One or both of 7 and 8 are to be performed. This section examines some hypothetical situations in which a design or optimization process is applied to the same site, requirements, and constraints, to determine how the building might have been built differently. The intended process is for the energy model(s) to be altered to observe the effect. This could include a change in form, technology, or wall construction, for example. These hypothetical case studies allow the designer to explore design decisions for which they may not have had sufficient resources or tools (e.g., if tools have advanced considerably since the building was originally designed). Also, if the building is low-energy or near net-zero energy, this study can examine how to achieve net-zero energy performance. Two processes can be applied:

7. *Redesign* (heuristic) with consideration to different technologies, controls, tools, procedures or other building characteristics. The following steps should be performed.

a. If the model has not already been created in one (or a set of complimentary) simulation tools, create it/them. All inputs should be clearly documented according to the template. If the simulation tool has any particular assumptions or simplifications, they should be documented.

b. If the building is built and has been monitored, compare simulation results to measured data.

c. Brainstorm potential new concepts that could lead to performance improvements, just as in early stage design. Document the brainstorming process.

d. Implement the new concepts either in the model or simplified calculation methods. The base model from step (a) should be adapted to include the new concepts. The concepts can either be sequentially or simultaneously (of course, the most rigorous approach would be to apply all possible subsets of the new concepts). This process should be thoroughly documented to discuss why and how things were done (e.g., why one tool was used over another or why a certain level of model resolution (i.e. level of complexity) was used).

e. The results should be tabulated to clearly compare the performance of all new design concepts with the original.

8. *Optimization of the design* with consideration of different technologies, controls, tools, procedures, or other building characteristics.

a. The model should be created and set up such that variables of interest can be easily modified, as required for batch simulations.

b. All variables, constrains, and the cost function should be carefully documented. The thought process behind the selection of these three components is particularly important.

c. Perform the optimization. Clearly document which tool was used or whether it was custom tool.

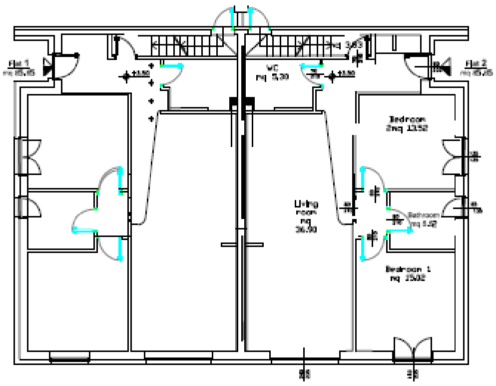
d. Describe the optimal design, as determined by the optimization. Document the performance of the optimization process (e.g., number of simulations performed and duration of process).

e. How realistic is the optimal design? Do all of the optimal variables make sense?

The Leaf House

The LH is located in Angeli di Rosora (Ancona, Italy), the latitude and longitude of the site are respectively 43°28'43.16N, 13°04'03.65E while the altitude is 130 m (426ft) above the sea level. The site is characterized by a moderate climate (mean annual temperature of 15.8 °C (60.44 °F), mean humidity of 67% and mean horizontal solar radiation of 302 W/m2 (95.76 Btu/(h ft2))). The house has a rectangular shape and is composed of six flats with an inner symmetrical division.

Its net conditioned floor area is 477 m2 (5134ft2). Four apartments are occupied by two people each while two apartments are only occasionally occupied.



Plant of the Leaf House

The initial goal of the design was to develop a carbon neutral house, but during the design stage the NZEB concept was added. This house is an application of new concepts of the architectural design: comfort, sustainability, energy and economy.

It was also built as a laboratory where new sustainable technologies are studied and further developed; indeed in the building there is a monitoring system able to record data about the quality of the air, the humidity, the CO2 level by means of several sensors that are installed in all the rooms of the six apartments.

Description of the thermal plant

In the LH the heat and cold generation is carried out by a geothermal heat pump (GHP) that exchanges with the ground through three vertical probes (100 m). In each flat of the LH there is a radiant floor supplied by the GHP. During the summer season, the cooling system uses free cooling provided by a ground coupled heat exchanger.

In the LH there is a mechanical ventilation system with heat recovery and pre-conditioning in an underground duct. The ventilation rate is automatically provided according to the CO_2 levels registered in the rooms. The efficiency of the heat recovery system is 80%.

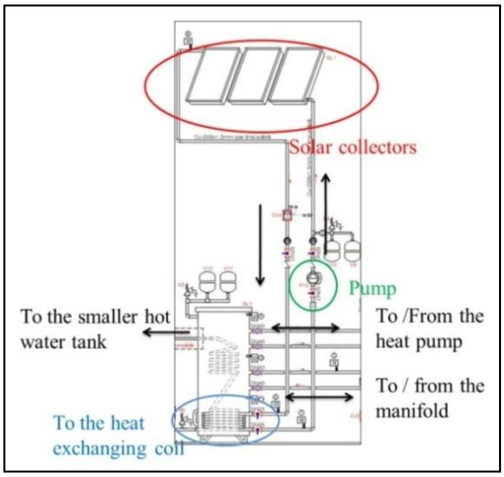
The electric energy needs of the heat pump are covered by the energy produced on site by the photovoltaic panels covering the roof facing the south.

The LH energy system includes seven sub-systems:

- The solar collector system;
- The geothermal probes;
- The heat pump;
- The air handling unit (AHU);
- The auxiliary boiler;
- The photovoltaic system;
- The radiating floors.

The solar collector system

Seven solar thermal collectors (2.6 m^2 each) integrate, or completely replace (according to the season), the heat pump in the production of domestic hot water. A recirculation system allows the occupants to immediately get hot water reducing water wastes. The heat is transferred from the solar collectors to the coil of the storage tank by means of a glycol-water mixture. A pump drives the fluid back to the collectors. The difference between the outlet water temperature of the solar panels and the water inside the storage tank is less than 10 degrees; otherwise the pump is turned off.

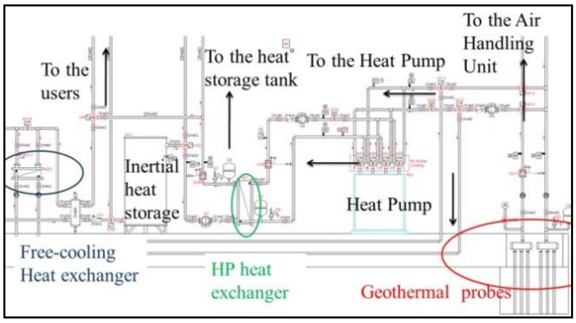


The geothermal probes and heat pump

The figure represents a simplified scheme of the geothermal probes and the heat pump. The officially declared COP of the GHP is 4.6, lower than the measured value during the first year of monitoring. The efficiency reduction is probably due to:

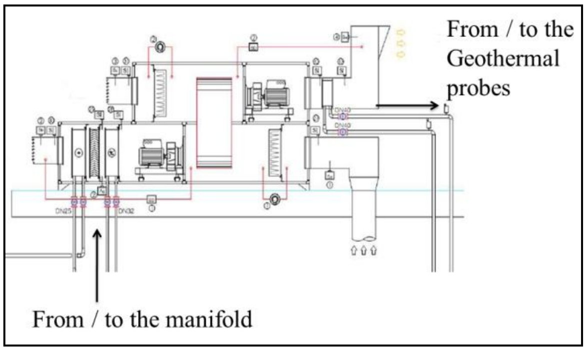
- the non-optimal use of thermal devices;
- the anomalous electrical absorption of the compressor respect to the declared data (7-8 % higher);
- a mis-management of the ignition system characterized by too fast cycles.

The geothermal circuit, which regularly supplies the heat pump, during the summer season is connected to the free-cooling heat exchanger.



The air handling unit (AHU)

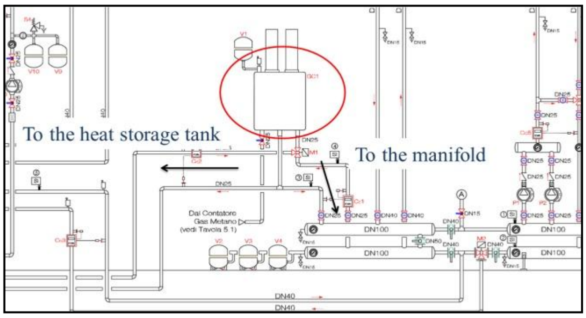
As previously described, to exchange air in the rooms an AHU has been installed. Before introducing air into flats, the outer air is heated in winter and cooled in summer exchanging thermal energy with the water produced by the heat pump. To avoid thermal wastes, the thermal energy is extracted from the inner air before the expulsion. The outer air is also naturally pre-conditioned through an underground path of about 10 m before getting to the AHU.



Scheme of the AHU

The auxiliary boiler

An auxiliary boiler is used to heat the fluid when the target temperature is not reached by the other systems. In figure it is possible to see the position of the boiler respect to the other plants.



The auxiliary boiler

The photovoltaic system

A grid-connected PV system characterized by a 20 kW nominal power generates electricity for the LH. The PV field , which is composed by 115 panels, covers the entire roof surface (150m^2), facing the south. The panels are arranged in nine strings and are connected to three inverters. The nominal declared efficiency of the PV panels is 12%.

The radiating floors

In each flat there is a radiant floor fed by the GHP. The temperature in the rooms is controlled by a regulation system that is able to check the hot water flow through each tubing loop. Zoning valves and thermostats permit to reduce the energy consumption. During the summer season, excluding the hottest days, the cooling system uses the natural cooling provided by a ground coupled heat exchanger.

In winter, the water that circulates in the tubing has a temperature of 25-28°C.

Other energy efficiency measures

To pick up the natural light in the LH, wide windows face the south while in the rear part of the house facing the North the sunlight is carried by solar tubes. Furthermore, efficient fluorescent lamps are used. The rain water is collected and reused for WC and irrigation, thus reducing the water total consumptions of 69%. Drinkable water is supplied by public utility and the taps providewater through a three-way valve that supplies hot and cold water. This solution avoids to buy bottled water.

The control system

The monitoring and building automation system has been developed by the Loccioni Group, it uses an innovative approach based on the so called Leaf Framework. The Leaf Framework is a software platform between the system devices and the logic level which includes graphical user interfaces, building automation algorithms, business intelligence tools and databases. In other words it behaves like a software gateway between different devices and systems. More than 1,200 sensors and actuators have been integrated with drivers which allow communication between devices and systems by means of different protocols. The sensors are classified in three main groups: apartment sensors (CO_2,air temperature and humidity sensors, electricity and thermal energy meters), mechanical plant sensors (temperature sensors, thermal energy meters, water flow meters, etc.) and weather station sensors. All data are normalized and stored in a database. The Leaf framework allows the building automation system to use all the available strategies with energy efficiency algorithms. For example the HVAC system stops if windows are open. The inlet temperature of the water in the radiant floor is regulated according to the external temperature. The air flow rate is regulated according to the CO_2 level in each apartment. The LH is considered as a laboratory whose stored data are analysed using business intelligence tools and used to test predictive algorithms.

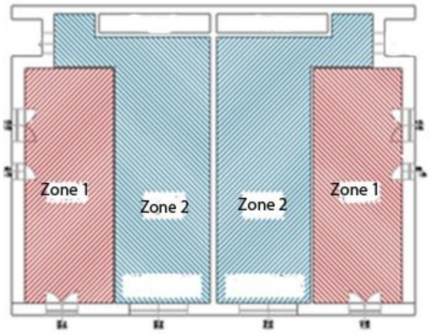
TRNSYS Model

In the TRNBuild simulation each flat has been divided in:

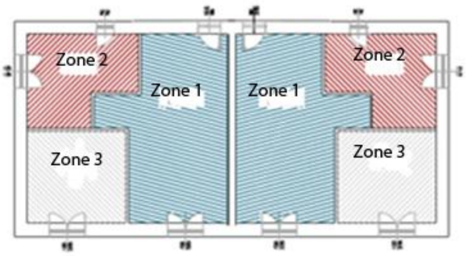
- two symmetrical zones for the ground and first floor apartments : Zone 1 (red area), Zone 2 (blue area);
- three symmetrical zones for the second floor flat (Figure 6b-c): Zone 1 (blue area), Zone 2 (red area) and Zone 3 (white area).

During the summer season, the solar circuit is completely by-passed by diverting valves. The fluid used to provide the cooling effect is driven to a geothermal heat exchanger that works exchanging heat directly with the ground. The GHP in the cooling mode is activated manually.

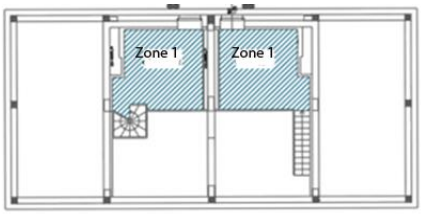
The modeled heat pump control system is set up at a temperature of 20°C of the fluid coming from the radiant floors.



The thermal zones of the ground floor

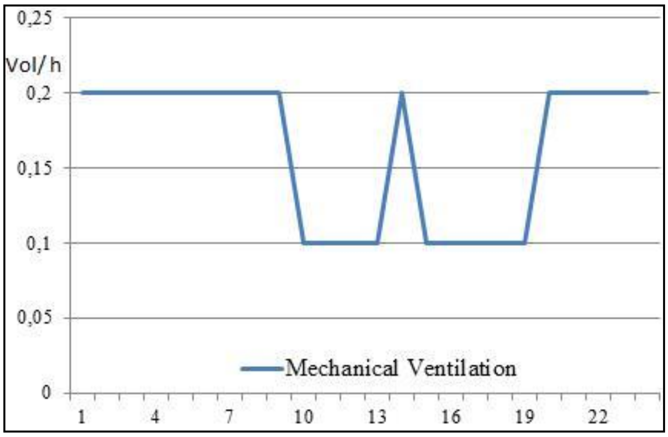


The thermal zones of the first floor



The thermal zones of the second floor

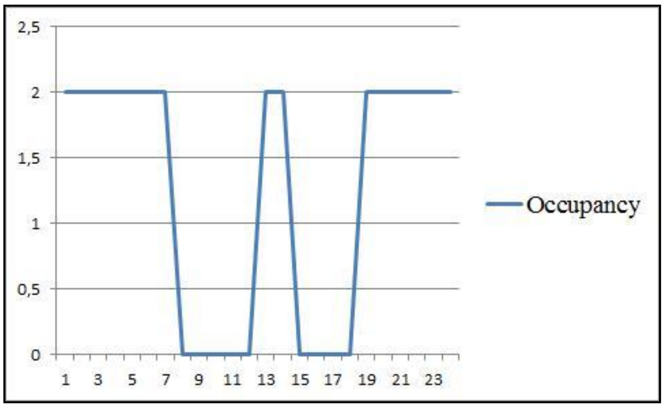
Each zone is simulated taking into account the real orientation of the building to better assess the solar gains. The thermal exchanges due to mechanical ventilation are evaluated setting up 0.1 or 0.2 volumes/hour of ventilation, depending on day time schedule. The $C0_2$ sensors activate the mechanical ventilation only when the CO_2 concentration is higher than the set point value while other sensors automatically stop the mechanical ventilation when windows are open.



Example of the mechanical ventilation daily schedule for flats 1-4

The thermal gains of the zones are calculated through the TRNSYS "Gains" function : a detailed function that considers the number of people inside the house at all hours of the day, every day. Furthermore, different activity levels for the people in the house were set up.

To obtain reliable results we have developed a data climate file containing the climate time series of 2009 collected by the LH weather station.



Example of the occupancy level daily schedule for flats 1-4

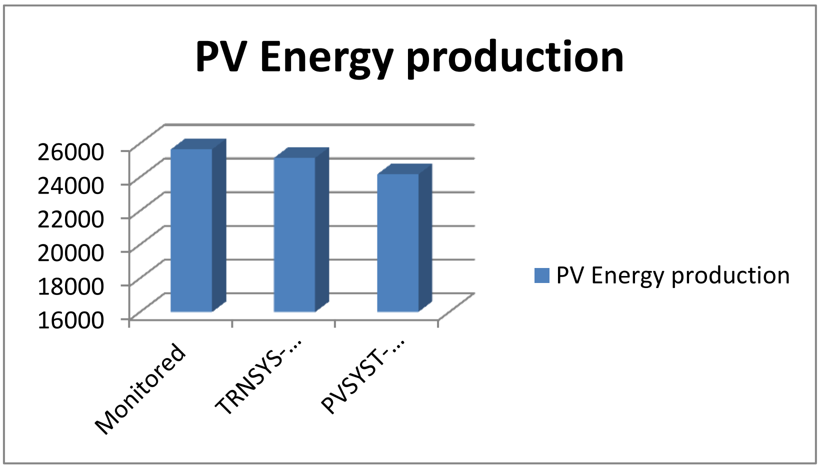
Results of the simulation

Photovoltaic model

The monitored data for 2009 show an energy production of 25651 kWh from the photovoltaic panels. The simulated production from TRNSYS is 25143 kWh for the year, while the PVSYST simulation gives as result 24160 kWh / year. The precision of the two results is high enough to consider significant and solid the two models.

Both approaches give a lower value than the monitored one : the TRNSYS model has an error of the 2 %, while the PVSYST reaches the 6 %.

The results are summarized in the following graph.



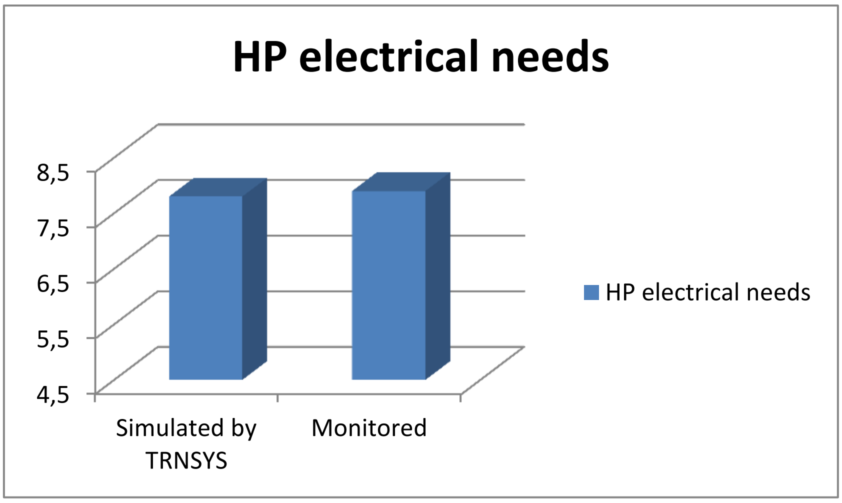
Monitored and simulated photovoltaic energy production

HVAC model

The calibration of the model has been made on both the temperature results compared to the average values in the year and on the heat pump electricity demands, calculated by TRNSYS.

The heat pump electricity absorption results will be briefly described.

The real HP uses nearly 5.3 MWh for the heating season and 2.6 MWh for the cooling one. The simulated data for the heating season is close to 4,7 MWh while the simulated cooling consumption is 2.7 MWh. Those data are close enough to claim the simulation results as acceptable: the difference between simulated and monitored data is around 6 %.



Simulated and monitored heat pump electrical needs

Redesign

The energy performances of the building show that the envelope is already very effective while a partial redesign of the thermal plant could permit reaching a nearly Net Zero Energy performance.

Furthermore, the adoption of a better building automation system could significantly improve the energy behavior of the building.

Redesign studies should identify better alternative solutions for plants, building envelope or impact on the environment that significantly modify the building.

A brief summary of the 2009 data for the LH plant and electrical needs follows: both simulated and real values are arranged in a table for a quick comparison of the Scenario 0 with the redesign options.

PV (kWh)		
Energy production		**Energy Needs**
Simulated 25143	Monitored 25651	Monitored 37080

Scenario 0, Energy production and needs

The forecasted energy needs were way lower than the monitored ones. That leads to an Energy produced\Energy needs ratio equal to 0,69 : in order to reach the NZEB status this ratio must be equal to one, in the chosen time interval.

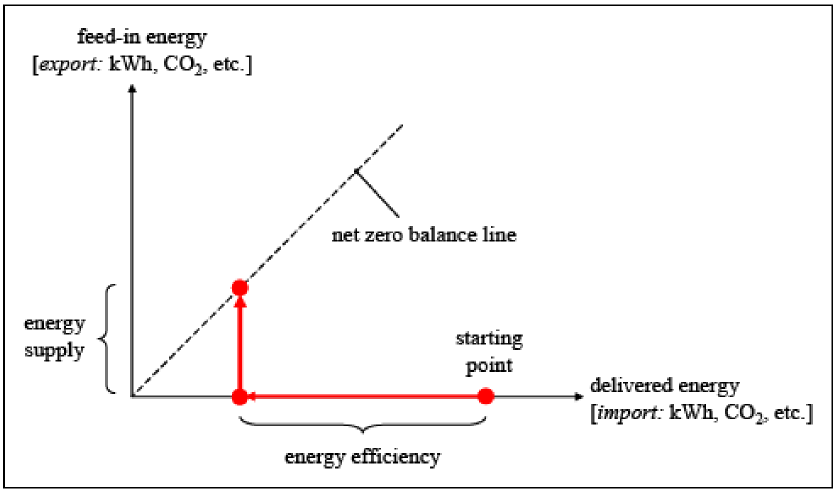
An in-depth analysis should be conducted, in order to examine in a higher detail the electrical needs of the Leaf House. It has been conducted an in-depth simulation on the weight of the heat pump electrical needs on the overall needs.

HP electrical needs (MWh)	
Simulated	Monitored
7,4	7,9

Scenario 0 , HP electrical needs

The heat pump electrical needs \ total needs ratio is around 0,26 : it has an overall high enough impact to justify redesign options in this direction.

In order to obtain a NZEB performance two different level of intervention can be pursued: obtain better performances with higher energy efficiencies and thus reducing the energy needs (moving from right to left on the x axis in the graph) or higher energy supplies \ production values (moving on the y axis).



Example of the redesign process

To achieve the goal of NZEB, different scenarios have been proposed to improve the real plant-building system.

In detail, to increase the energy performance of the building it has been decided to simulate four scenarios:

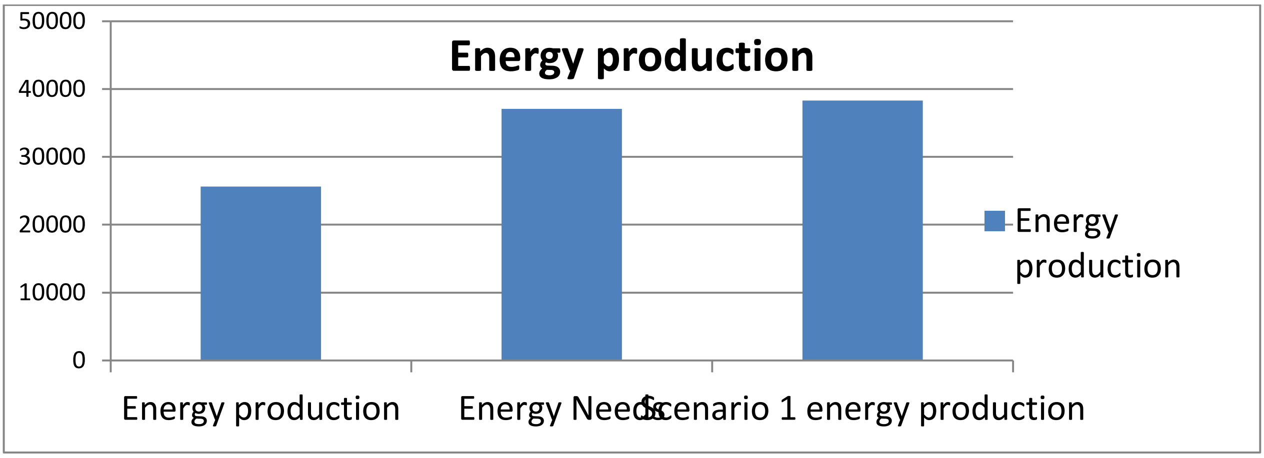
- Scenario 1: Increase PV energy production;
- Scenario 2: A more efficient GHP (COP 4.6);
- Scenario 3 : Elimination of the heat pump heat exchanger and the use of glycol-water in the main system line,
- Scenario 4 : Combination of scenario 2 and 3.

Scenario 1

The first scenario touches the PV energy production.

The monitored data for 2009 show an energy production of 25651 kWh from the photovoltaic panels. The simulated production from TRNSYS is 25143 kWh for the year.

With the substitution of a different model of PV panels (19 % efficiency) the energy yield forecasted (TRNSYS simulation) would be 38296 kWh: this solution should allow a complete covering of the total electrical needs of the LH.



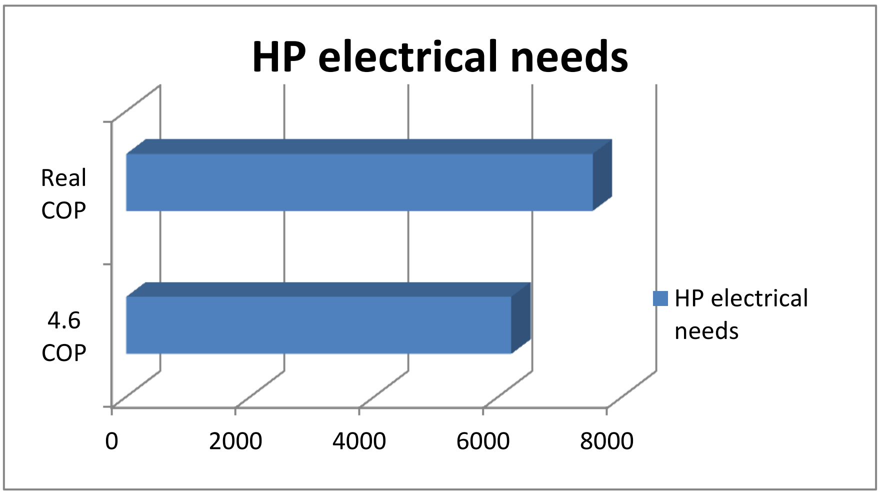
Energy production

	ON-SITE	REDESIGN
PMAX [W]	175,00	240,00
VMP [V]	36,40	43,70
IMP [A]	4,67	5,51
OPEN CIRCUIT V [V]	43,50	52,40
SHORT-CIRCUIT I [A]	5,20	5,85

Scenario 2

The second scenario takes in consideration a COP higher than the one resulting from monitored data. A 4.6 COP heat pump simulated with the same model and assumptions gives an overall yearly data of around 5.4 MWh.

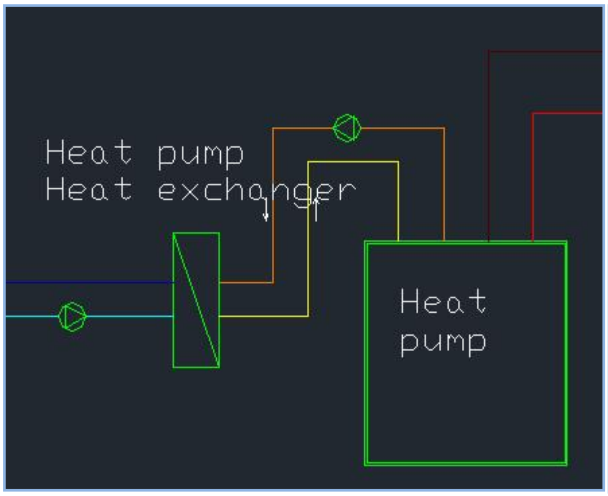
This value is 2 MWh (26 % lower) lower than the scenario 0 simulated one.

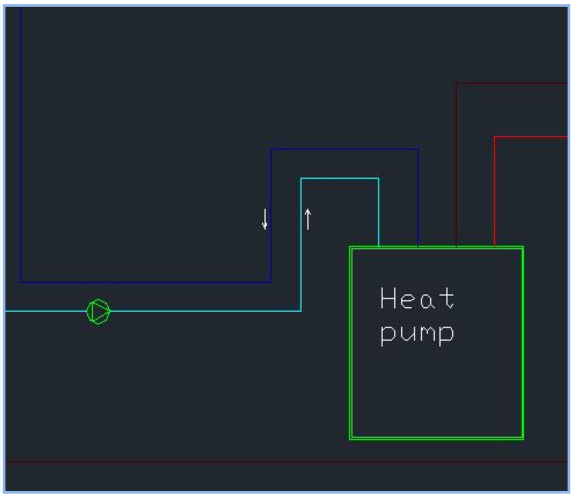


Scenario 2

Scenario 3

The third hypothesis was the elimination of the heat pump heat exchanger and the use of glycol-water in the main system line.

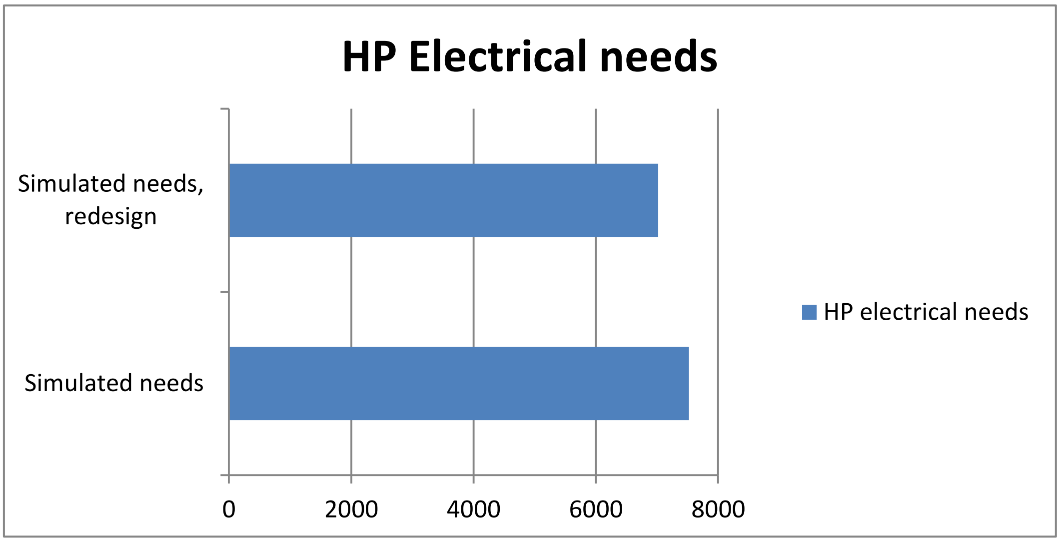




Real plant scheme

Scenario 3

The impact on the overall electrical needs was significant: around 500 kWh were saved during the year. While simulated needs were 7524 kWh, the simulated results of this redesign option are 7020 kWh.

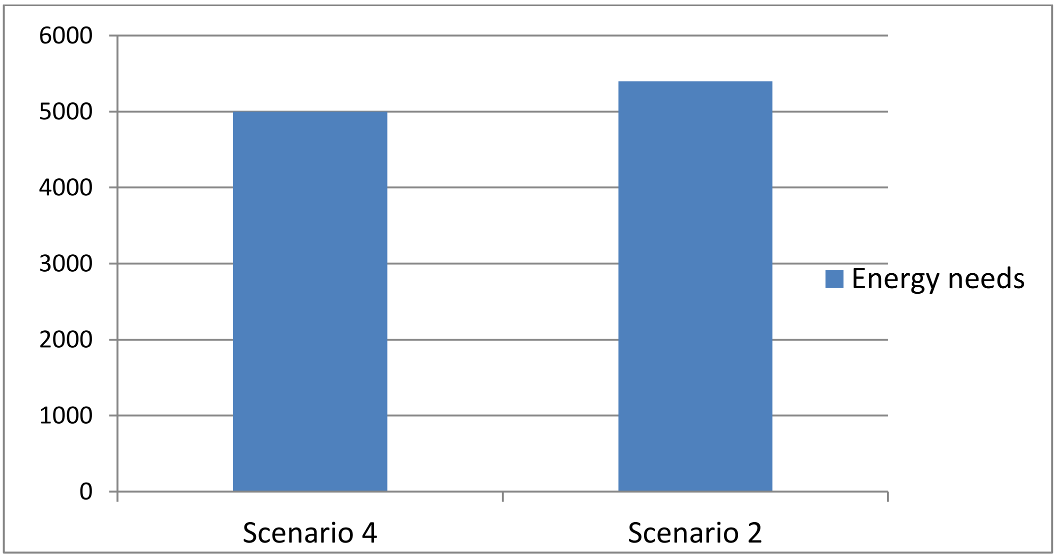


Hp electrical needs, scenario 3

Scenario 4

The combination of the adoption of a more efficient GHP proposed in the scenario 2 and the new system configuration described in the scenario 3 leads to an energy saving of around 400 kWh on the energy needs forecasted in the second scenario.

The energy needs forecasted are around 5 MWh for the year taken in consideration.



HP energy needs (kWh)

The substitution of the PV panels allows the possibility to reach the NZEB standards with no other interventions. However further investigations on the GHP shows that achieving 2 MWh savings or more is possible by choosing another heat pump with better performances.
The results are summarized in the following tabs.

Scenario	Simulated PV production	MonitoredPV production	Energy needs
0	25143	25651	37080
1	38296		37080

PV re-design options (kWh)

Scenario	Monitored	Simulated
0	7,9	7,5
2		5,4
3		7
4		5

HP-related re-design options (MWh)

The best option is the combination of scenarios 1 and 4.