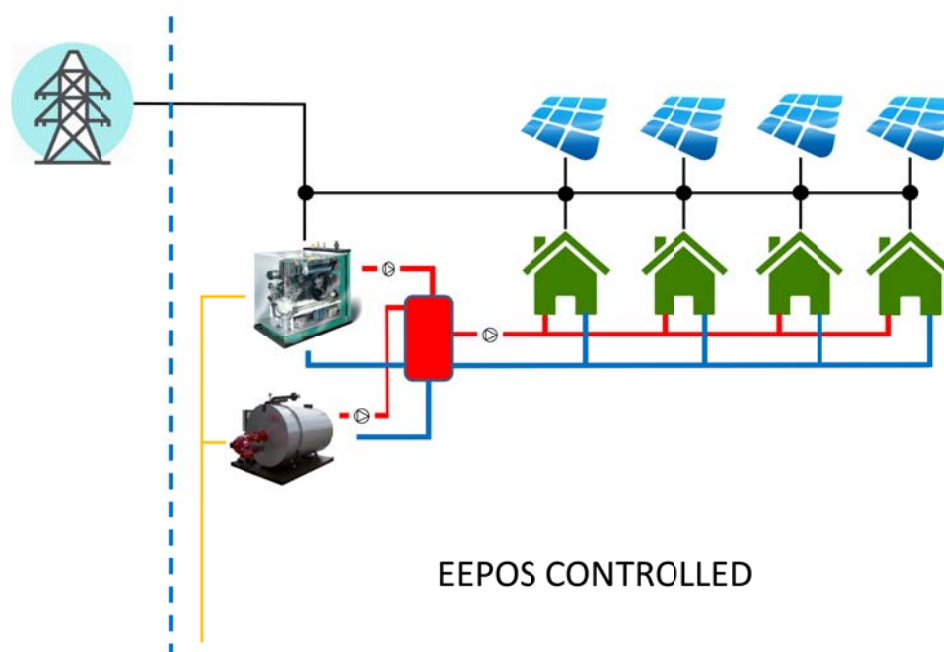


Deliverable 4.3 Virtual Prototype



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1. PUBLISHABLE EXECUTIVE SUMMARY

EEPOS project focuses on neighbourhood energy management and decision support systems that will integrate local consumers & producers (prosumers) with the main electrical and heating grids.

This deliverable is aimed to apply some of the energy management and decision support system developed within the project, to the realistic environment of Araia municipality.

In order to do this, the partner ARA representing the Spanish municipality of Araia, has provided data regarding public building characteristics, schedules, energy consumption, etc.

SOL has used this data to calibrate some RC (resistance-capacitor) models that are able to represent the thermal behaviour of the target buildings.

As the electricity management has been widely treated in other deliverables, a combined heat and electricity management has been analysed in this deliverable.

In order to build a realistic district heating network, not all the Araia public buildings could be included in the network. However, some of the main heat consumers that are located close to each other were included in a feasible district heating network.

Beside the district heating, renewable energy sources like PV have been included in the district. The energy supplied by these RES systems has been considered for the optimization process, emulating the PV generation forecast application developed within the EEPOS project

The main aim of the energy management system is controlling the heat and electricity produced by the CHP generator at each time, in order to supply as much energy as possible to the district, reducing its dependency on the public grid, shaving peaks and increasing the economic profitability.

Taking advantage of the building thermal models, the flexibility for storing heat in the buildings has been used in the simulations. Temperature set points are no longer fixed in the simulation, instead a set-point range is provided. This thermal flexibility allows a bigger range of possibilities to optimize the energy management.

After carrying out the simulations and analysing the results, it can be said that a neighbourhood energy management and decision support systems like EEPOS can be very useful to shave the peaks of a neighbourhood like this, when combined with CHP units. The EEPOS system also allows generating a big part of the electric energy needed by the district, when it is really needed, diminishing the amount of electric energy drawn from the main grid.

After applying the EEPOS philosophy to the existing buildings of Araia, by using a virtual prototype, it can be said that the main EEPOS targets are fulfilled:

Maximum utilisation of local DER in the neighbourhood: the distributed energy resources were dimensioned accordingly to the district needs. District electric consumption was the limiting factor for sizing the CHP. Regarding the PV panels, the peak power was chosen to avoid PV electricity surplus at any time of the year. However this could happen occasionally when some buildings do not consume electricity as usual (e.g. buildings are not occupied).

Electricity market support (balancing market): in this virtual prototype scenario, the district demands more electric energy during the daytime. For the particular weeks that have been analysed, the grid electricity price is over the CHP profitability threshold when the CHP is turned on. Therefore the CHP is producing electric energy when it is more expensive, helping to balance the market.

Distribution grid support (congestion management and peak load shaving): as a result of the EEPOS control, the electric peak load has been reduced by 40% (from 27kW to 16kW) during the cold and mild seasons, when the CHP heat can be used. As the EEPOS system tries to maximize the local DER in the neighbourhood, the energy surplus that is sent to the grid is minimum, to avoid any grid congestion. The grid electric consumption can be reduced more than 30% in a yearly basis. Reducing consumption supports the main distribution grid.

Although some economic savings could also be obtained by installing the whole system and operating it with the EEPOS system, the cost of the district heating network is too high to recoup the funds expended in the investment, in a reasonable period of time.

An alternative layout has been suggested to improve the economic indicators, where the CHP units are directly installed in the bigger buildings that will be used to store the CHP heat and no district heating network is installed. Although less thermal storage is available in this case, the lower investment helps to improve the profitability.

2. INTRODUCTION

2.1 Purpose and target group

The purpose of this deliverable is integrating the results of WP2 “Neighbourhood automation and management system” in a virtual prototype based on the real characteristics of the municipality of Araia (Spain). This deliverable is aimed to prove that the energy management and decision support systems developed within the EEPOS project would be useful in a real case like the municipality of Araia.

2.2 Contributions of partners

ARA has contributed with all the information regarding building and systems, solving the questions asked by SOL in order to understand the behavior of the target buildings. SOL has modelled the target buildings, and used some supervisory and predictive control techniques developed in WP2 and WP3 to manage energy in an optimized way, in the virtual prototype of Araia.

2.3 Scope

Araia municipality has provided public buildings characteristics and energy consumption associated to those buildings. The task consists of analyzing how an energy management and decision support system could optimize the energetic behavior of a group of buildings in Araia.

2.4 Relations to other activities

This activity is quite independent from other demonstration activities, and also from the technical tasks regarding the real implementation of control algorithms and applications on the OGEMA framework. Some of the control algorithms principles developed in D2.3 “Supervisory and Predictive Control Methods and Applications: Technical documentation & Implementation” have been used in the virtual environment to prove that the energy can be better managed. For this optimized management, renewable forecast is also needed and this virtual prototype uses the outputs from simulation environments as if it were the results of the PV generation forecast application. The simulation cases developed are closely connected to the business model called “considering power and heat” developed in WP1 deliverables.

3. ARAIA PUBLIC BUILDINGS

Cinema Andra Mari, Gross Floor Area = 276 m², 1 storey building

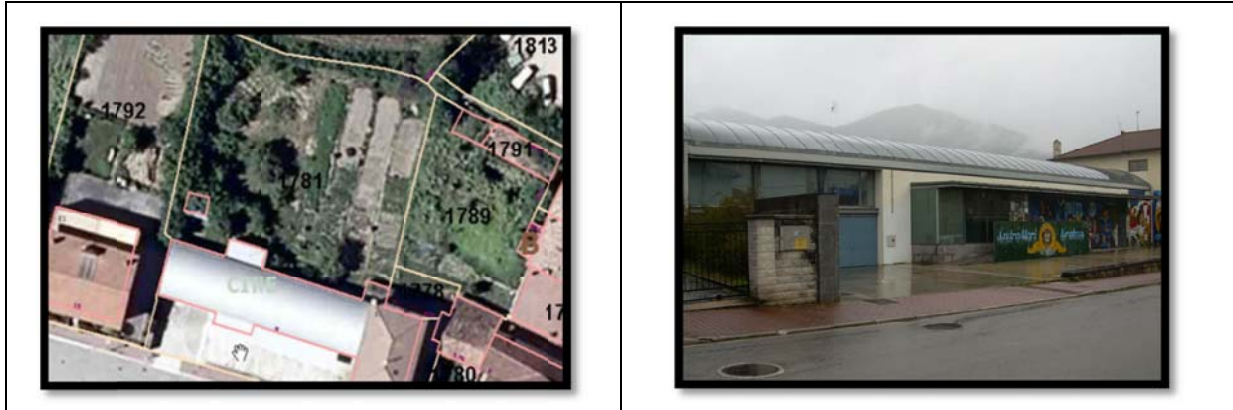


Figure 1. Cinema Andra Mari

Town Hall, Gross Floor Area = 878 m², 3 storey building

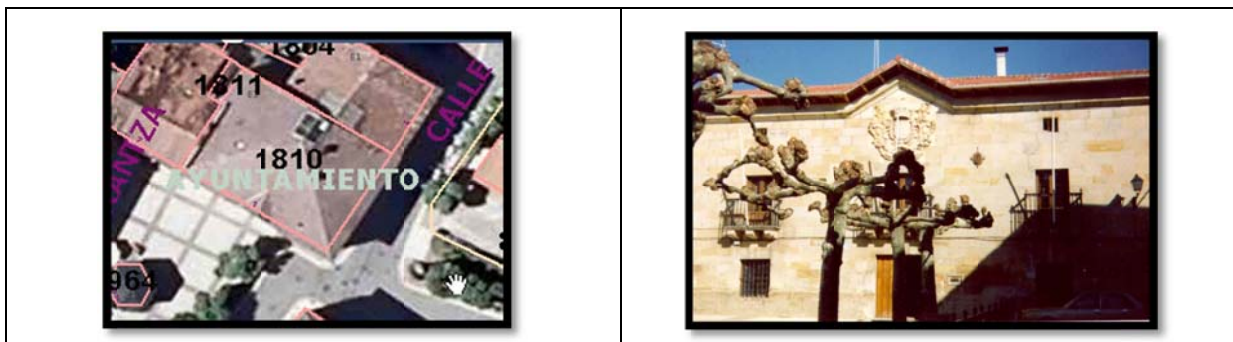


Figure 2. Town hall

Nursing home, Gross Floor Area = 720 m², 3 storey building



Figure 3. Nursing home

Old schools, Gross Floor Area = 354 m², 1 storey building



Figure 4. Old schools

Culture house, Gross Floor Area = 1247 m², 3 storey building

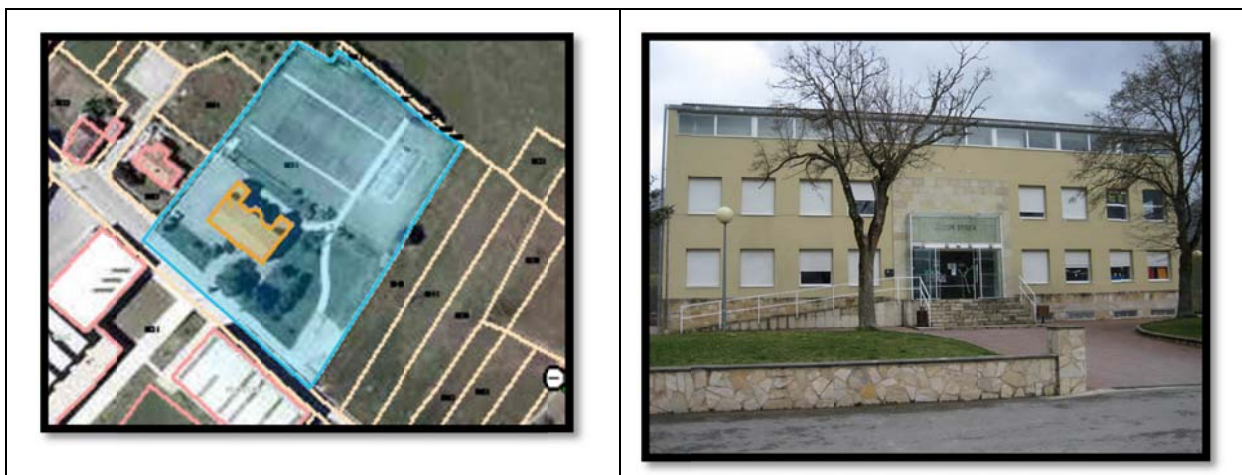


Figure 5. Culture house

Outpatient clinic, Gross Floor Area = 245 m², 1 storey building



Figure 6. Outpatient clinic

Public school, Gross Floor Area = 2017 m², 3 storey building

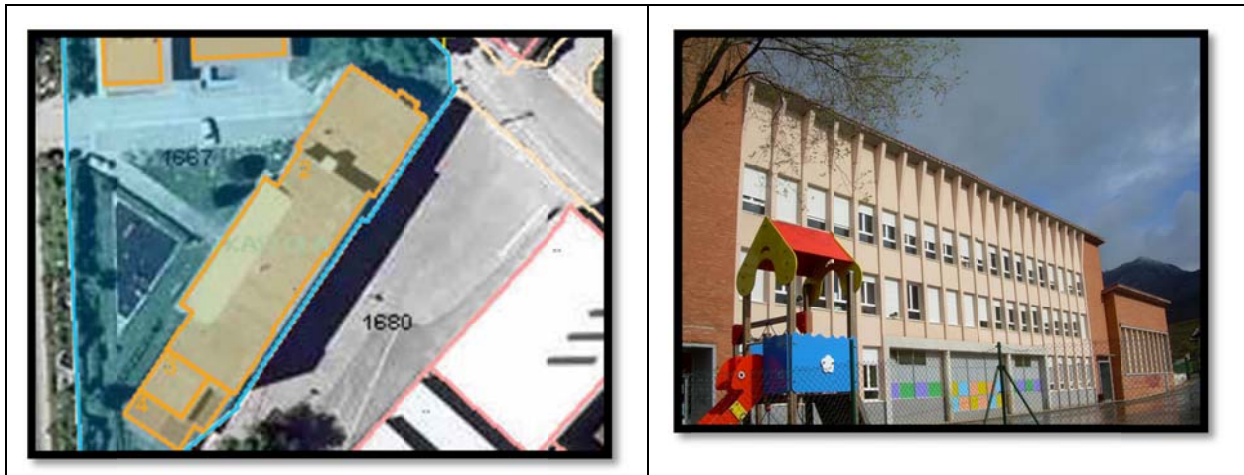


Figure 7. Public school

Nursery school, Gross Floor Area = 151 m², 1 storey building

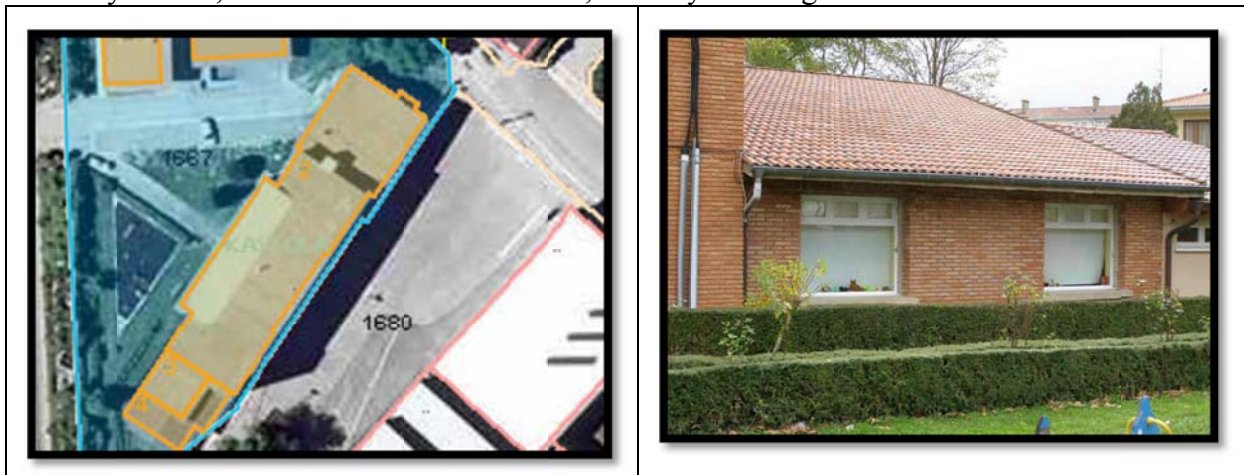


Figure 8. Nursing school

Sport centre, Gross Floor Area = 2672 m², 2 storey building



Figure 9. Sport centre

4. TARGET DISTRICT

It has been decided to develop a combined energy management of heat and electricity for Araia. Due to the long distances between buildings, a reduced district integrating the biggest heating consumers seemed to be the only feasible solution for Araia.

The buildings within the grid are:

- Public school (including nursery school).
- Culture house.
- Outpatient clinic.
- Social housing.
- Two private houses (optional). They will not be considered for this study, as they are private houses. However they could be connected to the district heating network easily, due to its closeness.

The piping layout is shown in the next picture. It also presents a realistic site to build a small industrial unit to house the boiler, CHP, pumps and any additional necessary equipment.



Figure 10. Piping layout

As previously said, EEPOS project focuses on neighbourhood energy management and decision support systems, integrating local consumers & producers (prosumers) with the main electrical and heating grids.

The following diagram shows the considered neighbourhood, where the public buildings are connected to the district heating network.

Regarding electricity, it will be considered that all the buildings are connected to a private grid, where renewable energy is produced by PV (or other renewable sources) and a CHP generator, while electricity is consumed by the buildings with no load-shifting capabilities.

What the EEPOS system is going to control in this case is the CHP operation, the boiler operation, and the thermal energy supplied to each building. The EEPOS system will aim to maximize the utilisation of local DER (PV and CHP in this case), while fulfilling the heating set-points of each building. It has been considered that the buildings heating set-points are not fixed and there is a range of indoor temperatures allowed. This thermal flexibility allows a thermal load-shifting by using the buildings' thermal mass to store energy.

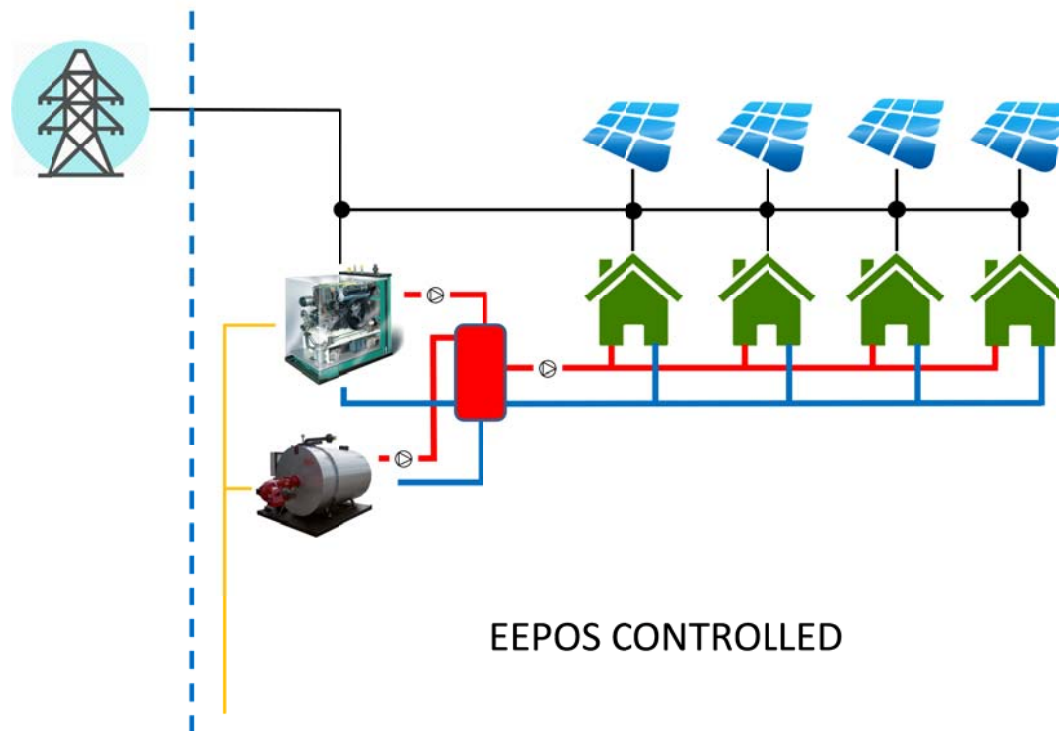


Figure 11. Neighbourhood and EEPOS concept applied

As the target buildings are public buildings belonging to the Municipality of Aspárrena, the idea of a private electrical grid for all of them could be feasible. The same happens for the heating grid. However, laws and regulation will be left out of this theoretical deliverable, to focus on the technical capabilities of an intelligent neighbourhood energy management like EEPOS.

5. BUILDINGS ENERGY DEMAND

This section analyses the thermal energy demanded by the particular buildings included in the target district.

5.1 Thermal energy data

The following graph shows the daily average temperatures recorded in a meteorological station close to Araia, in 2013.

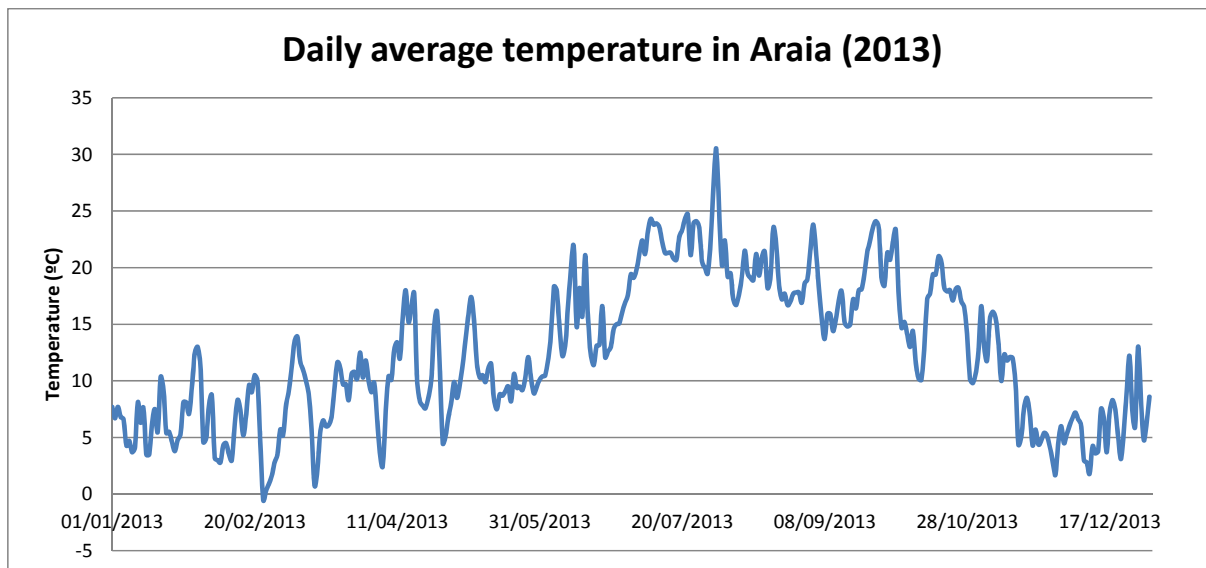


Figure 12. Daily average temperature in Araia (2013)

These recorded daily average temperatures are going to be used to calculate the Heating Degree Days of Araia in 2013.

Heating degree days are a measure of how much (in degrees), and for how long (in days), the outside air temperature was below a certain level. They are commonly used in calculations relating to the energy consumption required to heat buildings.

An example calculation: if the outside temperature was 2 degrees below the base temperature for 2 days, there would be a total of 4 heating degree days over that period (2 degrees * 2 days = 4 degree days)

Heating degree days are defined for a period of time, and they are determined by adding the temperature difference between a base temperature value "a" and the daily average temperature, when this last one is below other temperature value called "b".

$$HDD_{a/b} = \sum_{i=1}^n (a - T_{daily\ average,i}) * X_c$$

- "a" is the base temperature

- "b" is the base temperature for the daily average external temperature. If the daily average temperature is higher than "b", then the building does not need heating.

- "X_c" is a coefficient that is equal to 1 when Tdaily_average is lower than b, and it is equal to 0 if Tdaily_average is higher than b.

In this study, the values considered for "a" and "b" are 15°C, therefore the Heating Degree Days shown will be named HDD(15/15).

PERIOD	HDD(15/15)
Jan	257
Feb	272
Mar	192
Apr	150
May	142
Jun	36
Jul	0
Aug	0
Sep	2
Oct	34
Nov	190
Dec	273
TOTAL 2013	1548

Table 1. Heating Degree Days (15/15) of Araia in 2013

In the following sections, the HDD is plotted versus the kWh obtained from the bills, for each building. For a heated building, it is assumed that the energy consumption for any particular period is proportional to (or driven by) the number of degree days over that period. This is acceptable because for the school, culture house and outpatient clinic, natural gas is only used for heating purposes and not for domestic hot water generation. For the social housing, unlike the others, domestic hot water is also produced by natural gas. However, due to the small amount of energy dedicated to domestic hot water globally, the same assumption will be applied to the social housing, for the sake of simplicity.

5.1.1 Public school (plus nursery school)

The kWh of natural gas that have been consumed in 2013 are going to be plotted versus the HDD (15/15) that have been calculated per each specific period. The different number of school days per period is a factor that affects the relationship between these variables, however this will be taken into account later on, when developing the thermal model.

Billing period		kWh gas	HDD (15/15)
From	to	(from bill)	(w. station)
21/12/2012	29/01/2013	38538	323
30/01/2013	25/02/2013	30392	240
26/02/2013	25/03/2013	34787	205
26/03/2013	26/04/2013	19100	138
27/04/2013	29/05/2013	21393	167
30/05/2013	26/06/2013	8010	47
27/06/2013	29/07/2013	683	0
30/07/2013	28/08/2013	0	0
29/08/2013	25/09/2013	3072	2
26/09/2013	29/10/2013	9009	25
30/10/2013	27/11/2013	32380	166
28/11/2013	26/12/2013	42674	272
27/12/2013	30/01/2014	43553	236

Table 2. Public school thermal energy consumption (gas) and HDD(15/15) per period

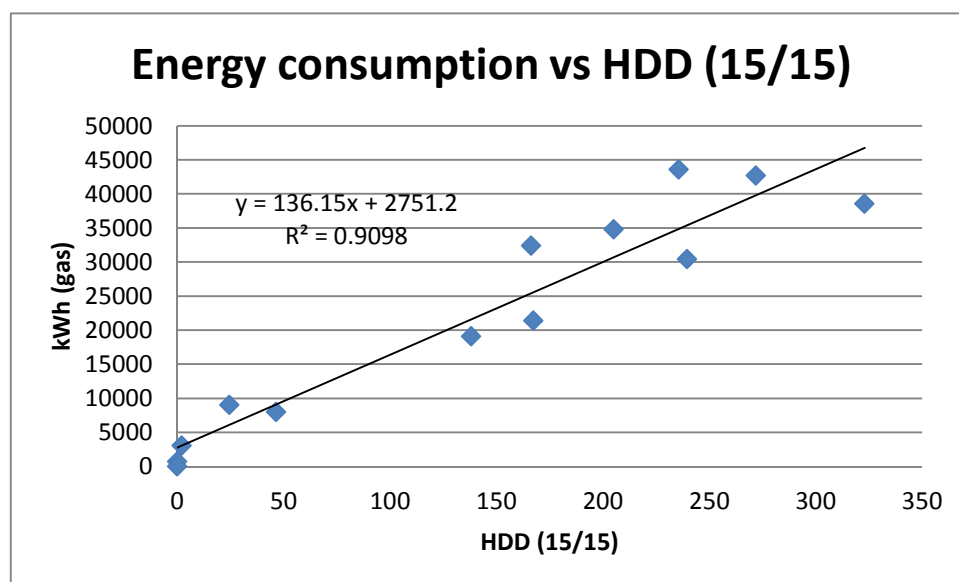


Figure 13. Thermal energy consumption vs HDD (15/15) for the public school

5.1.2 Culture house

In an analogous way, the kWh of natural gas that have been consumed in 2013 are going to be plotted versus the HDD (15/15) that have been calculated per each specific period. The different number of labour days per period is a factor that affects the relationship between these variables, however this will be taken into account later on, when developing the thermal model.

Billing period		kWh gas	HDD (15/15)
From	to	(from bill)	(w. station)
22/12/2012	29/01/2013	36288	319
30/01/2013	25/02/2013	26792	240
26/02/2013	25/03/2013	24838	205
26/03/2013	26/04/2013	16692	138
27/04/2013	29/05/2013	17611	167
30/05/2013	26/06/2013	4567	47
27/06/2013	29/07/2013	96	0
30/07/2013	28/08/2013	0	0
29/08/2013	25/09/2013	901	2
26/09/2013	29/10/2013	3448	25
30/10/2013	27/11/2013	15523	166
28/11/2013	21/12/2013	16720	237
22/12/2013	30/01/2014	23022	271

Table 3. Culture house thermal energy consumption (gas) and HDD(15/15) per period

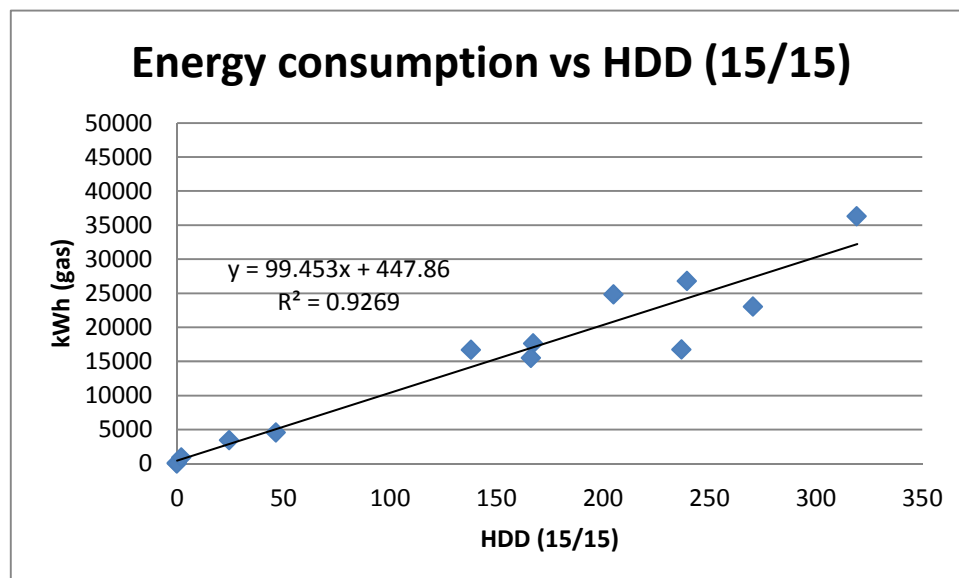


Figure 14. Thermal energy consumption vs HDD (15/15) for the culture house

5.1.3 Outpatient clinic

The outpatient clinic is smaller (less gross floor area) than the previous buildings, therefore the gas consumption is lower too. In the same way, the kWh of natural gas that have been consumed in 2013 are going to be plotted versus the HDD (15/15) that have been calculated per each specific period.

Billing period		kWh gas	HDD (15/15)
From	to	(from bill)	(w. station)
16/04/2013	11/06/2013	3871	238
12/06/2013	12/08/2013	463	18
13/08/2013	08/10/2013	436	5
10/10/2013	11/12/2013	6189	331
12/12/2013	14/02/2014	8673	474.8

Table 4. Outpatient clinic thermal energy consumption (gas) and HDD(15/15) per period

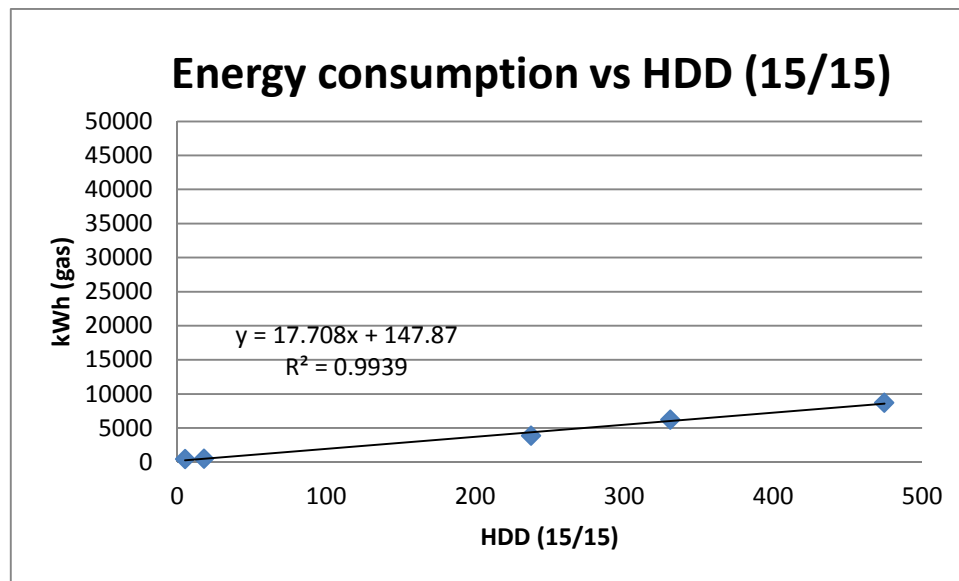


Figure 15. Thermal energy consumption vs HDD (15/15) for the outpatient clinic

5.1.4 Social housing

In Araia, social housing is let at low rents on a secure basis to those who are most in need or struggling with their housing costs. Therefore natural gas in those flats is also paid by the city council. The kWh of natural gas that have been consumed in 2013 are going to be plotted versus the HDD (15/15) that have been calculated per each specific period.

Billing period		kWh gas	HDD (15/15)
From	to	(from bill)	(w. station)
12/06/2013	12/08/2013	850	18
13/08/2013	09/10/2013	976	5
10/10/2013	11/12/2013	13401	331
12/12/2013	14/02/2014	19174	475

Table 5. Social housing thermal energy consumption (gas) and HDD(15/15) per period

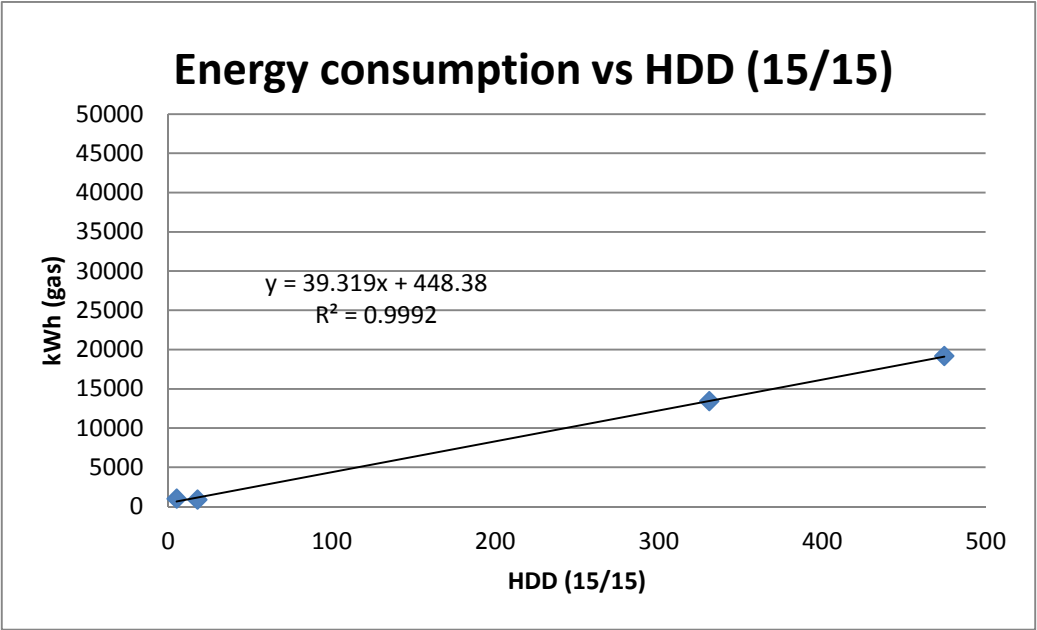


Figure 16. Thermal energy consumption vs HDD (15/15) for the social housing

5.2 Electric energy data

In the following subsections the electric energy consumption of every building is going to be analysed.

5.2.1 Public school (plus nursery school)

The approximate gross floor area of the public school (including nursery school) altogether is 2168 m². According to the bill, the maximum electric power is limited to 24 kW for this building.

Billing period		kWh electricity (from bill)	# non school days	# school days	Estimated kWh/non school day	Estimated kWh/school day
From	to					
11/01/2013	14/02/2013	4302	9	25	40	158
14/02/2013	12/03/2013	3431	5	21	40	154
12/03/2013	12/04/2013	2968	16	15	40	155
12/04/2013	14/05/2013	3533	11	21	40	147
14/05/2013	12/06/2013	3378	10	19	40	157
12/06/2013	11/07/2013	2182	21	8	40	167
11/07/2013	14/08/2013	1364	34	0	40	NO
14/08/2013	12/09/2013	1632	29	0	40	NO
12/09/2013	10/10/2013	3181	11	17	40	161
10/10/2013	12/11/2013	4099	11	22	40	166
12/11/2013	13/12/2013	4256	10	21	40	184
13/12/2013	14/01/2014	3039	23	9	40	235

Table 6. Public school electric energy consumption

The billing period corresponding to the summer holidays has been used to estimate the electric energy consumption associated to a non-school day. It is approximate 40 kWh.

Taking into consideration the approximate distribution of school and non-school days during a billing period, a rough estimation of the typical consumption of electricity during a school day has been done for every billing period.

According to the data, the electricity consumption does not change much through the year for a typical school-day. The average daily consumption is about 170 kWh.

Two daily schedules will be used to take into account the electric consumption through the year. Each schedule is composed by two sub-schedules that take into account the main electricity consumers: lighting and plug loads.

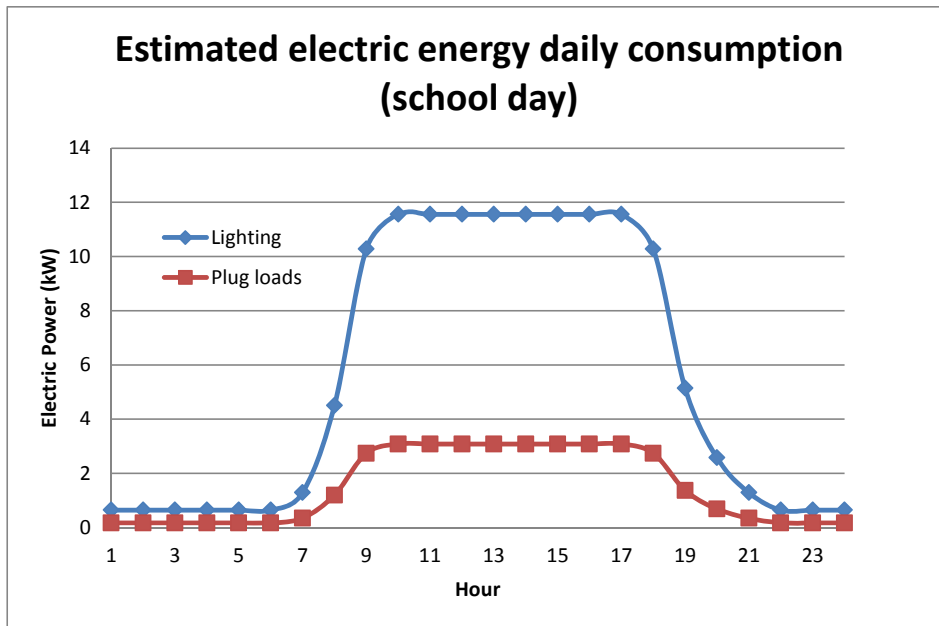


Figure 17. Estimated electric energy consumption for the public school on a school day

The integration of the previous graph gives rise to an electric energy consumption that is about 170 kWh. The maximum peak power (around 16 kW) is compatible with the maximum power limit allowed by the bill, 24 kW.

It has been considered that the non-school day’s consumption schedule is as follows.

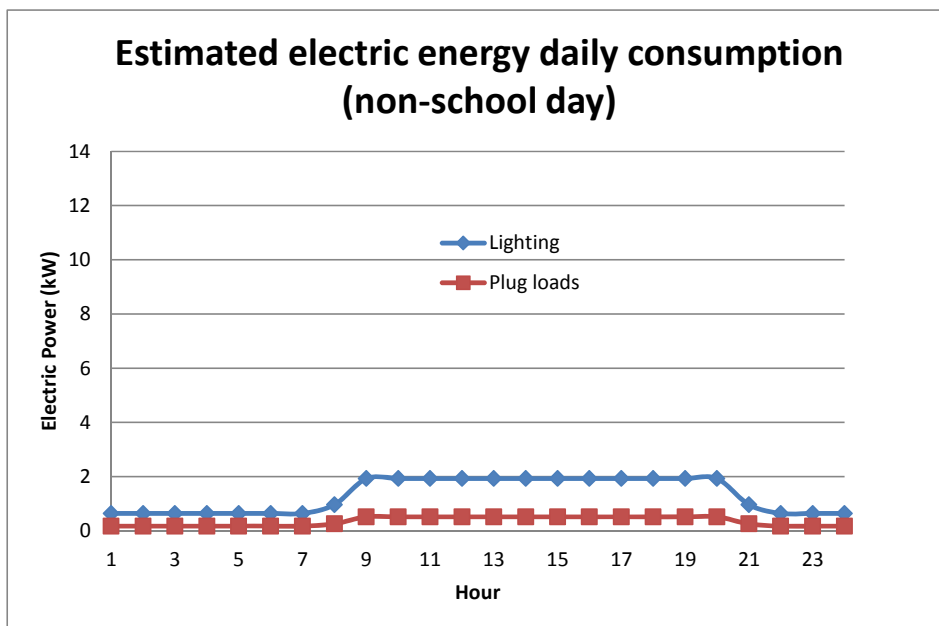


Figure 18. Estimated electric energy consumption for the public school on a non-school day

The integration of the previous graph gives rise to an electric energy consumption that is about 40 kWh.

5.2.2 Culture house

The approximate gross floor area of the culture house is 1247 m². According to the bill, the maximum electric power is limited to 13 kW for this building.

Billing period		kWh electricity	# high occupancy days	# medium occupancy days	Estimated kWh/high occup. day	Estimated kWh/medium occup. day
From	to	(from bill)				
14/12/2012	11/01/2013	950	7	21	61	25
11/01/2013	14/02/2013	1384	17	17	56	25
14/02/2013	12/03/2013	988	13	13	51	25
12/03/2013	12/04/2013	1126	15	16	48	25
12/04/2013	14/05/2013	1227	16	16	52	25
14/05/2013	12/06/2013	1303	15	14	64	25
12/06/2013	11/07/2013	873	0	29	NO	25
11/07/2013	14/08/2013	849	0	34	NO	25
14/08/2013	12/09/2013	598	0	29	NO	25
12/09/2013	10/10/2013	1001	14	14	47	25
10/10/2013	12/11/2013	1431	16	17	63	25
12/11/2013	12/12/2013	1378	15	15	67	25

Table 7. Culture house electric energy consumption

The billing period corresponding to the centre of the summer season has been used to estimate the electric energy consumption associated to a medium occupancy day. It is approximate 25 kWh. It has been considered that this average daily consumption associated to that occupancy level is constant during the year.

Taking into consideration the approximate distribution of high occupancy days and medium occupancy days during a billing period, a rough estimation of the typical consumption of electricity during a high occupancy day has been done for every billing period.

According to the data, the electricity consumption does not change much through the year for a typical high occupancy day. The average daily consumption is about 56 kWh.

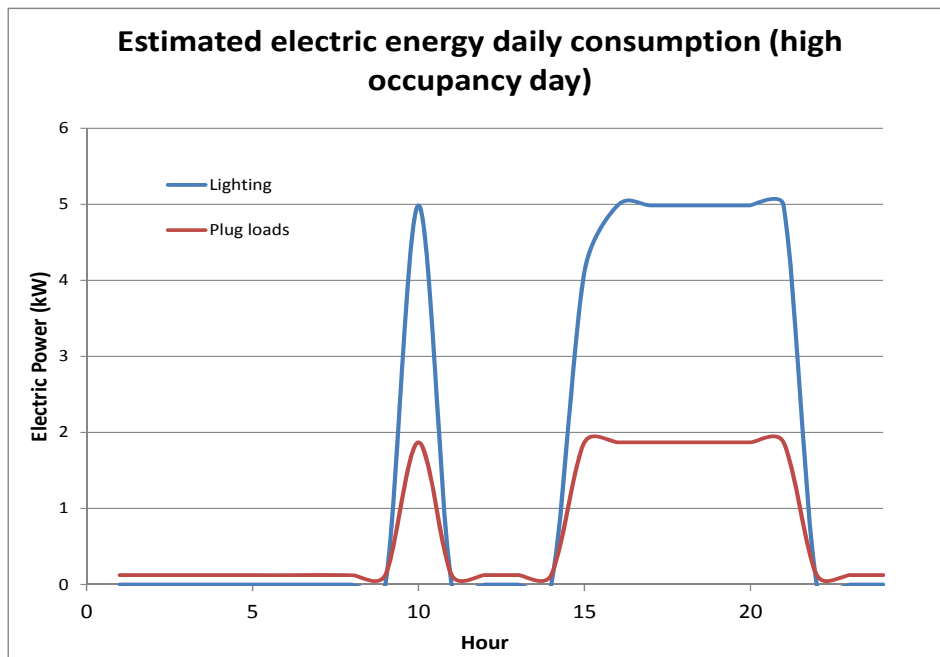


Figure 19. Estimated electric energy consumption for the culture house on a high occupancy day

The integration of the previous graph gives rise to an electric energy consumption that is about 56 kWh. The maximum peak power (around 7 kW) is compatible with the maximum power limit allowed by the bill, 13 kW.

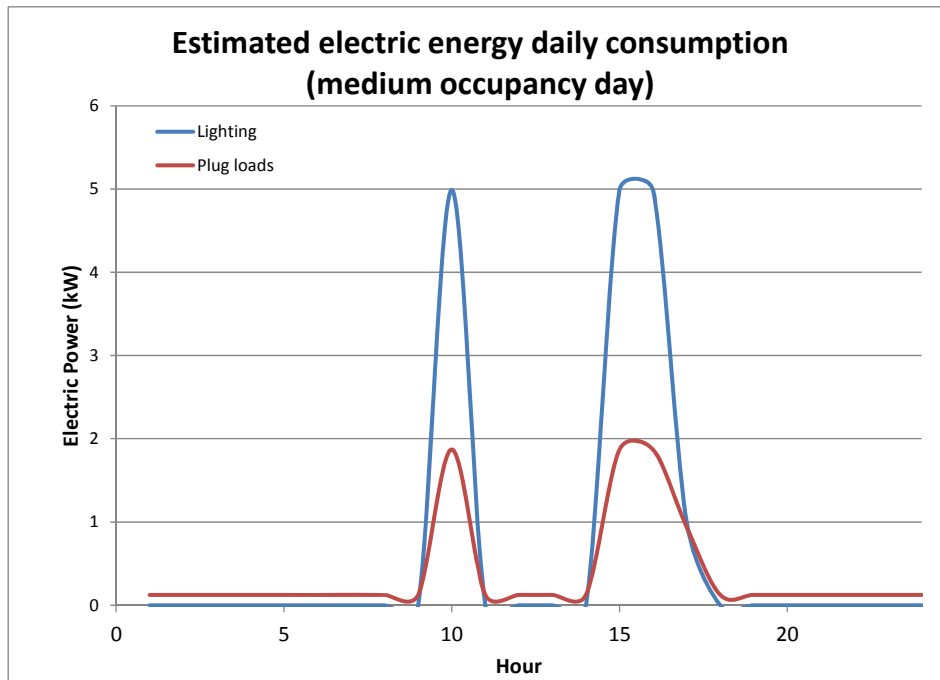


Figure 20. Estimated electric energy consumption for the culture house on a medium occupancy day

The integration of the previous graph gives rise to an electric energy consumption that is about 25 kWh.

5.2.3 Outpatient clinic

The approximate gross floor area of the outpatient clinic is 245 m². According to the bill, the maximum electric power is limited to 5.5 kW for this building.

The outpatient clinic is open from Monday to Friday, from 8:00 to 15:00. On holidays and weekends it is open just for 1 hour, from 12:30 to 13:30 (outpatient emergencies). Approximately, the electricity consumption should be proportional to the open hours. When assuming this assumption, the following daily consumption are obtained.

Billing period		kWh electricity (from bill)	# weekdays	# weekends and holidays	Estimated kWh/weekday	Estimated kWh/holiday
From	to					
08/11/2012	07/01/2013	1867	38	22	45	6
07/01/2013	07/03/2013	1911	42	17	43	6
07/03/2013	10/05/2013	1994	43	21	43	6
10/05/2013	09/07/2013	1684	42	18	38	5
09/07/2013	09/09/2013	1512	43	19	33	5
09/09/2013	07/11/2013	1689	41	18	39	6
07/11/2013	14/01/2014	2185	44	24	46	7

Table 8. Outpatient clinic electric energy consumption

Consistent consumption values are obtained, except for the summer months. It seems probable that there are some additional summer holidays, or reduced opening time during the summer months. Therefore these months will be left out of the analysis.

Considering this, the average daily consumption for a working day is 43 kWh and 6 kWh per day for a weekend/holiday.

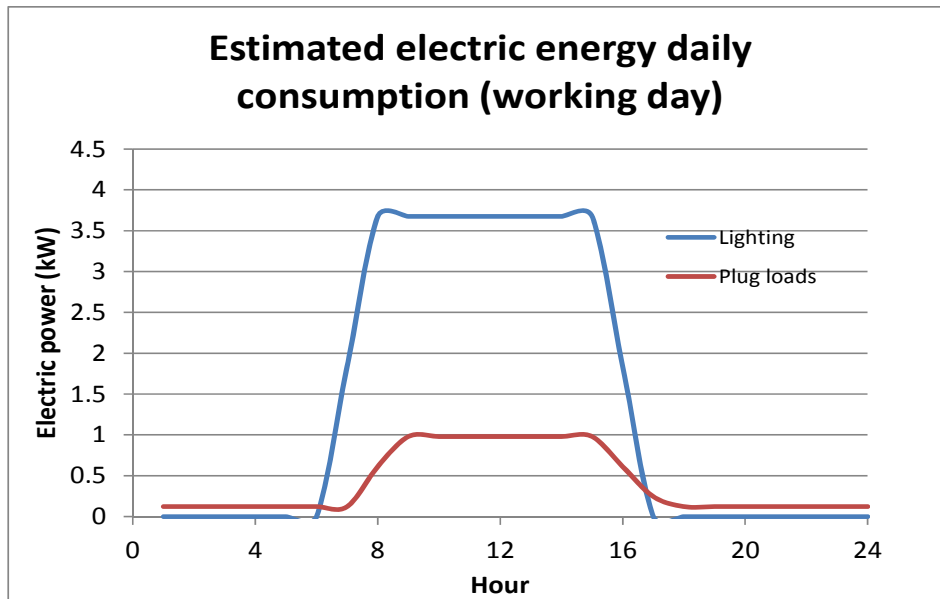


Figure 21. Estimated electric energy consumption for the outpatient clinic on a working day

The integration of the previous graph gives rise to an electric energy consumption that is about 43 kWh. The maximum peak power (around 4.7 kW) is compatible with the maximum power limit allowed by the bill, 5.5 kW.

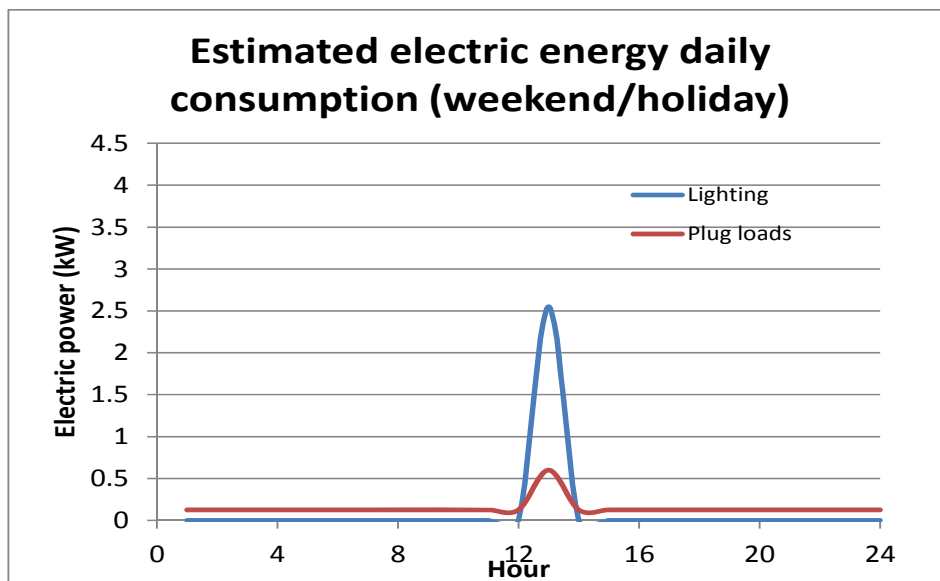


Figure 22. Estimated electric energy consumption for the outpatient clinic on a weekend/holiday (per day)

The integration of the previous graph gives rise to an electric energy consumption that is about 6 kWh.

5.2.4 Social housing

The approximate gross floor area of the social housing is 302 m². According to the bill, the maximum electric power is limited to 9.9 kW for this building.

Billing period		kWh electricity	Estimated kWh/day
From	to	(from bill)	
07/01/2013	07/03/2013	2349	40
07/03/2013	10/05/2013	2465	39
10/05/2013	09/07/2013	2156	36
09/07/2013	09/09/2013	1999	32
09/09/2013	07/11/2013	2084	35
07/11/2013	14/01/2014	2698	40

Table 9. Social housing electric energy consumption

The average consumption when the house is occupied, considering that weekdays consumption is similar to weekends and holidays, is 38 kWh per day. The summer months have been left out of the analysis as some of the apartments are empty during that period.

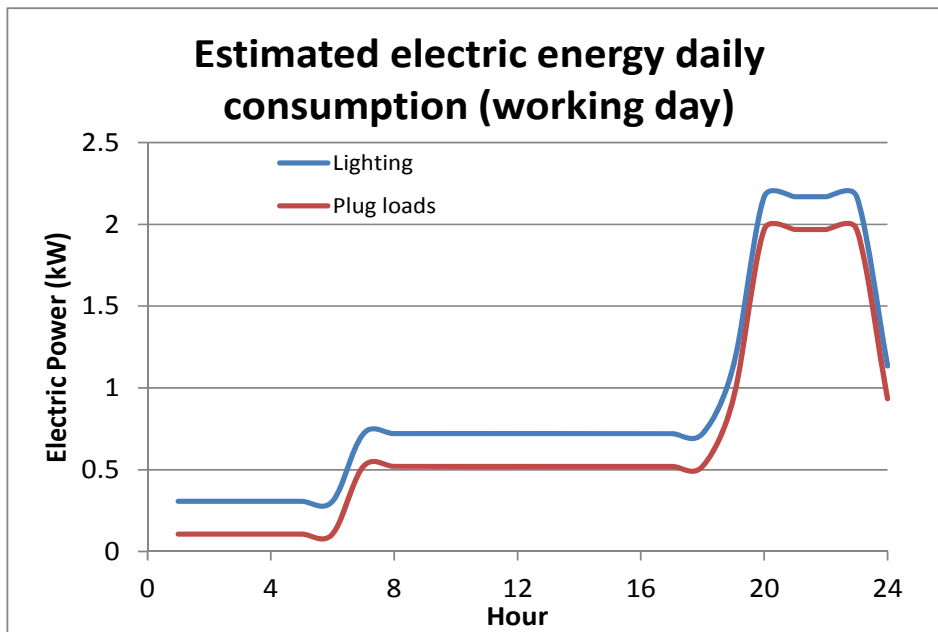


Figure 23. Estimated electric energy consumption for the social housing on a working day

The integration of the previous graph gives rise to an electric energy consumption that is about 38 kWh. The maximum peak power (around 4.2 kW) is compatible with the maximum power limit allowed by the bill, 9.9 kW.

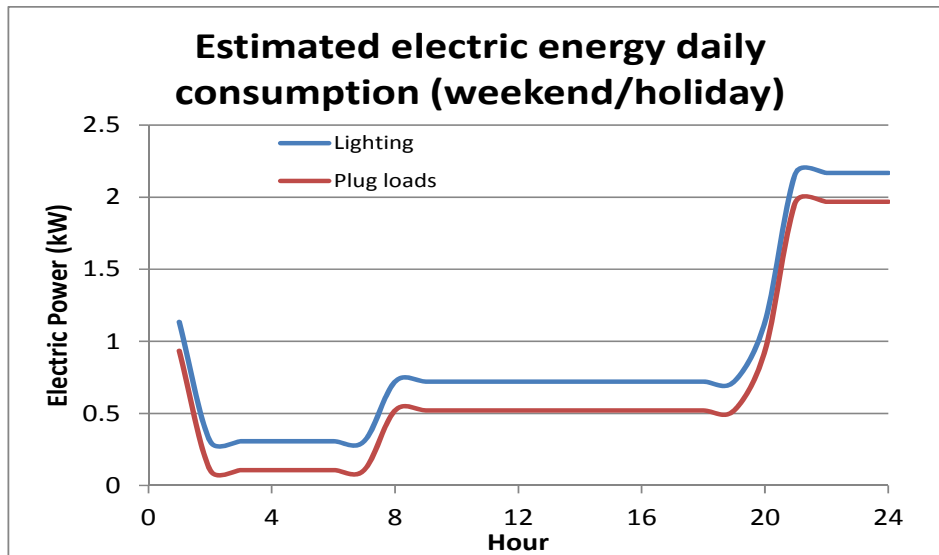


Figure 24. Estimated electric energy consumption for the social housing on a weekend/holiday (per day)

For the sake of simplicity, the same curve used for the weekdays has been used with a 1 hour delay for the weekend/holiday days. Therefore the integration of the graph also equals 38 kWh per day.

6. BUILDING AND DISTRICT MODELS

6.1 Introduction

The thermal building model explained in [1] is going to be used to model the municipal buildings described in previous sections. The equivalent RC circuit is shown in the following picture.

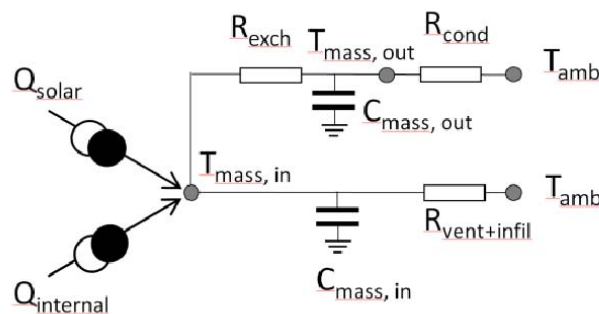


Figure 25. Simplified model of a building, consisting of two thermal masses connected by a heat resistance and thermal resistances to the ambient

For the sake of simplicity of the global thermal simulation, both R_{cond} resistance and C_{mass_out} capacitor are going to be neglected. Therefore, the building will be defined by the remaining three parameters: $R_{vent+infil}$, C_{mass_in} and R_{exch} .

T_{amb} is the ambient temperature, which is an input in the simulation. An hourly climatic weather file of Araia will provide that variable.

Q_{solar} is the amount of solar radiation entering the building; it is related to the solar radiation obtained from the weather file, but also to the amount and type of glazing and shading of the target building.

$Q_{internal}$ are the internal gains. People, lighting and loads are the main contributors to this input.

6.2 Building calibration

After including realistic internal heat gains (people, lighting and plug loads) and the windows area per façade, in order to take into account the solar heat gains, it was time to adjust the building parameters. The following parameters were finally chosen to accurately represent each building (see [1]).

	Rexch (K/W)	Rvent+infil (K/W)	Cmass_in (J/K)
Public school	0.000287	0.0009188	6.94E+08
Culture house	0.00045	0.00159	400E+06
Outpatient clinic	0.00205	0.00813	78.4E+06
Social housing	0.0013	0.00659	96.8E+06

Table 10. Building model parameters

By using these parameters, the annual heating demanded per building when running an annual simulation equals to the value obtained from the bills' correlation, that were previously shown.

6.3 District demand

In the following graph, the annual heating demanded by all the buildings composing the district is shown. The power values demanded per hour have been arranged in a monotonically decreasing curve. In order to get the values, it has been considered that the heating system works continuously.

The same procedure has been applied to the electricity demand, which is also plotted.

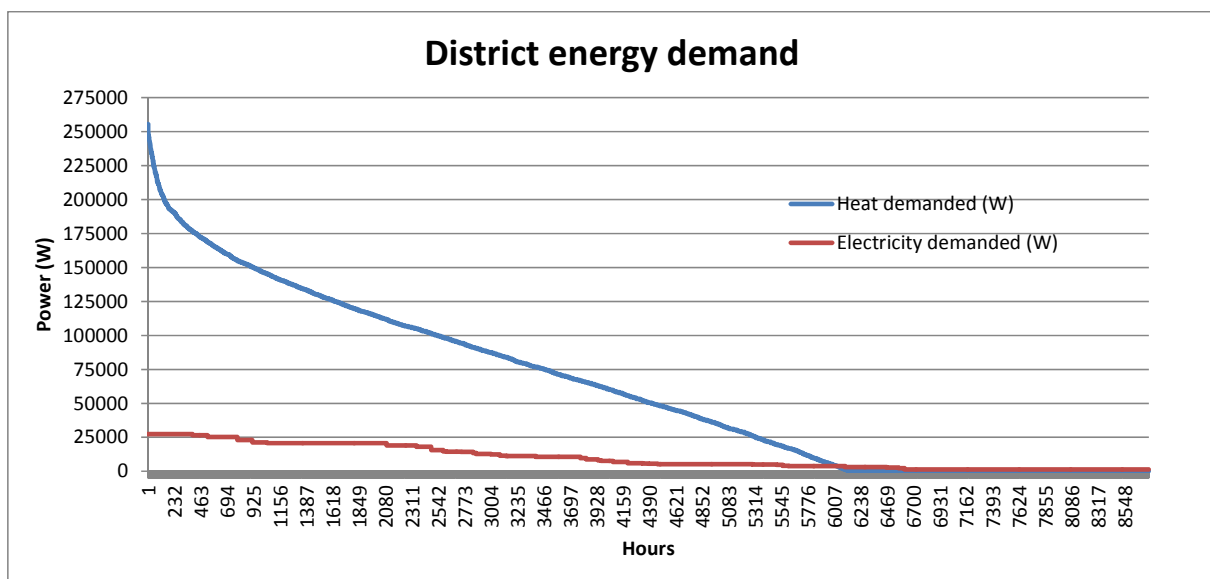


Figure 26. District energy demand

In the previous graph it can be observed that the heat demanded is much more important than the electricity needs, in terms of energy.

As one the EEPOS aims is to achieve the maximum utilisation of local DER in the neighbourhood, the CHP generator will be dimensioned to use all the released energy (thermal and electricity) within the district.

6.4 District generators

As previously seen, electricity demand is much lower than heat demand. Therefore, if the energy produced by a CHP is intended to be used locally, the electricity demand will be the limiting factor. By focusing on the electricity demand graph, and aiming for a CHP generator

that is able to work at least 3000 hours per year (for profitability reasons), it seems that an electrical output about 10 kW could be suitable for this district. The final number of annual working hours will depend on the capability of the EEPOS system to use or store the heat coming from the CHP, as it will be shown later on.

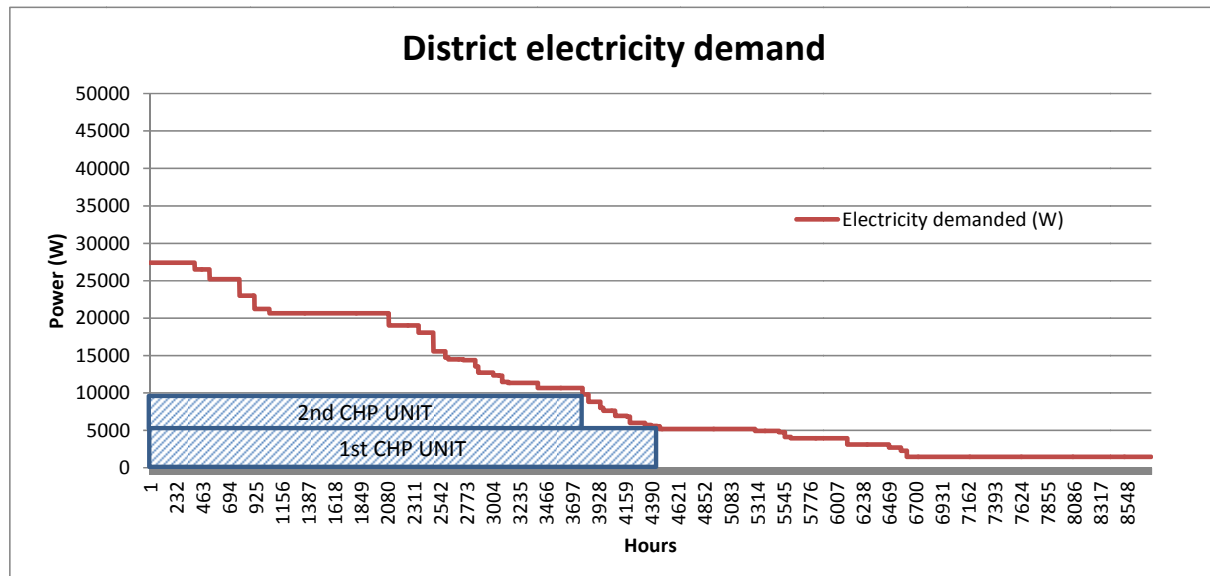


Figure 27. District electricity demand

Two CHP units as the one shown in Table 11 will be controlled by the EEPOS system, in order to maximize the utilisation of local DER.


	CHP Technical data	
	Fuel	Natural gas
	Electric power output (kW)	5.5
	Thermal power output (kW)	12.5
	Fuel consumption (kW)	20.5

Table 11. CHP technical data

Besides the CHP units, a conventional boiler is needed to provide the maximum thermal peak load demanded by the district. The thermal energy that can be supplied by the CHP will not be used to diminish the size of the boiler because in some occasions the EEPOS control can choose to operate only with the boiler.

The maximum district peak demand when operating in a continuous way is about 256 kW, according to the graphs. However this power can be too small to heat up the buildings after, for instance, a night/weekend disconnection. This is the reason why a bigger central boiler has to be chosen. As there are already boilers installed in each building, a reasonable criterion is

providing at each building the same thermal power as the existing boiler does. This leads to a 500 kW central boiler.

6.5 District heating network

The following piping network has been designed in order to provide enough power to each building. It has been considered that the supply temperature is 80°C and the return temperature is 60°C with a variable flow rate to modulate the thermal power provided.

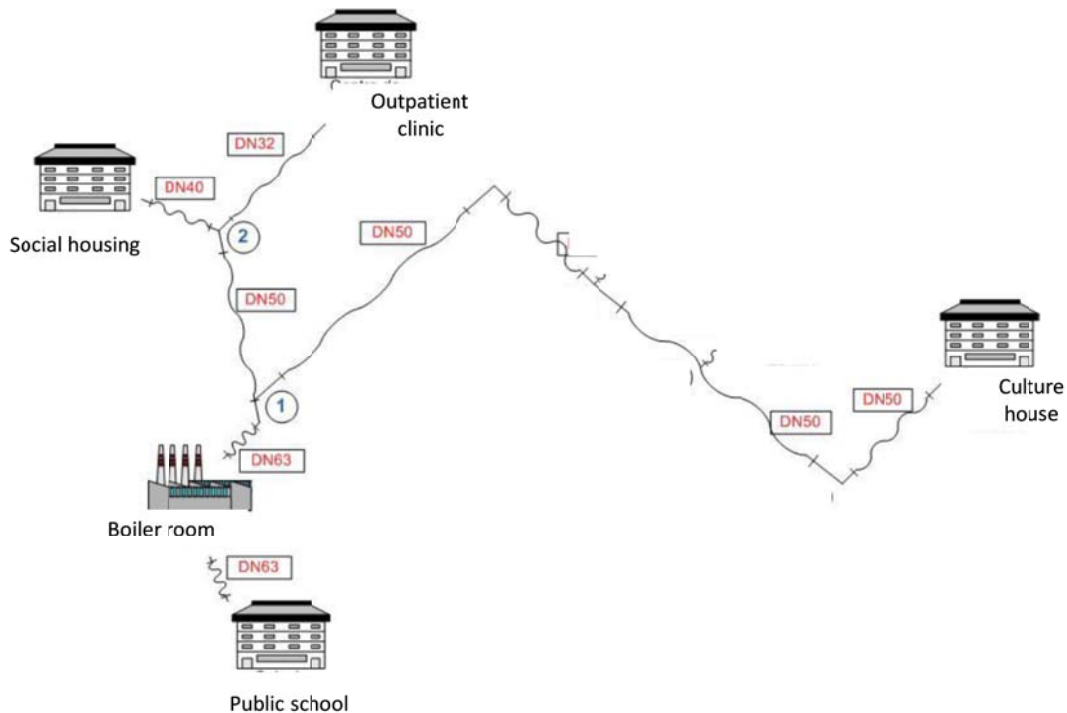


Figure 28. District heating network

The following table shows thermal power, design flow, length and nominal diameter associated to each pipe.

Pipe	Thermal power (kW)	Flow rate (m ³ /hour)	Length (m)	Nominal diameter (mm)
Boiler room - Node 1	237	10.2	5	63
Node 1- Node 2	135	5.8	8	50
Boiler room - School	251	10.8	27	63
Node 2 – Social housing	100	4.3	5	40
Node 2 – Outpatient clinic	35	1.5	5	32
Node 1 – Culture house	102	4.4	200	50

Table 12. Piping characteristics

Therefore, the maximum thermal power provided the network will be 488 kW.

In order to model the pipe heat loss, the following equations will be used:

$$\dot{Q} = \lambda * (T_{fluid} - T_{soil})$$

- Q = pipe heat loss per length (W/m)
- λ = heat transfer coefficient (W/mK)
- T_{fluid} = average fluid temperature (around 70°C)
- T_{soil} = undisturbed soil temperature (°C)

The following assumptions have been considered in order to calculate the heat transfer coefficient (λ):

- There are two pipes, supply and return, in a trench. The heat transfer coefficient will consider the heat loss from both pipes.
- Pipes distance = 0.1 m.
- Pipes depth = 0.6 m.
- Soil conductivity = λ_{soil} = 1.2 W/mK.
- PE-X foam conductivity = 0.043 W/mK.
- PE-Xa pipe conductivity = 0.38 W/mK.
- PEHD cover conductivity = 0.09 W/mK.

The resulting heat transfer coefficient (λ) per each pipe diameter is:

Diameter	λ (W/mK)
DN32	0.191
DN40	0.223
DN50	0.225
DN63	0.277

Table 13. Heat transfer coefficient per pipe diameter

By considering the respective pipe lengths and diameter, the resulting circuit heat loss equation is:

$$\dot{Q} = 57.7 * (70^{\circ}\text{C} - T_{soil})$$

In this equation, Q is the total heat loss of all the pipes, as all the lengths and diameters have been included in the calculation.

Although the heat loss from the pipes will be calculated at each time step in the simulation, an average value can be obtained by considering the average annual external temperature extracted from a standard weather file (11.2°C). Therefore the average heat loss from pipes is 3393 W.

In order to take into consideration the pumping energy, it is not enough to calculate the piping losses, even with the balancing valves. The reason is that heat exchangers and control valves create additional head losses that are sometimes bigger than the circuit head losses.

According to [2], the following pump consumption rates can be used, depending on the hydraulic quality of the district heating network.

	Low consumption	Medium consumption	High consumption
Pump consumption (kWh _e /MWh _t)	5	7	10

Table 14. Pump typical consumption rates

As the pumping circuit will have variable frequency drives to modulate the amount of flow provided (depending on the thermal needs), it will be considered that low pump consumption could be achieved. Therefore a rate of 5 kWh of electricity per 1 thermal MWh will be used to quantify the pumping energy associated to the piping network.

7. DISTRICT ENERGY CONSUMPTION ANALYSIS

In order to speed up the process of energy management for the target district, the simulations will be performed by using a time step of 1 hour, for a consecutive week. As the main difference between weeks is the heating demand and heating is mostly related to the external temperature, different weeks with different average temperatures will be simulated. Solving the energy management for different weeks during the year will be useful to understand how the EEPOS system evolves when the boundary conditions change.

A standard weather file from Araia has been analysed. This file has been composed by using weather data obtained from different years. It does not represent any year in particular, but it is representative of the weather conditions of Araia.

When plotting the average daily temperature for the whole year, the following graph is obtained.

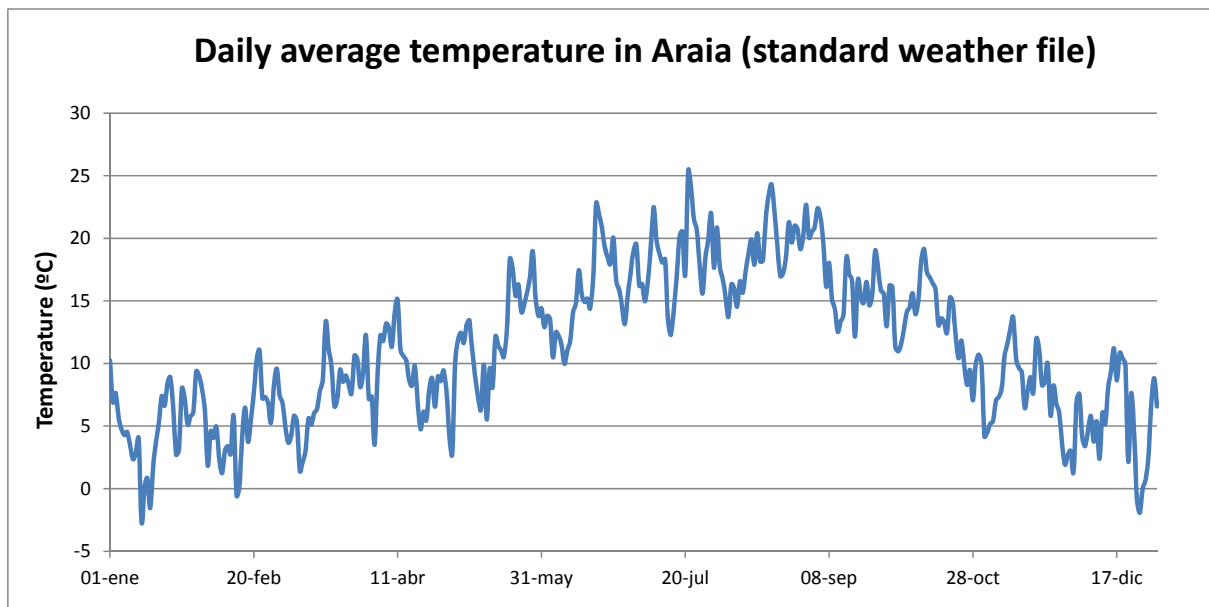


Figure 29. Daily average temperature in Araia (standard weather file)

By taking the same values and ordering the values, a monotonically decreasing curve is created. According to the experimental data regarding heating, when the average ambient temperature is around 15°C or higher there are no heating needs and the district heating should be off during this period (summer period). The remaining days with daily average temperatures lower than 15°C have been subdivided in two periods (same days per period): "mild weather" and "cold weather". The average daily temperature of the "mild weather" is 11.5°C while for the "cold weather" is 4.9 °C. This can be seen in the next graph.

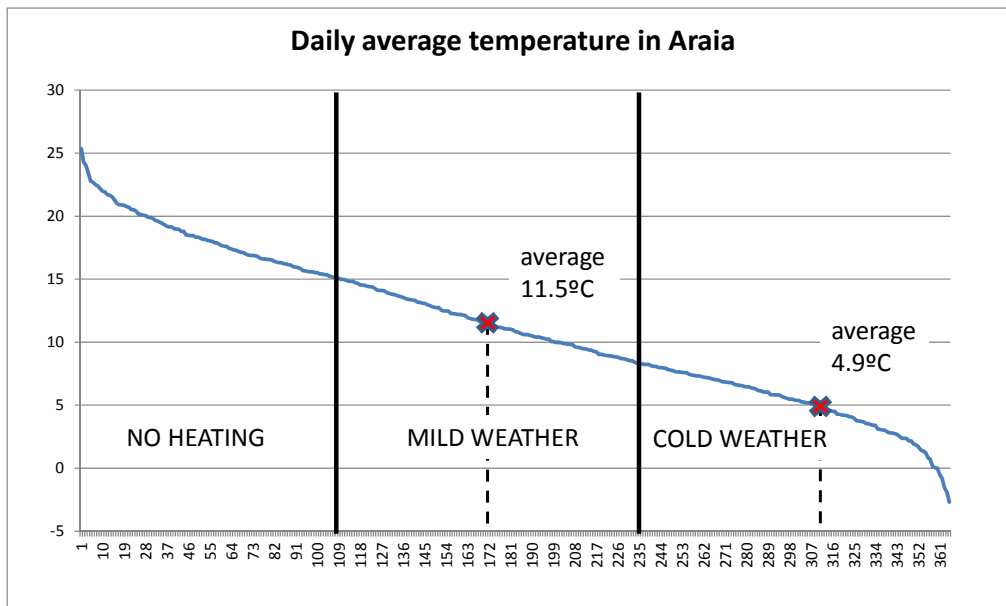


Figure 30. Monotonic decreasing curve of average daily temperature in Araia (standard weather file).

A week representing the "cold weather" should have an average temperature around 4.9°C. Having a look to the standard weather file, the week going from the 15th of January to the 21th of January has an average temperature of 4.5°C. This week will be used to simulate the "cold weather" conditions. In order to use realistic electricity prices, real Spanish electricity prices from 2013 will be used. As this particular week started on Tuesday in 2013, the electricity demands of Araia buildings will be adapted consequently.

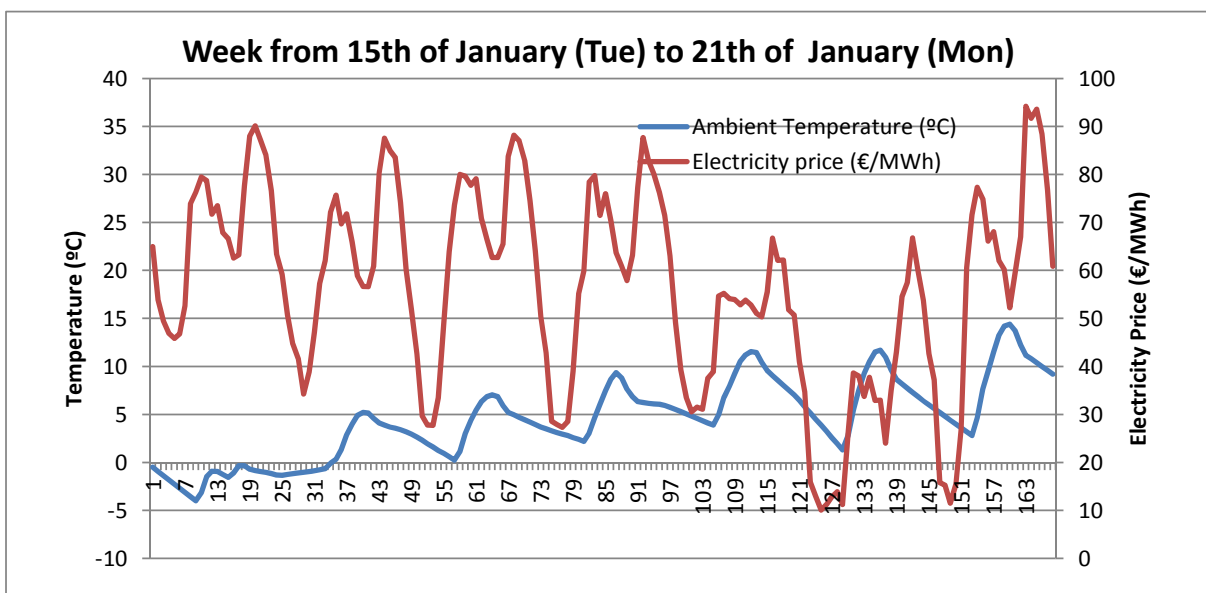


Figure 31. Ambient Temperature and Electricity Price for the "cold weather" week

A week representing the "mild weather" should have an average temperature around 11.5°C. Having a look to the standard weather file, the week going from the 4th of June to the 10th of June has an average temperature of 11.4°C. This week will be used to simulate the "mild

weather" conditions. In order to use realistic electricity prices, real Spanish electricity prices from 2013 will be used. As this particular week also started on Tuesday in 2013, the electricity demands of Araia will be adapted consequently.

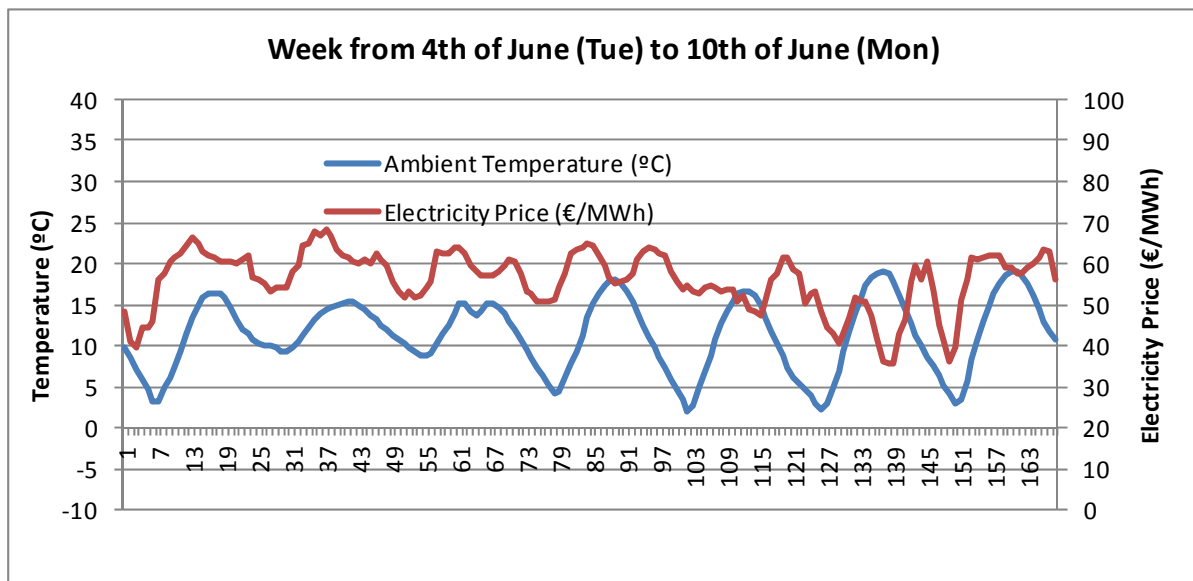


Figure 32. Ambient Temperature and Electricity Price for the "mild weather" week

7.1 Baseline

The baseline case considers that the buildings are connected to the main electric grid and each one of them has an individual gas natural boiler (efficiency = 85%), providing the heating required per building. Therefore, there is no district heating in the case.

7.1.1 Cold weather

The following graph represents the electrical energy demanded by the buildings for the "cold weather" week. As this is the baseline case, the same amount of energy (and peak power) will be extracted from the main grid.

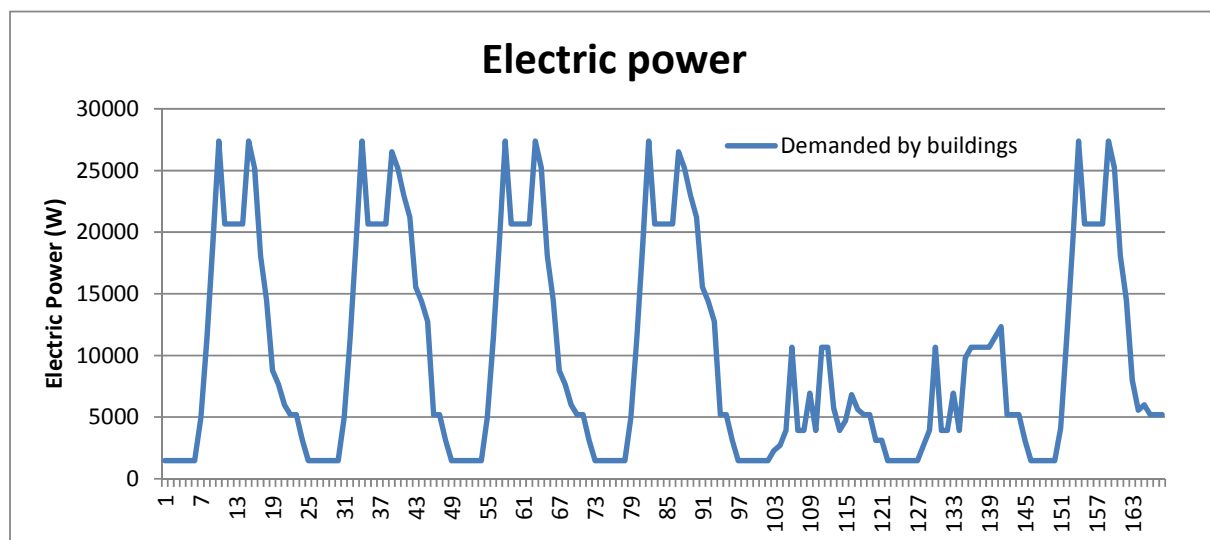


Figure 33. Electric power for the simulated week (cold weather – baseline)

The amount of thermal energy needed for all the buildings is plotted in the following graph.

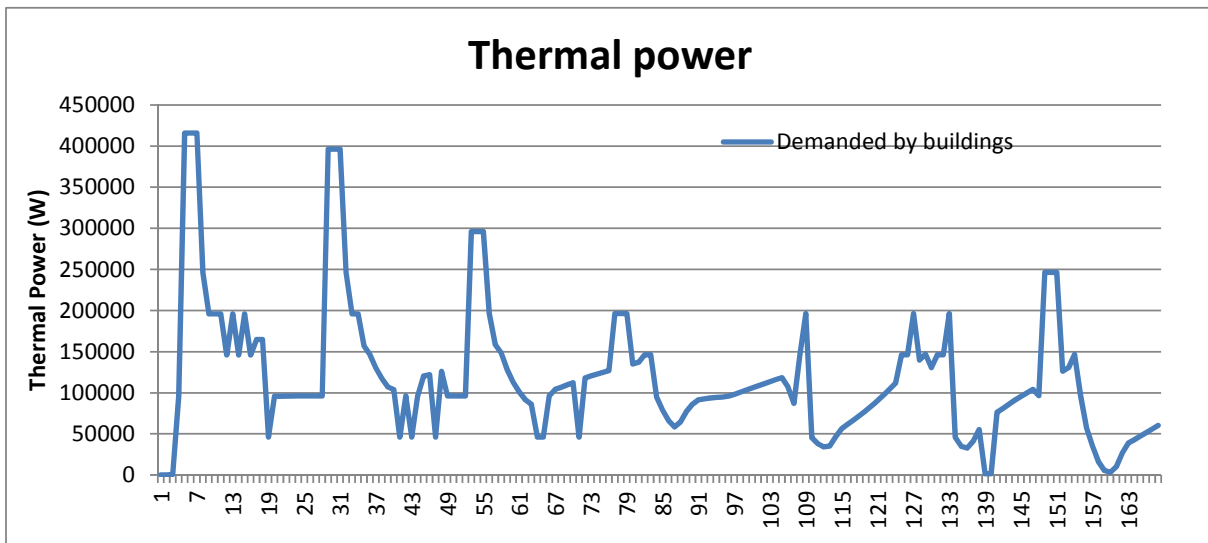


Figure 34. Thermal power for the simulated week (cold weather – baseline)

By providing this total thermal power, which is independently produced in each building by an individual boiler, the indoor temperature of each building fulfills the set-point requirements, as it is shown in the next graph.

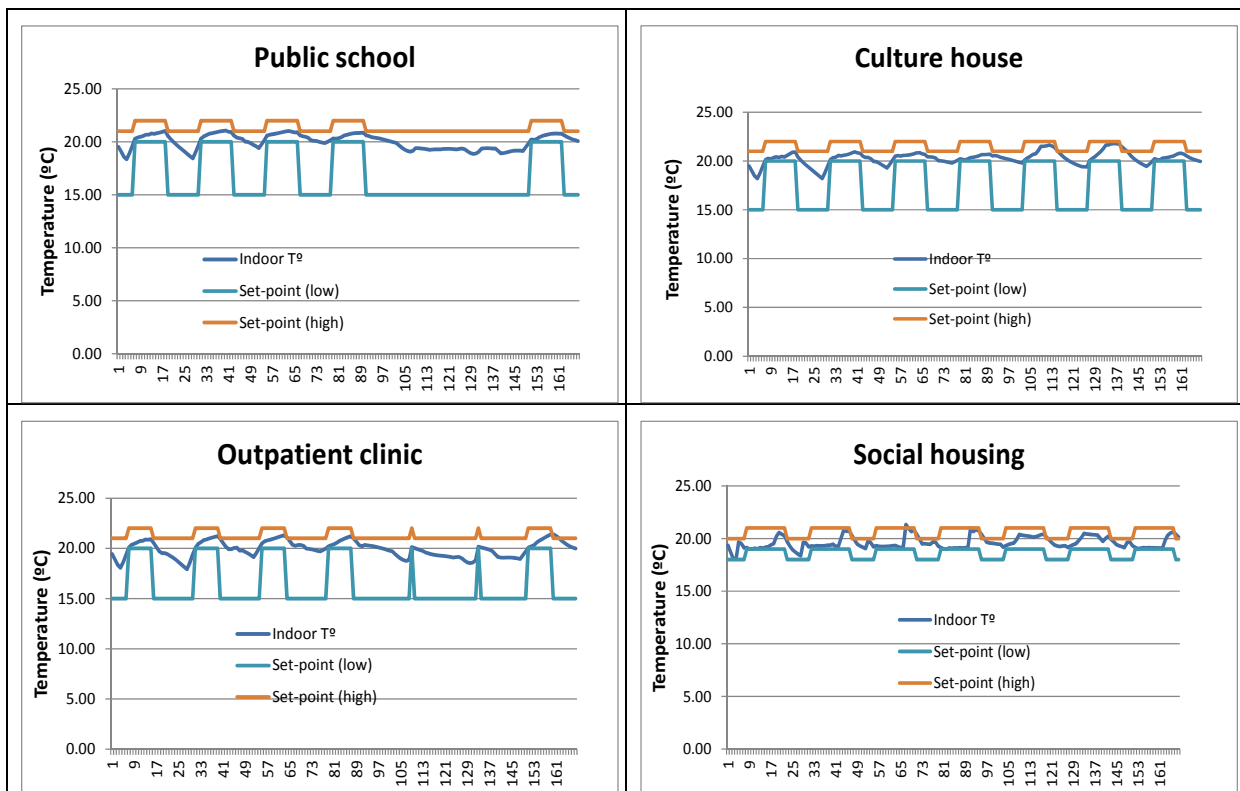


Figure 35. Indoor temperature and set-points for the simulated week (cold weather – baseline)

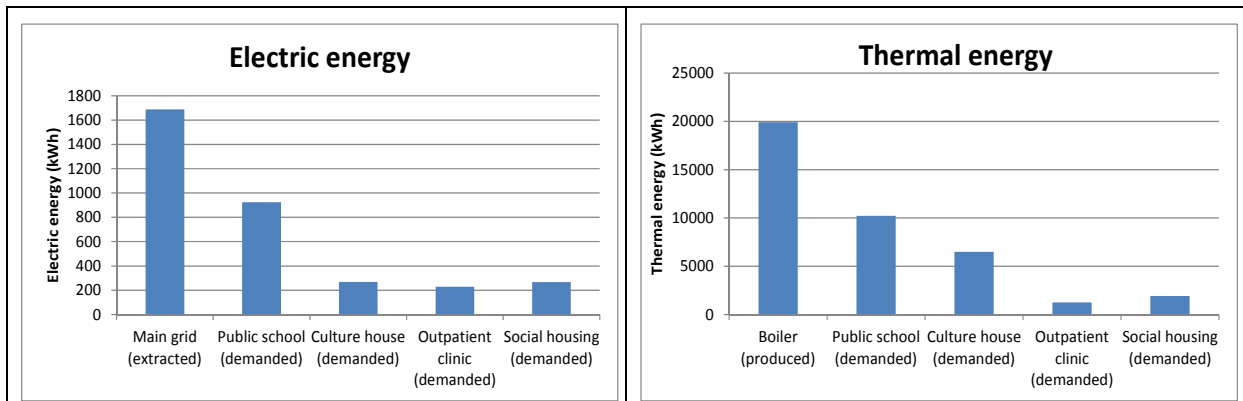


Figure 36. Energy needs for the simulated week (cold weather – baseline)

The electric energy extracted from the grid during that week is 1687 kWh. The amount of electricity supplied at each time has been multiplied for the specific electricity price per hour already shown and a grid access fee of 44.027 €/MWh has also been considered. The total cost of electricity for that week is 185 € (vat not included).

Regarding thermal needs, the total amount of thermal energy needed is 19920 kWh. By considering a seasonal efficiency of 85% for the boilers, the natural gas consumption is 23435 kWh. Assuming a realistic average cost of 0.06 €/kWh for natural gas, the weekly cost of the natural gas is 1406 € (vat not included).

The estimated total energy cost for that week is 1591 €.

7.1.2 Mild weather

The following graph represents the electrical energy demanded by the buildings for the "mild weather" week. As this is the baseline case, the same amount of energy (and peak power) will be extracted from the main grid.

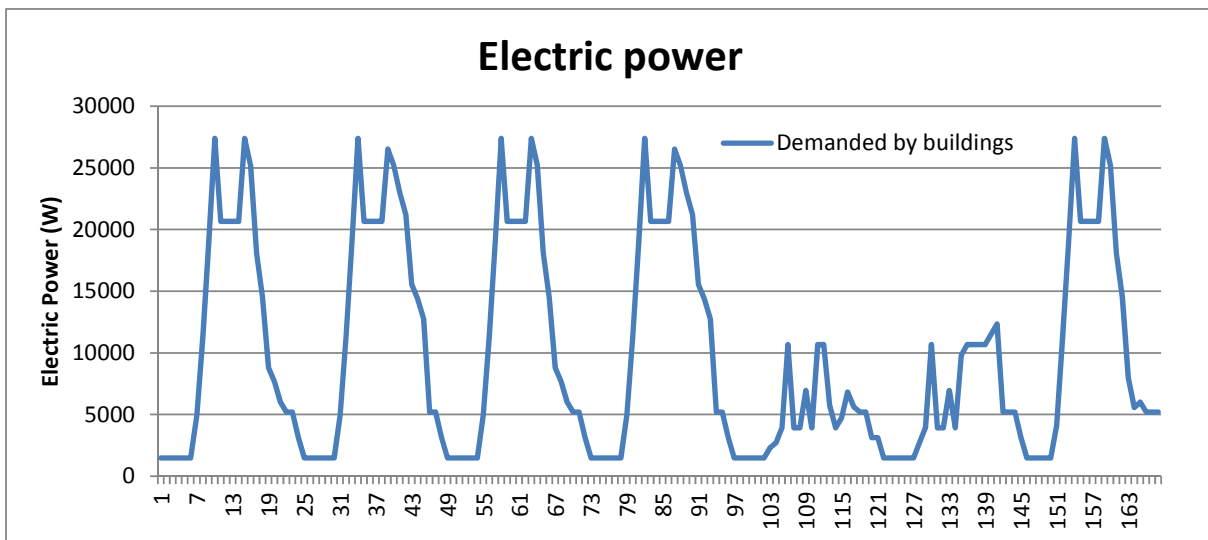


Figure 37. Electric power for the simulated week (mild weather – baseline)

The amount of thermal energy needed for all the buildings is plotted in the following graph.

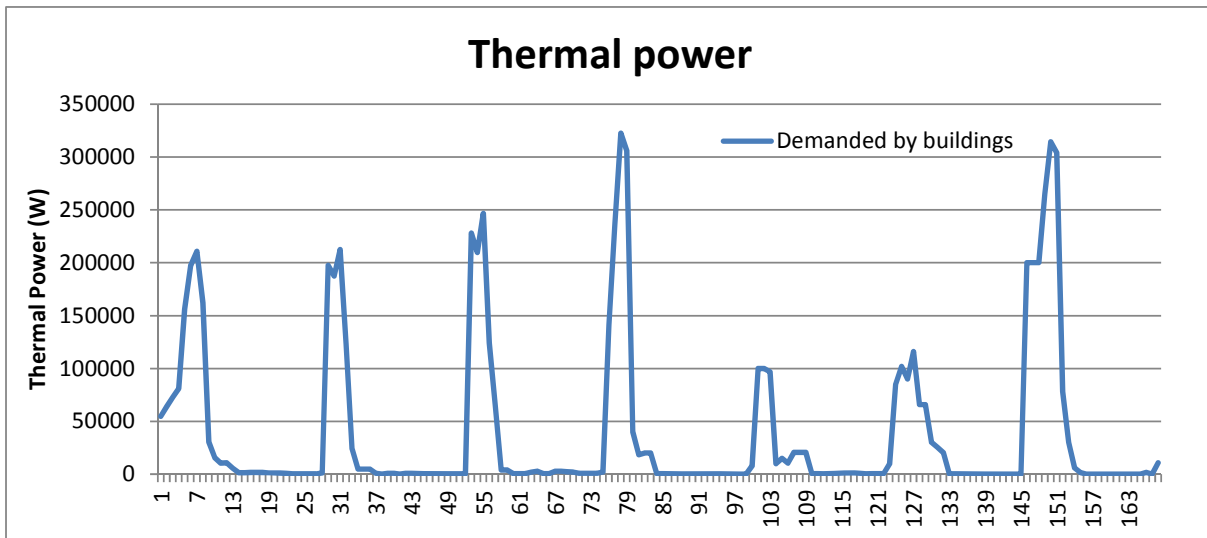


Figure 38. Thermal power for the simulated week (mild weather – baseline)

By providing this thermal power, the indoor temperature of each building fulfills the set-point requirements, as it is shown in the next graph.

It can also be observed in the graph that due to the mild conditions, indoor temperature raises during the day in some buildings. This is mostly due to internal heat gains and solar gains because once the buildings are heated-up in the morning, they do not usually require more heating during the day for a “mild weather” week.

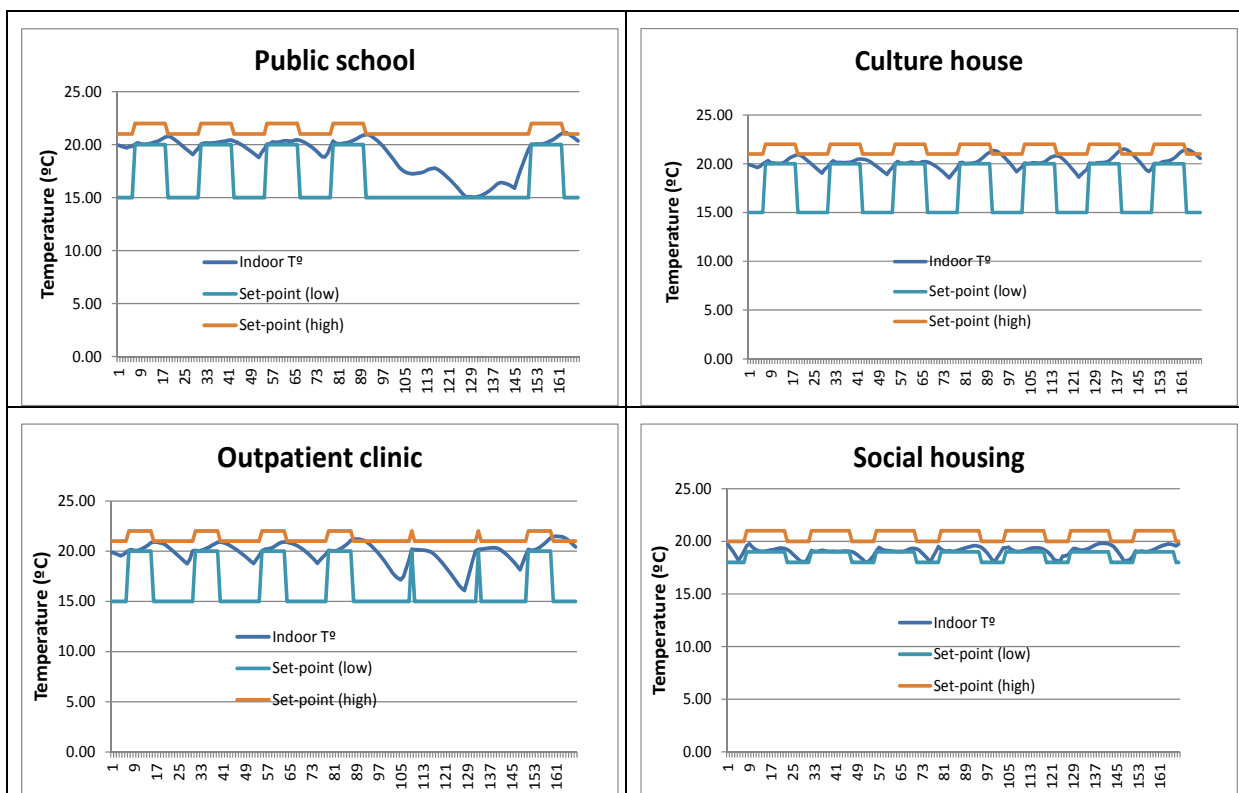


Figure 39. Indoor temperature and set-points for the simulated week (mild weather – baseline)

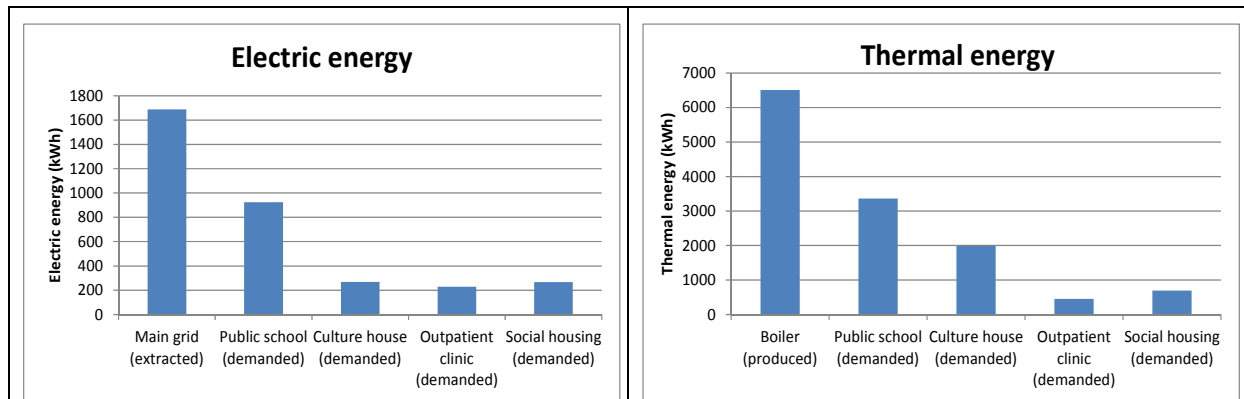


Figure 40. Energy needs for the simulated week (mild weather – baseline)

The electric energy extracted from the grid during that week is 1687 kWh. The amount of electricity supplied at each time has been multiplied for the specific electricity price per hour already shown and a grid access fee of 44.027 €/MWh has also been considered. The total cost of electricity for that week is 174 € (vat not included).

Regarding thermal needs, the total amount of thermal energy needed is 6508 kWh. By considering a seasonal efficiency of 85% for the boilers, the natural gas consumption is 7656 kWh. Assuming a realistic average cost of 0.06 €/kWh for natural gas, the weekly cost of the natural gas is 459 € (vat not included).

The estimated total energy cost for that week is 633 €.

7.2 District heating + CHP + EEPOS control

In this scenario, the public buildings are connected to the district heating network that has been explained in previous sections.

Regarding electricity, all the buildings are connected to a private grid, where energy is produced by a CHP generator and electricity is consumed by the buildings with no load-shifting capabilities. The additional electricity needed is taken from the main grid.

What the EEPOS system is going to control in this case is the CHP operation, the boiler operation, and the thermal energy supplied to each building. The EEPOS system will aim to maximize the utilisation of local DER (CHP in this case), while fulfilling the heating set-points of each building. It has been considered that the buildings heating set-points are not fixed and there is a range of indoor temperatures allowed. This thermal flexibility allows a thermal load-shifting by using the buildings' thermal mass to store energy.

In order to maximize the utilisation of local DER, the EEPOS system will activate the CHP if there is enough electricity demand and if the thermal energy provided can be used within the district. Therefore, the EEPOS system has to be able to forecast the indoor temperature inside the buildings by using simplified building models like the one presented in this deliverable. Once experimental measurements are available, the calibrated building model can be very accurate to forecast the indoor temperature at a specific time. This capability will allow the EEPOS system to determine if the buildings can be thermally "charged" or not, and how much energy can be introduced at every time.

From an economic point of view, and according to the CHP specifications, selfproduction of electricity by the selected CHP units is usually cheaper than buying electricity from the grid, due to the grid access fee (44.027 €/MWh). Only when electricity price is lower than about 30€/MWh it is preferable to buy electricity instead of producing it, but this price does not

usually happen at the times the CHP is operating. Therefore the peak shaving and the profitability requests are fulfilled by means of this strategy.

7.2.1 Cold weather

The following graph represents the electrical energy demanded by the buildings for the "cold weather" week. It can be seen how the power drawn from the main grid is reduced thanks to the operation of the CHP engines.

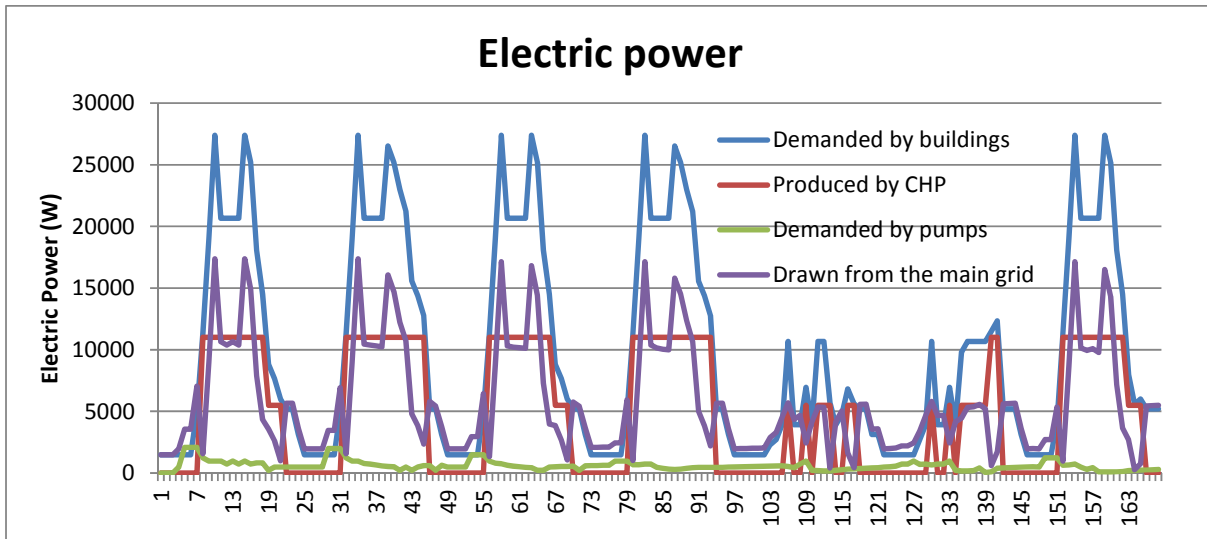


Figure 41. Electric power for the simulated week (cold weather – district heating+CHP+EEPOS control)

The thermal energy needed for all the district is shown in the next graph. The heat produced by CHP, boiler and thermal losses are also plotted.

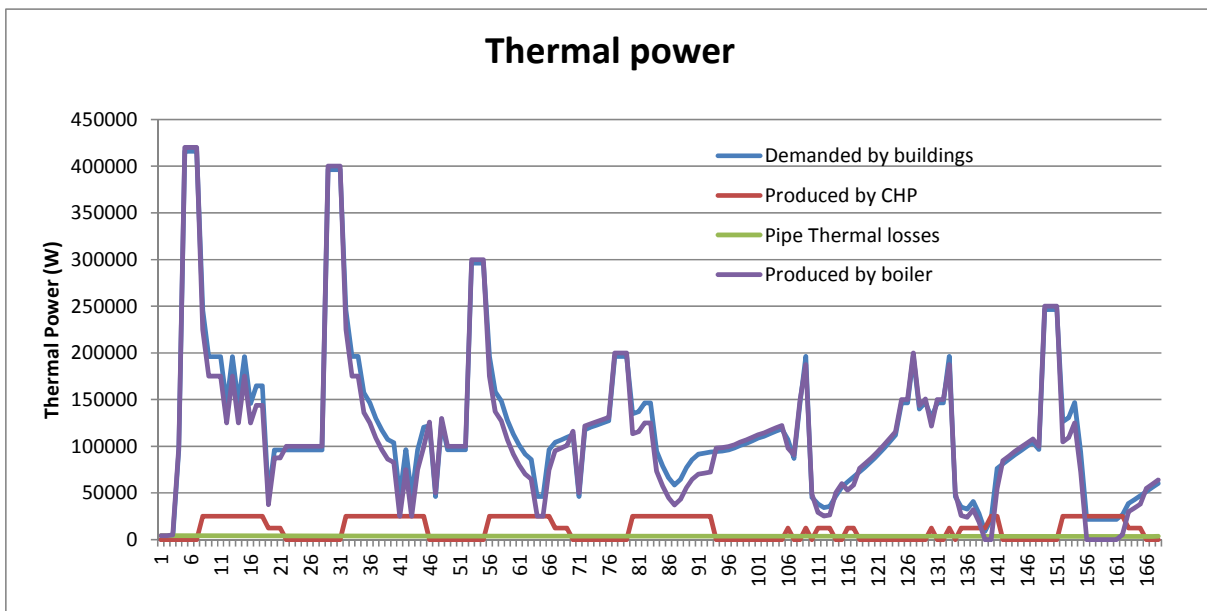


Figure 42. Thermal power for the simulated week (cold weather – district heating+CHP+EEPOS control)

By providing this thermal power, the indoor temperature of each building fulfills the set-point requirements, as it shown in the next graph.

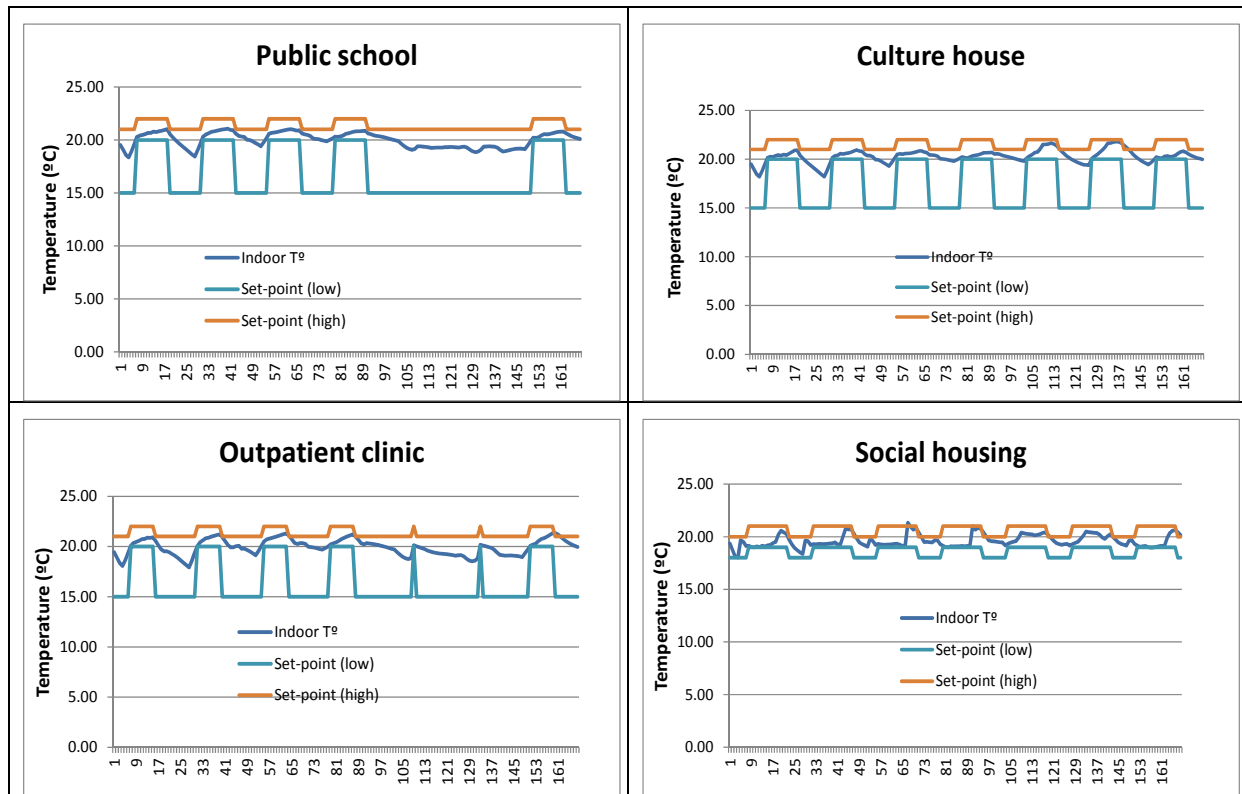


Figure 43. Indoor temperature and set-points for the simulated week (cold weather – district heating+CHP+EEPOS control)

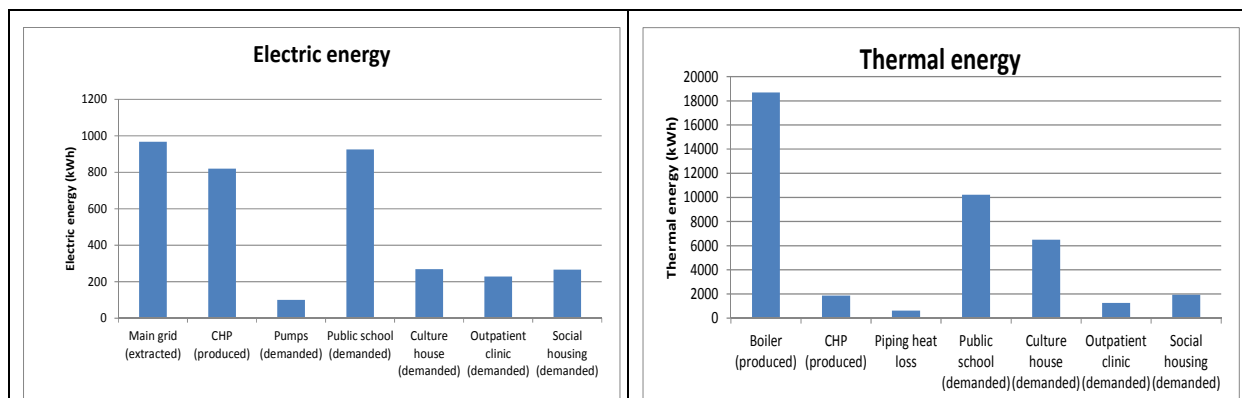


Figure 44. Energy needs for the simulated week (cold weather – district heating+CHP+EEPOS control)

The electric energy extracted from the grid during this week is 967 kWh. The amount of electricity supplied at each time has been multiplied for the specific electricity price per hour already shown and a grid access fee of 44.027 €/MWh has also been considered. The total cost of electricity for that week is 103 € (vat not included). The CHP has provided 820 kWh of electricity that has been used within the district. The total amount of electric energy used is able to satisfy the energy demanded by the buildings plus the energy consumed by the district heating pumps (about 100 kWh for this week).

Regarding thermal needs, the total amount of thermal energy needed is 20548 kWh. A central boiler supplies 18685 kWh while the CHP provides 1863 kWh. By considering a seasonal efficiency of 90% for the central boiler and the previously shown efficiencies for the CHP, the total amount of gas natural needed is 23816 kWh. Assuming a realistic average cost of 0.06 €/kWh for natural gas, the weekly cost of the natural gas is 1429 € (vat not included).

The estimated total energy cost for that week is 1532 €.

7.2.2 Mild weather

The following graph represents the electrical energy demanded by the buildings for the "mild weather" week. It can be seen how the power drawn from the main grid is reduced thanks to the operation of the CHP engines.

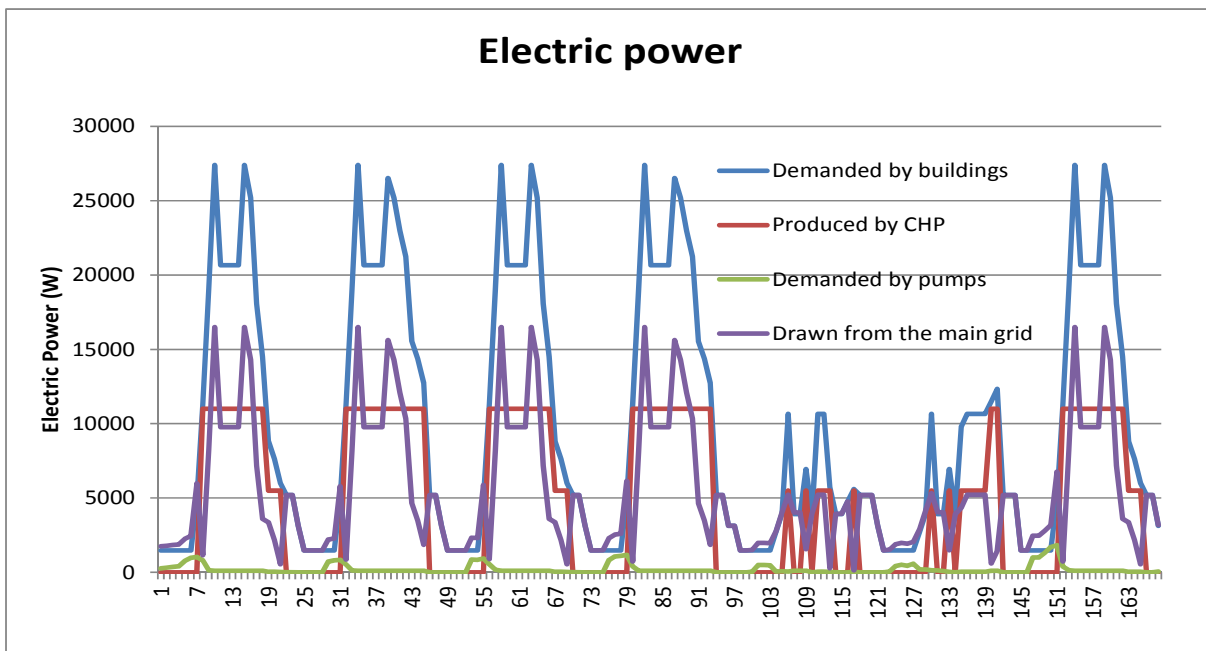


Figure 45. Electric power for the simulated week (mild weather – district heating+CHP+EEPOS control)

The thermal energy needed for all the district is shown in the next graph. The heat produced by CHP, boiler and thermal losses are also plotted.

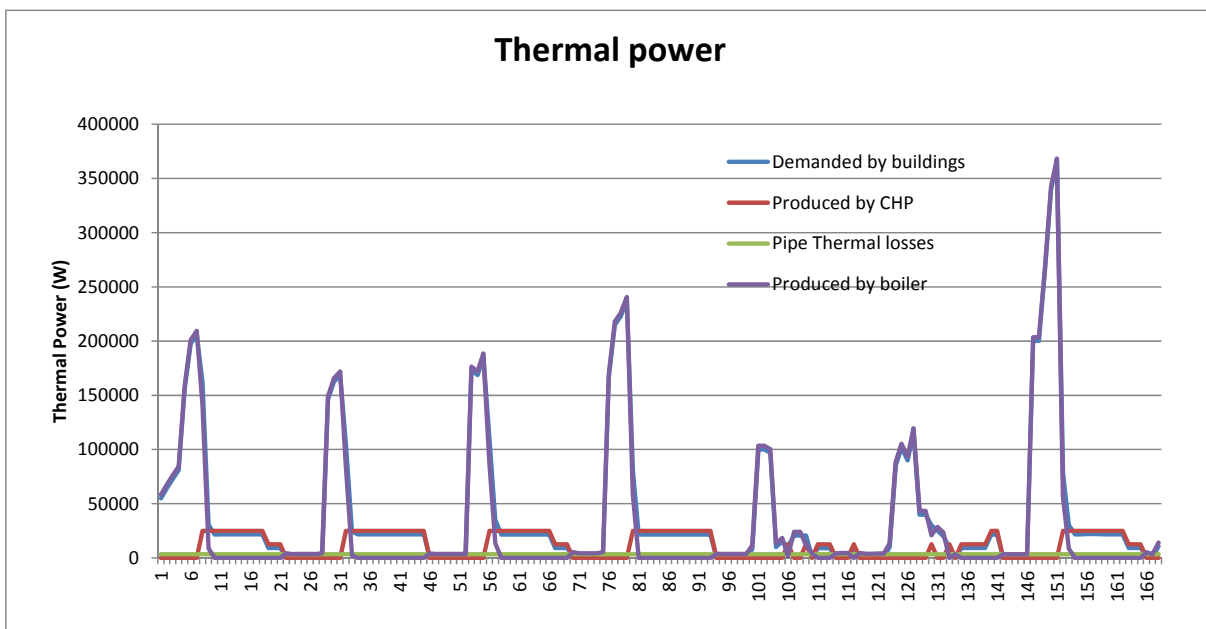


Figure 46. Thermal power for the simulated week (mild weather – district heating+CHP+EEPOS control)

During this week, after the initial warm-up period in the morning to reach thermal comfort conditions (before the building is occupied), there is no need of heating according to the simulations (see baseline). However, some heating is produced by the CHP and it has to be used.

This heat should be delivered according to internal temperatures, acceptable set-points, but also taking into consideration the indoor evolution of temperatures during the day. This kind of algorithms can be easily implemented in EEPOS. The algorithm used in the simulation suggests using the school to store the CHP heat. Therefore the indoor temperature of each building will be similar to the baseline case, except for the school.

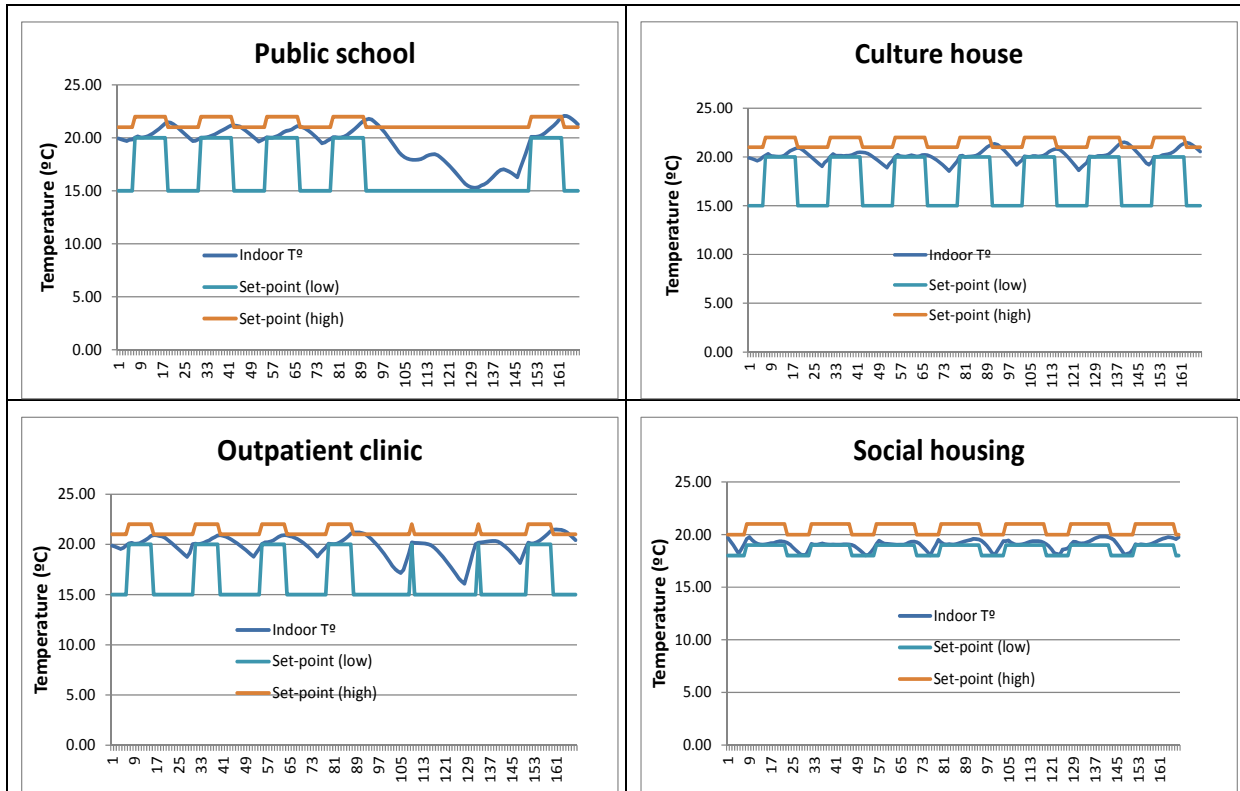


Figure 47. Indoor temperature and set-points for the simulated week (mild weather – district heating+CHP+EEPOS control)

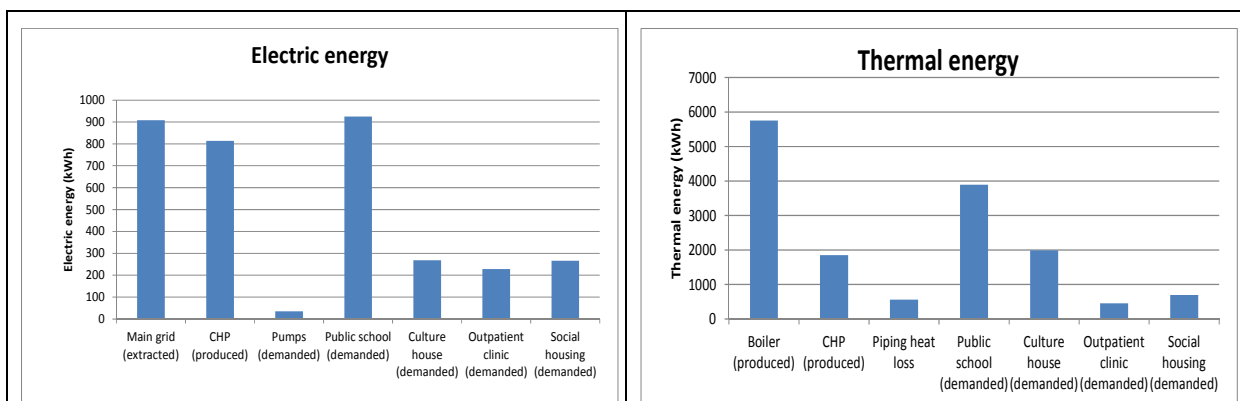


Figure 48. Energy needs for the simulated week (mild weather – district heating+CHP+EEPOS control)

The electric energy extracted from the grid during this week is 908 kWh. The amount of electricity supplied at each time has been multiplied for the specific electricity price per hour already shown and a grid access fee of 44.027 €/MWh has also been considered. The total cost of electricity for that week is 93 € (vat not included). The CHP has provided 814 kWh of electricity that has been used within the district. The total amount of electric energy used is able to satisfy the energy demanded by the buildings plus the energy consumed by the district heating pumps (about 35 kWh for this week).

Regarding thermal needs, the total amount of thermal energy needed is 7604 kWh. A boiler supplies 5754 kWh while the CHP provides 1850 kWh. By considering a seasonal efficiency of 90% for the central boiler and the previously shown efficiencies for the CHP, the total amount of gas natural needed is 9427 kWh. Assuming a realistic average cost of 0.06 €/kWh for natural gas, the weekly cost of the natural gas is 566 € (vat not included).

The estimated total energy cost for that week is 659 €.

7.3 District heating + CHP + PV + EEPOS control

This scenario is similar to the previous one with the addition of PV panels. What the EEPOS system is going to control in this case is the CHP operation, the boiler operation, and the thermal energy supplied to each building, taking into account the PV production forecast. The PV generation forecast application has been developed and explained in D2.3 “Supervisory and Predictive Control Methods and Applications: Technical documentation & Implementation”, so the EEPOS system will have a PV production forecast in order to properly make energy management decisions. This control is simulated here.

A PV installation of 5 kWp installation, South oriented with a tilt angle of 45° has been considered in the simulation. This system has been dimensioned in order to use the PV energy within the district. Therefore the daily production forecast has been compared to the typical electrical demand in order to not have a PV energy surplus, although this can happen occasionally.

7.3.1 Cold weather

The following graph represents the electrical energy demanded by the buildings for the “cold weather” week. It can be seen how the power drawn from the main grid is reduced thanks to the operation of the CHP engines and the PV panels. The main grid is only providing electricity, never receiving, as planned.

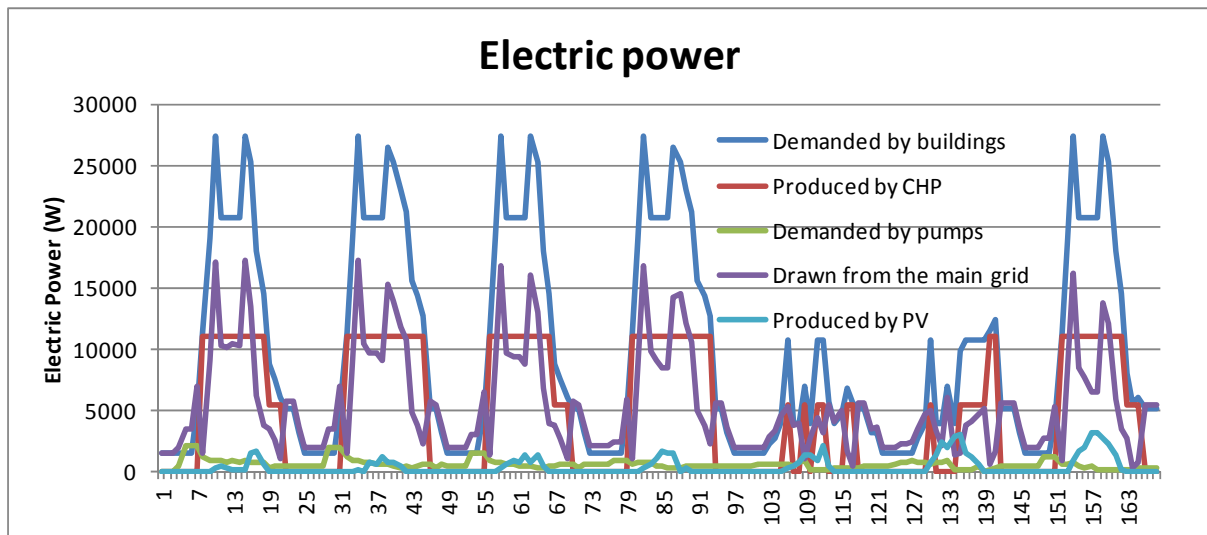


Figure 49. Electric power for the simulated week (cold weather – district heating+CHP+PV+EEPOS control)

The thermal energy needed for all the district is shown in the next graph. The heat produced by CHP, boiler and thermal losses are also plotted.

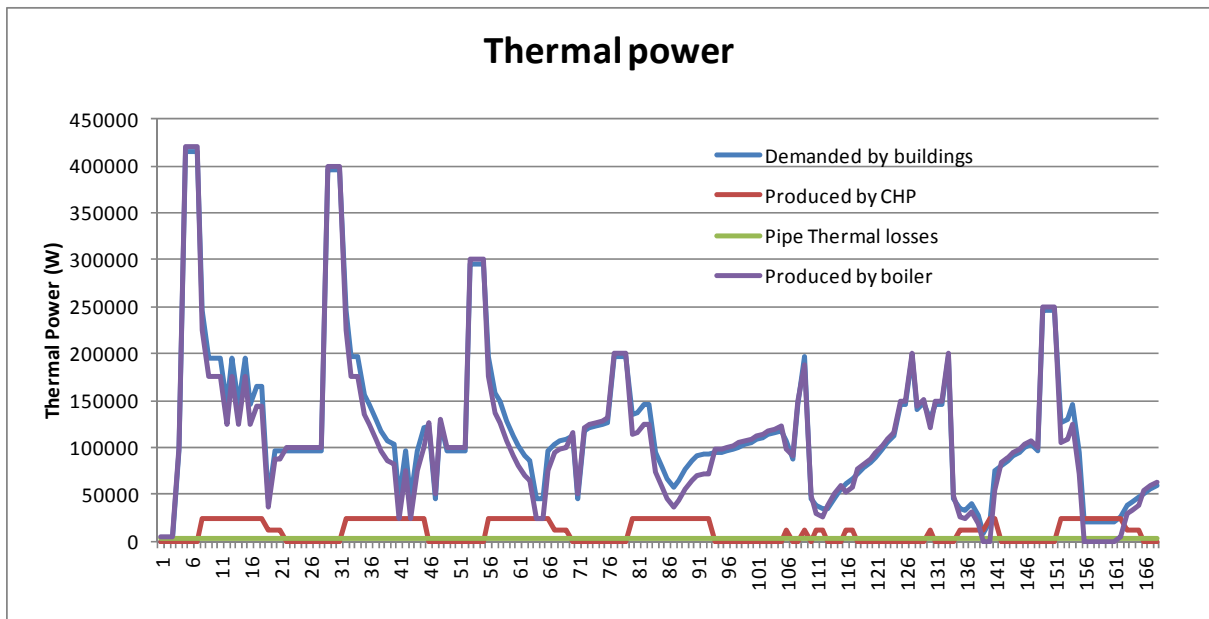


Figure 50. Thermal power for the simulated week (cold weather – district heating+CHP+PV+EEPOS control)

By providing this thermal power, the indoor temperature of each building fulfills the set-point requirements, as it shown in the next graph.

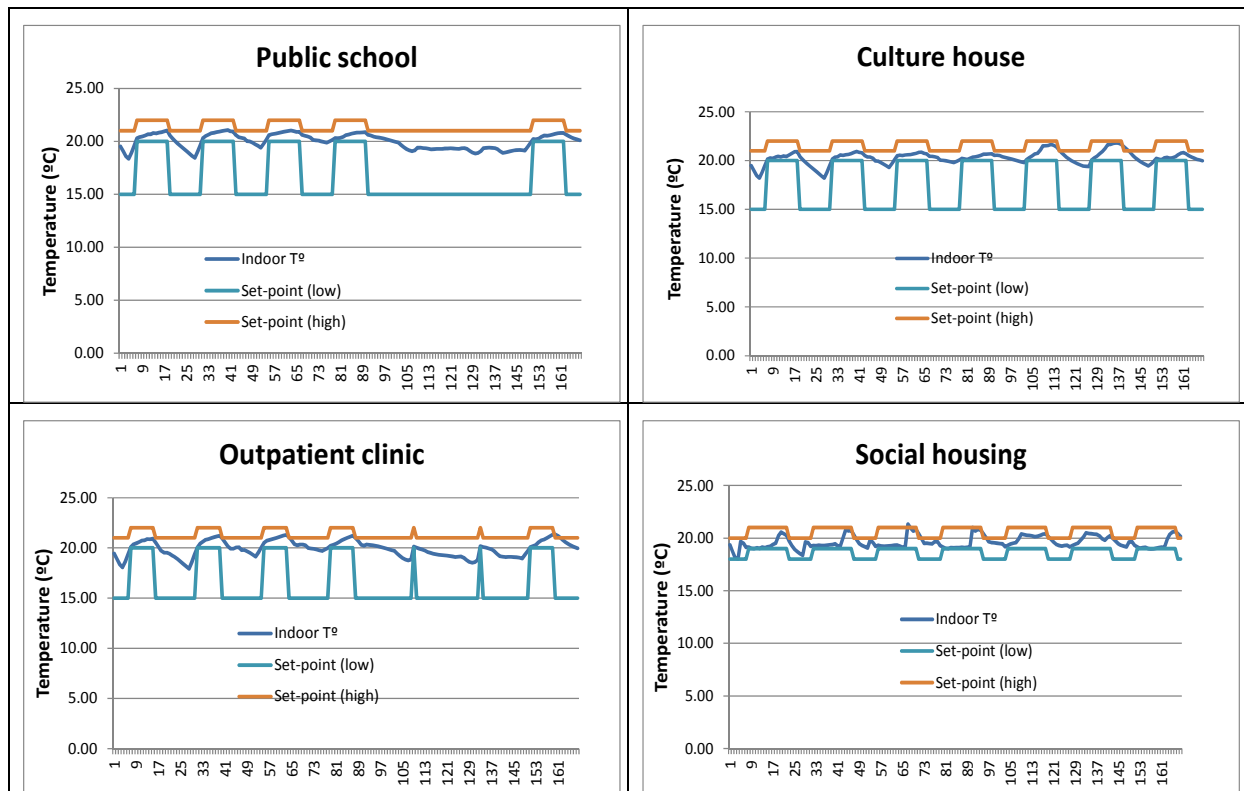


Figure 51. Indoor temperature and set-points for the simulated week (cold weather – district heating+CHP+PV+EEPOS control)

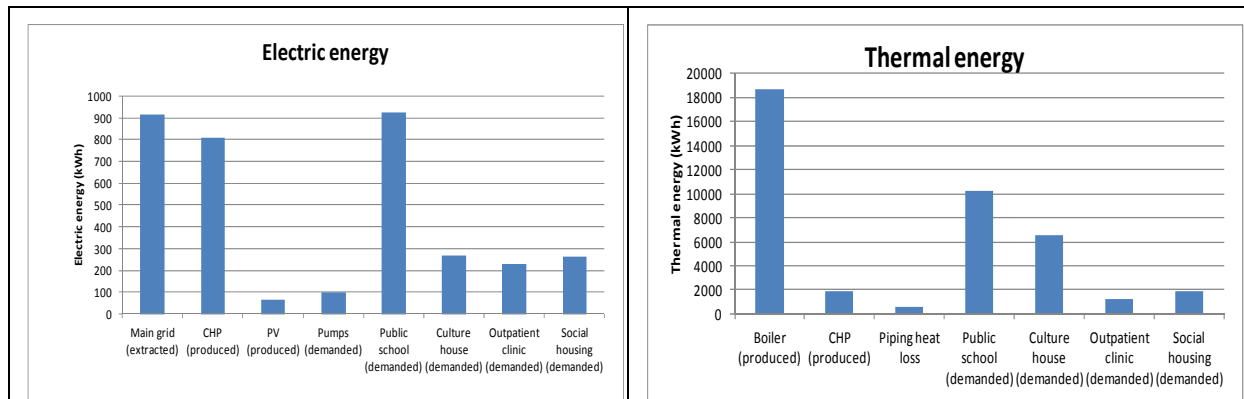


Figure 52. Energy needs for the simulated week (cold weather – district heating+CHP+PV+EEPOS control)

The electric energy extracted from the grid during this week is 914 kWh. The amount of electricity supplied at each time has been multiplied for the specific electricity price per hour already shown and a grid access fee of 44.027 €/MWh has also been considered. The total cost of electricity for that week is 97 € (vat not included). The CHP has provided 809 kWh and the PV panels 65 kWh. All this energy has been used within the district. The total amount of electric energy used is able to satisfy the energy demanded by the buildings plus the energy consumed by the district heating pumps (about 100 kWh for this week).

Regarding thermal needs, the total amount of thermal energy needed is 20548 kWh. A boiler supplies 18710 kWh while the CHP provides 1838 kWh. By considering a seasonal efficiency of 90% for the central boilers and the previously shown efficiencies for the CHP, the total amount of gas natural needed is 23803 kWh. Assuming a realistic average cost of 0.06 €/kWh for natural gas, the weekly cost of the natural gas is 1428 € (vat not included).

The estimated total energy cost for that week is 1525 €.

7.3.2 Mild weather

The following graph represents the electrical energy demanded by the buildings for the "mild weather" week. It can be seen how the power drawn from the main grid is reduced thanks to the operation of the CHP engines and the PV panels.

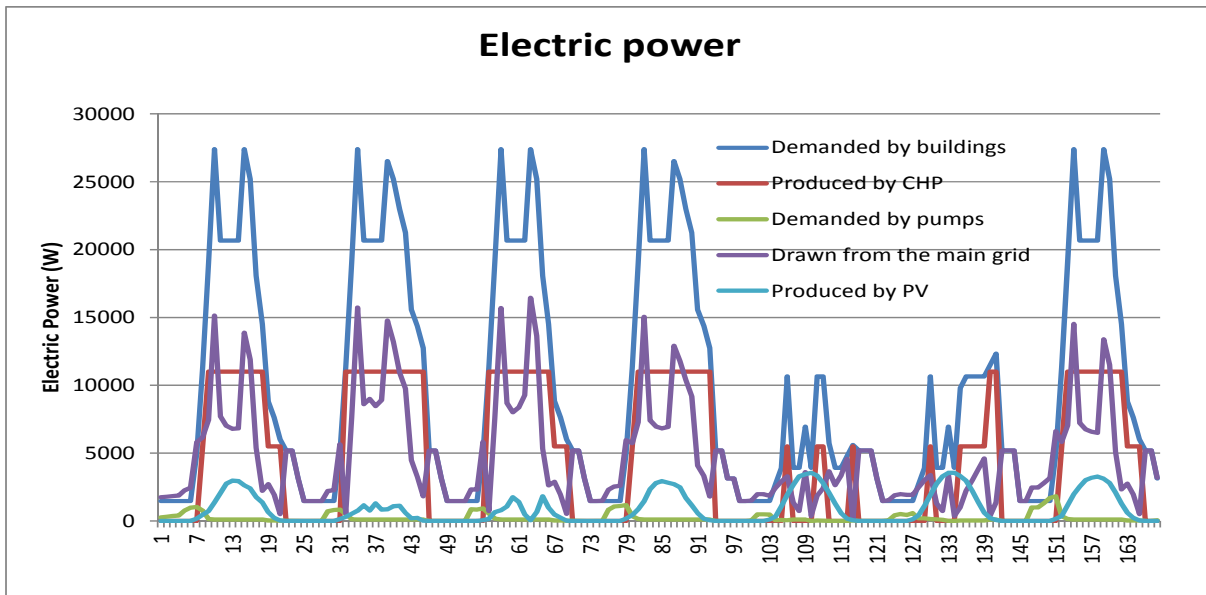


Figure 53. Electric power for the simulated week (mild weather – district heating+CHP+PV+EEPOS control)

The thermal energy needed for all the district is shown in the next graph. The heat produced by CHP, boiler and thermal losses are also plotted.

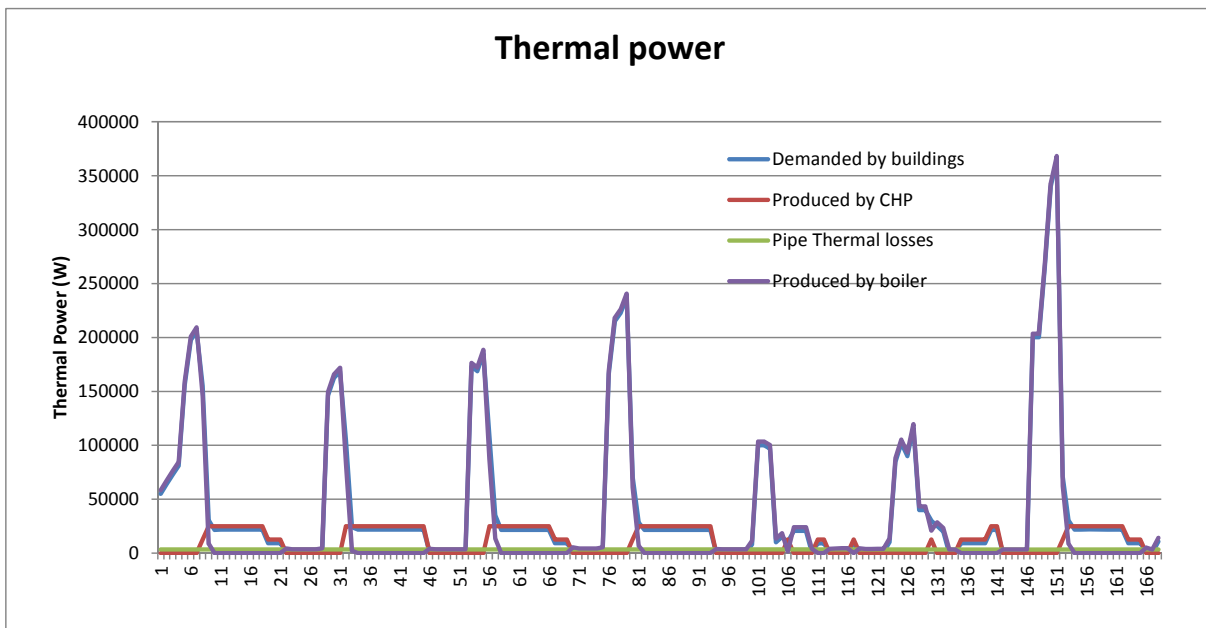


Figure 54. Thermal power for the simulated week (mild weather – district heating+CHP+PV+EEPOS control)

During this week, after the initial warm-up period in the morning to reach thermal comfort conditions (before the building is occupied), there is no need of heating according to the simulations (see baseline). However, some heating is produced by the CHP and it has to be used. The addition of PV diminishes the CHP operation hours and consequently less CHP heat has to be stored in the buildings’ thermal mass.

This heat should be delivered according to internal temperatures, acceptable set-points, but also taking into consideration the indoor evolution of temperatures during the day. This kind of algorithms can be easily implemented in EEPOS. The algorithm used in the simulation suggests using the school to store the CHP heat. Therefore the indoor temperature of each building will be identical to the baseline case, except for the school.

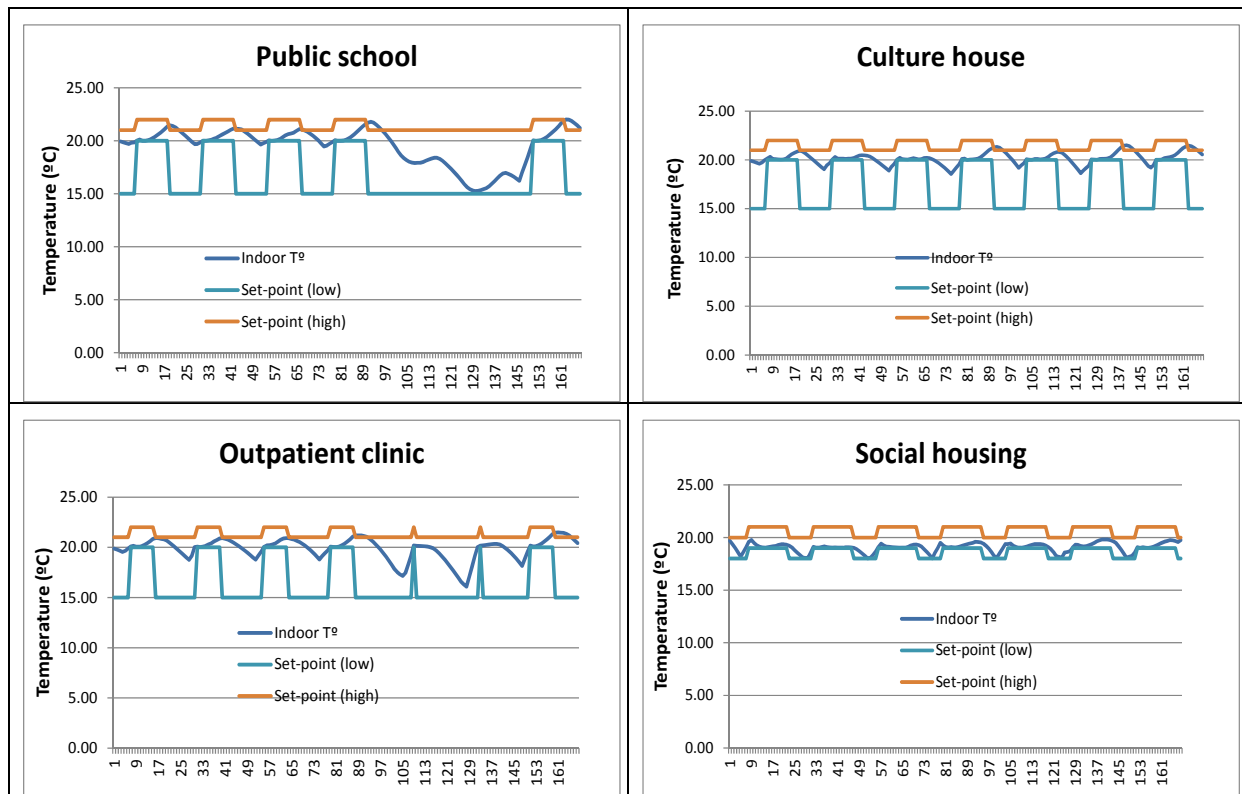


Figure 55. Indoor temperature and set-points for the simulated week (mild weather – district heating+CHP+PV+EEPOS control)

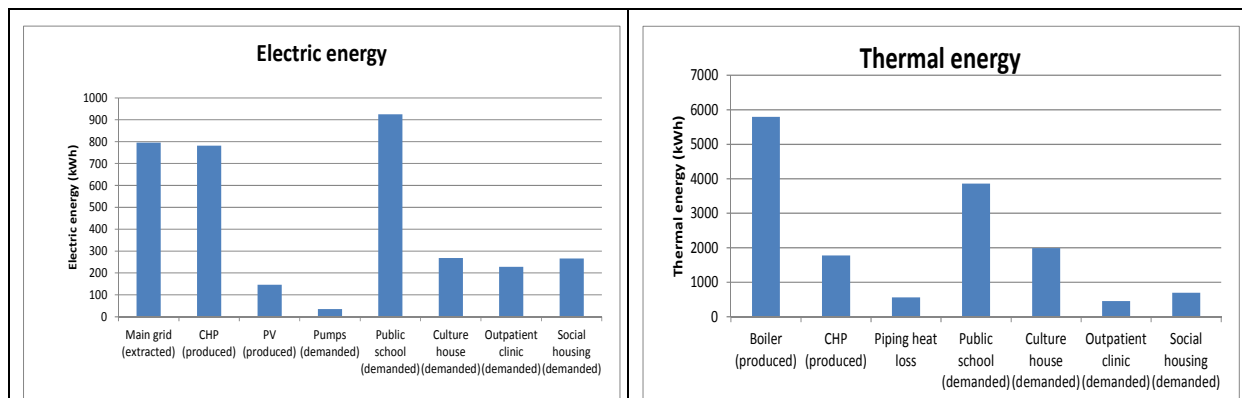


Figure 56. Energy needs for the simulated week (mild weather – district heating+CHP+PV+EEPOS control)

The electric energy extracted from the grid during this week is 795 kWh. The amount of electricity supplied at each time has been multiplied for the specific electricity price per hour already shown and a grid access fee of 44.027 €/MWh has also been considered. The total cost of electricity for that week is 82 € (vat not included). The CHP has provided 781 kWh and the PV panels 146 kWh. All this energy has been used within the district. The total amount of electric energy used is able to satisfy the energy demanded by the buildings plus the energy consumed by the district heating pumps (about 35 kWh for this week).

Regarding thermal needs, the total amount of thermal energy needed is 7569 kWh. A boiler supplies 5794 kWh while the CHP provides 1775 kWh. By considering a seasonal efficiency of 90% for the central boiler and the previously shown efficiencies for the CHP, the total

amount of gas natural needed is 9349 kWh. Assuming a realistic average cost of 0.06 €/kWh for natural gas, the weekly cost of the natural gas is 561 € (vat not included).

The estimated total energy cost for that week is 643 €.

7.4 Summary of results

The following table shows the grid electricity and the gas consumed per week, in kWh. The percentage in brackets shows the energy consumed compared to the baseline. When the EEPOS system is applied to the CHP installation described, an important amount of electricity can be self-produced (over 40%) if the CHP heat can be used within the district. As the weather goes milder, the heat rejected by the CHP is less necessary and the buildings indoor temperature is higher than the minimum set-point (maximum threshold is not exceeded either). While the indoor temperature is acceptable, electricity can be produced by the CHP although the buildings will consume more thermal energy because of the higher indoor temperature. It will be shown later on, in the economic analysis, that “mild weather” operation does not generate profit although the system is still capable of self-producing more than 40% of the electricity needed.

When the released CHP heat starts causing building overheating, it is time to disconnect the CHP and finally to turn off the district heating during the summer season. Energy consumption will be as usual (baseline) during that season, except for the case of PV panels where some reduction will be achieved thanks to the renewable energy generated.

	Energy consumption (kWh)							
	"Cold weather" week		"Mild weather" week		Summer week		Yearly extrapolation	
	Grid electricity (kWh)	Gas (kWh)	Grid electricity (kWh)	Gas (kWh)	Grid electricity (kWh)	Gas (kWh)	Grid electricity (kWh)	Gas (kWh)
Baseline	1687	23435	1687	7656	1687	0	87965	568521
District heating + CHP + EEPOS control	967 (-42.7%)	23816 (+1.6%)	908 (-46.2%)	9427 (+23.1%)	1687 (+0%)	0	60555 (-31.2%)	607872 (+6.9%)
District heating + CHP + PV + EEPOS control	914 (-45.8%)	23803 (+1.6%)	795 (-52.9%)	9349 (+22.1%)	1541 (-8.7%)	0	55246 (-37.2%)	606208 (+6.6%)

Table 15. Energy consumption

In order to extrapolate the yearly energy consumption, 109 days have been considered as summer period, when no heating is needed, 128 days have been considered as “cold weather” and another 128 days have been considered as “mild weather” days as previously shown in the definition of reference weeks.

In the table it can be observed that the annual self-production of electricity is over 30% when using the district heating + EEPOS control.

Self-production of electricity is not the only benefit of the system. Electricity peak load is reduced by 40% during the cold and mild season. This is a very important achievement of the EEPOS system.

8. ECONOMIC ANALYSIS

In order to quantify the savings obtained, a simple economic analysis is going to be carried out in this section.

8.1 Capital cost

The following table contains realistic cost estimations to develop the district heating system that has been detailed in this document.

District heating system		Cost (€)
Soil preparation		1612
Infrastructure and Energy supply		16749
Urbanisation		49782
Civil work (industrial unit)		40546
Electricity and Fire safety installation		15431
HVAC equipment and CHP	Boiler	35000
	CHP#1	20000
	CHP#2	20000
	Thermal Storage tank	3200
	Hydraulic installation	16906
	Electric and control installation	6500
	Piping	Civil work
	Hydraulic components	49500
Quality control		5600
Health and safety		6547
Waste disposal		449
Engineering		29000
Total		369630

Table 16. District heating capital cost

In order to buy and install a 5 kWp PV plant, the estimated capital cost is the following:

PV system (5kWp)	Cost (€)
Total	11700

Table 17. PV plant capital cost

8.2 Payback period

In order to know the payback period, the yearly energy consumption per case has to be extrapolated. According to the external temperatures, 109 days will be considered as summer period, when no heating is needed. 128 days will be considered as “cold weather” and another 128 days will be considered as “mild weather” days.

During the summer period, it will be assumed that the district heating system is off. It will be also considered that summer weeks are regular weeks (e.g. no holidays). Therefore the electric consumption will be as usual during the summer, for the sake of simplicity. The CHP

will not provide any electricity during the summer as the district heating is off. The PV panels will supply electricity when installed.

	Energy cost (€)			
	"Cold weather" week	"Mild weather" week	Summer week	Yearly extrapolation
Baseline	1591	633	180	43470
District heating + CHP + EEPOS control	1532	659	180	42867
District heating + CHP + PV + EEPOS control	1525	643	164.4	42203

Table 18. Energy cost

	Annual savings (€)	Capital cost (€)	Payback period (years)
Baseline	-	-	-
District heating + CHP + EEPOS control	603	369360	Over 100
CHP + PV + EEPOS control	1267	381060	Over 100

Table 19. Payback period

It can be observed that, from an economic point of view, constructing this district heating and operating it is a non-profitable business. Although some economic savings could be obtained, the cost of the district heating network is too high to recoup the funds expended in the investment, in a reasonable period of time.

An alternative system is proposed in the following section, in order to diminish the capital cost while still having lower energy costs due to the EEPOS system.

9. ALTERNATIVE LAYOUT

As the district heating costs are very high, an alternative layout is going to be proposed and some rough estimations will be given too. The alternative layout suggests installing the CHP units in the school that is the bigger building. Another possible layout is installing one CHP unit in the school and the other in the culture house. This kind of decisions should be studied in depth in future cases, to get a good match between thermal generation and storage.

The advantages of this layout are: there is no need of a district heating network, there are no pumps consuming electricity and there are no thermal losses associated to district heating piping.

The disadvantages are that the heat released by a CHP unit has to be consumed by the building housing the unit. Therefore there is less thermal storage flexibility.

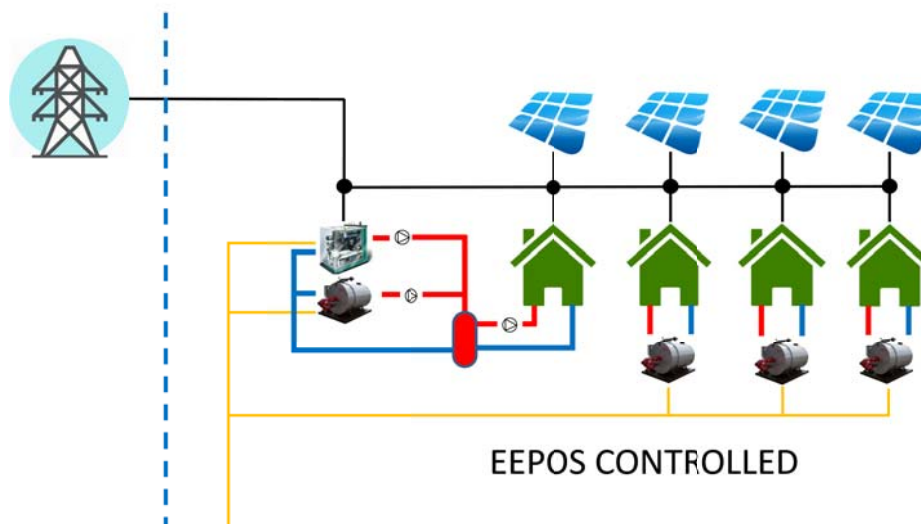


Figure 57. Alternative layout

The EEPOS system will decide if the CHP units have to be activated or no, depending on the electricity demanded and the thermal storage capacity of the building housing the units.

In order to provide a rough estimation of the energy performance and the economic indicators, it will be assumed that the buildings housing the CHP units are able to store the heat released by the CHP units during the “cold weather” and the “mild weather”, as the whole district did in the presented simulations. For this alternative layout there will be neither district pumping energy nor piping thermal losses. Obviously, there will be no high efficiency central boiler either. When applying these assumptions to the results obtained from previous simulations, the following table is obtained:

	Energy consumption (kWh)							
	"Cold weather" week		"Mild weather" week		Summer week		Yearly extrapolation	
	Grid electricity (kWh)	Gas (kWh)	Grid electricity (kWh)	Gas (kWh)	Grid electricity (kWh)	Gas (kWh)	Grid electricity (kWh)	Gas (kWh)
Baseline	1687	23435	1687	7656	1687	0	87965	568521
District heating + CHP + EEPOS control	868 (-48.5%)	24298 (+3.7%)	873 (-48.3%)	9139 (+19%)	1687 (+0%)	0	58104 (-33.9%)	611419 (+7.5%)
District heating + CHP + PV + EEPOS control	814 (-51.7%)	24286 (+3.6%)	760 (-54.9%)	9063 (+18.4%)	1541 (-8.7%)	0	52777 (-40%)	609810 (+7.3%)

Table 20. Energy consumption – alternative system

The following table contains realistic cost estimations to develop the alternative system that has been explained in this section.

Alternative system	Cost (€)	
HVAC equipment and CHP	CHP#1	20000
	CHP#2	20000
	Thermal Storage tank	3200
	Hydraulic installation	2500
	Electric and control installation	2000
Engineering	3000	
Total	50700	

Table 21. District heating capital cost – alternative system

The estimated energy costs when operating according to the alternative systems can be calculated from the energy consumption values.

	Energy cost (€)			
	"Cold weather" week	"Mild weather" week	Summer week	Yearly extrapolation
Baseline	1591	633	180	43470
District heating + CHP + EEPOS control	1551	638	180	42830
District heating + CHP + PV + EEPOS control	1544	622	164.4	42167

Table 22. Energy cost – alternative system

	Annual savings (€)	Capital cost (€)	Payback period (years)
Baseline	-	-	-
District heating + CHP + EEPOS control	640	50700	79.2
CHP + PV + EEPOS control	1303	62400	47.9

Table 23. Payback period –alternative system

The resulting payback period is much lower than the district heating case. It seems that “splitting” the CHP and placing CHP units according to the amount of thermal energy that every building can store is a much cheaper solution than installing a district heating. However the resulting payback periods are still quite high.

10. CONCLUSIONS

A neighbourhood energy management and decision support systems like EEPOS can be very useful to shave the peaks of a neighbourhood like this, when combined with CHP units. The EEPOS system also allows generating a big part of the electric energy needed by the district, when it is really needed, diminishing the amount of electric energy drawn from the main grid.

After applying the EEPOS philosophy to the existing buildings of Araia, by using a virtual prototype, it can be said that the main EEPOS targets are fulfilled:

Maximum utilisation of local DER in the neighbourhood: the distributed energy resources were dimensioned accordingly to the district needs. District electric consumption was the limiting factor for sizing the CHP. Regarding the PV panels, the peak power was chosen to avoid PV electricity surplus at any time of the year. However this could happen occasionally when some buildings do not consume electricity as usual (e.g. buildings are not occupied).

Electricity market support (balancing market): in this virtual prototype scenario, the district demands more electric energy during the daytime. For the particular weeks that have been analysed, the grid electricity price is over the CHP profitability threshold when the CHP is on. Therefore the CHP is producing electric energy when it is more expensive, helping to balance the market.

Distribution grid support (congestion management and peak load shaving): as a result of the EEPOS control, the electric peak load has been reduced by 40% (from 27kW to 16kW) during the cold and mild seasons, when the CHP heat can be used. As the EEPOS system tries to maximize the local DER in the neighbourhood, the energy surplus that is sent to the grid is minimum, to avoid any grid congestion. The grid electric consumption can be reduced more than 30% in a yearly basis. Reducing consumption supports the main distribution grid.

Although some economic savings could also be obtained by installing the system and operating it with the EEPOS system, the cost of the district heating network is too high to recoup the funds expended in the investment, in a reasonable period of time.

An alternative layout has been suggested to improve the economic indicators, where the CHP units are directly installed in the bigger buildings that will be used to store the CHP heat and no district heating network is installed. Although less thermal storage is available in this case, the lower investment helps to improve the profitability.

11. ACRONYMS AND TERMS

CHP Combined Heat and Power

DER..... Distributed Energy Resources

12. REFERENCES

- [1] Simplified building model of districts, Koene et al. BAUSIM 2014.
- [2] District Heating Pipe Laying in combination with Horizontal Drilling Methods. Project 2002:S4. MVV Energie AG. Germany. 2002.