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Energy and economic analysis of an under-ground water source heat pump system for a historical valuable building

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Abstract

The heating, ventilation and air conditioning plant of a historical valuable building in the centre of Vicenza (Italy) was retrofitted during 2007-2012 period. An underground water source electrical compression heat pump was installed with a monitoring and data logging system. In this paper the analysis of the performance data of the last three cooling seasons and the last two heating seasons (2014-2016) is developed. The analysis reveals that some critical aspects determined poor energy performance of the plant during the first operation period. Such issues and the technical solutions suggested by the Authors are presented in this work.

Keywords: underground water; renewable energy; energy monitoring; hydronic heat pump; economic analysis

1. Introduction

The large number of historical buildings in Italy with poor energy performance urges to identify energy saving interventions which are not conflicting with the conservation requirements [1]. Even if passive retrofitting interventions (such as external walls thermal insulation or solar shielding) could be the first choice in terms of

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energy saving, they are often unfeasible due to architectonic and aesthetic restrictions. One of the most potentially effective active energy efficiency interventions is the use of heat pumps in Heating, Ventilation and Air Conditioning (HVAC) plants. One favourable heat source/sink (respectively for heating and cooling operation) is underground water, as the lower the temperature difference between the heat source/sink and the indoor thermal energy distribution system, the higher the energy efficiency of the plant. Underground water is widely available in the Po Valley (North Italy) even if local regulations often do not easily allow the use for energy purposes. The real performance of operating plants has to be carefully monitored: the underestimation of energy consumption of some auxiliary systems (for example the pumps, particularly in high pressure drop circuits) may cause very poor energy performance of the HVAC plant so increasing the primary energy consumption. This paper presents an example of such an issue; the analysis of the energy and economic performance of the recently retrofitted HVAC plant of the Basilica Palladiana in Vicenza (North-East of Italy) is here presented. The paper deals with the many drawbacks, the technical solutions proposed by the Authors and the measured energy performance improvement after the accomplishment of the proposed actions.

2. The building and the HVAC plant

The historical building, designed by Andrea Palladio in the 16th century, is sited in one of the most famous square in the centre of Vicenza. It was deeply retrofitted between 2007 and 2012 to make it a cultural centre for the city (Figure 1). The new HVAC plant is an open loop water source heat pump system using underground water as heat source (heat pump operation) or as heat sink (chiller operation) ([2] [3] [4] [5] [6] [7]). Two wells were built (distance about 50 m) to produce and inject the water from the layer (40 m deep). The four thermal users of the heated/chilled water are:

- the showroom (mixed hydronic/aeraulic plant with radiant floor and air handling units coils);
- the offices (hydronic plant with fan-coils);
- the stores (hydronic plant with fan-coils).

Figure 1. The Basilica Palladiana: external view (left) and the showroom (right)

The use of underground water in heat pump plants is strictly regulated (and till 2015 forbidden) in the territory of Vicenza for environmental reasons. So the realization of the plant here described was allowed by local Authority to have a benchmark for the use of underground water for air conditioning uses. For such reasons the installation of a data logging system was prescribed in order to evaluate the energy and environmental performance of the HVAC plant. The underground water is available at 14 °C and used as heat source (during heating season to supply hot water at 45 °C, return at 40 °C) or as heat sink (during cooling season to supply cold water at 7 °C, return at 12 °C). The project provides three main circuits (Figure 2):

- underground water layer circuit: it is an open loop with the pumps to circulate the well water (two pumps, one backup, 18 kW nominal power at 70 m water column head each, controlled by inverter). Sand filters are enclosed as well. This circuit exchanges heat with primary circuit by means of two stainless steel heat exchangers (one backup), 700 kW nominal power each. The control logic is set up to operate (by an inverter) the production well pump as a function of a set point of the condensation/evaporation water circuit;
- primary circuit: it allows the heat exchange between the underground water and the water of the evaporator/condenser circuit of the heat pump/chiller avoiding the direct use of the former. This is done by two pumps (cooling pump in Figure 2, one backup, constant flow rate – 90 m^3 h^{-1} –, 5 kW power, 12 m head). The heat pump/chiller is an electrical water/water one, six scroll compressors set up in two parallel circuits, R410A as refrigerant; the compressors operate by on/off and step by step logic. Table 1 reports the performance at full load as a function of inlet and outlet water temperatures. The chiller is equipped with a heat exchanger to recover the heat of condensation during the cooling season to feed the post-heating coils in the air handling units (AHU). Such a system revealed to be not suitable due to the high variability of the demand that caused very frequent shutdowns of the chiller;
- users circuit: hot (45 °C) or cold (7 °C) water exiting the heat pump/chiller feeds a storage tank (2000 l) that is connected by two pumps (one backup, constant flow rate – 85 m^3 h^{-1} –, 3 kW, 8 m head). Finally, a series of pumps, controlled with inverters, supplies hot/cold water to each user circuit.

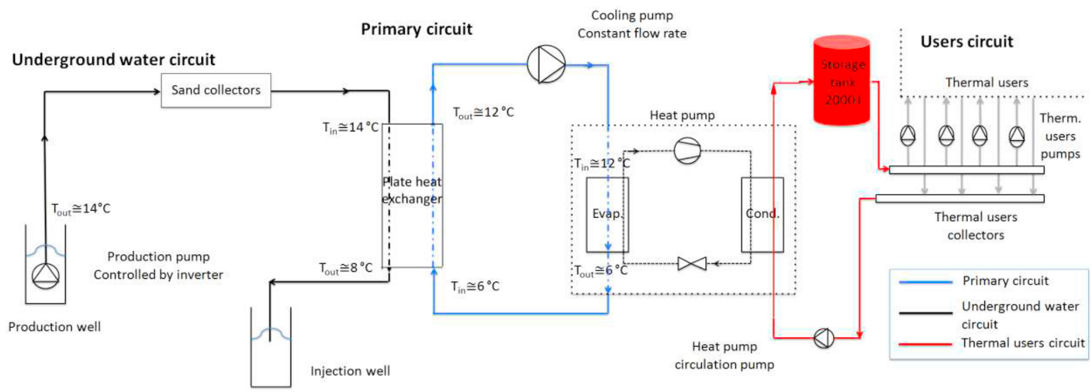


Figure 2. Scheme of the underground water open loop heat pump plant with the three main circuits (the scheme refers to the operation in heating mode as heat pump)

Table 1. Nominal data of the ground water heat pump/chiller in function of the inlet water temperatures (cond=condenser; ev=evaporator; eq=equipment)

T_{cond} in [°C]	15		18		25		35		45	
T_{cond} out [°C]	22.5		25.5		32.5		42.5		52.5	
Cooling power [kW]	690	784	671	780	625	727	553	665	472	553
Thermal power [kW]	792	894	780	891	752	856	713	807	676	758
Electric power [kW]	102	109	109	111	128	129	161	162	204	206
T_{ev} in [°C]	10	15	10	15	10	15	10	15	10	15
T_{ev} out [°C]	5	10	5	10	5	10	5	10	5	10
Equipment Energy Efficiency Ratio (EER_{eq})	6.8	7.2	6.2	7.0	4.9	5.6	3.4	4.1	2.3	2.7
Equipment Coefficient Of Performance (COP_{eq})	7.8	8.2	7.2	8.0	5.9	6.6	4.4	5.0	3.3	3.7

The showroom is heated by radiant floor as water terminal unit and displacement ventilation with very low velocity diffusers fed by two air handling units (15000 m^3 h^{-1} each). A smaller size air handling unit (1500 m^3 h^{-1}) supplies the ventilation of the ticket office. The plant is connected to the local district heating network (heating backup) by a 600 kW (nominal thermal power) plate heat exchanger. The backup service during cooling season is made by a water/water electrical chiller (rated cooling power 330 kW, rated electrical power 66.9 kW, Energy Efficiency Ratio (EER) 4.95). This chiller feeds chilled water directly to users collectors and transfers the condensation heat to the primary circuit. Finally, direct expansion air conditioners (CDZ) serve two technical rooms (transformers and general switchboard and Uninterruptible Power Supply (UPS) rooms): they are cooled by the ground water circuit as well.

3. Energy monitoring: first year of operation of the HVAC plant

Due to the experimental characteristics of the HVAC plant (at least in Vicenza province), the local Authority demanded the installation and the continuous operation of a monitoring and data logging system to evaluate:

- the underground water flow rates and temperature variation due to heat exchange both at production and injection well;
- the chemical and physical characteristics of underground water both at production and injection well (this specific monitoring task was assigned to a geology society);
- the energy balance, consumption and performance of the whole plant.

The data logging and monitoring system did not operate during the first year of operation of the HVAC plant, so data till March 2014 are missing. Table 2 reports the main parameters monitored and the relative log frequency.

Table 2. Monitored data and data logging frequency

Parameter	Definition	Unit	Freq.*
E_{prod}/E_{inj}	Produced/injected thermal energy	MWh_{th}	10 min
$T_{out-well}$	Production well water outlet temperature	°C	10-60 min
$T_{in-well}$	Production well water inlet temperature	°C	10-60 min
Q_{well}	Production well water flow	m^3	10 min
E_{el-hp}	Electric energy consumption by heat pump/chiller	kWh_{el}	15 min
$E_{el-well}$	Electrical energy consumed by underground water circuit pumps	kWh_{el}	15 min
$E_{el-prim}$	Electrical energy consumed by primary circuit pumps	kWh_{el}	15 min
$E_{el-chil}$	Electrical en. consumed by backup chiller	kWh_{el}	15 min
E_{el-cdz}	Electrical energy consumed by direct expansion air conditioners (CDZ)**	kWh_{el}	15 min

* Since August 2015 data logging frequency is 15 min for all the monitored parameters.
** These are two underground water condensed air conditioners to cool the electrical room and UPS room (we use CDZ as achronym). Nominal data: cooling power=10.3 kW, electrical power=2.67 kW, COP=3.22, EER=3.9.

3.1. First operating periods: summer 2014 and winter 2014/2015

The first period of the monitoring activity was April-September 2014. The analysis of the main data reported in Table 3 reveals a poor energy performance due to some important drawbacks, here some major remarks are synthesized.

Table 3. Results of the first monitoring period (cooling period 2014)

Period	$E_{el\text{-}well}$	$E_{el\text{-}hp}$	$E_{el\text{-}prim}$	$E_{el\text{-}cdz}$	$E_{el\text{-}chil}$	$E_{el\text{-}tot}$	E_{inj}	E_{useful}	$E_{useful\text{-}dh}$	EER_{eq}	EER_{tot}	Q_{well}	Q_{wat}
2014	kWh_{el}	kWh_{el}	kWh_{el}	kWh_{el}	kWh_{el}	kWh_{el}	kWh_{th}	kWh_{cool}	kWh_{th}	-	-	m^3	$l\ kWh_{cool}^{-1}$
Apr	457	3190	2386	4190	344	10567	21500	16660	24840	5.22	1.58	2601	139
May	180	856	2384	1094	345	4859	6000	3845	1540	4.49	0.79	1369	233
Jun	116	24	2837	1557	297	4831	1400	0	0	0.00	0.00	1057	311
Jul	129	0	2931	1753	306	5119	1200	0	0	-	0.00	907	232
Aug	517	3675	2932	1748	307	9179	22800	16152	0	4.40	1.76	3311	165
Sep	239	1218	2843	1434	297	6031	5200	1582	0	1.30	0.26	1191	256
Total	1638	8963	16313	11776	1896	40586	58100	38239	26380	4.27	0.94	10436	223

- Electrical energy consumptions of the primary circuit pumps were extremely high (3000 kWh_{el} per month, 44 % of the total electricity consumption). This was due to the unfavourable control logic of the pumps operating 24 h a day also in periods with very low or null cooling load. Such a situation was mainly caused by the fact that the CDZ need to be cooled by underground water in every season, so they are responsible for 22 % of the total energy rejected into the ground water circuit in the summer period.
- The backup chiller consumed 300 kWh_{el} per month constantly only for stand-by operation.
- Electrical consumption of the CDZ was quite constant in the range 1400-1700 kWh_{el} per month. The system has decidedly an inefficient operation mode when the only cooling load is the CDZ.
- The electrical consumptions in the whole period April-September 2014 was quite high (28800 kWh_{el} excluding the backup chiller), considering that the HVAC plant did not operate during the hottest period (June and July). The high consumption was especially due to the continuous operation of the primary circuit pumps also when the HVAC plant was off.
- Energy performance indexes (EER_{eq}=energy efficiency ratio of heat pump/chiller equipment; EER_{tot}=energy efficiency ratio of the whole plant that is considering the auxiliary needs) resulted to be very low: EER_{eq}=4.27 instead of a predicted value of 5 is not dramatically different, but EER_{tot}=0.94 is unbelievably low.
- Underground water consumption index Q_{wat} (defined as the ratio between the underground water produced and the useful cooling energy) was higher than designed: 223 l kWh_{cool}^{-1} instead of 172 l kWh_{cool}^{-1}. The flow rate control capacity was not sufficient (note the consumption by 1000 m^3 $month^{-1}$ during the off operation periods). The large ground water flow rate with limited ΔT was due to a ground circuit pumps oversizing (100 kPa was the real head at the maximum flow rate (80 m^3 h^{-1}) against 500 kPa nominal head of the two installed pumps). This caused a very discontinuous operation of the production well pumps with poor modulation capacity and very high on-off frequency (20-30 on-off per day also during very low cooling needs periods).

The first heating period monitored (from 15th October 2014 till 15th April 2015) confirmed the previous analysis. During this heating period some technical problems determined the stop of the heat pump and the use of the district heating as the only heating source. One of the main causes was the obstruction of the injection well due to bubbling and excessive oxygenation of water that caused metals precipitation. The main data are reported in Noro et al. [7].

The results of the first two monitoring periods revealed that potential improvements in energy performance could be obtained if some technical interventions described in the next section 4 (the most of them obtainable by modifications in the control logic of the plant) would be adopted. The further sections 5 and 6 report on the effects of these actions analyzing the further heating period (winter 2015/2016) and cooling periods (summers 2015 and 2016).

4. Technical interventions after the first monitoring periods

Because of the very poor energy performance and technical problems detected during the first period of operation, in October 2014 the local Authority approved a series of technical interventions suggested by the Authors (realized between April and August 2015):

- a tube extension in the injection well in order to avoid bubbling and excessive water oxygenation that could cause metals precipitation and following well obstruction (frequently occurred during 2014 and 2015) (Figure 3). A deep video-inspection and cleaning activity on the well were carried on in August 2015;
- inserting two sensors (temperature and piezometer) in the extraction well in order to monitoring the extraction process;
- inserting a balancing valve to optimize the pumps field operation and to limit the maximum flow rate of ground water;
- modifying the operation logic of the production well pumps by increasing the operation range and making the second pump operate under inverter as well.

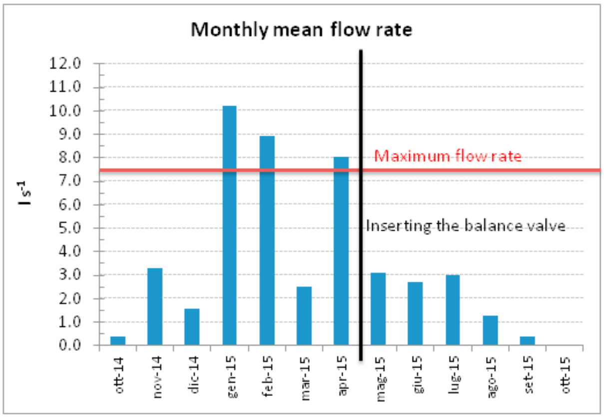
Figure 3. Insertion of a 12 m length tube inside the injection well to favour the injection of water and thus avoiding bubbling and excessive oxygenation

After the realization of these three interventions some tests were carried out in order to check the real water absorption capacity of the injection well. The maximum value of water flow rate deliverable continuously resulted to be only 27 m^3 h^{-1} (7.5 l s^{-1}). Figure 4 confirms that such a value was not exceeded after the insertion of the balance valve. Then the operation of the production well pumps was stabilized. Of course a lower water flow rate limits the maximum thermal power exchangeable by the plant with the underground water and so with the building. The evaluations of the original project were lacking. Then a TRNSYS simulation was carried out: the evaluated heating and cooling peaks were respectively 400 kW_{th} peak power for heating [8] and 600 kW_{cool} for cooling [9]. These values are consistent with the recorded peaks of 315 kW_{th} in heating operation and 484 kW_{cool} in cooling. The new deliverable flow rate considering the nominal underground water temperature and its ΔT is acceptable for heating, whereas it appears low for peak cooling and a suitable solution shall be identified for the injection well. A partial solution can be to use higher ΔT in cooling operation, even though with a little penalization in heat exchange. The installed heat pump capacity of around 700 kW is surely exceedingly oversized with respect to the peak load. The equipment may be supposed to have been selected as a function of cooling load, again oversized but not as much (about 700 kW_{cool} against an evaluated peak of 600 and a surveyed peak in these years less than 500 kW_{cool}). Particularly the heating operation is strongly penalized by a nominal capacity more than double than the maximum demand. Probably a different equipment selection with two heat pumps with half than the chosen capacity would have been preferable.

Further interventions adopted during summer 2015 were:

- modifying the condensation heat recovery system of the ground water chiller, connecting directly the primary circuit to the post-heating coils of AHUs (Figure 5). This intervention was necessary because the condensation heat recovery system revealed to be not suitable due to the high variability of the demand, to the oversizing of the heat exchanger, and to the absence of a thermal storage in this circuit. Such drawbacks caused very frequent shutdowns of the chiller during the first period of operation;

- installing a separate dry-cooler to dissipate the CDZ condensation heat and modifying the control logic of the primary circuit pumps making them operate strictly connected to the real users' cooling needs (Figure 5).



(a)

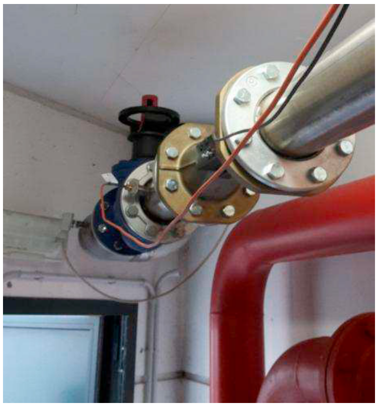

(b)

Figure 4. Water flow rate of the production well before and after the insertion of the balance valve (a); picture of the intervention (b)


(a)


(b)

Figure 5. Derivation in the primary circuit for the heat recovery for post-heating in AHUs during cooling season (a); dry-cooler installation for CDZ (b)

The main objectives of the implementation of such interventions were:

- reducing the underground water withdrawal in terms of both total and instantaneous flow rate by modulating the pumps frequency operation as often as possible;
- enhancement of the energy performance of the HVAC plant by reducing the electrical energy consumption of the equipment (optimizing operation conditions and timing) and increasing the condensation heat recovery during cooling season;
- balancing the heat exchange with ground water between heating and cooling seasons.

5. Further operation periods: energy analysis

During the period April-August 2015 many of the improvement interventions just described were realized. Figure 6 to Figure 8 report the main results of the monitoring activity useful to do a comparison between the three cooling seasons (summers 2014, 2015 and 2016) and the two heating seasons (winters 2014/2015 and 2015/2016) from the energy point of view.

It has to be highlighted that comparing absolute values of energy consumption is not so meaningful as very different useful energy needs and plant operation modes were recorded during the different periods. During summer 2015 the Basilica was much longer used than in summer 2014 due to the "Tutankhamon Caravaggio Van Gogh" exhibition from April till July 2015: very strictly indoor conditions were requested by this exhibition (20 °C temperature, 50 % humidity) (Figure 6). Afterwards, other exhibitions opened with more "comfortable" indoor conditions (indoor air temperature 26 °C, humidity 50 %). During 9th-12th May 2015 underground water heat pump system was off due to injection well obstruction; from 12th May 2015 the plant was full operating with injection well flow rate limited to 25.2 $m^3 h^{-1}$ and injection well was by-passed by a drainpipe to a drain well. During 3rd-5th August 2015 maintenance activity on injection well (cleaning, video-inspection and flow rate tests) was done. Since 6th August 2015 the plant was full operating with injection well flow rate limited to 27 $m^3 h^{-1}$, the injection well by-pass was removed and the condensation heat recuperator of the heat pump/chiller and the dry-cooler for the CDZ condensation heat exchange were fully operating.

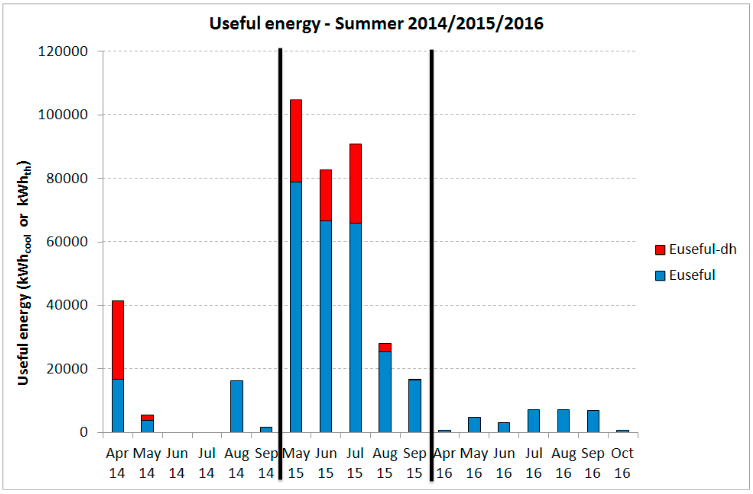


Figure 6. Useful energy needs of the Basilica supplied by the chillers - ground water, CDZ and backup - (E_{useful}) and by the district heating for the post-heating of air in the AHUs ($E_{useful-dh}$): comparison of the three monitored cooling seasons (summers 2014-2015-2016)

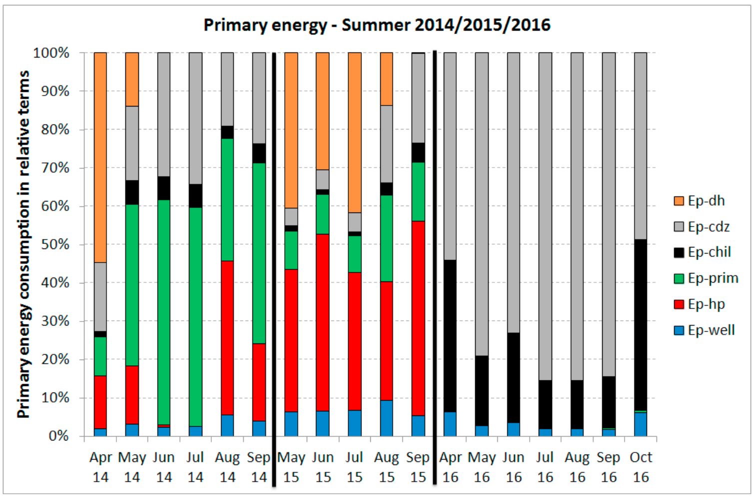


Figure 7. Primary energy consumptions of the main equipment: comparison of the three monitored cooling seasons (summers 2014-2015-2016)

Comparing summer 2014 to summer 2015, electricity consumption increased by 30000 kWh_{el} only (+73 %), practically due to the ground water chiller increased use (+32500 kWh_{el}), despite operation time of the ground water chiller strongly increased (+324 %) due to higher cooling needs of the Basilica (Figure 6). Accordingly, in terms of primary energy there was a lower relative weight of electrical energy consumption of the auxiliaries (pumps of the production well and primary circuits, CDZ and backup chiller) (58 % in 2014, 27 % in 2015) against the higher relative consumption of the ground water chiller (17 % vs 39 %, Figure 7). Table 4 reports the factors for the conversion to primary energy of electrical energy (mean global efficiency was assumed to be 46 % (AEEGSI, 2008)), natural gas (lower heating value fixed at 8250 kcal Sm^{-3}), and district heating (considering a mean thermal efficiency of 90 %).

It is apparent in Figure 7 the very high weight of the district heating use in summer for post-heating because of no operation of heat recovery system, and the very positive effect in reducing it by the direct connection of the primary circuit to the post-heating coils in AHUs realized in August 2015.

Table 4. Factors for conversion to primary energy ([10])

Energy vector	unit	toe $unit^{-1}$
Electrical energy	kWh	1.870E-04
Natural gas	Sm^3	8.250E-04
District heating	kWh	9.556E-05

During December 2015 the injection well was obstructed newly despite the recent cleaning. Actually the injection well can receive a very low water flow rate (around 3 m^3 h^{-1}), definitely insufficient to let the heat pump operate. Then from December 2015 the underground water heat pump system has been turned off. The utilization of the Basilica for exhibitions was very limited in 2016 summer and the ground water chiller was fortunately not needed. At the same time, the use of air free-cooling to reduce the indoor air temperature when necessary was sufficient. In any case, it is worth to highlight that the intervention based on installing a separate dry-cooler to dissipate the CDZ condensation heat and modifying the control logic of the primary circuit pumps allowed a very appreciable energy and economic saving. Comparing the summer 2014 vs 2016 with similar useful energy demands (Figure 6), the electrical energy saving was nearly 18000 kWh_{el} (about 3500 €) against an investment cost of about 7000 €.

Because of the injection well block from December 2015, it is difficult to compare energy performance of the plant between the two heating seasons: 2014/2015 (pre technical interventions, section 4) and 2015/2016 (post interventions). Nevertheless it is worth to state that against a slight decrease of the total useful energy needs of the Basilica (-14 %) the electrical energy consumption of the auxiliaries (primary circuit pump, CDZ and backup chiller) strongly decreased (-82 % in terms of primary energy). This was due to the new control logic of the primary circuit pumps and the installation of the dry-cooler.

Looking at the energy balance and performance, against a strong increase of cooling needs (+215000 kWh_{cool}, +562 %, Figure 6), the increase of underground water production was of only 18000 m^3 (+175 %) in summer 2015 with respect to 2014. This implied a strong decrease of the underground water consumption index from 223 to 108 l kWh_{cool}^{-1} (Figure 8). The same figures in the August-September period (with more similar cooling needs between 2014 and 2015) highlight a greater improvement as, against an increase of energy cooling needs by 24200 kWh_{cool} (+137 %), water consumption substantially remained constant and electrical consumption reduced by 7 %.

The comparison between the two heating seasons it is not worth because of the use of district heating for large part of winter 2015/2016. The comparison limited to the only two months with heat pump operating (October and November 2015) reveals a similar reduction of the specific underground water consumption (from 421 to 215 or 277 l kWh_{th}^{-1}, between -49 % and – 34 %).

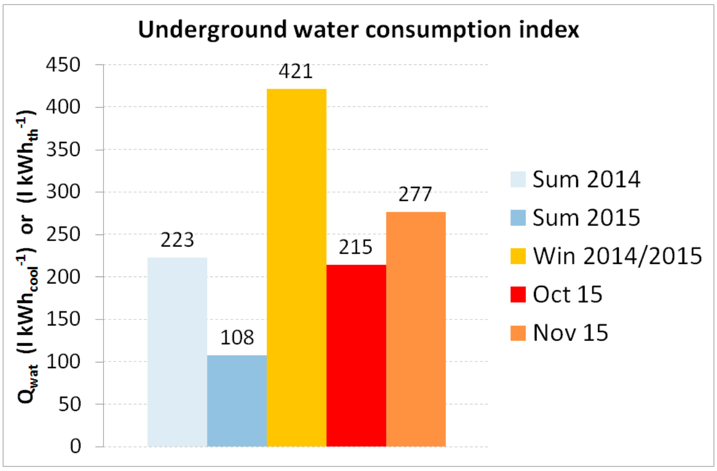


Figure 8. Underground water consumption index: comparison of the whole monitored period

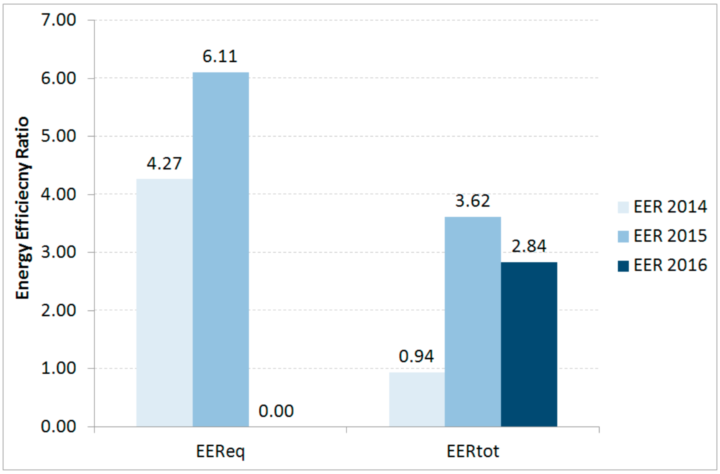


Figure 9. Energy performance indexes for the ground water heat pump only (subscript "eq") and for the whole HVAC plant (subscript "tot"): comparison of the three cooling periods

In terms of global performance indexes, only the two cooling seasons 2014 and 2015 can be correctly compared. In this case EER_{eq} and above all EER_{tot} (calculated as the ratio between useful energy and the total HVAC plant electrical energy consumption) greatly improved (the latter by 280 %) (Figure 9). This impressive result is mainly due to the improved efficiency in using the pumps of underground water circuit and primary circuit thanks to the technical interventions previously described. The decrease of EER_{tot} during summer 2016 is still due to the stop of the ground circuit. For this reason and the consequent utilization of district heating for large part of winter 2015/2016, the two heating periods are not comparable at all.

6. Further operation periods: economic analysis

It is worth to present a comparison between the energy cost of the operation of the Basilica's HVAC plant, considering the different energy performance pre and post technical interventions previously described, and other "traditional" alternatives for heating and cooling.

Figure 10 and Figure 11 report the specific energy cost for the climatization of the Basilica (no maintenance costs are included). This is the cost of the useful thermal (winter) and cooling (summer) unit of energy delivered to the

Basilica's rooms. The figures depict the bill for the different heating and cooling seasons in comparison with "more traditional" alternatives. For cooling (Figure 10) a reference solution with an air-water chiller with a mean EER_{tot}=2.70 was considered (electrical energy cost of 0.188 € kWh_{el}^{-1}). The existing plant according to Figure 10 is profitable only if it operates correctly as in summer 2015 when the specific energy cost is 52.3 € MWh_{cool}^{-1}, lower than the reference solution (70 € MWh_{cool}^{-1}) and lower than the plant operating as before the technical interventions (summer 2014, 200.6 € MWh_{cool}^{-1}).

The specific energy cost of the plant operating in winter 2014/2015 and 2015/2016 is compared to a traditional (seasonal mean efficiency equal to 80 %) and a condensing (seasonal mean efficiency equal to 90 %) natural gas boiler (cost of natural gas of 0.854 € Sm^{-3}). The comparison is extended also to the district heating solution (cost 0.135 € kWh_{th}^{-1}), and finally to an air-water heat pump (COP_{tot}=2.50) (Figure 11). In this case the lowest specific cost could be obtained using the air-water heat pump (75.2 € MWh_{th}^{-1}). The existing plant in 2014/2015 winter operation period (so before the technical interventions) allows a slightly higher specific cost (83.1 € MWh_{th}^{-1}). The higher cost of the following operation period (114.4 € MWh_{th}^{-1} for winter 2015/2016) is due to the stop of the ground water heat pump from December 2015 with prevalent heat supply in the coldest months by district heating. The lower specific cost than district heating (114.4 against 135.0 € MWh_{th}^{-1}) must be attributed to the two months (October and November 2015) when the heat pump operated correctly. The specific cost in these two months was the lowest (respectively 69.6 and 75.0 € MWh_{th}^{-1}).

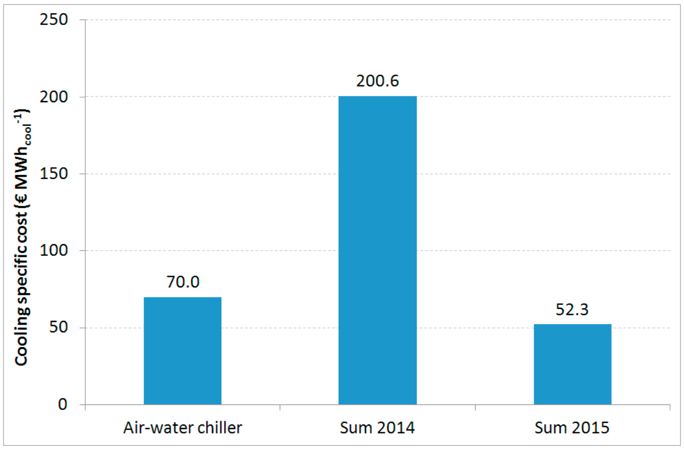


Figure 10. Specific useful energy cost: comparison of the monitored cooling seasons with the "air-water chiller" reference alternative

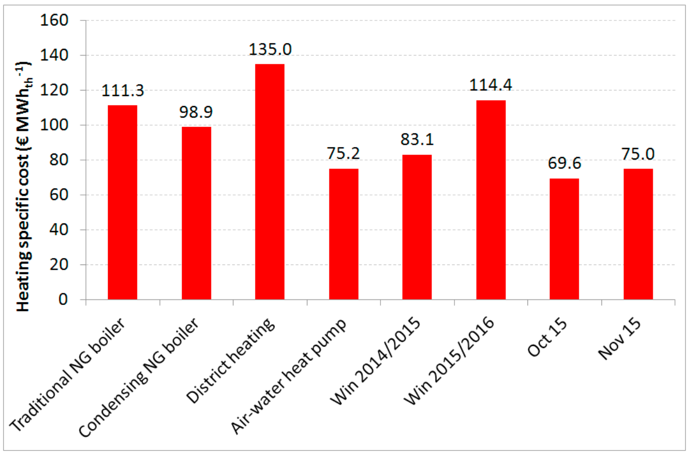


Figure 11. Specific useful energy cost: comparison of the two monitored heating seasons (winters 2014/2015 and 2015/2016) with other heating reference alternatives

7. Conclusions

The monitoring activity of the HVAC plant of the Basilica Palladiana in Vicenza, based on an underground water open loop heat pump, revealed very poor energy performance with respect to the design. The main reasons were an inefficient control logic and a general oversizing of many pieces of HVAC equipment, first of all the pumps of the underground water and primary circuits. Other examples are an oversizing of the thermal/cooling power of the ground water heat pump/chiller, particularly in heating mode, and of the total recovery heat exchanger. Also other drawbacks were highlighted by the Authors and technical interventions were suggested to the local Authority. Some interventions were realized during summer 2015 allowing an impressive improvement of energy performance of the plant with respect to the previous summer: energy efficiency ratio of the total plant increased by 280 % while underground water consumption was reduced by 51 %. Such an improvement was confirmed also by the only doubling of the total primary energy consumption during the cooling season 2015 with respect to 2014 even if the cooling needs of the building increased by more than six times. A strong reduction (in relative terms) of the pumps primary energy consumption was detected (18 % and 33 % of the total consumption respectively in 2015 and 2014). The block of the injection well (sometimes during 2014 and 2015, and continuously from December 2015) caused a more expensive use of district heating during the heating season 2015/2016 with respect to 2014/2015 and a serious problem for heat dissipation during the cooling season. An alternative solution is actually under evaluation by the Vicenza local Authority in order to direct the water into the Retrone river, flowing nearby, instead of using the injection well, whose utilization appears definitely compromised. The monitoring activity will continue in the future to evaluate the effectiveness of the interventions on energy performance of the plant.

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