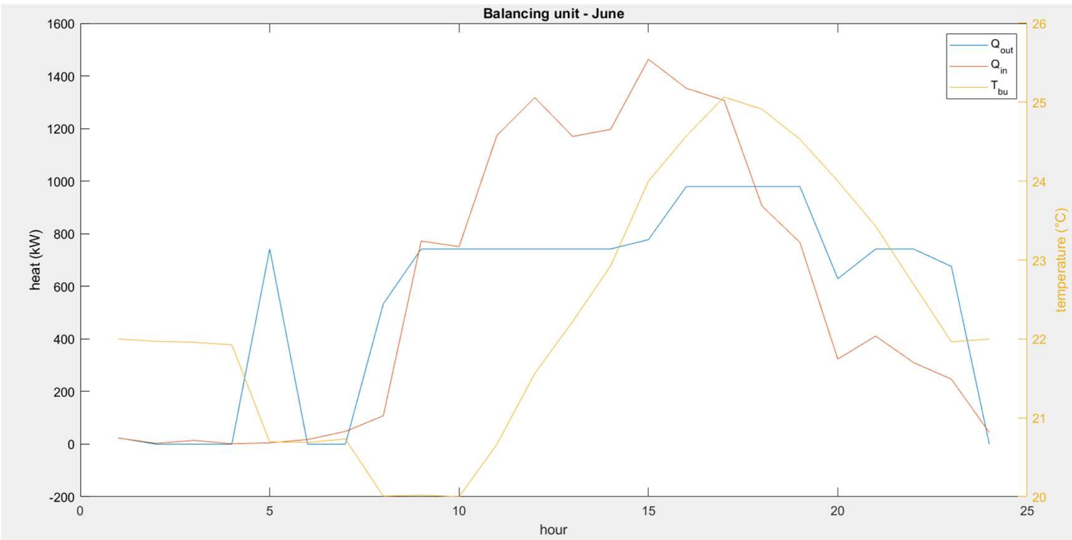

Figure 12: Balancing Unit, June

Figure 12 shows cooling. Q_{in} follows cooling demand, thus it is the heat injected into the balancing unit. Q_{out} represents heat injected into the groundwater. Balancing temperature unit rises during the peak, until cooling demand begins to drop, and the balancing unit temperature drops too.

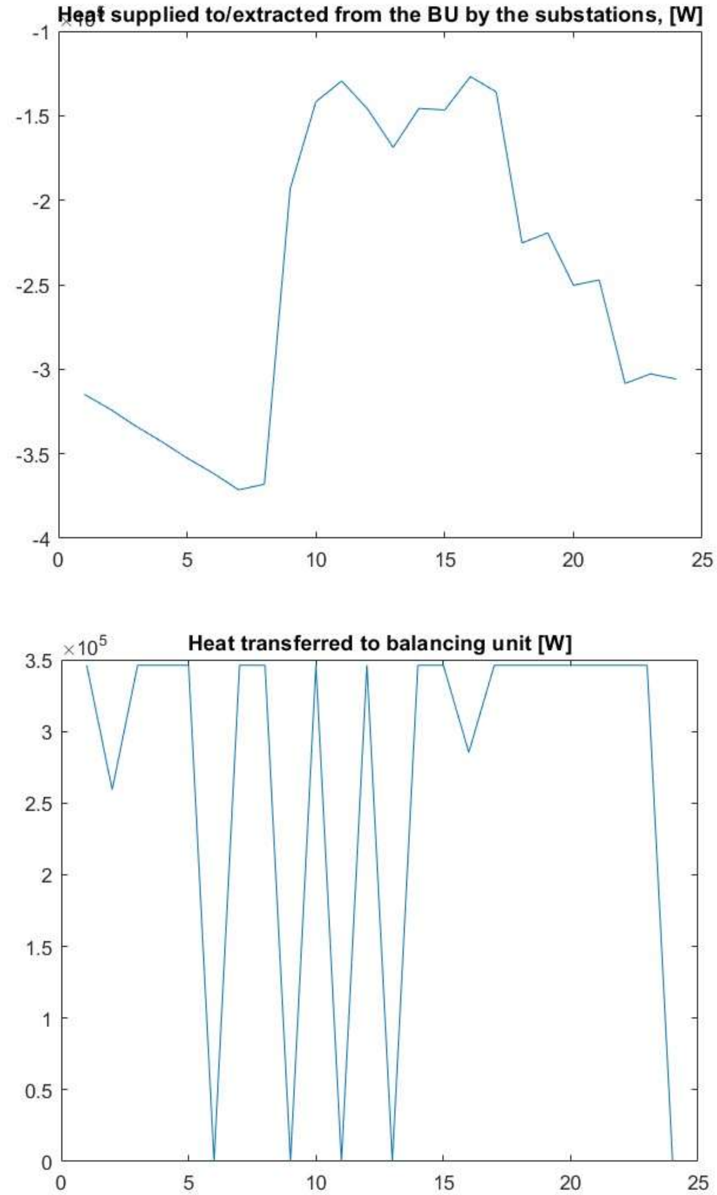

Figure 13 a: Cooling; heat extracted from balancing unit in June. Figure 13 b: Heating; heat transferred to balancing unit in January

PV System

A further analysis considers possible implementation of a photovoltaic system on the roofs of buildings in the district. Shading effects from other buildings, and the useful collector area are computed. For the former, the mean shading factor is calculated, indicating fraction of the surface in shadow. This is derived from solar irradiance on the surface, a function of direct beam irradiance, incidence angle, and diffuse radiation from both sky and ground. Incidence angle is a function of the tilt of the PV panels, as well as azimuth and zenith angles. The useful collector area considers row-to-row distance of the panels, to ensure mutual shading does not interfere with performance. Module length and tilt angle define the minimum distance required between panels. This gives the ratio between useful collector and ground area, “ground” referring to the roof the module is placed on. The azimuth angle, being the angle between module orientation and the South direction, must be defined for each building. Modules are oriented in the direction of the building wall closest to South-facing. This minimizes the azimuth angle; incidence angle is function of azimuth and keeping this minimal reduces the magnitude of incidence angle cosine losses, thus exploiting direct beam irradiance to the greatest extent. This leads to greater PV energy production.

Maximum power produced by the modules, as well as being a function of that which is produced by one module, is also dependent on losses. These are due to conversion, cable, and dust losses. Power produced by one module depends on fill factor, short circuit current, open circuit voltage, cell temperature, and temperature coefficient. Number of modules is a function of the ratio between collector and ground area, areas of roof and module. The latter is given by the dimensions of the module reported in the datasheet.

The sum of the power production over 24 hours gives daily energy production, this is then performed for 12 separate typical days representing each month of the year. A profile can then be obtained for a single month assuming each day of the month is a typical day. Production of electricity from photovoltaics over the year is presented in Figures 14, a and b.

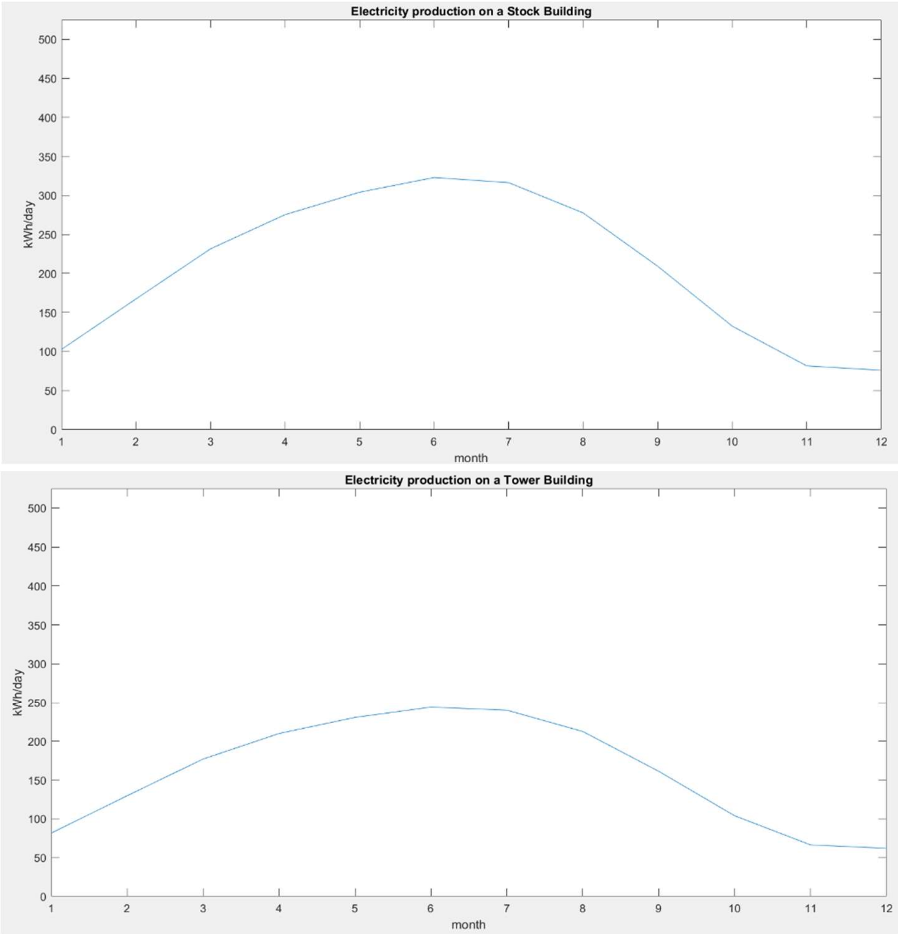

Figure 14 a: PV Production, Stock building. Figure 14 b: PV Production, Tower building.

Energy strategy and LCA analysis considers photovoltaic energy availability, district energy needs and emissions, energy loads, final electricity demand of energy centers and substations, and emissions mitigations through the use of renewables. Points of delivery (POD) are defined: two for each building substation, plus one for the energy center, for a total of 33 PODs. For the substations, the first POD concerns heating, cooling, and parasitic energy consumption; the second POD concerns user appliances. PODs are physical grid connections, for the supply of electricity. Photovoltaics supply the first kind of PODs, but not those associated with user appliances, or the energy center – panels are not placed on the energy center. The scope for the LCA considers only residential buildings as part of the renewable energy community – buildings with shared consumption. MATLAB tables required for the LCA analysis are created: “Ele_data”, hourly data related to the electricity demand, the PV electricity generation, the amount of electricity self-consumed, imported and exported to and from the grid, and “Embodied_data”, the information required for the calculation of the impact of capital goods on CO2 emissions. Results can be plotted for each hour of the year:

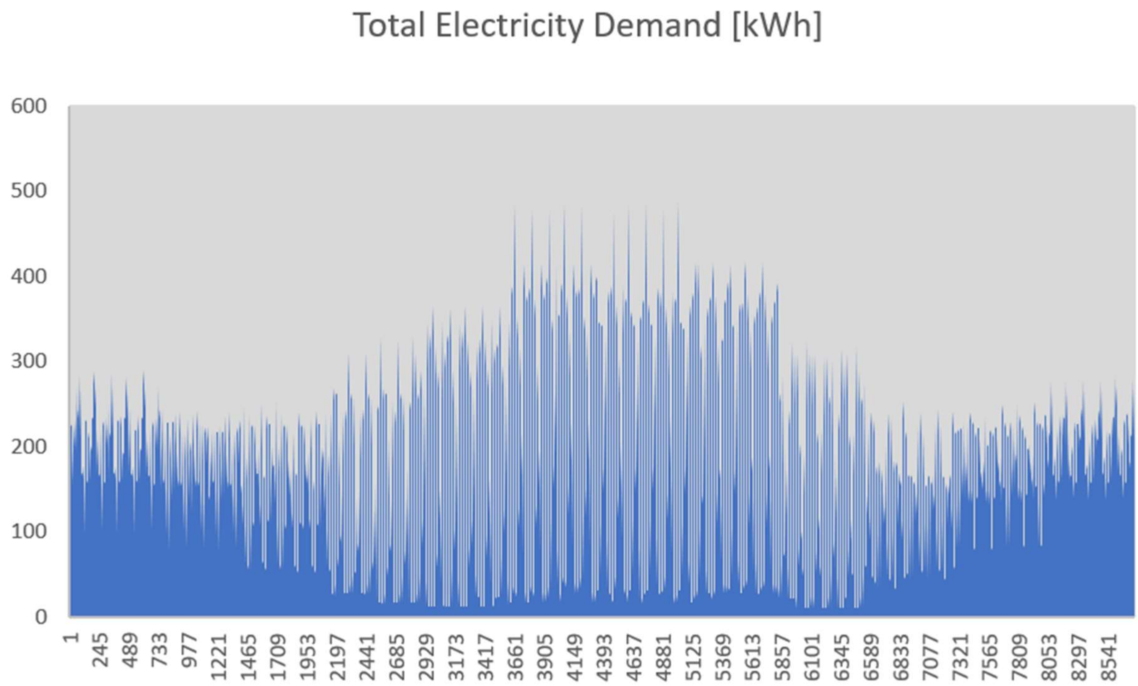

Figure 15: Electricity Demand over the year

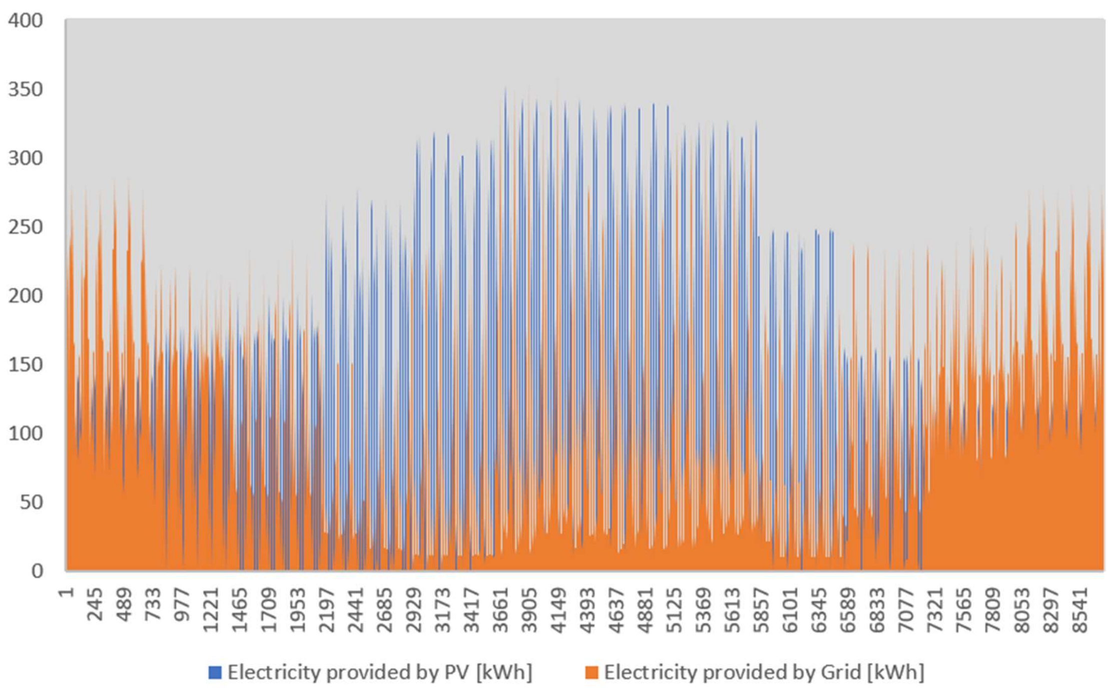

Figure 16: Source of Electricity to meet Demand

From Figures 15 and 16, it can be seen that the district's energy demands can be met mostly by the grid in winter, and by solar power in summer. The energy produced from PV is, however, not enough to fully cover loads. In Figure 17 electricity exported, due to a surplus of photovoltaic electricity, is plotted. However, it is only significant in spring. This is an issue for positive energy balance, as discussed in the according section.

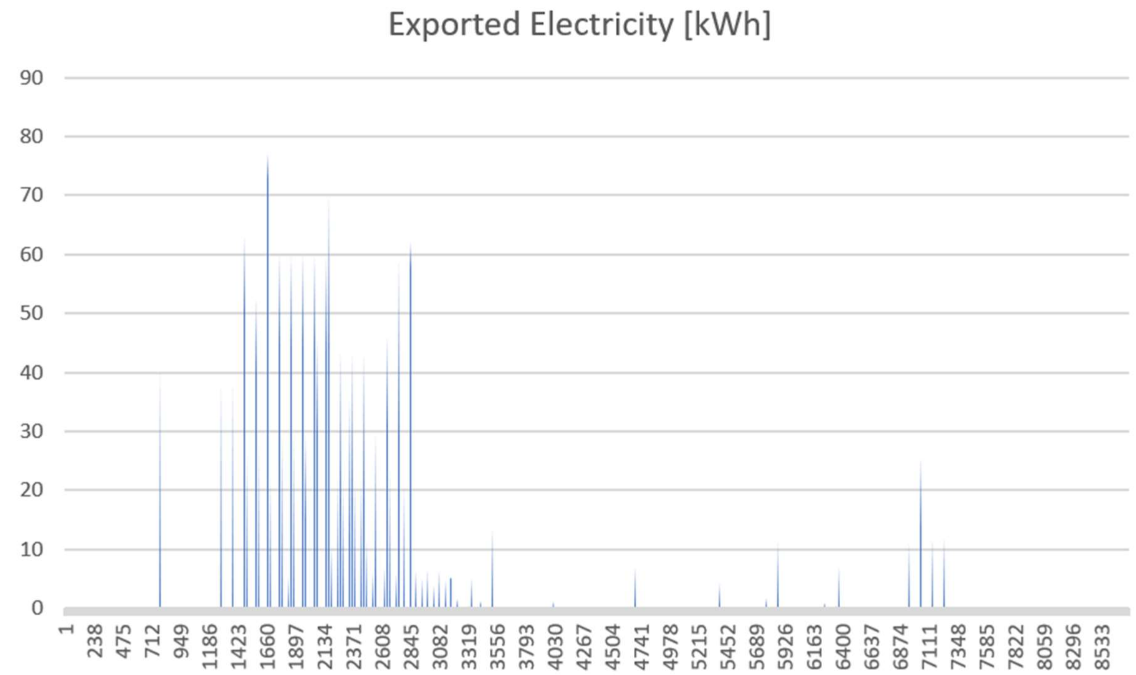

Figure 17: Surplus PV Electricity Exported

2. ***System Capacity Summary***

Table 5 presents energy needs for the fan-coil plus mechanical ventilation HVAC system, for three different cases.

Table 5: HVAC Capacity Summary

	Case 1		Case 2		Case 3	
	Building Needs [MWh]	**Plant Needs [MWh]**	**Building Needs [MWh]**	**Plant Needs [MWh]**	**Building Needs [MWh]**	**Plant Needs [MWh]**
Space Cooling	139.627	199.184	104.035	148.1	178.414	254.93
Cooling Dehumidification	11.8446	n/a	9.06127	n/a	14.2044	n/a
Cooling: Plant Heating Energy	n/a	0	n/a	0	n/a	0
Space Heating	112.457	56.3131	92.1973	47.6611	133.542	67.1059
Heating Dehumidification	0	n/a	0	n/a	0	n/a
Parasitic Energy	**Cooling**	14.5192	10.8519		17.8024	
	Heating	10.4198	8.3479		12.3012	
	Case 1		*Case 2*		*Case 3*	
VMC Volume Flow [m^3/h]	5761.34		4407.49		6833.04	
Fan-coil Cooling Input [kW]	-183.528		-139.511		-237.416	
Fan-coil Heating Input [kW]	75.1952		59.9814		88.8534	
Fan-coil Power Input [kW]	8.12962		6.21872		10.0795	

Table 6 presents a summary of sizing for the energy substations:

Table 6: Energy Substation Heat Pumps, DHW Storage Tank Volume

Chiller heat pump [kW]	110.6
Heat pump [kW]	25
DHW storage [m^3]	6.4

Energy center sizing is shown in Table 7:

Table 7: Energy Center BU Volume, Pump Sizing

Volume of balancing unit [m^3]	477
Full load central Heat Pump power [kW]	59
Maximum groundwater mass flow rate [kg/s]	16.4
Power input of Groundwater pump [kW]	11.7

Total electricity demand for the district is 1547.3569 MWh/year. Specific demand for useful area is 769.8293 kWh/m^2.

3. ***<u>Positive Electricity Balance Analysis</u>***

Figure 17 shows PV surplus exported, which is only in spring, not throughout the year, thus positive energy balance for the district can only be achieved for a short period in the year. Hourly profile of appliances use through the year is given below in Figure 18:

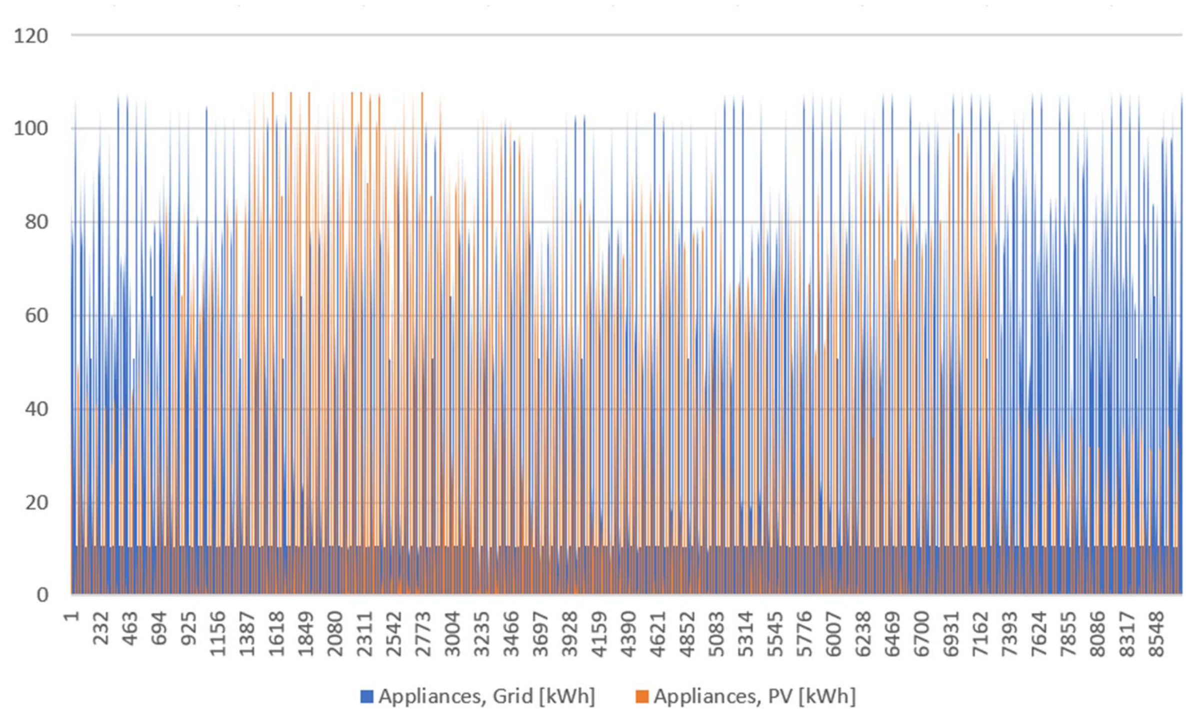

Figure 18: Appliance Loads

Photovoltaics can cover appliance loads in spring, although grid electricity is mostly required for the rest of the year. The district's energy requirements require grid connection. It remains to be seen if further renewable energy implementation can meet loads and create a positive energy district. The profiles if electricity for home appliances is excluded are given as follows:

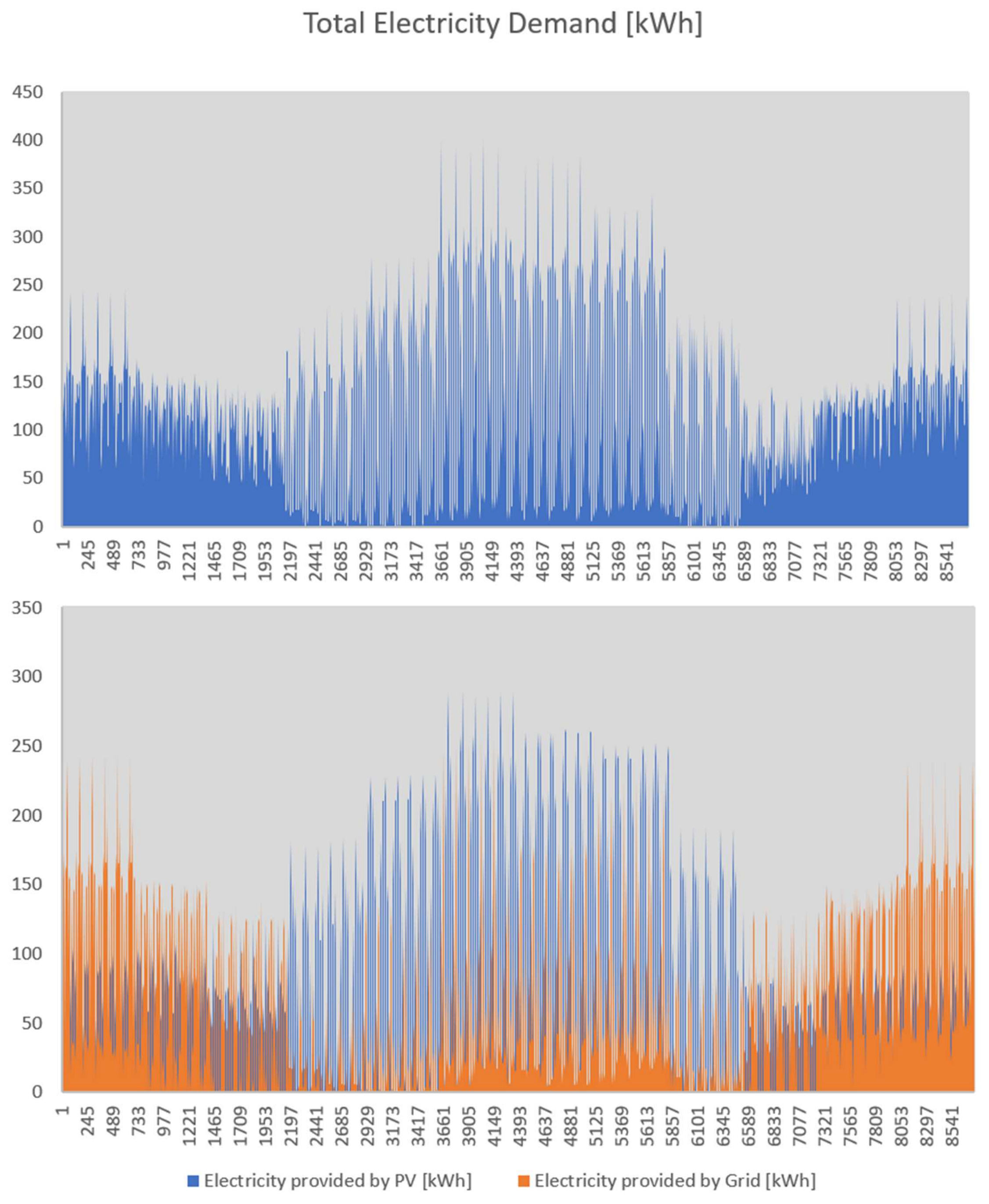

Figure 19 a: Total Electricity Demand excluding Appliances. Figure 19 b: Source of Electricity to meet Demand, excluding Appliances

Electricity demand is reduced, reaching peaks of around 400 kWh, instead of 500 kWh (see Figure 15). Dependance on grid electricity is reduced. The MATLAB code considers appliances as being grid-connected, but not PV-connected, thus neglecting user appliances reduces grid dependance. However, surplus PV remains unchanged, thus neglecting appliances is still not enough to create a positive energy district. Loads due to space heating and cooling, and parasitic losses mean the district is still reliant on the grid.

4. ***LCA Analysis***

Life Cycle Assessments (LCA) performed on buildings follow two European standards, EN15978 and EN15804, at building and product levels, respectively. The former regards the building's environmental performance, whilst the latter consists of the environmental product declaration. The building assessment spans the whole 'life' of the building, from raw material supply, through construction, building usage, demolition, to disposal. After disposal, recycling of materials may also be performed, which is considered a benefit beyond the system boundary. Another benefit beyond the system boundary is exported electricity. In designing a zero-emission energy district, exporting electricity plays a significant role. The use of photovoltaics can provide this, to achieve climate neutrality; in order to offset self-consumptions, energy can be provided to the grid. This allows mitigation of carbon emissions, which are inherent in building construction and use, through renewable energy production. The national grid's electricity originates from various sources, including fossil fuels, thus if districts implement renewables they can help to decarbonize the energy sector. A Power Purchase Agreement (PPA) allows a third party to install, for instance, a photovoltaic plant on the rooves of the district's buildings, allowing for renewable energy at a fixed price to be used in the buildings, as well as exporting any energy production above the required load.

An environmental LCA is performed using a MATLAB application. Construction technologies are selected based on their properties, these affect the CO2 emissions depending on materials and percentage of recycled content. The buildings are composed of foundations, load-bearing structures, internal slabs, and windows. Hourly and yearly emission profiles are obtained.

Inputs for the script regarding DHW tanks (steel_storage.mlx) consider an Estimated Service Life (ESL) of 40 years, a Reference Study Period (RSP) of 50 years, and a Required Service Life (ReqSL) of 60 years. Assembly stage calculates environmental burdens for modules A1 to A3, product stage raw material supply, transport, and manufacturing. Emission factor comprises activity name "market for heat storage, 2000l", geography global, reference product name "heat storage, 2000l". The "removevars" function is used to remove unwanted columns from the table. Environmental profile is calculated multiplying "Tanks_steel" by emission factor, then dividing by 2, as emission factor is for a reference of 2 m^3 storage, giving dimensionless units. Module B2 considers maintenance, being 1% of the value of environmental burden for modules A1 to A3. Module A4 is construction stage transport, units t*km. Thus "Tanks_steel" is multiplied by density to give units in tons, then multiplied by distance to get units of t*km. This is multiplied by emission factor to give environmental burden. The same procedure is followed for C2. Modules C3 and C4 are in kg, thus distance is not included, the same applies for module D. Modules C2 to C4 are then summed up. Module D considers 97% of the tank material, C4 3% and C3 100%. Module D considers recycling, whilst D_B4 considers avoided production. The former employs a recycling efficiency of 81.45%. The latter considers 55% of material recycled for the input (tank density of C3), and is multiplied by B4.

Module B4 considers replacements, given by the following equation:

$$No.of\ Replacements(i) = rounded\ up\left(\frac{ReqSL}{ESL(i)} - 1\right)$$

Multiplying by the ratio between RSP and ReqSL, the outcome is scaled accordingly, as RSP is shorter than ReqSL.

In the analysis, the foundation material chosen is ecocement. It is chosen for environmental impact reasons, comprising 95% recycled materials, much higher than traditional masonry, which is only 55% recycled. The vertical structure chosen is thus pre-cast ecocement. Basement, internal, and roof slabs are ecocement masonry. Window frame is in PVC, and opaque envelope in traditional masonry.

Emission factor of electricity from the national grid is shown in Figures 20 and 21, varying hourly and yearly, respectively. For the former, emission factor peaks around 600 gCO_2eq/kWh_e, around October, with a low in June around 400 gCO_2eq/kWh_e. For the latter, emissions are set to decrease over the next 50 years thanks to renewable energy implementation, from a mean of around 450 gCO_2eq/kWh_e in 2022, to around 250 gCO_2eq/kWh_e in 2072.

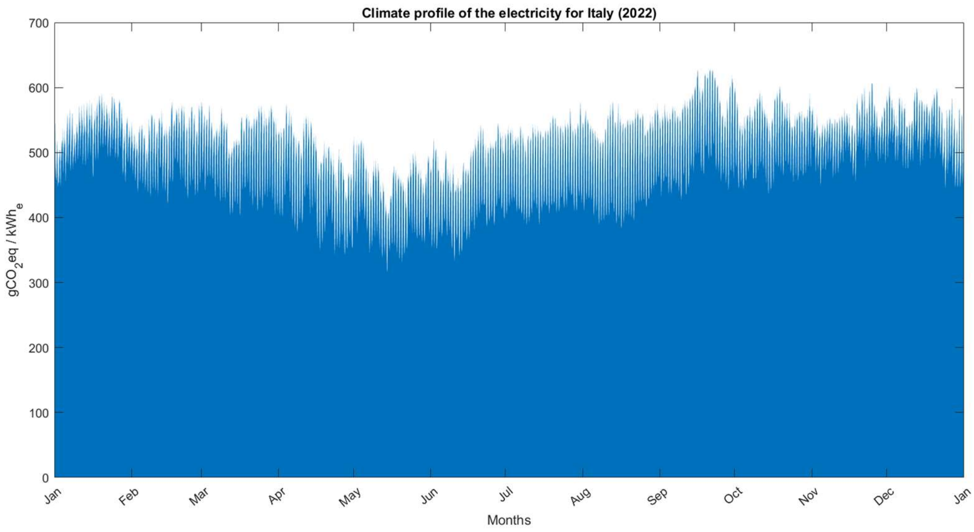

Figure 20: Emission Factor Profile, National Grid, 2022

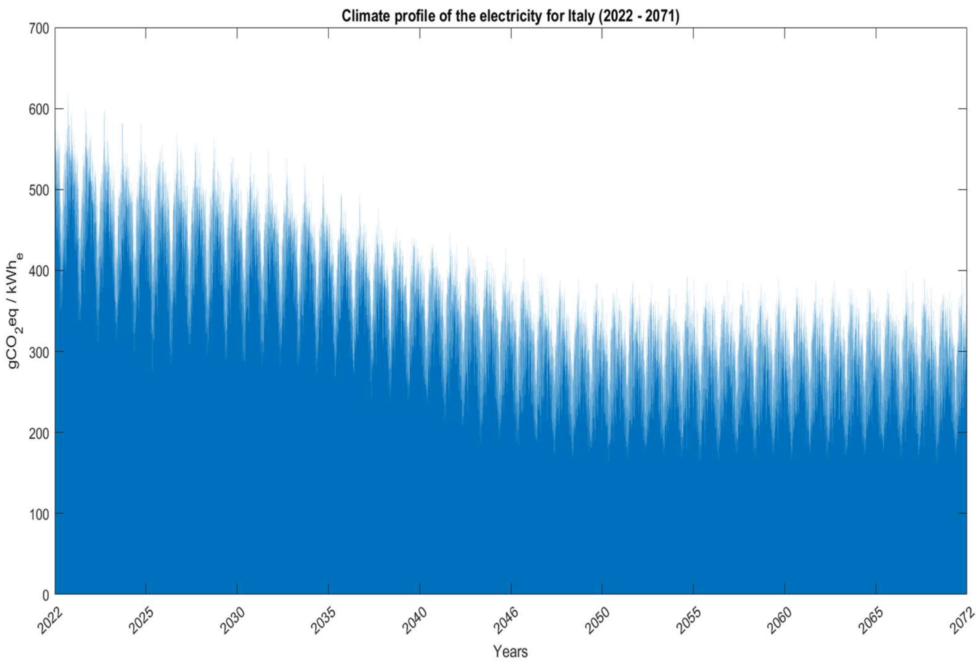

Figure 21: Emission Factor Profile, National Grid, Expected Trend

Outputs for the base case are as follows, with traditional foundation, traditional cast-in-place structure, traditional full basement slabs, traditional masonry for both internal and roof slabs, PVC window frame, and traditional masonry opaque envelopes:

Table 8: Emissions for Base Case

	Scenario No. 1 [ktCO2 eq]	Scenario No. 1 [kgCO2eq / m2]
Space heating and DHW	**7.5363**	**188.24**
Space Cooling	**3.1214**	**77.966**
Parasitic	**1.1578**	**28.92**
Home appliances	**5.9447**	**148.49**
Construction footprint	**39.318**	**982.09**
Ele. exported	**-1.4565**	**-36.38**
Total	**55.622**	**1389.3**

	Scenario No. 2 [ktCO2 eq]	Scenario No. 2 [kgCO2eq / m2]
Space heating and DHW	**7.5363**	**188.24**
Space Cooling	**3.1214**	**77.966**
Parasitic	**1.1578**	**28.92**
Construction footprint	**39.318**	**982.09**
Ele. exported	**-1.4565**	**-36.38**
Total	**49.677**	**1240.8**

	Scenario No. 3 [ktCO2 eq]	Scenario No. 3 [kgCO2eq / m2]
Space heating and DHW	**7.5363**	**188.24**
Space Cooling	**3.1214**	**77.966**
Parasitic	**1.1578**	**28.92**
Ele. exported	**-1.4565**	**-36.38**
Total	**10.359**	**258.75**

Scenario 1 comprises modules B6.1, B6.2, and B6.3 plus embodied emissions; scenario 2 being modules B6.1 and B6.2 plus embodied emissions; scenario 3 is modules B6.1 and B6.2 without embodied emissions. Embodied emissions are those related to production and transportation of goods, in this case it relates to building materials. For the base case, scenario 3 presents the lowest emissions, due to absence of both construction and home appliance emissions. Scope 1 shows the highest emissions as it includes construction materials, as well as module B6.3: energy use related to user activities. Embodied emissions can be reduced using recycled materials, such as ecocement. Districts aiming to minimize their carbon footprint must recycle materials, and aim to source locally, to decrease embodied emissions associated with transport.

5. ***<u>Groundwater Wells and PV modules</u>***

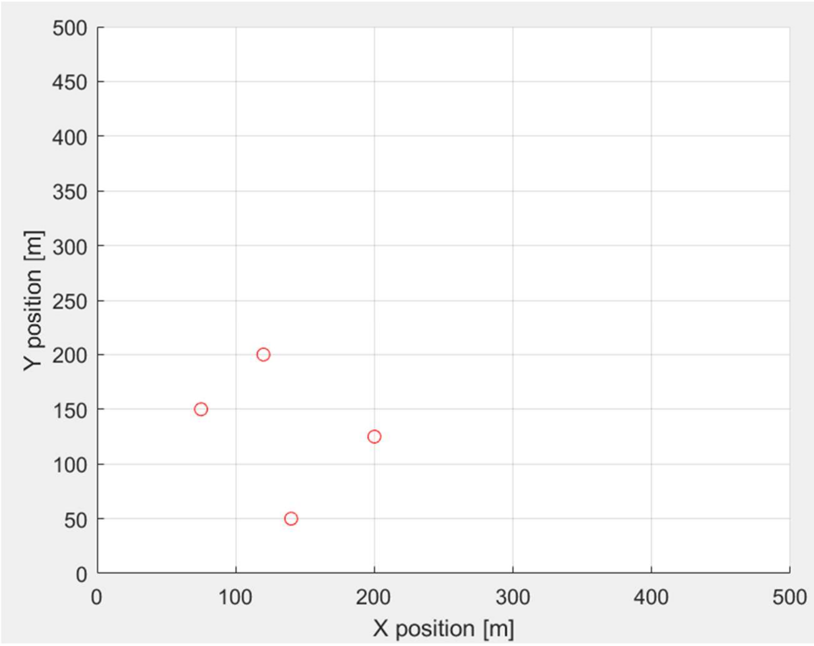

Figure 22: Groundwater Well Location

Figure 22 presents extraction and injection well locations, extraction wells on the bottom-left-hand-side, injection on top-right.

PV modules are inclined at 35 degrees. They are placed on roofs facing the wall nearest to South. Number of modules and direction from South is summarized below:

Table 9: PV on each Building

Building	Number of Modules	Gamma [°]
Bld_1	157	42.2332
Bld_2	226	42.5785
Bld_3	157	43.3767
Bld_4	215	42.4209
Bld_5	157	42.117
Bld_6	210	43.7478
Bld_7	202	42.9602
Bld_8	158	43.727

6. ***Thermal Plume Evolution in the Ground***

Thermal plumes are areas of significant temperature difference in the ground. Thermal plume evolution is performed over 10 years, during this time it is imperative that it not exceed the district's boundaries. Wells must be placed appropriately to avoid thermal plume exceeding the boundary. The code considers undisturbed ground temperature of 15 degrees, borehole radius of 0.1m, and a temperature difference of 5 Kelvin. A 4x2 matrix is made to represent the area of the district. Two extraction and two injection wells are designed, initial design at coordinates (75,150) and (120,200) for well 1's extraction and injection points, respectively, and (140,50) and (200,125) for well 2. Wells are placed 6 meters below the surface, the angle is set to 45 degrees due to the positioning of the geoplot. Heating and cooling needs are taken for three different building types calculated previously and summed for the eight buildings in the district. Heating requirements are divided from October to March, cooling from April to September.

In the following four figures the initial well location is presented. In Figure 23, impression cones are presented. Injection wells, represented as circular points, cause the rise of the water table, which may cause problems associated with flooding. In this case, as the wells are further apart, impression cones are limited.

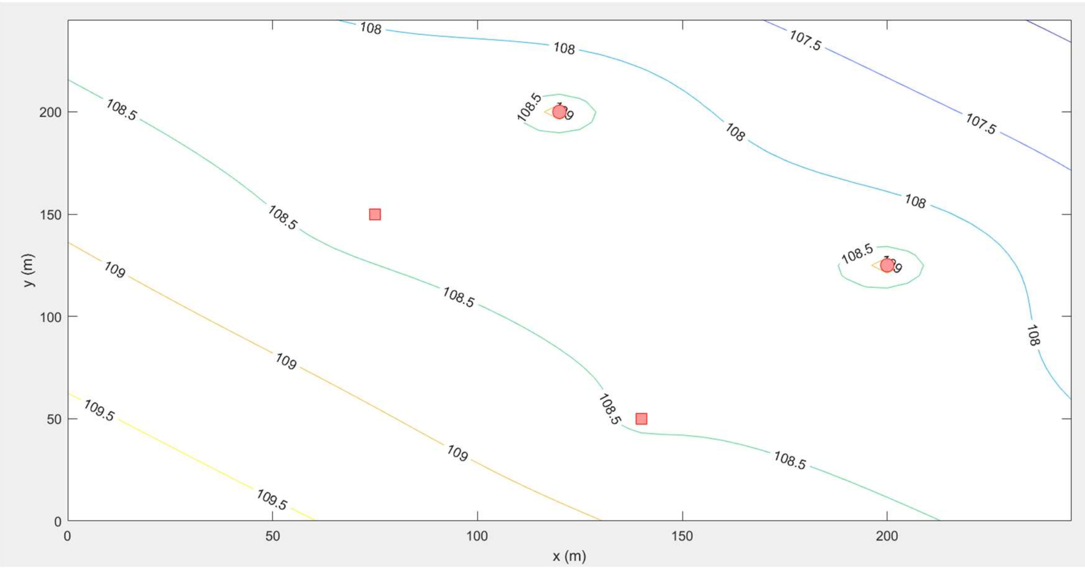

Figure 23: Impression Cones

Thermal plumes are areas of important temperature difference with undisturbed ground temperature. Over the course of the 10 years analyzed, water reinjected into the ground can change ground temperature. This is an environmental impact and should be limited. Thermal plumes are presented below. However, as injection wells are placed too far from the extraction wells, these far exceed the district's perimeter. A further analysis is performed to limit thermal plume evolution in the ground.

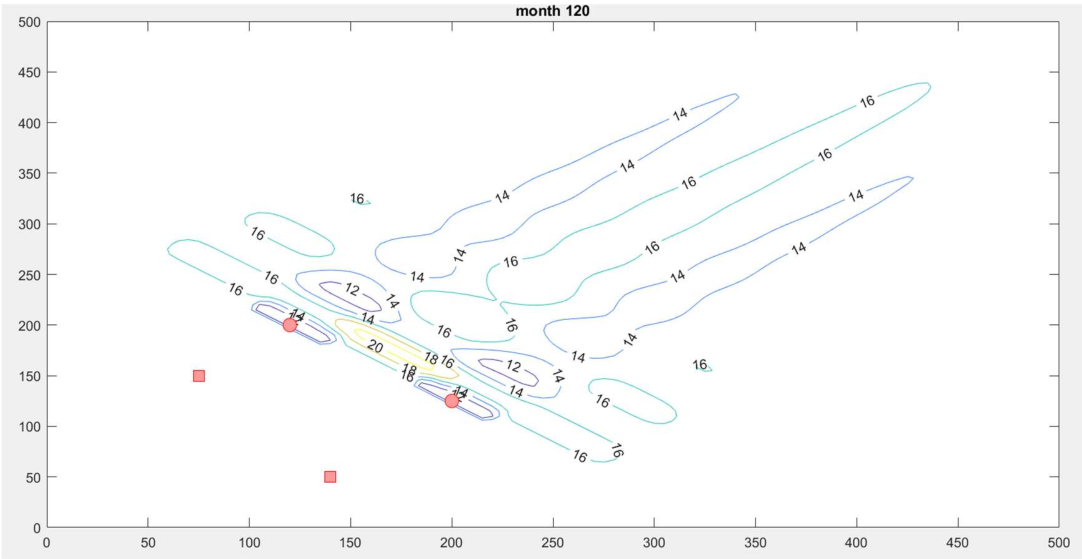

Figure 24: Thermal Plumes after 10 years

Extraction Wells 1 and 3 are shown in the following figures. Curves follow each other quite closely, thus minimizing delay between groundwater flowrate and well drawdown. Maximum drawdown is around -2 meters for the former, and -2.2 meters for the latter. A further analysis is performed to reduce drawdown, thus pumping costs.

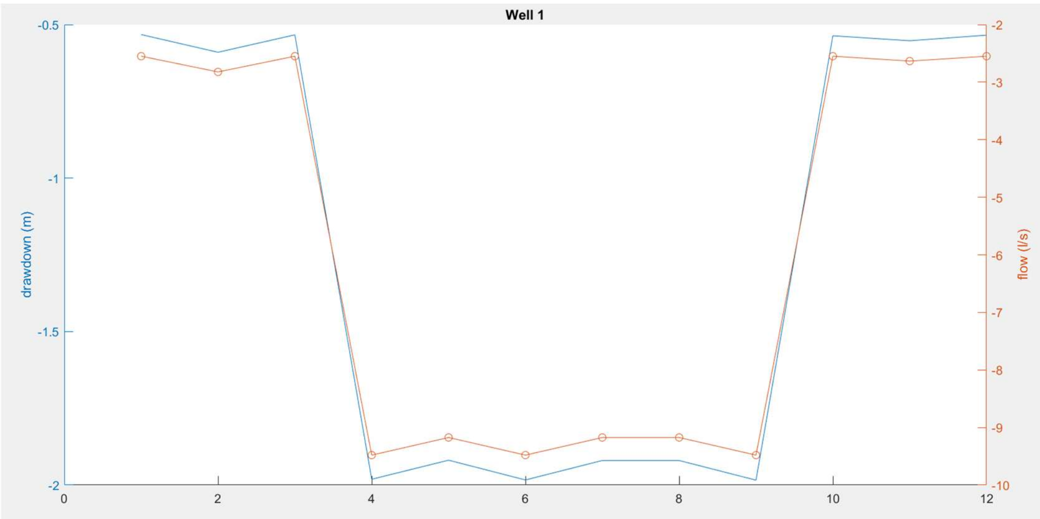

Figure 25: Drawdown and Flow, Well 1

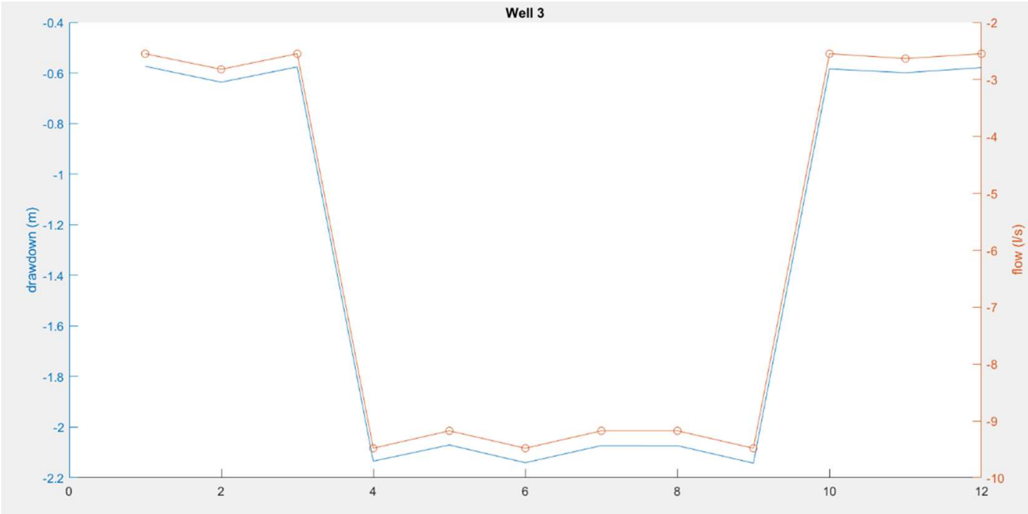

Figure 26: Drawdown and Flow, Well 3

Changing well position to limit thermal plume: coordinates (75,150) and (120,150) for well 1's extraction and injection points, respectively, and (140,50) and (170,100) for well 2. Impression cones may be too large, although thermal plumes are greatly reduced.

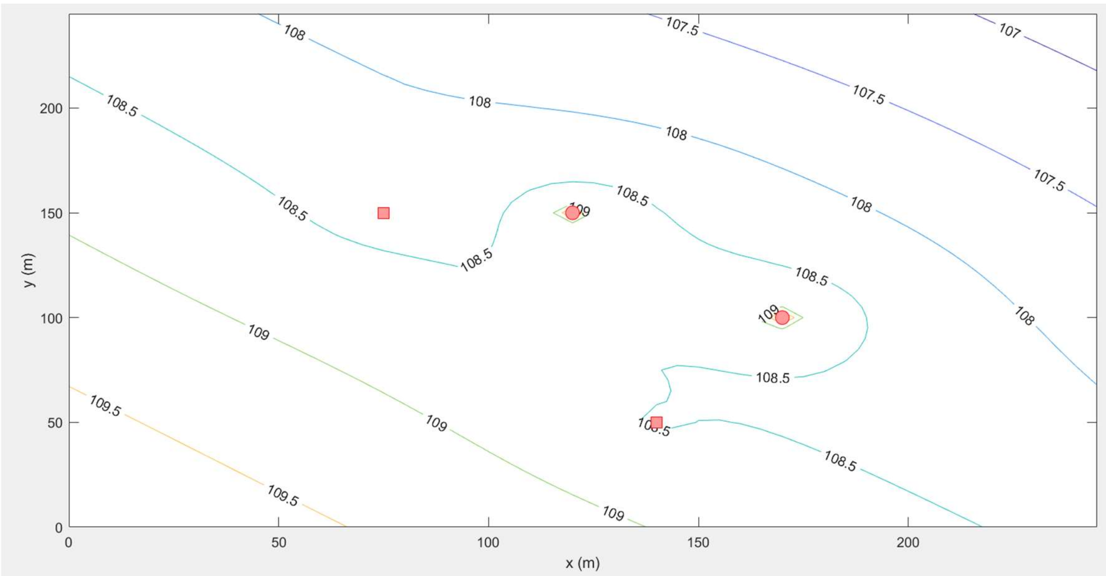

Figure 27: Impression Cones, 2nd Configuration

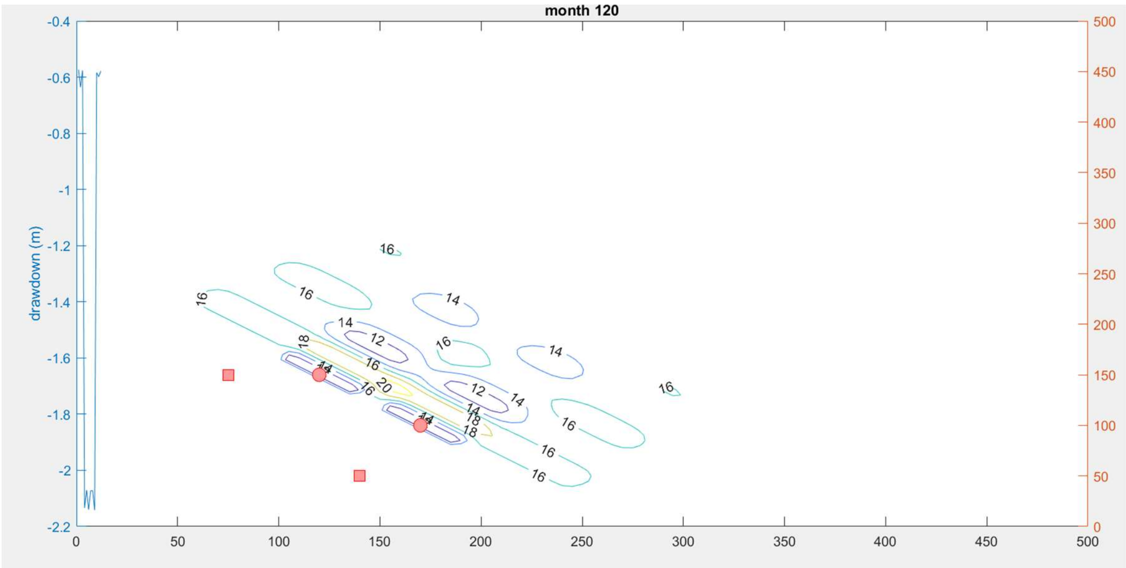

Figure 28: Thermal Plumes, 2^{nd} Configuration

In the new configuration, drawdown is reduced to -1.8 and -1.9 meters, for wells 1 and 3, respectively. The new well positioning is thus deemed appropriate for the district.

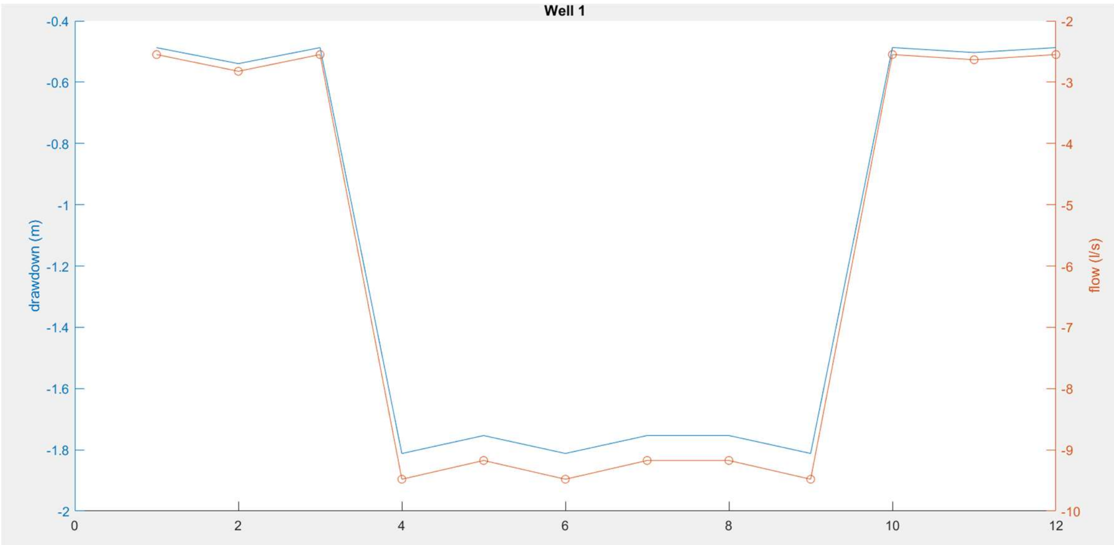

Figure 29: Drawdown and Flow, Well 1, 2^{nd} Configuration

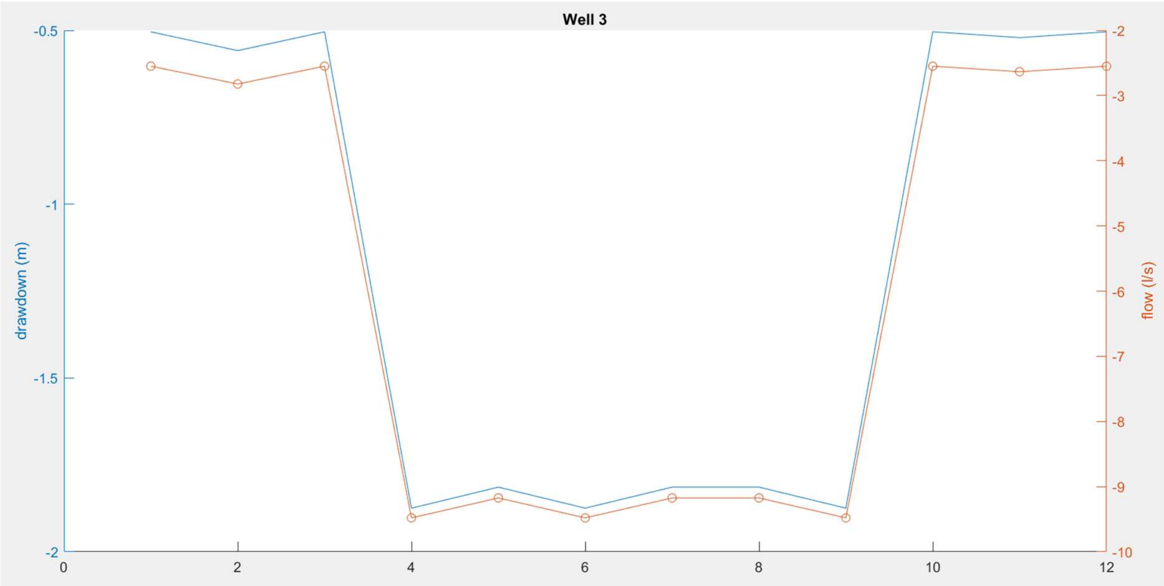

Figure 30: Drawdown and Flow, Well 3, 2nd Configuration

7. ***Resilience to Climate Change***

The effects of climate change will be more present in the next few years so it's important to check how the energy needs of the district will change during the years. A new simulation was run using a forecast of the weather in 2050 in the same location (Milan, Linate). We can see in Figure 31 that the average temperatures will increase all throughout the year reaching peaks of nearly 40°C. Also, humidity will increase but will become more variable with very dry periods. We can already expect higher cooling needs during summer and lower heating loads during winter.

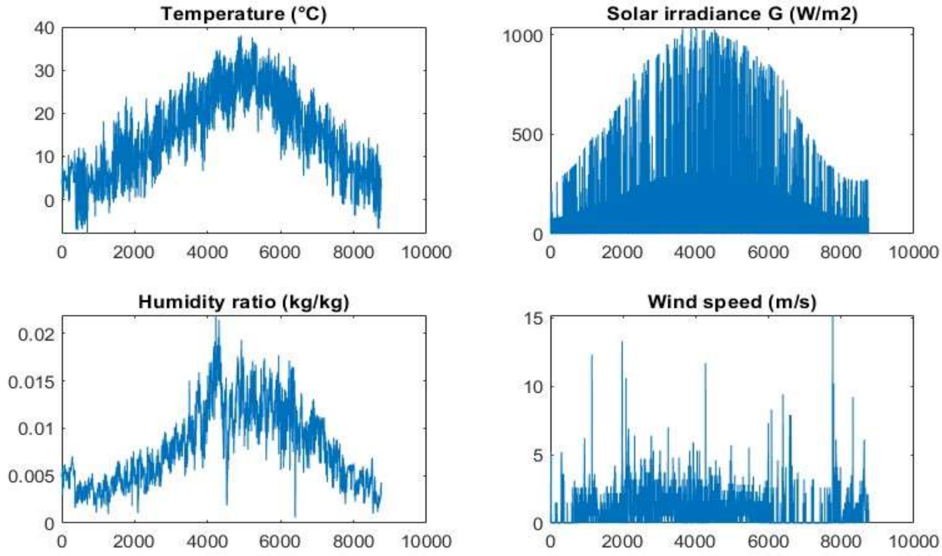

Figure 31: Weather Data, 2050

Heating load still has a peak of around 120 kW, but it’s reached less frequently throughout the year, in fact the overall heating demand is lower overall.

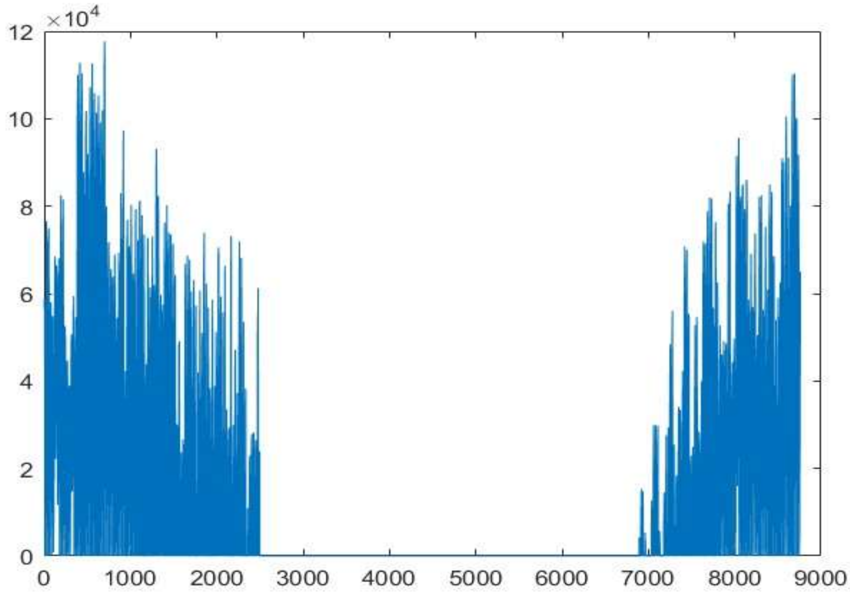

Figure 32:Heating Demand [W]

Also, the peak load for cooling doesn’t change; the big difference is that during summer cooling demand never goes to zero. In 2050 summer will likely be hotter and even during the night temperature stays high and the building requires to be cooled down.

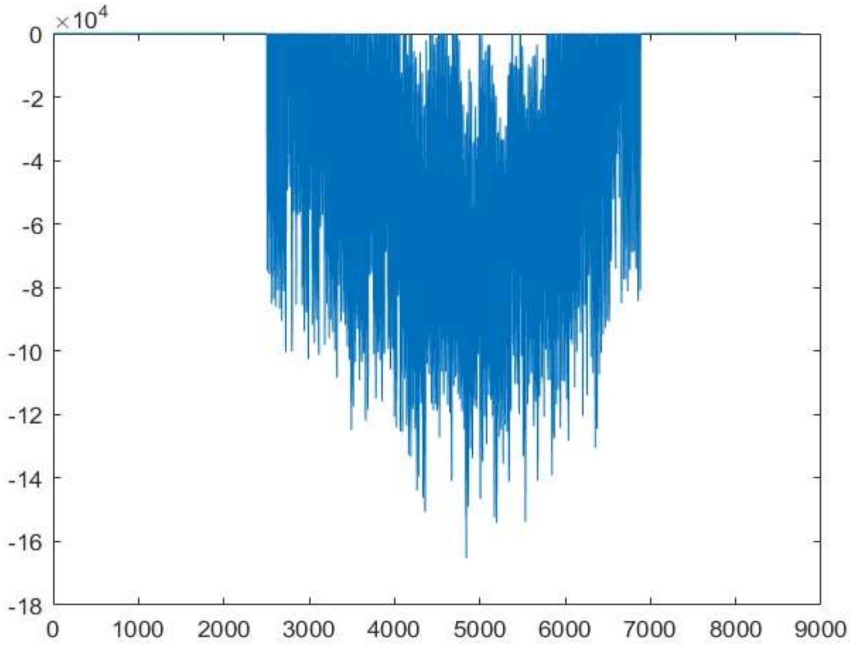

Figure 33: Cooling Demand [W]

Concerning domestic hot water the seasonal variation is quite similar but the peak load decreases to around 35 kW.

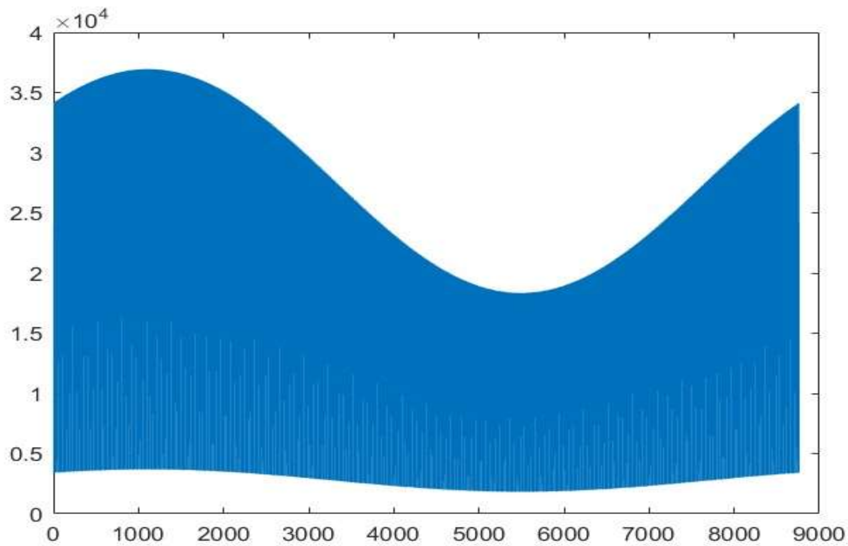

Figure 34: DHW Demand [W]

Thus, it can be concluded that climate change will increase mean temperatures, thus there will be a lower heating requirement, but higher cooling needs. It is important to design low-emission districts, such as through renewable energy implementation and materials selection, to reduce impact on climate change, to mitigate the negative effects associated with global warming.

Concerning the substations, the chiller heat pump and the heat pump are sized 27kW and 106kW respectively. These values are similar to the previously calculated ones because the energy need peaks don't change much considering the new weather data. Also, the energy center has similar sizes. The balancing unit has a volume of 430 m^3, slightly smaller than the previous case, meaning that it can store less energy. The maximum groundwater flow is 22.3 kg/s, this means that a bigger pump of 16kW is needed.

In the following figures the heat flowing in the balancing unit is reported, for a typical day in January and June, which are the worst cases for heating and cooling.

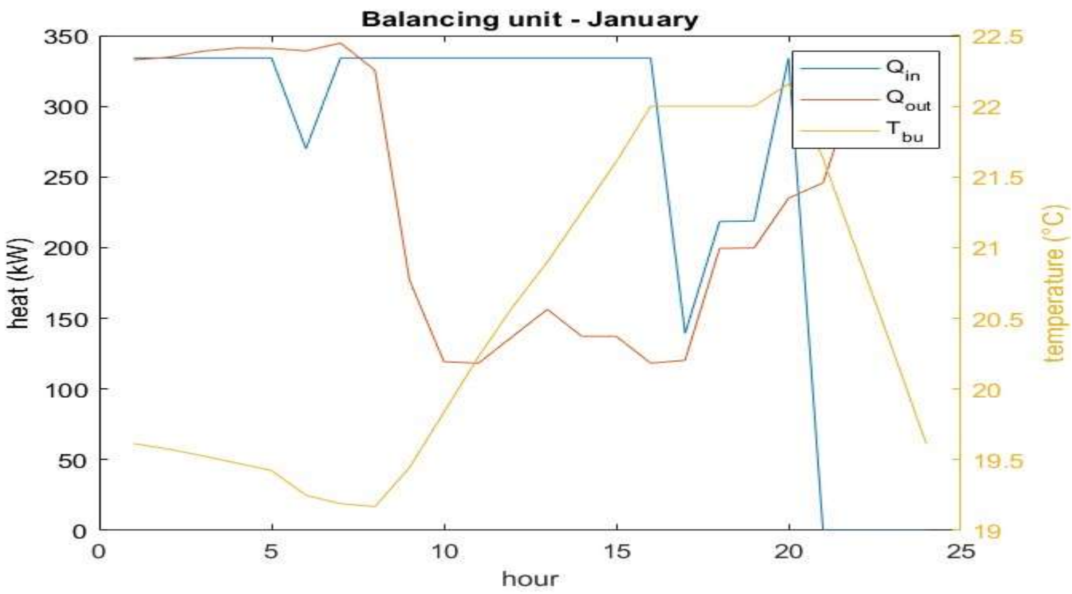

Figure 35: Balancing Unit Heat Flows, January

In the heating case where Q_{out} follows the heating demand, the trend is different from the previous case. Peak demand is lower due to higher temperatures and concentrated in the morning and in the evening, during the day groundwater is extracted so that the balancing unit temperature grows, ready to release heat during the night. In the cooling case the trend is the same, with higher demand during the morning and the afternoon. The balancing unit injects heat in the well quite constantly during peak hours and its temperature increases, while it decreases during the night when cooling demand is lower.

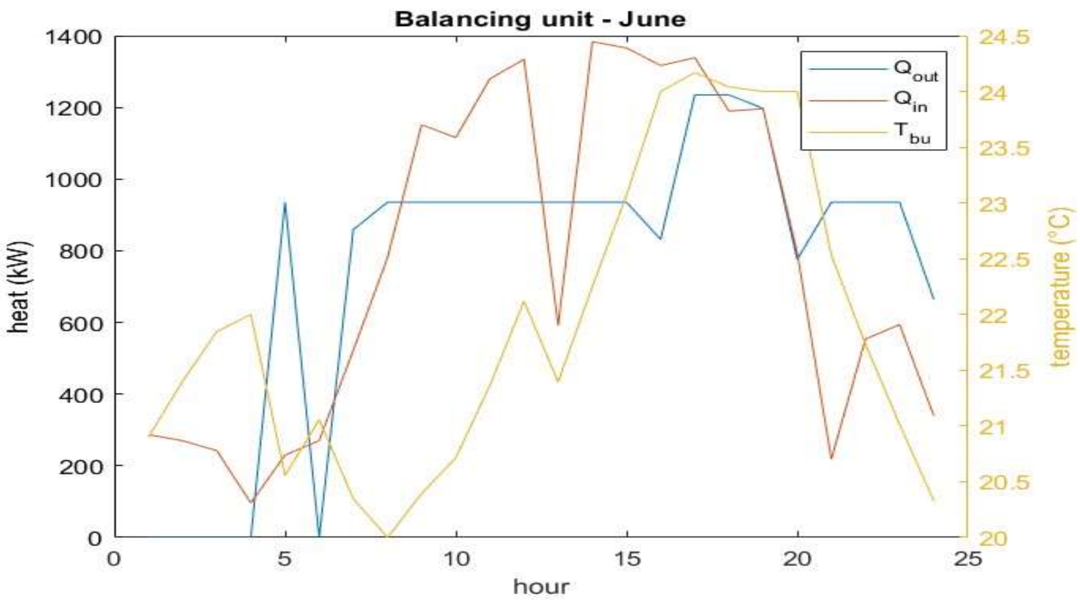

Figure 36: Balancing Unit Heat Flows, June

Repeating the analysis on PV production we can see that the same number of modules produces more energy and has a higher peak power. This is related to the fact that solar irradiance in 2050 is forecasted to be higher during the year, especially in summer, probably due to more sunny days and less precipitation.

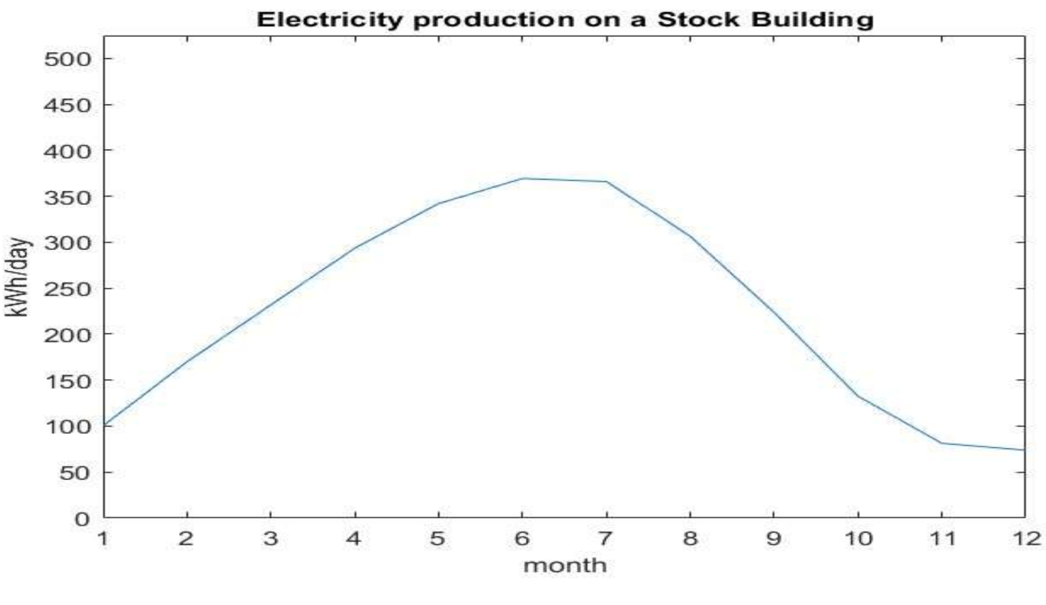

Figure 37: PV Electricity Production on Stock Building

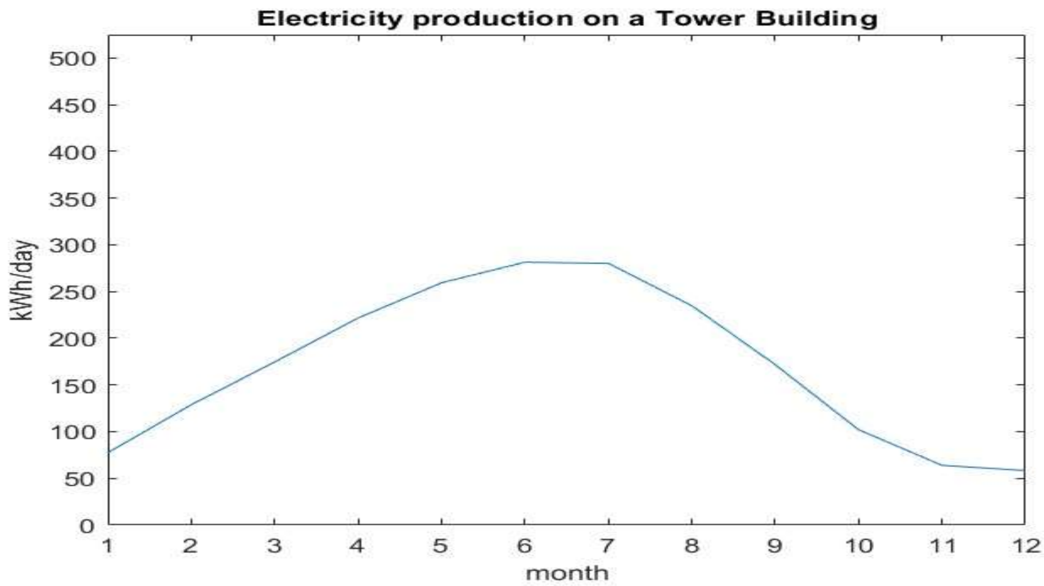

Figure 38: PV Electricity Production on Tower Building

Conclusion

In conclusion, a district was modelled in Crescenzago, Milan, Italy, using MATLAB. The goal was to design a zero-emission positive energy district. Aims included evaluating district energy needs, HVAC choice and sizing, renewable energy integration, energy system design and optimization, life cycle assessment, and analysis on resilience to climate change in 2050. Total electricity demand for the district was calculated, 1547.3569 MWh/year, with specific demand 769.8293 kWh/m^2. The result was a district with photovoltaic electricity implemented, although production was not enough to cover annual loads. Thus, a positive energy district was not achieved, although surplus renewable electricity could be produced for some of the year. Emissions throughout the life cycle of the district were not zero either, although materials selection could reduce carbon footprint. Although the desired objectives were not reached, the district performed well, being able to export electricity whilst maintaining indoor comfort levels through the use of space heating and cooling, district hot water, and user appliances. Electricity loads not covered by solar panels were met by importing electricity from the grid. It is the responsibility of Italy as a whole to decarbonize the grid as much as possible, through not only solar but also other renewable energy sources, which can be implemented on scales exceeding those of a single residential district. Examples include hydropower and wind energy, which do not suffer from lower production in winter, for instance. Reaching net zero emissions is a goal to be undertaken on both a national and international scale, not just on a district-level. It remains to be seen how Italy and the World develop sustainable technologies and lifestyles in the coming years.