Optimization of the electrical and thermal microgrids for a nearly zero-energy building located in Lisbon

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Abstract

This work is part of the European project IMPROVEMENT focusing on the challenge of renewable energy systems integration and energy efficiency improvement in public buildings for SUDOE region. The aim of the thesis is to develop a model for conducting optimization of operating costs for electrical grid using energy systems modelling tool for linear optimization OMEGAlpes. Additional objective is to minimize the imports from the heating network by maximizing self-consumption. In the work is described nZEB characteristics, review of technologies and nomenclature, the main characteristics of OMEGAlpes tool.

The model is developed with OMEGAlpes using Python programming language for a building located on the Lumiar campus of LNEG in Lisbon, Portugal for one week period in May. In the building there are installed electrical and thermal systems for self-production (photovoltaic and solar thermal panels) together with energy storage units (battery and water tank). The whole system is supported by a heat pump that uses electricity from PV panels to back up the heat load. The building is also connected to electrical and heating grids in case the self-production is insufficient to cover the loads.

As a result of the optimization process, a decrease in the electricity costs of 58% is obtained. The optimal storage capacities for the considered system are also established equal 21 kWh for the electrical storage and 90 l for the thermal storage. Thermal load is entirely covered from self-production together with water tank and a heat pump. No additional heat imports from the network are necessary.

Keywords: nearly zero-energy building, microgrids, optimization, OMEGAlpes.

1. Introduction

Global energy sector is undergoing constant transition towards more sustainable, carbon-neutral system. In pursue of the reduction of the impact on the environment, the building stock has been identified as a sector that could significantly contribute to achieving the EU climate and energy targets. Buildings represent the largest sector in the final energy consumption in Europe, consuming about 40% of the total final energy, of which 27% constitutes residential buildings and 13% non-residential buildings [1]. The building stock in the EU Member

States is relatively old, with 45% built pre-1970 and 75% built pre-1990, before widespread adoption of energy regulations [2]. The energy performance of a large share of the existing buildings is inadequate, as around 75% of the building stock is considered to be energy inefficient [3]. The rate of buildings renovation is estimated around 1.2%. In addition to the existing buildings, the current stock is expected to increase due to new constructions at a rate of 1% per year [4]. Consequently, reduction of the energy consumption in the building sector has become an important strategy in the European energy policies.

The Energy Performance of Buildings Directive (EPBD) 2010/31/EU sets the standards for new and already existing buildings across Europe. It introduces nearly Zero-Energy Building (nZEB) as the new construction target and provides a general definition of the term. It states that nearly Zero-Energy Building means a building with a very high energy performance, requiring nearly zero or very low amount of energy which should be covered to a significant extent by energy produced on-site or nearby from renewable sources [5]. The referenced definition presents no unified standard and can be subject to different interpretations, as the EPBD indicates that there cannot be a single performance level for the nZEBs across Europe. Flexibility is essential to account for the impact of climate, renewable energy sources, heating and cooling needs, building stock, financial conditions, etc. Therefore Member States are required to draw up National Plans towards nZEBs reflecting regional conditions.

While designing and constructing new buildings with high performance levels and in compliance with the nZEB requirements seems a pretty straightforward transition, it is the older, already existing buildings that pose a real challenge. As demolition and rebuilding is neither an economically viable nor an environmentally friendly solution at a large scale, introduction of the renovation and retrofitting strategies of the building stock is necessary. The existing buildings, which are predominantly of low energy performance, represent the vast majority of the building stock, therefore they have a great unrealized potential to deliver high energy and CO_2 savings, and benefit overall energy security throughout the EU.

Addressing the problem of buildings retrofitting is a European project IMPROVEMENT. This project focuses on the challenge of renewable energy systems integration and energy efficiency improvement in public buildings with critical loads (e.g. medical or scientific centers) and converting those buildings into nearly zero-energy public buildings by means of integration of combined cooling, heating and power microgrids under requirements of high power quality and continuity of service. The project is developed for typical climatic conditions of SUDOE region (Southwest of Europe), characterized by cold winters and extremely hot summers, which results in a highly seasonal dependent renewable energy generation.

The project develops technology for two pilot buildings: LNEG in Lisbon, Portugal and Hospital Axarquia in Spain, to be used as prototypes for future integration in public buildings, where sensible high-tech equipment is predominant, in the SUDOE region. For buildings with sensitive loads, power quality and continuity of supply are fundamental aspects, e.g. for sanitary reasons in hospitals, scientific considerations in universities and technological centers or security reasons in banks and airports. Those buildings require large amounts of electricity, steam for space heating and hot water, and energy for ventilation and cooling. They also often operate equipment with extreme sensibility to power disturbances.

2. Objectives

This work is part of the European project IMPROVEMENT and will develop, validate and demonstrate a system for the modernization of existing public buildings, converting them into nZEB buildings by integrating micro-networks of combined heat, cold and electricity generation with storage systems in a system designed for typical climatic conditions of SUDOE regions.

Specifically, the thesis will focus on optimization of operating costs for electrical microgrid in a public building located on the Lumiar campus of LNEG in Lisbon using energy systems modelling tool for linear optimization called OMEGAlpes.

3. Methodology

For the purposes of this thesis OMEGAlpes platform is chosen to develop a model and conduct an optimization, as it is a free, open-source tool based on Python, a widely used high-level programming language. OMEGAlpes stands out for being intuitive and easy to operate, and for providing an additional function of model graphical representation creation.

OMEGAlpes library aims to generate MILP optimization models. The most basic form of an optimization problem is adjusting a set of decision variables in order to minimize an objective function (1).

$$Minimize\ F = f(x_1, x_2, \dots, x_n) \tag{1}$$

The optimization problems have to respect physical laws that bound the values of some decision variables. The problems are denoted as constrained optimization problems (2).

$$\begin{cases} Minimize & F = f(x)\ for\ x \in E^n \\ Subject\ to: & a_i(x) = 0\ for\ i \in (1, 2, \dots, p) \\ & c_j(x) \geq 0\ for\ j \in (1, 2, \dots, q) \end{cases} \tag{2}$$

As only MILP formulations are considered, an optimization problem should take the following form to be classified as linear (3).

$$\begin{cases} Minimize & f(x) - c^T x \\ Subject\ to: & Ax = b \\ & x \geq 0 \end{cases} \tag{3}$$

Many energy systems problems include not only continuous variables (e.g. power, costs, etc.), but also integer variables are necessary for formulation of some constraints (e.g. system on/off), and then MILP formulation is required (4), with either continuous variables ($x \in R^n$) or integer variables ($y \in Z^m$).

$$\begin{cases} Minimize & f(x) - c^T x - h^T y \\ Subject\ to: & Ax + Gy \leq b \\ & x \geq 0\ for\ x\ in\ R^n \\ & y \geq 0\ for\ y\ in\ Z^m \end{cases} \tag{4}$$

This thesis is a part of the project IMPROVEMENT and is realized for an existing building located in Lisbon, Portugal that aims to become a nZEB. In the building there are installed electrical and thermal systems for self-production together with energy storage units. For electricity generation purposes 3 photovoltaic (PV) panels are mounted with total power of 4 kW, assisted by a battery with capacity of 31.68 kWh. For space heating, 2 solar thermal (ST) collectors are used, assisted by a water tank with capacity of 300 l. The whole system is supported by a heat pump that uses electricity from PV panels to back up the heat load. The building is also connected to electrical and heating grids in case the self-production is insufficient to cover the loads. The scheme of the system is presented in Figure 1.

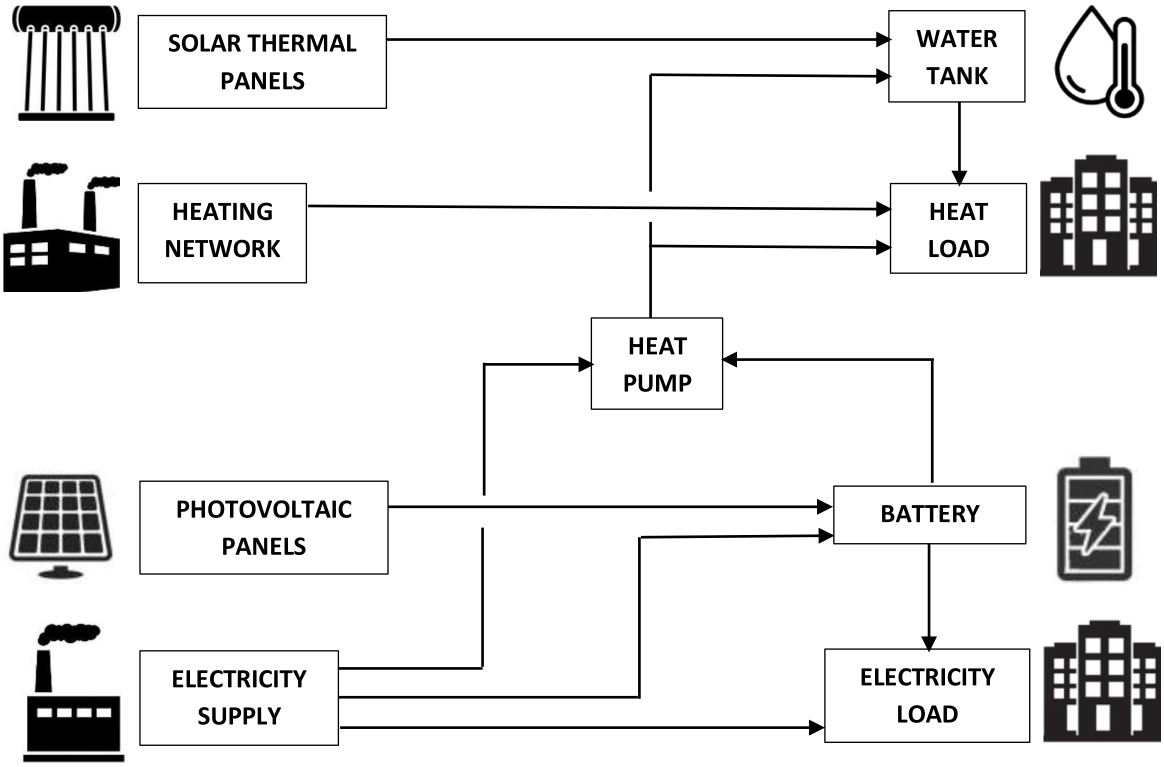

Figure 1 Schematic representation of the energy system installed in the considered building.

The main objective is to minimize the operating costs of the electrical grid. The additional objective is to minimize imports from the heating network by maximizing self-consumption from ST panels, supported by a thermal storage and a heat pump that is using PV generation to help cover part of the thermal load. The optimal electrical and thermal storages' capacities are also found.

For this case, data for PV and ST production profiles, together with electrical and thermal loads, collected in May for time period of one week in 15-minute time steps is considered. The hourly costs distribution throughout the day is presented in figure 2. The electrical storage is a battery with minimal and maximal state of charge equal 20% and 90%, respectively. Loses due to self-discharge amount 1% per hour. The maximal charging and discharging powers are both equal 5 kW. When it comes to the thermal storage in a water tank, the same parameters as for the battery are assumed. For both storage units the initial state of storage is assumed to be empty. The heat pump coefficient of performance is equal 3.

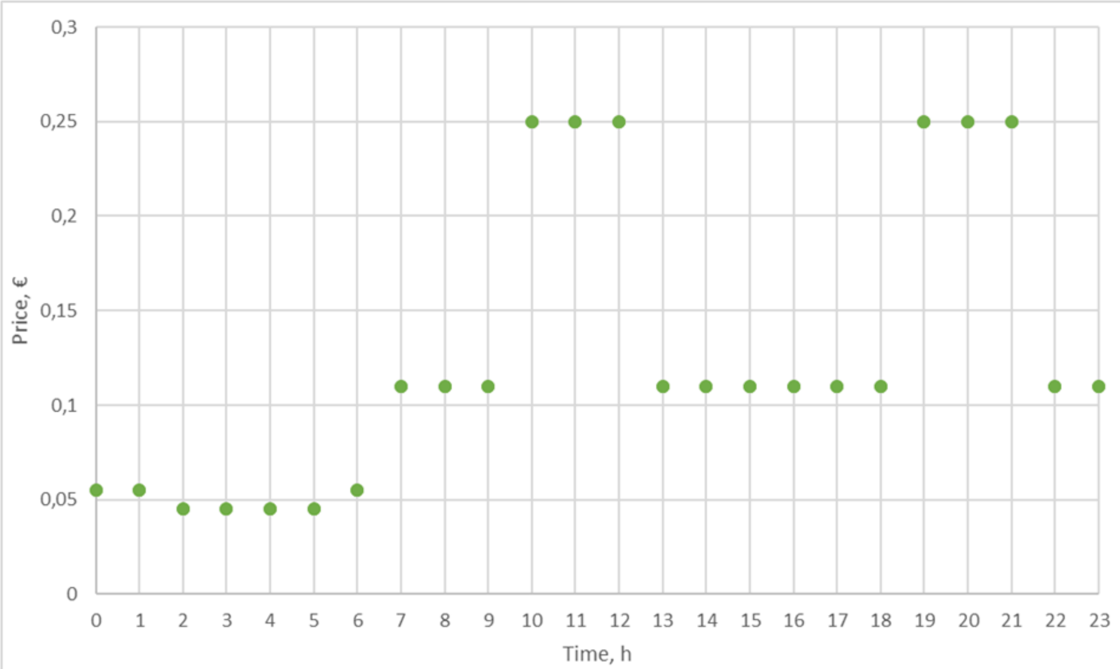

Figure 2 Electricity operating costs distribution.

4. Results and discussion

As a result of the optimization process the optimal electrical storage capacity is found to be around 21 kWh, and the thermal storage capacity around 90 l. Thermal load is entirely covered from self-production together with water tank and a heat pump. No additional heat imports from the network are necessary. Electricity to run the heat pump is either taken from PV panels production, battery discharge, or from the electrical grid.

Table 1 Optimization process results.

Electricity imports from the grid	34 kW
Electricity production from PV panels	153 kW
Electricity consumption	158 kW
Optimal electrical storage capacity	**21 kWh**
Heat imports from the network	0 kW
Heat production from ST panels	78 kW
Heat consumption	130 kW
Optimal thermal storage capacity	**90 l**
Heat pump electricity consumption	19 kW
Heat pump heat production	56 kW

For the examined period, PV panels produced around 153 kW. The electricity consumption amounts 158 kW. Additionally, for its operation, heat pump consumed 19 kW of electric energy to produce 56 kW of thermal energy. This shows that the self-production of electricity covers about 86.5% of the demand. With the production from ST panels equal 78 kW and heat demand equal 130 kW, self-production covers 60% of the thermal load, and the rest is supplied by the heat pump. All the results are presented in Table 1.

It can be noticed in figure 3 that for electrical grid self-production together with storage battery is mostly sufficient to cover the demand, as well as drive the heat pump. Imports from the grid are necessary mainly at the beginning of the considered period, as the energy storage starts with low level of charge, and after day 6, as a result of lower generation from PV panels. The imports from the grid are also necessary when the state of charge of the storage unit approaches minimal constraint.

As already mentioned, the thermal system, depicted in figure 4, does not require the support of the district heating network. Part of the load is covered from ST panels, and the rest from the heat pump. The peaks in the heat demand are shifted in comparison to the electricity demand. The highest electricity loads are observed in the middle of the day, during working hours in the office building. When it comes to heat load, it is highest during nights, when temperature is the lowest. Because of this, generation from ST panels during the day is mainly directed to charging the water tank storage, and discharging takes place during the night (figure 19). This causes the necessity of choosing larger storage capacity, able to store most of the heat generated throughout the day. However, heat pump operates mainly during the nights, which helps to balance the electrical load.

Figure 3 Power flow for the units connected to the electrical node.

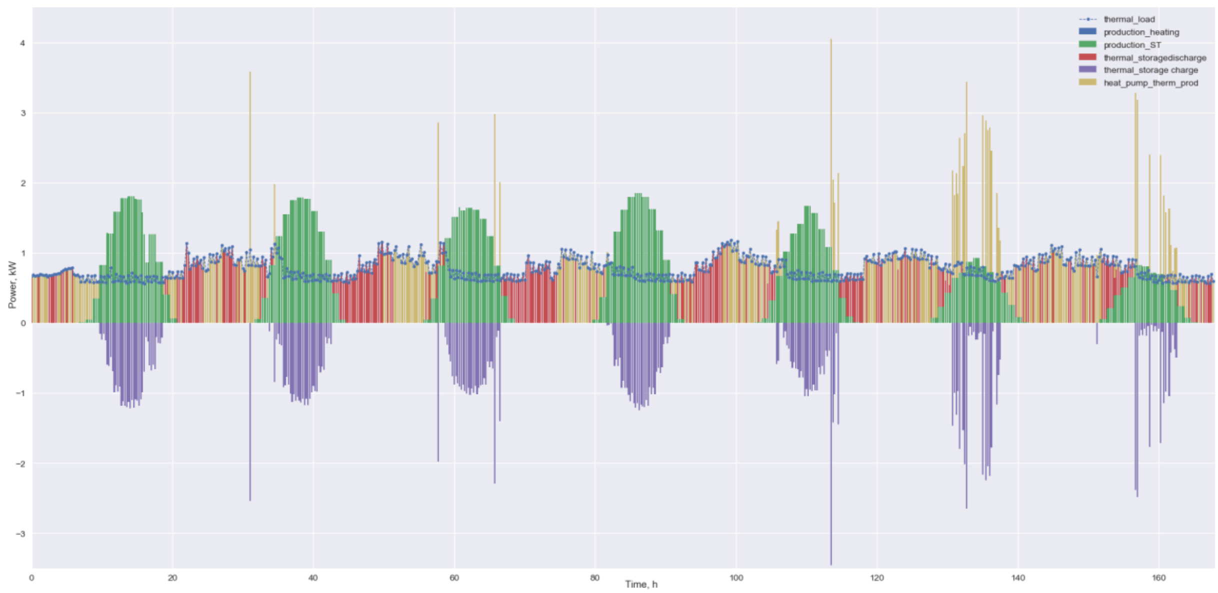

Figure 4 Power flow for the units connected to the thermal node.

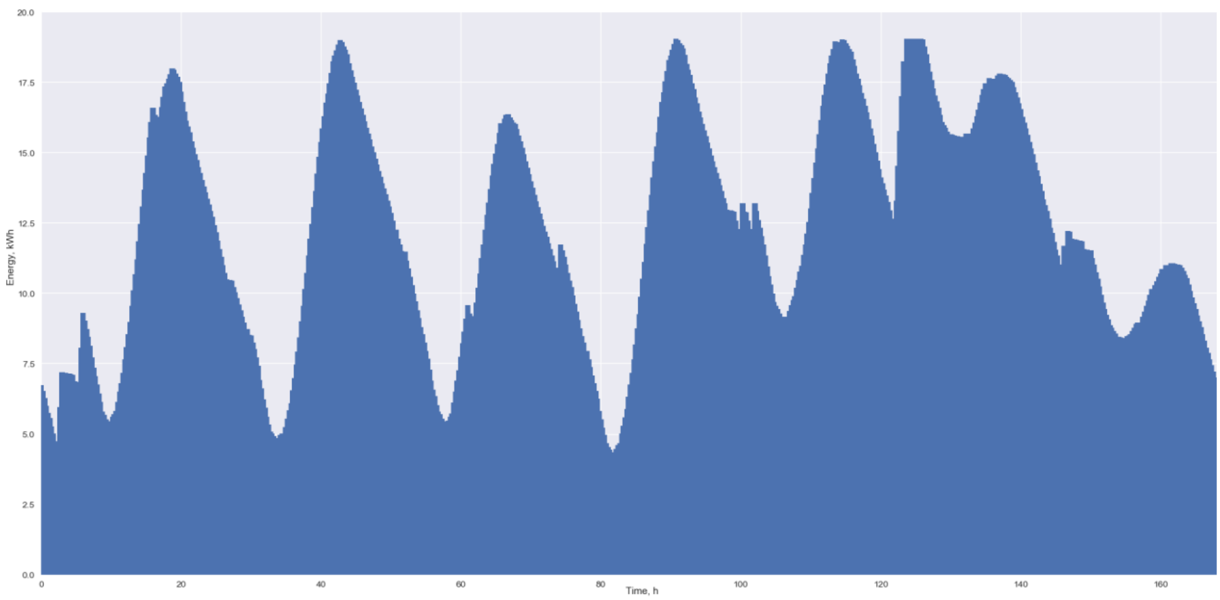

Figure 5 State of charge of the electrical storage.

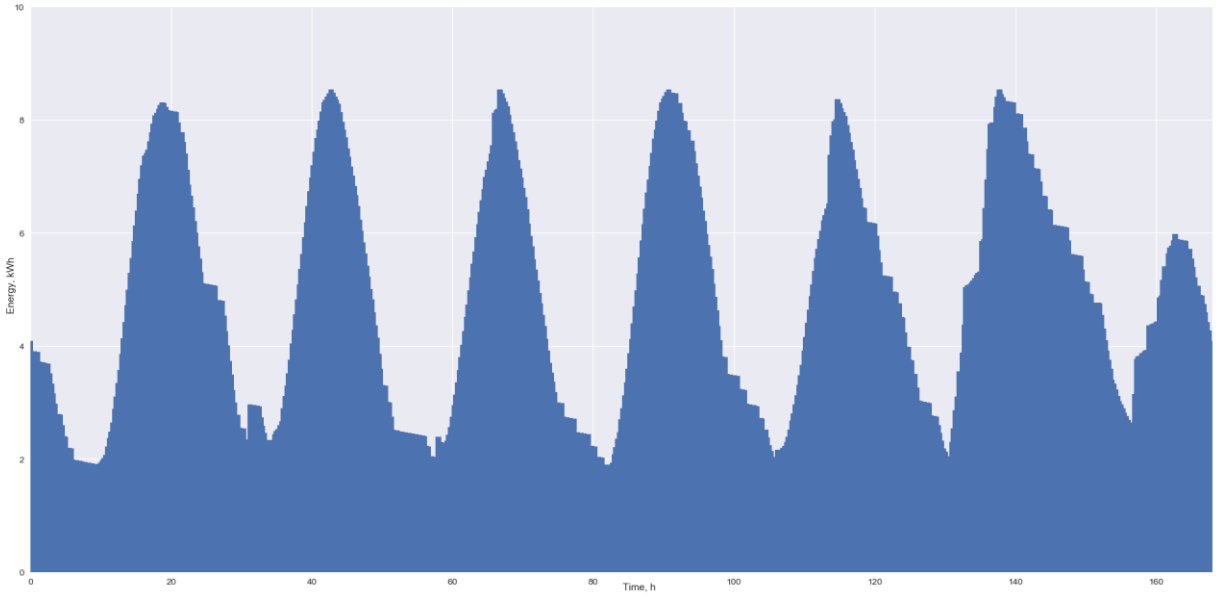

Figure 6 State of charge of the thermal storage.

Analysis of the power flow for the electrical units (figure 3) shows that the electricity imports from the grid take place only during night hours for which the electricity price is the lowest. Charging of the battery storage (figure 5) from the grid is also conducted in the time range, when it is cheapest. The close-up of the first day to better depicture the time when the grid is used is presented in figure 7. It can be noticed that electricity imports to cover the load, as well as to charge the storage, take place in the time range 2 AM - 5 AM, when price reaches the lowest point, equal 0.045 € for the energy unit (figure 2). The optimization process yielded decrease in the electricity costs of 58% in relation to the system before optimization.

Figure 7 Close-up of the power flow for the units connected to the electrical node for day 1.

5. Conclusions

This work focuses on a nZEB office building located in Portugal. The main model is developed using OMEGAlpes tool to optimize the work of the microgrid in a way that the costs of the electricity imports from the electrical grid are minimized. Additionally, the coverage of the thermal load from self-production from ST panels together with the heat pump driven by PV panels is maximized, so that the support of the heating network is not needed. Further the optimal electrical and thermal storages' capacities are found for the modelled system.

As a result of the optimization of the work of the system, 58% reduction in the electricity costs was achieved. The results also show that for the examined period of time the energy storage units are oversized. The currently installed battery for electricity storage has got a capacity of 31.68 kWh, when the conducted studies show the optimal battery size is 21 kWh. For the water tank for thermal energy storage, instead of 300 l capacity, the optimal size is found to be 90 l. As the storage units are already installed in the building, the best solution would be to increase the self-production, as there is still a potential to cover more of the load from on-site generation and in this way lower the imports from the electrical grid even more. In current state the building covers about 86.5% of the electricity demand and 60% of the heat demand from self-production from the renewable resources.

The building could be also further developed into a Positive Energy Building, if the self-production surpassed the loads throughout the whole operating period. Then the building would be considered as a kind of power unit, sharing its energy surplus with the infrastructure in the vicinity, like outdoor lighting. It could be a first step to going even further and developing the concept of a Positive Energy District, where the energy surplus would be used to balance other buildings' loads.

6. References

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