DISTRHEAT

Digital intelligent and scalable control for
renewables in heating networks

Deliverable D3.2

Definition of the test site control baseline, which is the result of the first monitoring phase

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Executive summary

The deliverable D3.2 summarizes the process of definition of the baseline functioning of the energy plant after the first monitoring phase. The baseline analysis has been carried out considering the test-site characteristics and the energy plant composition. Indeed, while on the one hand no structural or consistent modifications have been made on the energy plant perimeter, on the other hand it has been necessary to isolate the effect on the energy plant consumptions and productions due to external factors such as the machines availability and the weather conditions, that may affect the hospital energy needs. In this document, all the equations as long as the computation procedure to perform the baseline analysis and the economic evaluation deriving from the model predictive controller application are illustrated.

1. Introduction

This report is the Deliverable D3.2 of Work Package WP3 of the DISTRHEAT project, led by Siram Veolia. The work package "WP3 - Prototyping and demonstration for small DHC" aims to implement and demonstrate the novel control algorithm developed in WP2 in a real test site.

2. Baseline analysis

The test-site control baseline has the primary objective of determining the standard operations of the energy plant, independently of changes of the external environment (outdoor temperature, variation of heated volume, etc.). In this sense, regression analysis must be introduced on the test-site perimeter in order to tackle these changes; in this way, an unbiased comparison can be applied between the baseline functioning and the model predictive control one, since all the external and non-controllable effects have been isolated.
Indeed, the whole process of normalization and comparison is composed of the following steps:

- identification of the baseline energy consumptions
- determination of the independent external variables to be use for the regression process
- elaboration of the baseline mathematical model
- normalization of the baseline energy consumptions with respect to the external variables identified
- comparison between the current energy consumptions and the baseline one

For the purposes of this study, linear regressions have been used on the hospital consumptions; then, an economic evaluation formula has been elaborated.

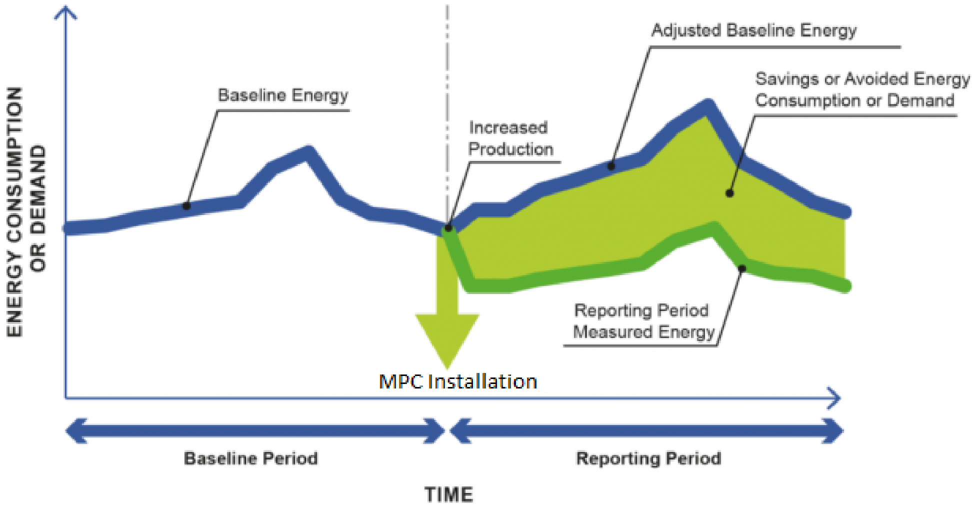

Figure 1. A graphical representation of a baseline analysis.

The baseline definition mainly concerns the energy plant perimeter (Figure 2) and, more specifically, the demand side and the hospital utilities; in essence, any variation on this side must be detected, isolated and parametrized in order to make the baseline analysis independent of external conditions. Nevertheless, considering that the model predictive controller acts also on the demand side by reducing the hospital energy needs, any decrease in the heating and cooling demands not related to external conditions must be considered as an additional energy saving due to the algorithm application.

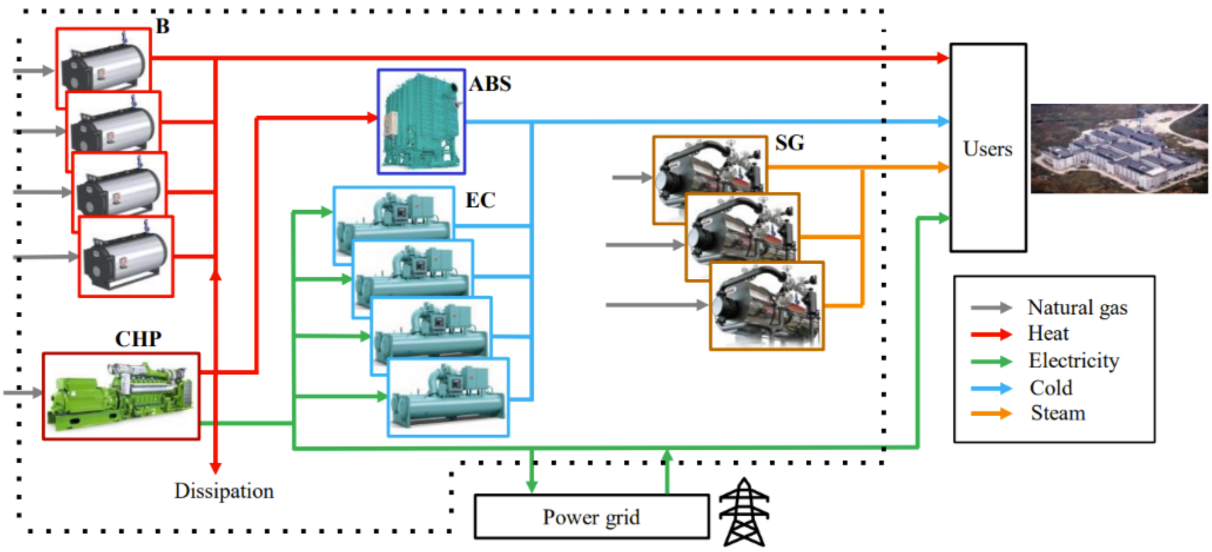

Figure 2. The energy plant perimeter (dot line) identified for the baseline analysis.

The linear regression models adopted, have been elaborated respecting the following acceptance criteria:

- $R^2 > 0.75$
- CV RMSE < 0.2
- Stat t > 2
- MBE < 0.005%

Considering the type of application and the test-site characteristics, the following assumptions have been made:

- steam consumption is not considered for the baseline analysis, as the optimization algorithm has not been applied on the steam circuit which, additionally, is independent of the rest of the energy plant
- static variations on energy consumption are not considered, as no major efficiency intervention have been made on the test-site
- variations in room occupancies and heated volume are neglected due to their limited impact and the insufficient statistical accuracy of data retrievable

Cogenerator electricity production

Considering that the standard functioning of the cogenerator was at a fixed point (fixed electricity output), the baseline cogenerator electricity production is only affected by the machine availability. In other words, ordinary and extraordinary maintenance activities are the only one external factors that can influence electricity production. Therefore, the formula to compute the baseline production is:

$$E_{chp} = a \cdot h_{chp} + b \tag{1}$$

where:

- E_{chp} is the electricity production of the cogenerator;
- h_{chp} is the cogenerator availability in hours;
- a and b are the two regression coefficients.

Cogenerator thermal production for heating use

On the other hand, the cogenerator thermal production for heating use is not only affected by the cogenerator availability, but also by the hospital heating demand. Indeed, the cogenerator dissipates heat when the production exceeds the global demand. For this reason, a multi-linear regression on the cogenerator availability and the heating degree days (representative of the global heating demand) has been used to determine the cogenerator useful thermal production for heating use. Indeed, the formula obtained is:

$$H_{chp,\,heat} = H_{chp} = a \cdot h_{chp} + b \cdot HDD + c \tag{2}$$

where:

- $\boldsymbol{H_{chp,\,heat}}$ is the heating production of the cogenerator for heating use;
- $\boldsymbol{H_{chp}}$ is the useful heating production of the cogenerator;
- $\boldsymbol{H_{abs}}$ is the heating consumption of the absorption chiller;
- $\boldsymbol{h_{chp}}$ is the cogenerator availability in hours;
- $\boldsymbol{H_{demand}}$ is the heating demand of the hospital;
- ***a***, ***b***, *and* ***c*** are the three regression coefficients.

Cogenerator gas consumption

Considering that the standard functioning of the cogenerator was at a fixed point (fixed electricity output) the baseline cogenerator gas consumption is only affected by the machine availability. In other words, ordinary and extraordinary maintenance activities are the only one external factors that can influence electricity production. Therefore, the formula to compute the baseline production is:

$$NG_{chp} = a \cdot h_{chp} + b \tag{3}$$

where:

- $\boldsymbol{NG_{chp}}$ is the gas consumption of the cogenerator;
- $\boldsymbol{h_{chp}}$ is the cogenerator availability in hours;
- ***a*** and ***b*** are the two regression coefficients.

Natural gas consumption for heating use

In order to elaborate a model for the natural gas consumption for heating use, the heating degree days (HDD) have been identified as the main external variable, with a monthly frequency. Moreover, the cogeneration heat recovery has been reconducted to the consumption of an equivalent boiler through the application of standard production efficiencies, after subtracting the useful heat entering the absorption chiller. In this way, the monthly natural gas consumption can be computed by the following formula:

$$NG_{cons,\,th} = \frac{H_{chp,\,heat}}{\eta_{chp,\,th}} + NG_{boil} = a \cdot HDD + b \tag{4}$$

where:

- $\boldsymbol{NG_{cons,\,th}}$ is the natural gas for heating use;
- $\boldsymbol{H_{chp,\,heat}}$ is the heating production of the cogenerator for heating use;
- $\boldsymbol{\eta_{chp,\,th}}$ is the standard thermal efficiency of the cogenerator;
- $\boldsymbol{NG_{boil}}$ is the gas consumption of the boilers;
- ***HDD*** are the monthly heating degree days;

- ***a*** and ***b*** are the two regression coefficients.

Static factors such as the volumetric variation of the heated area as well as the variation in room occupancy have not been included due to their negligible effect during the period considered for the baseline evaluation.

Absorption chiller cooling production

Considering the standard energy plant operations, the absorption chiller cooling production is mainly dependent on the cogenerators availability and on the external temperature. Indeed, the chiller is usually activated during summer to enhance the heat recovery from cogeneration, and maintenance stops are not frequent and usually programmed during the winter season. By identifying the cooling degree days as the additional independent variable, the baseline absorption chiller cooling production can be computed as:

$$C_{abs} = a \cdot h_{chp} + b \cdot CDD + c \tag{5}$$

where:

- C_{abs} is the cooling production of the absorption chiller;
- h_{chp} is the cogenerator availability in hours;
- ***CDD*** are the monthly cooling degree days;
- ***a***, ***b***, and ***c*** are the three regression coefficients.

Electricity consumption

Since no relevant interventions have been made on the electricity side (no changes in volume heated or in the installed electric capacity), only the variations in the external weather conditions are considered during the period under investigation for the baseline analysis. Moreover, to isolate the absorption chiller contribution in reducing the electric chillers consumption, an additional electricity demand is estimated starting from the absorption chile cooling production. Overall, considering the large impact of electricity consumption for cooling use, the cooling degree days are introduced in the baseline model with the following formula:

$$E_{cons} = E_{chp} + E_{with} - E_{sell} + \frac{C_{abs}}{COP_{chill}} = a \cdot CDD + b \tag{6}$$

where:

- E_{cons} is the electricity consumption;
- E_{chp} is the electricity production of the cogenerator;
- E_{with} is the electricity withdrawn from the grid;
- E_{sell} is the electricity sold to the grid;
- C_{abs} is the cooling production of the absorption chiller;
- COP_{chill} is the standard coefficient of performance of the electric chillers;
- ***CDD*** are the monthly cooling degree days;
- ***a*** and ***b*** are the two regression coefficients.

Electricity exchange with the grid

Analyzing the historical data of the test-site, due to the high amount of electricity demand compared to the installed production capacity, electricity exchange can be considered as always directed from the grid to the hospital. In other words, as a first approximation, electricity selling can be assumed equal to zero while the electricity withdrawal can be estimated starting from the electricity consumption and the absorption chiller production. The formulas are the following:

$$E_{sell} = 0 \tag{7}$$

$$E_{with} = E_{cons} - E_{chp} - \frac{C_{abs}}{COP_{chill}} \tag{8}$$

where:

- **E_{sell}** is the electricity sold to the grid;
- **E_{with}** is the electricity withdrawn from the grid;
- **E_{cons}** is the electricity consumption;
- **E_{chp}** is the electricity production of the cogenerator;
- **C_{abs}** is the cooling production of the absorption chiller;
- **COP_{chill}** is the standard coefficient of performance of the electric chillers.

Economic evaluation

Overall, the overall economic balance of the plant can be evaluated by means of the following formula:

$$EB = E_{sell} \cdot p_{el, sell} - E_{with} \cdot c_{el, with} - NG_{chp} \cdot c_{NG, chp} + NG_{boil} \cdot c_{NG, boil} \tag{8}$$

where:

- **EB** is the economic balance;
- **E_{sell}** is the electricity sold to the grid;
- **$p_{el, sell}$** is the average electricity selling price to the grid;
- **E_{with}** is the electricity withdrawn from the grid;
- **$p_{el, with}$** is the average electricity withdrawal price from the grid;
- **NG_{chp}** is the gas consumption of the cogenerator;
- **NG_{boil}** is the gas consumption of the boilers;
- **$c_{NG, chp}$** is the average cost of natural gas for the cogenerator;
- **$c_{NG, boil}$** is the average cost of natural gas for the boilers;
- **H_{abs}** is the heat consumed by the absorption chiller;
- **$\eta_{chp, th}$** is the standard thermal efficiency of the cogenerator;
- **NG_{th}** is the natural gas consumption of the hot water boilers;
- ***a*** and ***b*** are the two regression coefficients;
- ***HDD*** are the monthly heating degree days over the period considered.

Computational procedure

In order to compare the current energy plant functioning with respect to the baseline, the following steps must be followed:

1. Compute the baseline cogenerator productions and consumption with the equations (1), (2), and (3) by using the current cogenerators operating hours;
2. Following the equation (4), compute the natural gas consumption for heating use with the current degree days;
3. Still with equation (4), derive the natural gas consumption of boilers with the baseline heat production of the cogenerator for heating use;
4. Compute the baseline cooling production of the absorption chiller from equation (5) with the current cooling degree days;
5. Compute the baseline electricity consumption from equation (6) with the current cooling degree days;
6. Compute the electricity selling and withdrawal with equations (7) and (8);

7. Evaluate the baseline economic balance, since all the baseline variables have been computed;
8. Evaluate the current economic balance by using the real, measured quantities;
9. Compare the current economic balance with the baseline one.

3. Conclusions

After accounting for the energy plant characteristics and complexity, the baseline analysis has been successfully carried out and external parameters have been isolated. In the next steps, the baseline will be verified and the contribution of the algorithm application will be assessed.