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Efficient Heating Ventilation and Air Conditioning in Buildings

W. Grattieri, G.L. Lapini, R. Vanzan
CESIRICERCA SpA
Via Rubattino 54, 20134 Milano, Italy (grattieri@cesiricerca.it)

In the last years, the fast growth of the air conditioning demand in Italy is causing a significant increase in electricity consumption with a dramatic impact on the summer peak load. The consequence is a sharp reduction of the reserve margin during the summer heat waves, that involves repeated calls for interruptible loads and stresses the prices on the energy markets. In perspective the situation may worsen even in winter, as an additional electricity demand for heating can be expected, due to the diffusion of heat pumps which can operate year round.

The problem could be mitigated thanks to technology solutions that minimize the electricity consumption and the system load impact of air conditioning and heating. For this reason a monitoring and verification program has been launched in Italy with the aim of assessing the actual on-field efficiency and consumption of said systems, that rely either on heat pumps supplied with thermal sources different from the outdoor air, or with gas fired absorption chillers.

This paper highlights the first results of the auditing campaign, where primary consumption, load impact, and operating problems are shown for a sample of plants. The analysis allows to ascertain the energy pros and cons of the technologies examined and provides useful information to engineers and plant managers for a correct design and operation of the equipments.

1. Introduction

One of the main problems for the Italian electric system is the fast growth of the air conditioning demand which is causing a significant increase in electricity consumption with a dramatic impact on the summer peak load. In the 1996-2005 period, the annual consumption of electric energy has increased in Italy from 262.9 to 330.4 TWh, which means a growth of over 25 %. The peak load on the national electric grid has had a even higher percentage increase, passing from about 42,000 MW to about 54,000MW (+ 28%), but while in the past the maximum peak load always happened in December or in January, in the last years the summer and winter peaks approached each other, and in 2006 the maximum hour peak was no longer recorded in winter, but in July[1].

The problem could be mitigated through technology solutions that minimize the electricity consumption and the load impact of air conditioning and heating. For this reason a monitoring and verification program has been launched in Italy by CESI

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[1] More information on this topic can be found on “Gallanti et al.”(2006).

RICERCA[2] with the aim to assess the actual on-field efficiency and consumption of some of the air conditioning systems which could potentially mitigate the summer problem: they rely either on heat-pumps supplied with thermal sources different from the outdoor air, such as water from lakes, rivers and underground water table, or on gas fired absorption chillers.

The paper will synthetically present the results of monitoring campaigns performed both on plants operated in real buildings and at the CESI RICERCA test facilities, in simulated conditions.

2. Results of monitoring campaigns

2.1 Water-to-water heat-pump with lake water cooling

As it's well known the electric heat pumps (H-P) supplied by water as a thermal source (water-to-water heat pumps), can theoretically have better C.O.P. and better overall energy efficiency than heat pumps driven by outside air, because of more suited temperature along the year, of waters derived from the sea, from lakes or rivers, and from underground strata. In Italy there is a good potential for this kind of machines. CESI RICERCA monitored for a long period a HVAC[3] plant installed in an historical building on the banks of a big lake, about 50 km north of Milan.

The general layout of this plant is shown on Fig. 1: the supply water is sucked from the lake through three 5 kW pumps and its thermal energy is exchanged in a plate-type heat exchanger. A couple of 5 kW pumps activate the primary circulation of refrigerated water between the heat-pump and the heat exchanger. A ballast tank is inserted between the primary and secondary circuit. The water-to-water H-P has a maximum capacity of about 500 kWt and its maximum electric power is about 200 kW.

The plant has been equipped with a proper set of sensors and metering devices, and by a monitoring system, in order to measure electricity consumption, thermal energy supplied to the building and climatic conditions.

The plant was continuously monitored for several winters and summers, and seasonal balances were calculated; comparisons were made between the measured seasonal data and the data which would have been measured using a reference air-to-water H-P of analogous power and characteristics, in the same weather and operation conditions. When the plant was new these comparisons were fairly in favor of the water-to-water H-P (particularly in winter), but as reported on Tables 1 and 2, quite surprisingly after three years of operation the winter balance was no more positive and the summer balance became heavily in favor of the reference air-to-water H-P. The main explanations of this fact come from some peculiar characteristics of the plant, which negatively cooperated to produce poor balances:

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[2] CESI RICERCA SpA has been established at the end of 2005 as a separate company by **CESI** "Centro Elettrotecnico Sperimentale Italiano Giacinto Motta" SpA, with the mission to take over funded research activities of national and international interest. The company, that employs four hundred researchers and technicians, and who has important laboratory facilities in the towns of Milan, Bergamo and Piacenza, performs research in the electricity and energy sector, with strong emphasis on experimental applications.

[3] Heating Ventilation Air Conditioning

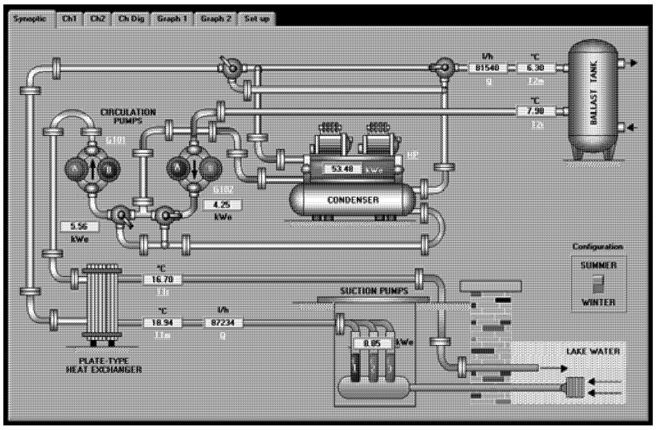

Fig. 1 Layout of the heat pump plant supplied with water by a lake

- the heat-pump was oversized both for the winter heating and for the summer cooling loads of the building, and its load factor is particularly low in summer;
- after the commissioning period, the regulation and maintenance of the plant have been neglected;
- during summer, due to very peculiar local conditions, the temperature of the lake water was not always as favorable as expected;

Tab. 1 – Summer balance for a lake water heat-pump

Parameters[4]	H-P w-to-w (lake)	H-P air –to-w (ref.)	Δ	Δ%
T_m (°C)	23.0	23.0	--	--
E_f(MWh$_f$)	126.8	126.8	--	--
E_e (MWh$_e$)	130.9	44.6	86.3	193.5%
C.O.P.	1.0	2.8	1.8	-64.3%
E_p (toe)	28.8	9.8	19.0	193.5%
P_p (kW)	61.0	23.2	37.8	162.9%

Tab. 2 – Winter balance for a lake water heat-pump

Parameters	H-P w-to-w (lake)	H-P air –to-w (ref.)	Δ	Δ%
T_m (°C)	9.4	9.4	--	--
E_f(MWh$_f$)	140.6	140.6	--	--
E_e (MWh$_e$)	72.6	66.3	6.3	9.5%
C.O.P.	1.9	2.1	-0.2	-8.7%
E_p (toe)	16.0	14.6	1.4	9.5%
P_p (kW)	45.7	49.2	-3.5	-7.0%

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[4] The meaning of abbreviations used in this and in the following similar tables, is: T_m = average seasonal temperature; E_f = seasonal cooling energy; E_e = seasonal electric energy consumption; C.O.P. = seasonal coefficient of performance; E_p = seasonal primary energy consumption, in terms of toe (tons of oil equivalent) ; P_p = seasonal electric power peak

- the auxiliary machinery (suction and circulation pumps) was over-sized, and its utilization was not optimized according to the real thermal needs of the building (the pumps were permanently on, even when they were not needed) and consequently a big amount of energy was wasted by this machinery.

This case-history was particularly instructive in order to underline that the potential advantages of using water from a lake as a thermal source for heat-pump must be accurately engineered, taking into account both the general and the local aspects of the design.

2.2 Water-to-water heat-pump supplied by underground water

The second plant which has been monitored for a long period is located in the experimental area of CESI RICERCA in Milan. A water-to-water H-P, which utilizes water from the underground strata, has been installed in a laboratory building, which simulates the typical air conditioning loads of a small family house. The underground water supply for this small heat-pump (5.5 kW_f) is delivered by a submerged electric pump, which is inserted in a tubular well at a depth of about 25 m, where the water temperature is nearly constant at about 15°C, all over the year. The general layout of this experimental facility is sketched in Fig. 2.

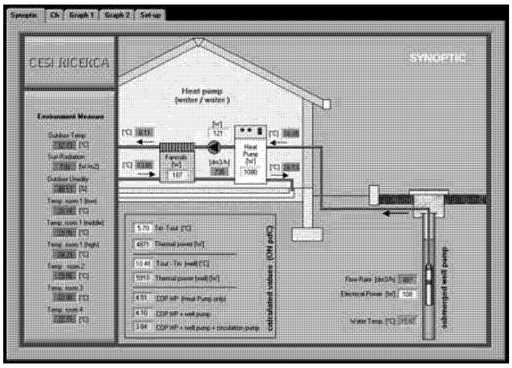

Fig.2 Layout of the heat pump plant supplied with underground water

The plant has been equipped with a proper set of sensors and metering devices, and by a monitoring system, in order to measure, consumed electricity, thermal energy supplied to the building and climatic conditions. The plant was continuously monitored along winter and summer, and a seasonal balance was calculated; comparisons were made between the measured seasonal data and the calculated consumption of a reference air-to-water H-P of analogous power and characteristics, in the same weather conditions.

Tables 3 and 4 summarize the results of a monitoring campaign performed along two typical summer and winter periods. In this case the comparisons between the water cooled H-P and the air cooled H-P were clearly in favor of the first one. In summer, in terms of electric and primary energy consumed by the plant the saving was about 36%; in addition there was also a reduction of almost 40% in the peak of electric power absorbed by the plant.

In winter the advantages were a little lower, but still very significant.

From the economic point of view the advantage of using underground water is mainly dependant on the cost of drilling the water well. However, due to the increasing cost of electricity in summer periods, the return of the investment should be interesting in most cases.

Tab. 3 – Summer balance for an underground water heat-pump

Parameters	H-P w-to-w (underground)	H-P air-to-w (ref.)	Δ	Δ%
T_m (°C)	24.4	24.4	--	--
E_f (MWh_f)	2.18	2.18	--	--
E_e (MWh_e)	0.56	0.88	-0.32	-36.4%
C.O.P.	3.89	2.48	1.41	56.9%
E_p (toe)	0.12	0.19	-0.07	-36.4%
P_p (kW)	0.64	1.06	-0.42	-39.6%

Tab. 4 – Winter balance for an underground water heat-pump

Parameters	H-P w-to-w (underground)	H-P air-to-w (ref.)	Δ	Δ%
T_m (°C)	6.7	6.7	--	--
E_f (MWh_f)	3.14	3.14	--	--
E_e (MWh_e)	0.95	1.12	-0.17	-15.5%
C.O.P.	3.44	2.91	0.53	18.3%
E_p (toe)	0.21	0.25	-0.04	-15.8%
P_p (kW)	0.8	0.96	-0.16	-16.6%

2.3 Absorption chiller, fuelled by natural gas

The third plant which has been monitored was located in an industrial/commercial facility in Northern Italy. In this case the air conditioning of the buildings was provided by a two-stage LiBr absorption chiller rated at 246 kW_f, which in principle didn't rely on electricity for its operation, but was fuelled by natural gas (even if electricity was used by its auxiliary equipments),. Data acquisition and monitoring was carried out in similar ways as to the two plants previously described. In this case the plant was continuously monitored along a summer, and a seasonal balance was calculated; comparisons were made between the measured data and the data which would have been measured using an air-to-water reference electric chiller of analogous power, in the same weather conditions (Table 5). It is evident from these data that the absorption chiller presents a sharp advantage over a conventional electric chiller in terms of consumed electric energy.

It also permits a large reduction of the peak of electric power during the summer time, while burning out natural gas in a period when its consumption is usually at its annual minimum. From these points of view this technology would be very beneficial for the containment of the possible summer problems of the electric network, but at the expenses of an overall energy balance which is sharply negative; in fact, as can be seen from Table 5, the primary energy ratio (P.E.R) is much lower and the consumed equivalent primary energy is much higher for the absorption chiller.

It has in fact be stated by several authors, that this kind of machine would be energetically convenient in case some waste thermal energy could be used, as for instance in the case of tri-generation.

Tab.5 – Summer balance for an absorption chiller, gas fuelled

Parameters[5]	Absorption chiller (natural gas)	Electric air-to-water chiller (reference)	Δ	Δ%
T_m (°C)	25.9	25.9	-	-
E_f(MWh_f)	139.6	139.6	-	-
E_e (MWh_e)	26.0	52.2	-26.2	-50.2%
Gas (Sm^3)	15,241	0	15,241	n/a
P.E.R.	0.65	1.05	-0.40	-38.1%
E_p (toe)	18.3	11.5	6.8	59.4%
P_p (kW)	17.5	37.2	-19.7	-53.0%

3. Conclusions

The experimental data collected by CESI RICERCA in some demonstration plants, confirmed that comparison between energy performance of water cooled and air cooled heat pumps was clearly in favour of the first one, provided that sufficient care is taken at correctly sizing and operating the whole equipment, in particular the auxiliary pumps. Otherwise, the un-expected over-consumption of the suction and circulation pumps (which are necessary in order to exploit water from lakes or underground strata) may negatively affect the overall efficiency, leading to relatively poor performance of the plants. In case of absorption chillers it is true that they contribute to lower the peak of electric power on strained electric networks, but this is obtained at the expenses of an increase in primary energy consumption, unless the chiller can be operated through waste heat, coming for instance from cogeneration plants.

4. References

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5. Acknowledgment

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[5] The meaning of abbreviations, in additions to the statements of footnote n. 4, is the following: Gas = seasonal (summer) natural gas consumtion; P.E.R = primary energy ratio, that is the ratio between the useful delivered energy (E_f) and the net consumed primary energy (E_p), in terms of toe.