Problems and solutions of an underground water source heat pump system for a historical valuable building: an energy analysis

Marco Noro[#1], Andrea D'Ascanio[*2], Renato Lazzarin[#3]

[#]*Department of Management and Engineering, University of Padua*
stradella San Nicola, 3 – 36100 Vicenza (VI) - Italy

[1]marco.noro@unipd.it

[3]renato@gest.unipd.it

[*]*Studio Centro Sicurezza Ambiente srl*
via dell'Economia, 131- 36100 Vicenza (VI) - Italy

[2]andrea.dascanio@scsa.it

Abstract

During 2007-2012 period a very important historical valuable building in the centre of Vicenza was retrofitted by both structural and energy/mechanical plants points of view. Particular attention was paid to the heating, ventilation and air conditioning plant; it was retrofitted installing an underground water source electrical compression heat pump.

A monitoring and data logging system was provided in order to log many data concerning energy flows and the main operating parameters. In this paper the analysis of the performance data of the 2014 and 2015 cooling seasons and the 2014/2015 heating seasons is developed. Such monitoring activity is also requested by the local Authority in order to verify both the utilization of underground water and the energy performances of the HVAC plant.

The analysis reveals that, even if appreciable energy savings with respect to more traditional plants were expected, some critical aspects determined poor energy performances of the plant in the first operation period. This work presents such issues and the technical solutions suggested by the Authors, recently implemented to improve the energy performances of the plant. Data of the first period after the technical optimization are also reported and analyzed.

Keywords: underground water – renewable energy – energy monitoring – hydronic heat pump

1. Introduction

Energy saving in historic building is a very urgent issue in Italy (one of the countries with the widest artistic heritage in the world). Passive retrofitting interventions such as external walls thermal insulation or solar shielding are often unfeasible due to architectonic and aesthetic restrictions. Among active energy efficiency interventions one of the most potentially effective is the use of heat pumps in Heating, Ventilation and Air Conditioning (HVAC) plants. As it is well known, the lower the temperature difference between the heat source/sink (respectively for heating and cooling operation) and the indoor thermal energy distribution system, the greater the energy efficiency of the plant. One of the most favourable heat source/sink is underground water. This is widely available in the Po Valley (North Italy) even if local regulations often do not easily allow the use for energy purposes. Despite potential very high energy efficiency, the real performance of operating plants has to be carefully monitored. The underestimation of energy consumption of some auxiliary systems (for example the pumps, even in high pressure drop circuits) may cause very poor energy performance of the HVAC plant so increasing the primary energy consumption. The analysis of the energy performance of the recently retrofitted climatization plant of the Basilica Palladiana in Vicenza (North-East of Italy) is a very representative example. This paper deals with the many drawbacks, the technical solutions proposed by the Authors and the first measured energy performance improvement.

2. Description of the building and the HVAC plant

The historic building was designed by Andrea Palladio in the 16th century, 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. 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) [1] [2] [3] [4] [5]. 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).

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 45-40 °C) or as heat sink (during cooling season to supply cold water at 7-12 °C). The project provides three main circuits (Fig. 1):

- 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 Fig. 1, 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 an heat exchanger to recover condensation heat during the cooling season; however such system is not suitable because of the high variability of the users circuit flow rate (post-heating coils in air handling units) that caused very frequent shut down of the chiller;

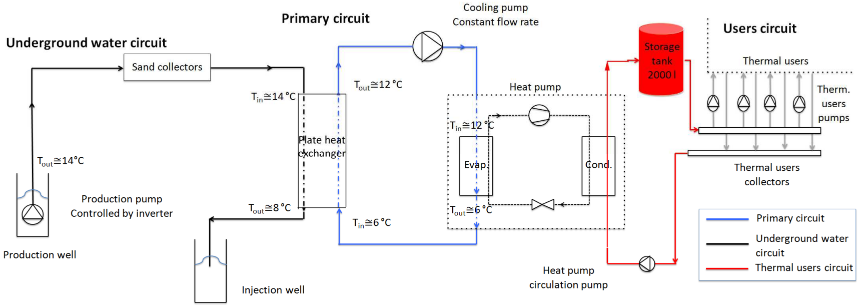

Fig. 1 Scheme of the underground water open loop heat pump plant with the three main circuits

Table 1 Nominal data of the 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
EER_{eq}	6.8	7.2	6.2	7.0	4.9	5.6	3.4	4.1	2.3	2.7
COP_{eq}	7.8	8.2	7.2	8.0	5.9	6.6	4.4	5.0	3.3	3.7

- 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, there are pumps, controlled with inverters, to bring hot/cold water to each user circuit.

The showroom is set up 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, EER=4.95). Such chiller feeds chilled water directly to users collectors and transfer 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 of the HVAC plant

As this is an experimental (for the Vicenza territory) HVAC plant, 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[1];
- 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
$T_{out\text{-}well}$	Production well water outlet temperat.	°C	10-60 min
$T_{in\text{-}well}$	Production well water inlet temperat.	°C	10-60 min
Q_{well}	Production well water flow	m^3	10 min
$E_{el\text{-}hp}$	Electric en. consum. by heat pump/chiller	kWh_{el}	15 min
$E_{el\text{-}well}$	Electrical energy consumed by underground water circuit pumps	kWh_{el}	15 min

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[1] This is a specific monitoring task assigned to a geology society.

$E_{el\text{-}prim}$	Electrical energy consumed by primary circuit pumps	kWh_{el}	15 min
$E_{el\text{-}chil}$	Electrical en. consumed by backup chiller	kWh_{el}	15 min
$E_{el\text{-}cdz}$	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. Cooling period 2014

The first period of the monitoring activity was April-September 2014. Major remarks on the main results reported in Table 3 are:

- 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 even in period with very low or null cooling load. Such 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. It is clear that the system has an inefficient operation mode when the only cooling load is the CDZ;

- considering that the HVAC plant did not operate during the hottest period (June and July), the electrical consumptions in the whole period April-September 2014 is quite high (35500 kWh_{el} excluding the backup chiller), especially due to the continuous operation of the primary circuit pumps even 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: $EER_{eq}=3.23$ instead of a predicted value of 5; $EER_{tot}=1.21$ strongly penalized by low partial load operation of the plant;

- underground water consumption index Q_{wat} (defined as the ratio between the underground water produced and the useful cooling energy) was higher than the designed one: 197 l kWh_{cool}^{-1} instead of 172 l kWh_{cool}^{-1}. The flow rate regulation capacity was not sufficient (note the consumption by 1000 m^3 $month^{-1}$ during the off operation periods). The very discontinuous operation of the production well pumps with poor modulation capacity and very high on-off frequency (20-30 on-off per day even during very low cooling needs periods) was one of the main problems.

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

Period	$E_{el\text{-}well}$	$E_{el\text{-}hp}$	$E_{el\text{-}prim}$	$E_{el\text{-}chil}$	$E_{el\text{-}cdz}$	$E_{el\text{-}tot}$	E_{inj}	E_{inj} [+]	E_{useful}	EER_{eq}	EER_{tot}	Q_{well}	Q_{wat}
	kWh_{el}	kWh_{el}	kWh_{el}	kWh_{el}	kWh_{el}	kWh_{el}	kWh_{th}	kWh_{th}	kWh_{cool}	-	-	m^3	$l\ kWh_{cool}^{-1}$
11/04/14 – 04/05/14 [*]	457	3190	2386	3440	4190	10473	21500	20100	16660	4.84	2.65	2601	139
05/05/14 - 31/05/14 [**]	180	856	2384	345	1094	4859	6000	4954	3845	3.47	1.39	1369	233
01/06/20 – 30/06/14 [***]	116	24	2837	297	1557	4831	1400	-	-	-	-	1057	311
01/07/14- 31/07/14 [***]	129	-	2931	306	1753	5119	1200	-	-	-	-	907	232
01/08/14- 31/08/14 [**]	517	3675	2932	307	1748	9179	22800	20134	16152	4.06	2.17	3311	165
01/09/14- 30/09/14 [*]	239	1218	2843	297	1434	6031	5200	3097	1582	1.04	0.34	1191	256
Total	1639	8962	16312	1803	8586	37302	58100	45526	34760	3.23	1.21	10435	197

[*] Period with cooling needs with no critical outdoor conditions.

[**] Period with scarce cooling needs due to limited use of building.

[***] Period with no cooling needs.

[+] Without thermal energy exchanged with underground water by CDZ.

3.2. Technical interventions after the first monitorig period

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):

- the extension of tube in the injection well in order to avoid excessive oxygenation and bubbling of water that could cause metals precipitation and following well obstruction (frequently occurred during 2014 and 2015);
- inserting two sensors and a balancing valve in the production well to verify the temperature and piezometric gradients and to regulate and optimize the field operation of pumps;
- modifying the operation logic of the production well pumps by increasing the operation range and making the second pump operate by the inverter as well;
- modifying the condensation heat recovery system of the ground water chiller and the backup chiller connecting directly the primary circuit to the post-heating coils;
- 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;

The main objectives of the implementation of such interventions were:

- reducing the underground water production in terms of both total and instantaneous flow rate by modulating the pumps frequency operation as much as possible;
- enhancement of the energy performance of the HVAC plant by reducing the electrical energy consumption of the equipment~~s~~ (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.

3.3. Heating period 2014/2015

The first heating period monitored was from 15th October 2014 till 15th April 2015, anyway before the implementation of the technical improvement interventions described in the previous section. During this heating period some technical problems with the heat pump compressors and with the injection well determined the stop of the heat pump and the use of the district heating as the only heating source. The main data are reported in Table 4 and Table 5. Major notes are here reported:

- the heat pump was mainly used during January and February (its electrical energy consumption reached 80 % of the total);
- consumption of the auxiliaries (mainly the primary circuit pump) was constant (so higher in relative terms) even with a low or null heating load;

Table 4 Energy results of the second monitoring period (heating period 2014/2015) (dh=district heating)

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_{prod}	E_{useful}	$E_{useful\text{-}dh}$ [§]	$E_{useful\text{-}tot}$	COP_{eq}	COP_{tot}
	kWh_{el}	kWh_{el}	kWh_{el}	kWh_{el}	kWh_{el}	kWh_{el}	kWh_{th}	kWh_{th}	kWh_{th}	kWh_{th}	-	-
15/10/14-31/10/14 [+]	86	309	1614	609	165	2783	3400	3709	0 (0%)	3709	-	-
01/11/14-18/11/14 [+]	961	0	2845	768	281	10245	4100	4100	20 (0%)	24010	-	-
19/11/14-30/11/14 [**]		5390					14500	19890			3.69	2.67
01/12/14-05/12/14 [**]	501	2796	2945	487	292	7143	6800	9596	98270 (89%)	110694	3.43	2.60
06/12/14-31/12/14 [*]		123					2700	2823			-	-
01/01/15-08/01/15 [*]	3276	0	2955	459	294	33463	0	0	41660 (31%)	132539	-	-
09/01/15-31/01/15 [++]		26479					64400	90879			3.43	2.85
01/02/15-19/02/15 [++]	2707	29282	2666	522	264	35556	46900	76182	23920 (24%)	101216	2.60	2.26
20/02/15-28/02/15 [*]		115					1000	1115			-	-
01/03/15-25/03/15 [*]	799	133	2942	737	292	7635	4800	4933	76600 (85%)	89865	-	-
26/03/15-31/03/15 [**]		2732					5600	8332			3.05	2.08
01/04/15-15/04/15 [**]	1775	5691	1054	321	114	8955	12100	17791	0 (0%)	17783	3.13	2.09
Total	10107	73050	17020	3903	1702	105781	166300	239346 (49.9%)	240470 (50.1%)	479817	3.28	2.39

[*] Period with underground water open loop heat pump system off due to maintenance.

[**] Period with heating needs with limited use of building or with no critical outdoor conditions.

[+] Period with no heating needs.

[++] Period with full heating needs.

[§] District heating consumption data were available on a monthly basis only so with no possibility to determine which periods such service was actually used.

Table 5 Water production data during the second monitoring period (heating period 2014/2015)

Period	Q_{well}	$Q_{well\text{-}avg\text{-}day}$	$\Delta T_{well\text{-}avg}$[§]		Q_{well}	Q_{wat}
	m^3	m^3	°C		m^3	$l\ kWh_{th}^{-1}$
15/10/14-31/10/14 [+]	689	22	4.2		689	-
01/11/14-18/11/14 [+]	8497	283	1.9		552	-
19/11/14-30/11/14 [**]					7945	399
01/12/14-05/12/14 [**]	4252	137	1.9		3758	392
06/12/14-31/12/14 [*]					493	-
01/01/15-08/01/15 [*]	27364	883	2.0		0	-
9/01/15-31/01/15 [++]					27364	301
01/02/15-19/02/15 [++]	21568	770	1.9		21364	280
20/02/15-28/02/15 [*]					204	-
01/03/15-25/03/15 [*]	6662	215	1.3		854	-
26/03/15-31/03/15 [**]					5808	697
01/04/15-15/04/15 [**]	17536	1461	0.6		17536	986
Total	86568	539	-		86568	364

[*] Period with heating needs with no critical outdoor conditions.

[**] Period with heating needs with limited use of building.

[***] Period with no heating needs.

[§] Estimation of average temperature difference between water production outlet and inlet was done dividing thermal energy supplied by the underground water by the water mass and the specific heat.

- a constant electricity consumption (about 290 kWh_{el} $month^{-1}$) was surveyed by the backup chiller during the heating period as well, due to the stand-by operation. It is worth to verify the completely turning off of that chiller during the heating period;

- the two heating sources (ground water heat pump and district heating) contributed by a half each to the heating needs of the building;

- total water production was just lower than the designed value (90300 m^3) but, considering the relative low utilization of the heat pump system, this value is still too high;

- when operating at partial load, production well water flow rates were too high and temperature differences were too low. The requirement of modifying the control logic of the production well pumps is confirmed also by the very high value of the water consumption index Q_{wat} (364 l kWh_{th}^{-1}) with respect to the design value (108 l kWh_{th}^{-1});

- a very discontinuous operation of the water production pumps (with poor modulation capacity and very high on-off frequency) was detected, just as surveyed during the cooling season;

- the COP of the whole plant (COP_{tot}) resulted acceptable during high heating load periods (end of November-begin of December and January) while it was very low (around 2) during partial load operation periods, confirming the inefficient modulating capacity of the plant;

- the very high impact of the electricity consumption of auxiliaries (pumps) was highlighted by the large difference between COP_{eq} and COP_{tot}. COP_{eq} measured (3.28) was lower than the design value (4) also because of the higher hot water production set point (53 °C) with respect to the design (45 °C); such a set point value has to be lowered.

The results of the first two monitoring periods revealed that potential improvement in energy performances could be obtained if the technical interventions described in the previous section (the most of them obtainable by modifications in the control logic of the plant) would be adopted. The next section reports on the effect of some actions during the last available cooling period.

3.4. Cooling period 2015

During the period April-August 2015 many of the improvement interventions just described have been realized. Table 6 reports the main results of the monitoring activity. Table 7 summarizes main data useful to do a comparison between the two cooling seasons[2].

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[2] During summer 2015 the Basilica has been used much more than in summer 2014 due to the “Tutankhamon Caravaggio Van Gogh” exhibition from April till July 2015 with very strictly indoor conditions requested (20 °C temperature, 50 % humidity) and successively with other exhibitions.

Table 6 Results of the third monitoring period (cooling period 2015)

Period	$E_{el\text{-}well}$	$E_{el\text{-}hp}$	$E_{el\text{-}prim}$	$E_{el\text{-}chil}$	$E_{el\text{-}cdz}$	$E_{el\text{-}tot}$	E_{inj}	E_{useful}	E_{useful}^{+}	EER_{eq}	EER_{tot}	Q_{well}	Q_{wat}
	kWh_{el}	kWh_{el}	kWh_{el}	kWh_{el}	kWh_{el}	kWh_{el}	kWh_{th}	kWh_{cool}	kWh_{cool}	-	-	m^3	$l\ kWh_{cool}^{-1}$
26/04/15 – 09/05/15 *	2067	12115	3306	431	1516	19435	92500	78868	5306	6.07	4.06	9042	115
12/05/15 - 31/05/15 *													
01/06/15 – 30/06/15 *	1772	12362	2803	300	1393	18630	80400	66645	4876	5.00	3.58	7070	106
01/07/15-31/07/15 **	2094	11071	2918	307	1523	17914	78400	65806	5330	5.46	3.69	8036	122
01/08/15-31/08/15 ***	876	2928	2140	308	1888	8138	22300	25397	6608	6.42	3.01	3381	133
01/09/15-30/09/15 ***	323	2994	906	298	1387	5908	10500	16562	4856	3.91	2.59	1036	63
Total	7177	41543	12097	1849	8216	70881	284100	255237	28935	5.45	3.61	28682	112

[*] "Tutankhamon Caravaggio Van Gogh" exhibition full open (indoor air temperature 20 °C, humidity 50 %). During 9th-12th May underground water heat pump system was off due to injection well obstruction; from 12th May 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.

[**] Other exhibitions open (indoor air temperature 26 °C, humidity 50 %).

[***] Other exhibitions open (indoor air temperature 26 °C, humidity 50 %). During 3rd-5th August maintenance activity on injection well (cleaning, video-inspection and flow rate tests) was done. Since 6th August the plant was full operating with injection well flow rate limited to 30 $m^3\ h^{-1}$, 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.

[+] Part of the useful cooling energy produced by the CDZ.

Table 7 Main results of the 2014 vs 2015 cooling period comparison

		Cooling period			Aug-Sep		
		2014	2015	Variation	2014	2015	Variation
$E_{el\text{-}well}$	[kWh_{el}]	1809	7177	297%	756	1198	58%
$E_{el\text{-}hp}$	[kWh_{el}]	9801	41543	324%	4892	5921	21%
$E_{el\text{-}prim}$	[kWh_{el}]	18497	12097	-35%	5774	3046	-47%
$E_{el\text{-}chil}$	[kWh_{el}]	1719	1849	8%	605	606	0%
$E_{el\text{-}cdz}$	[kWh_{el}]	9046	8216	-9%	2578	3275	27%
$E_{el\text{-}tot}$	[kWh_{el}]	40871	70881	73%	14605	14046	-4%
E_{inj}	[kWh_{th}]	61	284.1	366%	28	32.8	17%
E_{useful}	[kWh_{cool}]	64824	255237	294%	26993	41958	55%
EER_{eq}		3.90	5.45	40%	3.82	5.15	35%
EER_{tot}		1.20	3.61	201%	1.55	2.83	83%
Q_{well}	[m^3]	11424	28682	151%	4502	4417	-2%
Q_{wat}	[$l\ kWh_{cool}^{-1}$]	176	112	-36%	167	105	-37%

Despite operation time of the ground water chiller strongly increased (+324 %) due to higher cooling needs of the Basilica, electrical consumption increased by 30000 kWh_{el} only (+73 %), practically due to the ground water chiller increased use (+31700 kWh_{el}). Such an improvement is much more apparent when considering the last period (August and September) of the two seasons (with similar cooling needs): the weight of the auxiliary consumption was strongly reduced in 2015 (-47 % for the primary circuit pumps) while the ground water chiller consumption increased (+21 %).

Looking at the energy balance and performance, against a strong increase of cooling needs (+190000 kWh_{cool}, +294 %), the increase of underground water production was by 17000 m^3 only (+151 %). The same figures in the August-September period highlight a greater improvement as, against an increase of energy cooling needs by 15000 kWh_{cool} (+55 %), water consumption substantially remained constant and electrical consumption reduced by 4 %. In terms of global performance indexes, EER_{tot} greatly improved (by 200 %) and water consumption strongly decreased (by 36 %) considering the whole cooling season. The main reason was the improved efficiency in using the pumps of underground water circuit and primary circuit.

4. 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 the inefficient control logic of the pumps of the underground water and primary circuits with not optimized flow rates. Also other drawbacks were highlighted by the Authors and technical interventions have been suggested to the local Authority. These have been realized during summer 2015 allowing an impressive improvement of energy performance of the plant: energy efficiency ratio of the total plant increased by 200 % while underground water consumption reduced by 36 %, even if the cooling needs of the building nearly quadrupled. Such an improvement was confirmed also by the only doubling of the total primary energy consumption during the cooling season (19.9 toe vs 10.2 toe in 2015 and 2014 respectively [6]) with a reduction of the primary energy consumption due to the pumps (respectively 3.9 toe and 4.1 toe). Other issues are still present (too frequent block of the injection well that caused a more expensive use of district heating during the heating season and a serious problem for heat dissipation during the cooling season, the oversizing of the production well pumps, etc.). Anyway the monitoring activity is in progress also for the 2015/2016 heating season to evaluate the effectiveness of the interventions on energy performance of the plant.

Acknowledgment

Thanks to Matteo Borgato, Fadi Onza (Studio Centro Sicurezza Ambiente), Roberto Pedron (Sinergeo Srl), Vittorio Carli, Diego Galiazzo and Ingrid Bianchi (Vicenza local Authority), Igli Salviato (Gaetano Paolin SpA).

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