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Experimental analysis of the performances of a surface water source heat pump

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ABSTRACT

Nowadays the heat pump is gaining new interest thanks to recent regulations which include this technology among those able to exploit renewable energy sources in addition to the already acknowledged opportunity to achieve significant energy and economic benefits if well applied In particular the use of geothermal energy as heat source/sink looks very promising. Besides the use of ground heat exchangers and water from wells, an adequate availability of surface water can suggest its use for the heat pump especially when it is impossible the application of the other two alternatives. This is the case of the plant here reported. A heat pump installed in the historical centre of Venice and using lagoon water for the HVAC plant of a historical structure refurbished for hotel use. The plant characteristics and the adopted technical solutions are here illustrated as well as the results of an annual monitoring of the building-plant system. The experimental data have also permitted a comparison with the performances of alternative plant solutions simulated in front of the same operative conditions. For this aim the two case studies of a corresponding air source heat pump and a more traditional solution, based on condensing boilers and air cooled chillers, have been considered. The performance analysis shows a net superiority for the surface water heat pump.

1. Introduction

To achieve the targets of the Kyoto-protocol about the reduction of fossil fuel consumption and related CO_2 emission a significant spread in the use of renewable energy sources is fundamental besides the improvement of energy efficiency and the reduction of the demand. States and international organizations have elaborated energy action plans which set out the road-map towards this result. In particular the European Union with the recast of the Energy Performance Building Directive EPBD [1,2] has focused in the building energy consumption the most important sector where to act to achieve the target 20-20-20 (20% of decrease in CO_2 emissions, 20% of increase in energy efficiency, and 20% of energy generation through renewable sources taking 1990 as the reference) by 2020 and it promotes the use of renewable energy sources (RES) to supply a considerable quota of the building energy requirement. For this aim EPBD directive considers the heat pump as a renewable energy technology. In fact the aerothermal, geothermal or hydrothermal energy that the heat pump can withdraw from the outdoor ambient is considered renewable energy [3].

In particular, the ground source heat pump (GSHP) has met great interest owing to the less seasonal temperature variations with respect to the air source and then the possibility to achieve high energy efficiency. GSHPs are substantially subdivided into three categories by ASHRAE [4] on the basis of the use of ground water from wells, surface water or directly ground coupled by an heat exchanger, as a heat source or sink. The use of water usually permits marked advantages like a low initial cost and no surface area required. Ground water from wells normally involves outstanding energy performances [5,6], but various factors restrict its wide application. Besides limited water availability other feasibility problems associated with public regulations or water quality can indeed exist. In this case a surface water heat pump (SWHP) can be a valid alternative for the building sited in proximity of significant surface water bodies like rivers, lakes or seas [7–9]. In presence of great heat pump capacity, open loop systems are normally preferred where water is pumped from the surface aquifers through a heat exchanger and returned at some distance from the intake point [10].

The SWHP solution is particularly tempting in coastal cities even if seawater temperature is influenced by outdoor air and by sometimes unfavorable sea currents. The huge thermal inertia and vertical stratification besides the lower freezing temperature due to salinity suggest interesting possibilities for this solution, especially

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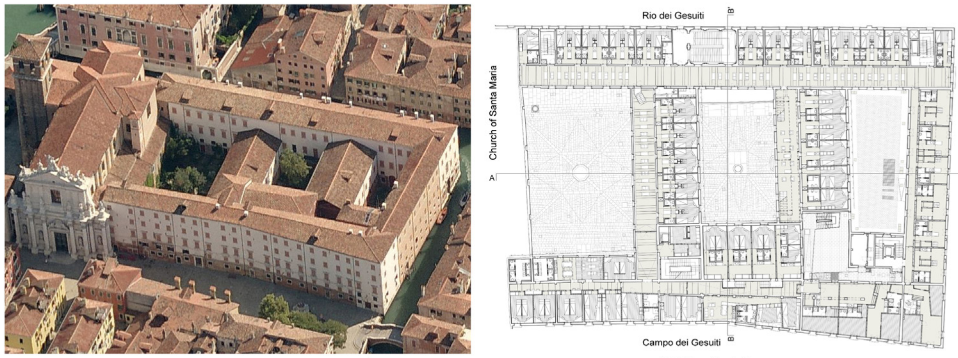

a) An aerial photo of the Southern part b) The first floor

Fig. 1. Views of the Crucifers complex. (a) An aerial photo of the Southern part (b) The first floor..

in comparison with air source, even in severe climate [11]. In air conditioning applications the advantages have been clearly highlighted [12]. These promising results have stimulated studies about economical and energy optimization concerning large-scale application of seawater source heat pump in district heating and cooling [13,14]. Design tools to be used in next demonstration projects has been elaborated [15].

In this paper the case study of a SWHP installed in the city of Venice is reported, i.e. in the context of a particular coastal city sited inside a lagoon. The Venetian lagoon is the largest wetland in the Mediterranean sea. The large surface aquifer is connected to the open sea by three inlets and is fully subject to tide effect with high variation in the water level, especially in autumn, which regularly floods most of the city. In the historical center preservation rules of the landscape and historical heritage are strictly applied. Consequently the use of RES requires much more design effort as the most diffuse solutions are often not available. For example solar thermal or PV plants are normally forbidden.

Especially in this case it is therefore necessary to address the attention to the other RES among those that the specific environmental context offers.

In this case a lagoon water coupled heat pump was installed in the retrofit of the Crucifers Convent, a historical building in Venice. In fact the availability of surface water with adequate circulation for the thermal renewal due to the proximity of the open lagoon has allowed to ensure interesting thermal levels for the machine. Instead in Venice the use of well water normally is not allowed because of the danger of subsidence. In fact the soil of the city is supported by a delicate system of multiple flaps. In the sixties the withdrawal of water for industrial uses provoked harmful lowerings. Furthermore, the installation of a ground coupled heat pump was not possible here, because of the relevant capacity of the heat pump requiring for the ground heat exchanger a large area unavailable in this case. Here is presented an analysis of the energy performance about the first operative year based on the monitoring data of the building-plant system.

2. The Crucifers complex and its plant

2.1. Building description

For its history and architectural value the Crucifers complex is subject to heavy historical preservation restrictions. The convent and hospital were founded in the middle of the 12th century by the order of Crucifers along the church of Santa Maria Assunta to aid and to give shelter to pilgrims and crusaders on their way to the Holy Land. Later it became a school managed by Jesuits and then a barrack during Napoleonic period the part on the South of the church was undergone a radical refurbishment. As showed in Fig. 1 the Southern sector presents two cloisters on the left side and two further smaller service courtyards on the right side of the complex. The frontal side towards Campo dei Gesuiti presents the main accesses, the back side is washed by the channel Rio dei Gesuiti. On the left there is the church of Santa Maria and on the right side the limit is a minor channel. The complex has three long buildings along the perimeter area and they present a total height of 26 m. Two lower buildings are located in the central part and they surround the cloisters and courtyards.

This area is the object of the intervention of renovation and new destination for university housing for students and visiting professors and ancillary services. In detail the creation of 177 apartments for students, each with two bed places, independent bathroom and kitchen and study area. Furthermore, 32 greater residential units are reserved for visiting professors. Facilities like laundry, meeting rooms, classrooms and workshop rooms will be at disposal of the internal guests. While community services: cafe, restaurant and related kitchen, gym, computer room and a library, will be opened also to the local community.

2.2. General description of the HVAC plants

In the residential unit the HVAC plant consists of a controlled ventilation system and of two-pipe fan coils fed by hot or chilled water embedded in the furnishings, and exploiting the opportunities of an interior design that makes extensive use of suspended ceilings and covering walls that integrate furnishings such as desktop and wardrobes. In the greater rooms at the floor level HVAC plants are based on fan coils and primary air distribution ducts. The bar and restaurant each present a dedicated air handling unit for the ventilation fed by hot or chilled water too. The whole ventilation plant is demand controlled and supervised by the building management system (BMS). The HVAC plants have been chosen to be supplied by low temperature water favorable to the working of the heat pump. In fact the lagoon environment has suggested the use of surface water coupled to a heat pump as a renewable energy source.

The technical devices are located in the tower between the two courtyards on the left side and in an underground room expressly excavated under the widest of these two courtyards. Here we have the installation of a reversible water to water heat pump used to produce hot water for heating and chilled water for air conditioning in summer. The lagoon water is withdrawn from channel Rio dei Gesuiti sited near the back side (Fig. 2a) and treated by an efficient self-cleaning filter (Fig. 2b).

Lagoon water filtering is fundamental and critical in Venice. Owing to the input of fresh water from rivers the lagoon water salinity, variable with the tide, near Crociferi site is normally less than one third of the Mediterranean sea water (36 g/l). But this water