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Monitoring experience of three fuel driven absorption HP systems

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Abstract

The seasonal efficiency of a heat pump during on-field operation may be different from the expected performance derived from laboratory tests. In fact, the installation layout and the control strategy may influence the overall energy performance of a heating system and cause the heat pump to operate with low efficiency.
Within this work, the performance of three heating systems, all based on the same type of gas absorption heat pumps, have been monitored for a winter season, with the purpose of pointing out the critical issues, which determine, in some cases, performance much lower than the expected values.
The investigated systems include from six to ten heat pump units installed in a rail set, and provide heating power to public buildings (schools and town hall), located in the North of Italy.
The heat pump system performance of each plant, expressed in terms of Gas Utilization Efficiency (GUE), has been measured and correlated with other parameters, which characterize the specific operating conditions.
Unnecessary transient operation, small temperature difference between supply and return, poor regulation of the supply temperature and distribution losses resulted to be the main issues reducing the heat pump system monthly efficiency.

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Introduction.

In the EU, buildings are responsible for 40% of total energy consumption and 36% of CO2 emissions, heating and DHW production representing the largest share. Consequently, several measures have been introduced to reduce the energy need of buildings, acting both on the envelope and of the systems, and to increase the share of renewable energy.
In this scenario, the role of heat pumps is growing in importance, thanks to its capability to exploit energy from different kind of sources (environment, waste heat, etc.), which, theoretically, allows to reach very high performances.
However, the gap between the performance tested in the laboratories and that one actually achieved in real applications can be very wide, as well documented in the available literature [1, 2, 3].
There are many factors that can compromise the efficiency, e.g. an improper design of the system (related for example to the choice of the heating power of the generator, or of the heating storage volume) or an incorrect control strategy.
In respect of this, Lombardy region (Italy) funded a monitoring campaign on heat pump systems installed in public buildings (schools, town halls, sport halls, etc.), with the aim of evaluating the performance on fields and investigating the influence of the real working conditions.
In this work, the monitoring results of three different gas absorption heat pumps systems are analyzed in detail. The plants, two installed in public schools, one in a town hall, have been selected in order to cover a wide range of seasonal efficiencies: a system performing well, an average system and a system performing poorly.
Being the three plants powered by the same type of absorption units, the comparison allow to underline the impact of the system design, installation and management.
An in depth analysis, based on experimental data collected along the heating season of the year 2014, is carried out on the three systems, underlining the main reasons for the very different performances. The average performance factors will be used to compare the three sites, with the addition of an analysis on representative days to exemplify the systems behavior.
The results reveals the strong influence of the dimensioning of the generator compared to the thermal request of the building, of the oversizing of the circulation pump that can determine high flow rate and consequently too small temperature difference between supply and return to the heat pumps, and of the regulation of the heat pump supply temperature.

1. Case studies

The paper presents the monitoring results of three air/water gas absorption heat pump systems, based on the data collected during the heating season of the year 2014.
All the three plants use the same model of heat pump, composed in groups of several heating units that work in parallel, to provide different thermal capacities. The heat pumps are of the on-off type, except for the plant C, where they can also operate with a capacity ratio of 50%. Thus, the regulation of the delivered heating power is obtained turning on or off the units according to the specific energy requirement.
In all of them there is a inertial storage that separates the primary circuit from the distribution circuits.

Table 1 describes the main characteristics of the systems.

Table 1: Characteristics of the analyzed plants

site	building use	system use	technology	n. of heating units	total thermal power	capacity modulation steps of the single heating unit	Degree days	Heating devices
A	school campus	space heating	air/water GAHP	10	383 kW	0 - 100%	2906	radiators
B	town hall	space heating	air/water GAHP	6	211 kW	0 - 100%	2906	fancoils
C	middle school	space heating + DHW	air/water GAHP	8	306 kW	0 – 50% - 100%	2046	fancoils

2. Monitoring procedure

The monitoring campaign aimed to measure the seasonal performance of the systems, expressed with the use of different indicators; in particular, within this work, the analysis are focused on the performance of the heat pump system, represented by *GUE (Gas Utilization Efficiency)*.
In order to contextualize the working conditions of the system and to investigate the reasons for good or bad efficiency, some representative parameters have bene monitored:

- external temperature, which corresponds to the temperature level of the energy source and, at the same time, determines the thermal energy requirements of the building and, consequently, the load factor of the heat pump;
- supply and return temperatures of the heat pump system, in order to understand the control strategies (for example if the supply temperature is fixed or if it changes according to the external temperature);
- thermal lift, derived from the previous parameters, which has a direct influence on the performance of the heat pump itself;
- load factor, calculated as the ratio between the heat pump current thermal power and the nominal heating capacity of the heat pumps. Heat pumps performances are usually affected by the load factor. However, the modular structure of the considered systems, composed of several heating units, should allow to cover a wide range of thermal request, without influence on the efficiency, except when the thermal request is lower than the thermal power provided by one single unit or when the control system forces continuous on-off of one or more units;
- average duration of the heating cycles of the heat pump units, which reveals whether they are mainly working in steady state conditions;

A monitoring system able to measure the required physical quantities has been set up, composed of the following measuring instruments:

- heat meters, comprehensive of couples of temperature sensors and water flow meters, to measure the thermal energy production of the heat pump system;
- gas flow meter, temperature and pressure sensors, to calculate and correct the energy input to the heat pump systems;
- electricity meters, to measure the consumption of the heat pump units and of their inner circulation pumps;
- external temperature and humidity probe to detect the conditions of the environment.

The sensors that measure the thermal production of the heating system are installed inside the mechanical room, on the hydraulic circuit that gathers the collectors of the groups of heating units, as shown in Figure 1: Example of monitoring system architecture on gas absorption heat pump system "B".
Thus, it is important to underline that this monitoring procedure can evaluate the performance of the system, affected by the specific in-site conditions, deriving from the design, the regulation and the boundary conditions, such as the thermal losses of the pipes coming from outside into the mechanical room; unfortunately the efficiency of the single heat pump units cannot be quantified.
The GUE is calculated according the following equation:

$$GUE = \frac{Q_{HP\ system}}{Q_F}$$

Where Q_F is the fuel energy input (GCV) and $Q_{HP\ system}$ is the thermal energy output of the heating system, which is calculated starting from the measurements of the sensors shown in Figure 1: Example of monitoring system architecture on gas absorption heat pump system "B": STM01, STR01, MIP01, multiplied by the specific heat and the density of the water.

In order to carry out sensitive analysis, including the effects of the transient states, a sample time of 1 minute has been set.
Additionally, the sensor type and accuracy are summarized in Table 2.

Table 2: type of technology and accuracy of the measuring instruments

Measure	**sensor**	**accuracy**
water flow	electromagnetic water flow meter	± 0.5%
water temperature difference	pair of PT100	± 0.05 K
gas flow	rotary gas meter	± 1% (6.5 m3/h < gas flow <= 65 m3/h) ± 2% (1.3 m3/h < gas flow <= 6.5 m3/h)
gas pressure	pressure meter	± 4 mbar
gas temperature	PT100	± (0.002·Tgas + 0.15) K
electrical energy	electric meter	± 0.5%
external temperature	capacitive temperature sensor	± 0.2 K
external relative humidity	capacitive humidity sensor	± 1.5% (10% <= rh <= 90%) ± 2% (rh < 10% and rh > 90%)

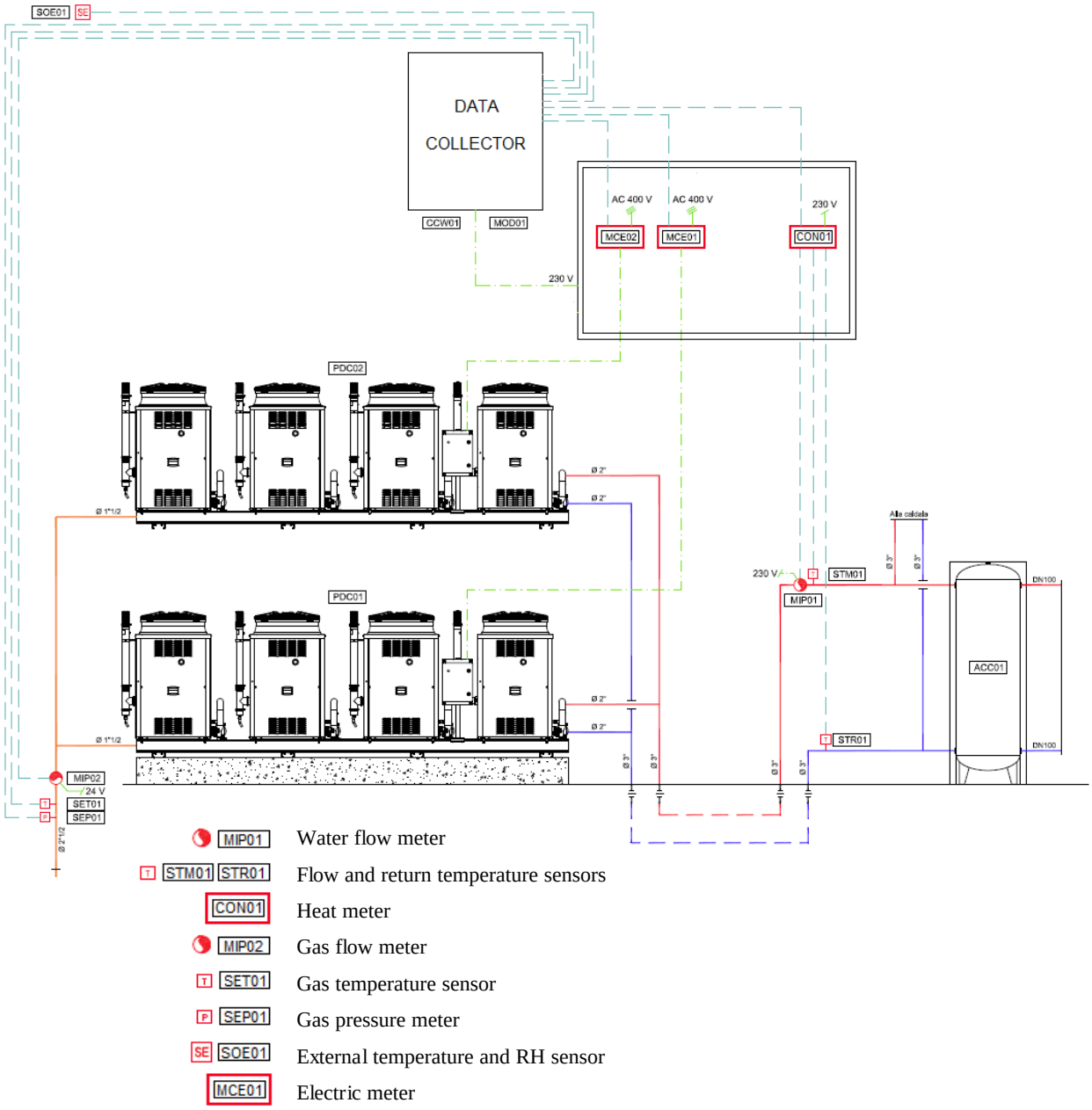


Figure 1: Example of monitoring system architecture on gas absorption heat pump system "B"

3. Result analysis

This paragraph investigates the main factors that influence the efficiency of the three systems. In particular, the trends of the main performance indicators, with respect of the other relevant parameters, are presented.
The analysis, made individually on each single site, are mainly based on daily values, with some focus on minute data of representative days, to provide a better insight on the systems behavior.

Figure 2: Monthly GUE of the three analyzed sites., which represents the monthly values of the GUE (the heating systems stops and restarts in different moments according the actual building energy needs), clearly proves that the three plants are characterized by different levels of efficiency:

- Site C has the poorest performance, being its seasonal GUE about 0.9, because of the influence of a bad control strategy, which determines very small temperature difference between supply and return and unstable working conditions, as explained below;
- Site B has average performance, with a GUE of about 1.15, rather constant along the heating seasons;
- Site A has the highest performance, with a GUE ranging from 1.25 to 1.50, higher during the mid-season than in the coldest months.

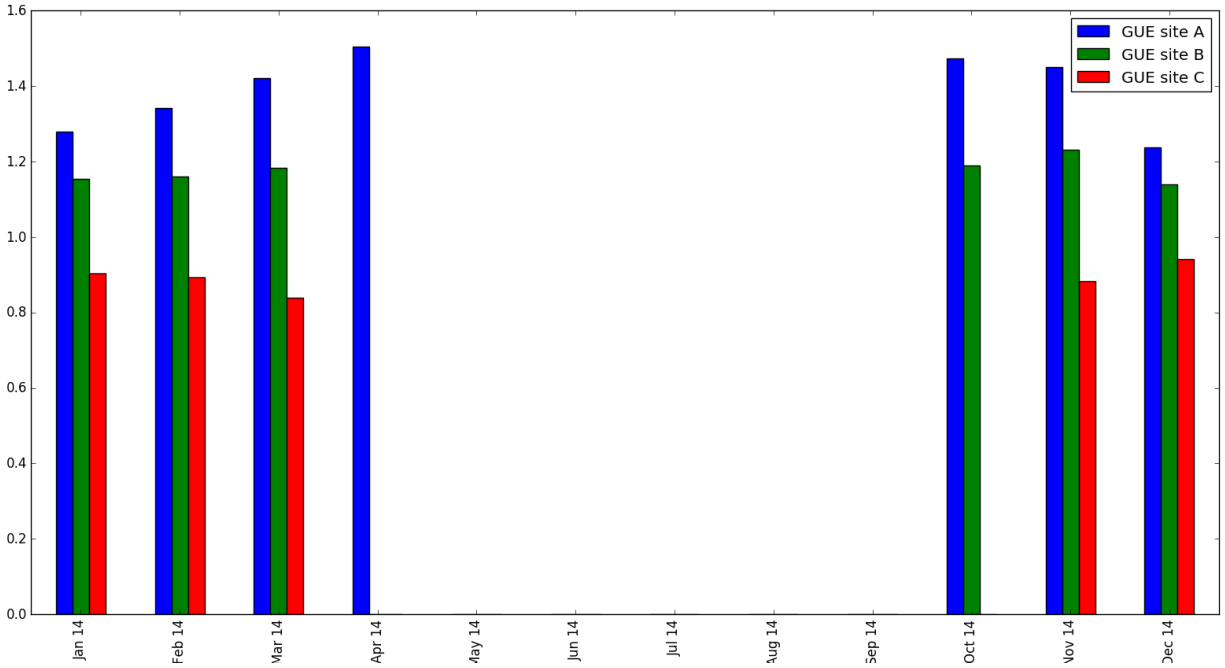


Figure 2: Monthly GUE of the three analyzed sites.

To understand the reasons for the differences among the systems, a more detailed analysis is carried out.

4.1. Site "C" – School

As shown in Figure 2, the system is characterized by low efficiencies, mainly caused by a bad control strategy, as explained below. Moreover, the thermal losses on the hydraulic circuit are probably higher than in the other two cases.

During the heating season, it is possible to distinguish two periods characterized by different behaviors of the system, due to different control strategies:

- period A, from the end of January to the end of March: the set point in the inertial tank is fixed at 60°C both during the day and during the night;
- period B, in the first part of January and from November to December: the set point in the inertial tank is set at 60°C during the day and it is reduced at 50°C during the night.

Since the school is closed during the night, the pumps on the distribution circuits are off from 23:00 to 7:00, therefore, without any heating demand from the plant, during this period the heat pumps work only for the maintenance of the set point of the inertial storage.
Figure 3 reports the supply temperature of the heat pump and the gas consumption along three consecutive days from the period A. As the circulation pump of the primary circuit is always on, the supply temperature corresponds to the temperature in the inertial tank. From the chart, it can be seen that during the night there are a lot of short and frequent heating cycles due to the need of maintaining the set-point in the inertial tank. The high frequency of the on-off cycles may be due to the narrow dead band implemented in the control system.
During period B, the reduction of the set point at 50°C reduces the cycling, as enlighten in Figure 4Figure 4. In fact, during the first part of the night the temperature decreases from 60 °C to 50 °C, without any activation of the heat pumps.

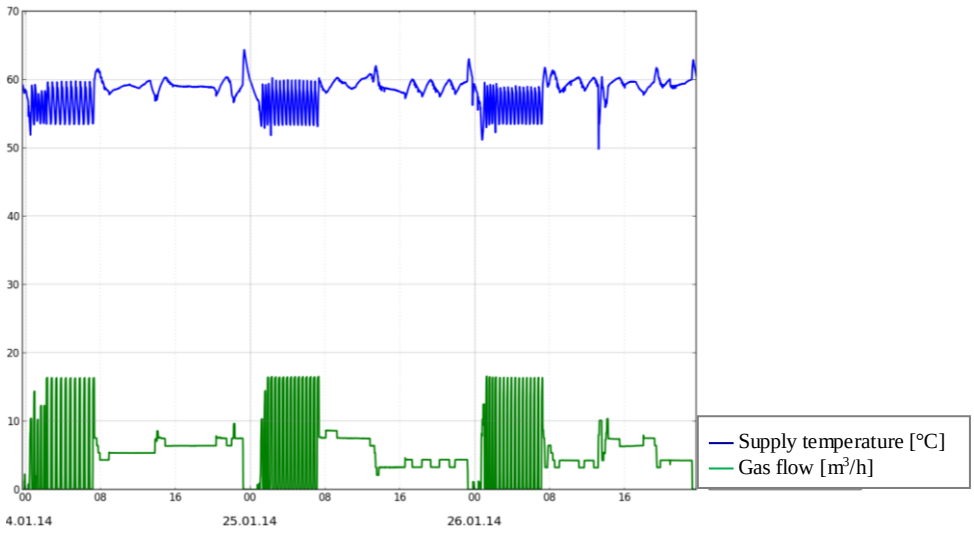


Figure 3: minute values of supply temperature and gas flow from 24/01/14 to 26/01/14 (period A)

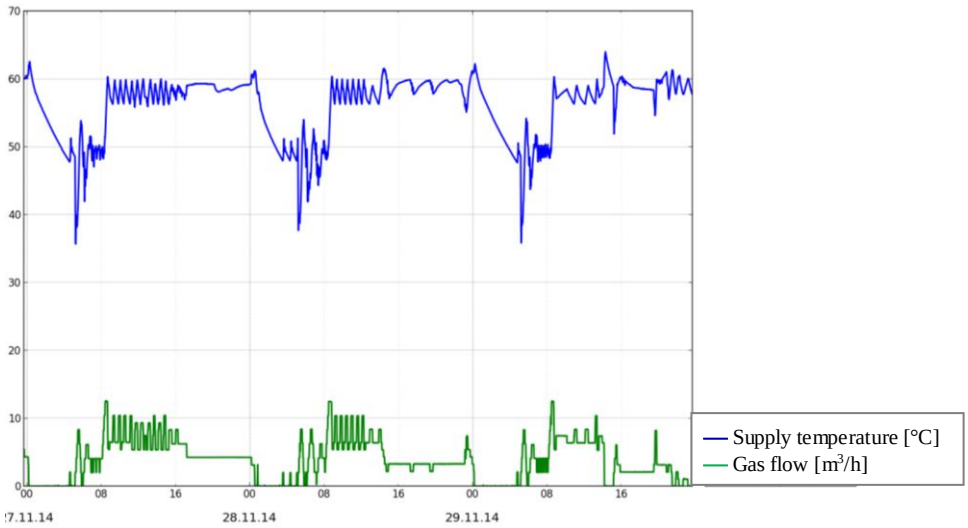


Figure 4: minute values of supply temperature and gas flow from 27/11/14 to 29/11/14 (period B)

The different regulation of the set-point temperature influences the behavior of the system, whose performance in period A are damaged because of the unstable working conditions during the night.
Figure 5 reveals that, in both the periods, the daily GUE values increase when the daily mean duration of the heating cycles grows. However in period B the performance reaches higher values, up to 1.1, while in period A the maximum value is 0.95. This difference does not derive from different environmental conditions, since Figure 6 demonstrates that the external temperature of the two periods are comparable. The critical factor is clearly represented by the mean duration of the heating cycles, between 13 and 170 minutes during period B, between 5 and 40 minutes during period A.

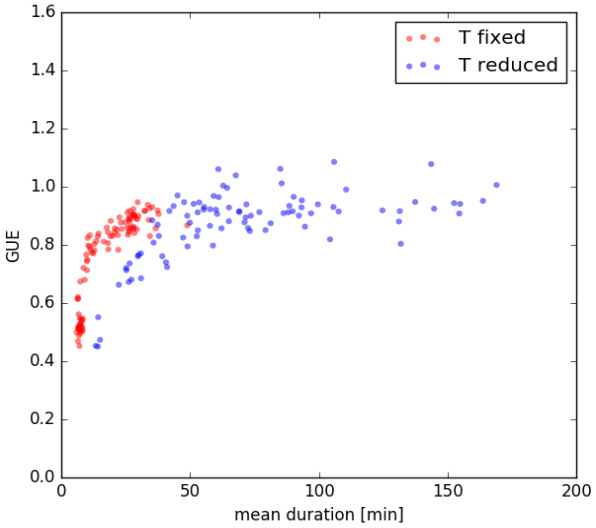


Figure 5: correlation between daily average duration of the heating cycles and daily GUE, during period A (fixed supply temperature) and period B (nightly reduction of the supply temperature).

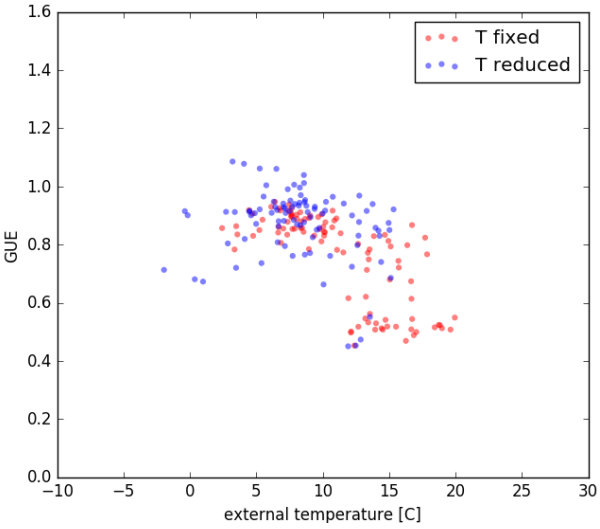


Figure 6: correlation between daily external temperature and daily GUE, during period A (fixed supply temperature) and period B (nightly reduction of the supply temperature).

Besides the short cycling of the appliances, an additional reason for the low seasonal performances lies in the control strategy applied for the supply and return water temperatures. As can be seen in Figure 7, a climatic curve is not applied, so the temperatures are always high, even when the outdoor temperature is mild.
Moreover, the mass flow rate through the heat pumps is high, resulting in a very small temperature difference between supply and return, around 3 K, which is detrimental for the GUE.

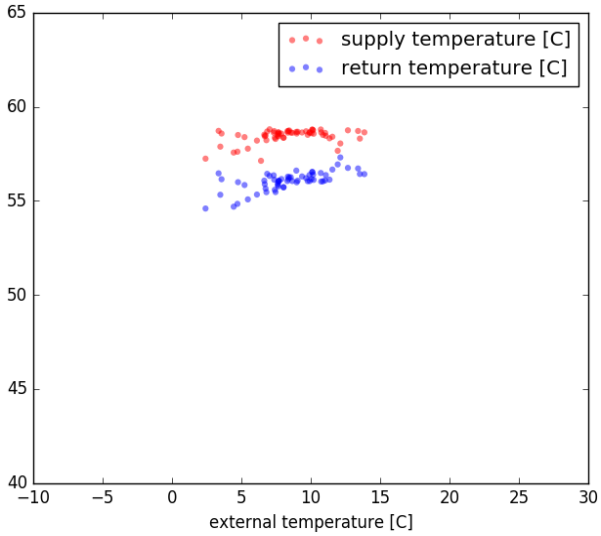


Figure 7: correlation between daily external temperatures and daily supply and return temperatures of the heat pumps, during period A (fixed supply temperature).

4.2. Site "B" – Town hall

For this site, the seasonal performance is higher than in the site C. As can be seen in Figure 8, the daily GUE is always between 1 and 1.35.
The variability of the performance is quite low, thanks to the stable behaviour of the system, which is not affected by particular problems.
The analysis of the correlations between GUE and the other parameters reveals that the only significant factor that influence the performance is the external temperature. As expected, the GUE increases with the external temperature (see Figure 8). However, as already observed from Figure 2, the monthly GUE is rather constant, meaning that the heat pumps benefit little from the milder season.
This because the lower heat demand reduces the load factor and the GUE. This effect is not compensated by a lower supply temperature because no climatic curve is implemented for this plant: the supply temperature is fixed at about 55 °C, during the whole heating season, as reported in Figure 9.
The performance could improve decreasing the set-point of the supply temperature when the thermal request of the building gets lower, in order to reduce the thermal lift on the heat pumps.

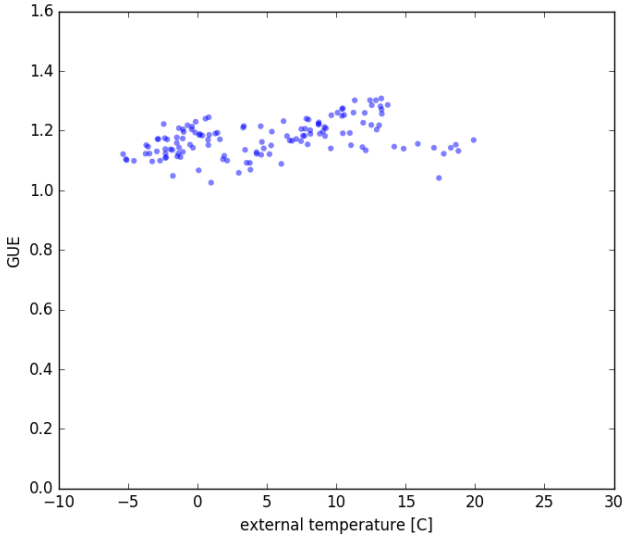


Figure 8: correlation between daily external temperatures and daily GUE.

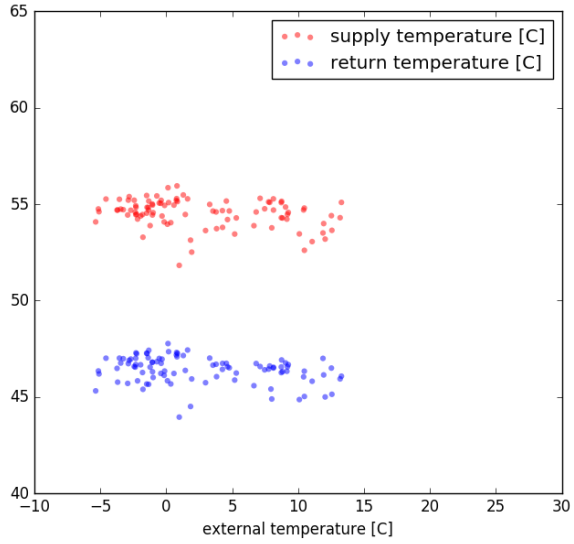


Figure 9: correlation between daily external temperatures and supply and return temperatures of the heat pumps.

4.3. Site "A" – School

The site A resulted to be the one with the highest seasonal efficiency among the ones that have been analysed. Except for few cases, the daily values of GUE are always between 1 and 1.5 (see Figure 13).
The factors reducing the GUE of the previous sites are not found here.
The thermal power of the units is properly sized and the control system operates well. Figure 11, which correlates the load factor with the external temperature, reveals that, as expected, the load factor decreases while the external temperature grows, but it is always between 0.4 and 1. This means that it does not happen that the thermal load is lower than the power of a single unit, making unnecessary short on-off cycles.
Moreover, there is a good control strategy of the supply temperature, which is reduced when the external temperature increases. Figure 10 shows that the supply temperature passes from 60 °C, when the external temperature is around -5 °C, to 50 °C, when the external temperature increases to 15 °C. As a consequence, the GUE values increase when the external temperature grows (see Figure 13). The performance improvement comes from the reduction of the thermal lift due to two combined effects: the increase of the external air temperature and the reduction of the supply temperature. This also explains why, as observed in Figure 2, the monthly GUE increases in the mildest months. The correlation between the GUE values and the thermal lift is shown in Figure 12.

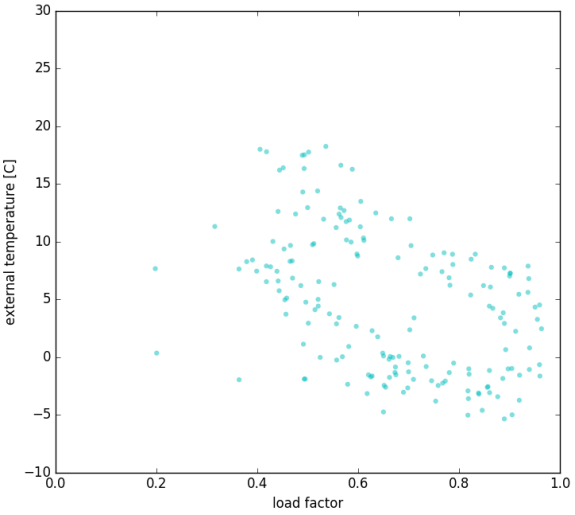


Figure 11: correlation between daily external temperatures and daily load factors.

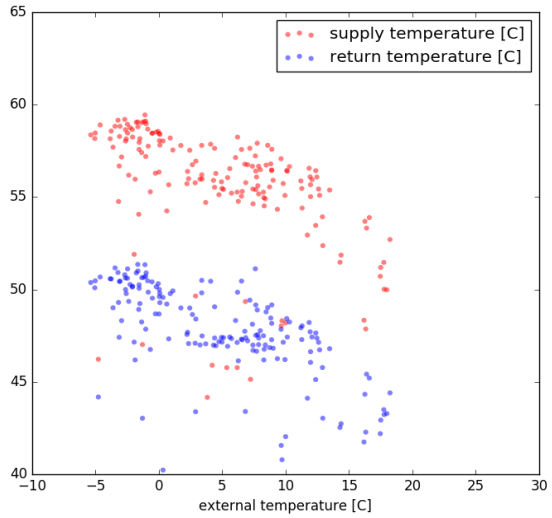


Figure 10: correlation between daily external temperatures and daily supply and return temperatures.

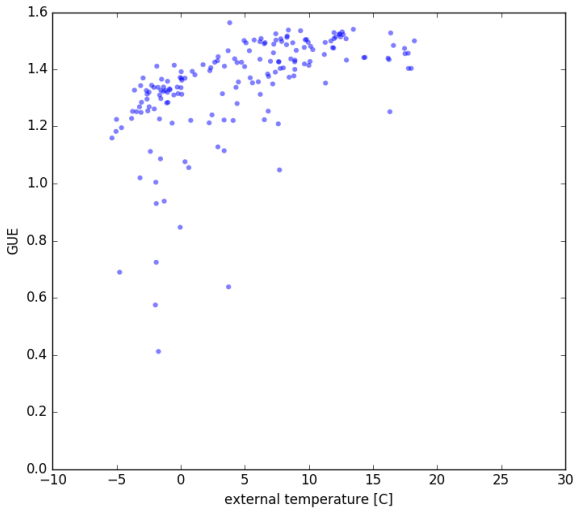


Figure 13: correlation between daily external temperatures and daily values of GUE.

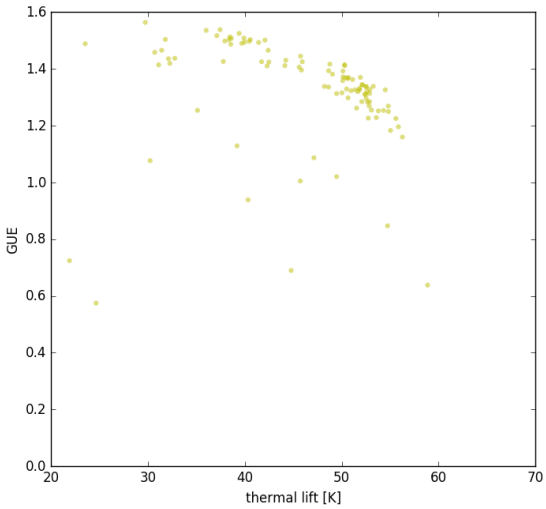


Figure 12: correlation between daily thermal lifts and daily values of GUE.

4. Conclusions

The analysis on the three gas absorption heat pump systems demonstrates that the integration of the heat pump in a specific plant plays a crucial role in determining the seasonal efficiency. In fact, as observed, the three plants, where the same heat pumps model is installed, perform very differently, because of the different system design and control strategies.
The main factors for obtaining good performances are: the proper sizing of the heat pumps and the use of a proper control strategy, in order to avoid continuous on-off operations, which lead to non steady-state operation, with low efficiency.
Moreover, it is important to limit the mass flow rate through the heat pumps, in order to avoid small temperature difference between supply and return, which is detrimental for the GUE.
A secondary but still relevant factor impacting on the seasonal performances is the proper setting of the supply temperature according to a climatic curve, function of the external temperature. This reduces the thermal lift and, consequently, improves the efficiency of the heat pump.
Finally the system efficiency is influenced by the specific in-site conditions, such as the thermal losses on the distribution circuits.
All these factors are well known, both in the scientific community and among the heat pump manufacturers. However, this work proves that inappropriate installation may compromise the efforts in improving the appliance performances. As a result, it appears that a proper training of the system designers is crucial for achieving high seasonal performances and the expected energy savings allowed by the heat pump technology.

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