Using Seawater for Urban Renewal Project

BY LUIGI DE ROSSI; GIACOMO FAVARO; DAMIANO ROSSI

An ambitious urban renewal project in the Italian seaport of Livorno on the west coast of Tuscany (Figure 1) is creating a complex of multiuse buildings from existing historical buildings and former shipyards. The Piazza Mazzini is one area of this large project (Figure 2). This building complex has 130,000 ft² (12,000 m²) of floor space; it is made up of five low-rise residential buildings under which three separate commercial areas have been built, with a total of 63 apartments and 37 shops. The basement is used for public and private parking, in addition to housing the mechanical room.

Plant Description

The residential zone is floor heated, while cooling in summer is carried out using independent split systems, the use of which is an optional choice of each leaseholder. The commercial shops are both heated and cooled by hydronic terminals. Furthermore, to ensure fresh air renewal, three heat recovery ventilators are installed. The commercial areas are subdivided into three different parts, each of which is related to a single unit, sized according to each area extension and characterized by a design recovery efficiency equal to 60%. Each of these ventilators includes a post heating exchanger to achieve the designed conditions for the temperature and humidity ratio on the premises’ terminals, both in cooling and in heating mode.

Hot water for room heating comes from common collectors both for commercial and residential zones, providing hot water at the constant temperature of 131°F (55°C). Domestic hot water is delivered with heat plate exchangers interfaced with thermal storage, using the same hot water for room heating (Figure 3). In this way, the DHW load can be satisfied even when the plant is not yet fully operative.

Therefore, the plant for the requested energy production to satisfy the buildings’ energy requirement is centralized (Figure 3). The heating and cooling demands make the installation of two heat pump units powered by electric motors more suitable, so enhancing the renewable energy property of this chosen source.

As a consequence of the geographic location and local natural resources, the source used is seawater to allow...
for a more constant and advantageous temperature compared to outdoor air. These factors ensure higher performance.

All year-round, buildings need both heating and cooling. In the summer, these demands occur simultaneously, as there is the need for cooling in commercial areas in addition to DHW and post heating AHU requirements.

To completely satisfy these needs, two smart heat pump units were installed. At their nominal conditions (Table 1), the heating capacity is 1.9 MBtu/h (567 kW), and the cooling capacity is 146 ton (514 kW) for each unit. Their performance is evaluated by these parameters: COP=4.09 and EER=4.76.

They represent the evolution of traditional reversible heat pumps. They are indoor units for use in four-pipe systems for the simultaneous and independent production of chilled and hot water by means of two independent water circuits. In this way, the system is able to adapt itself to variations in the building’s requirements.

Therefore, three heat exchangers are installed on each machine (Figure 3):
- Exchanger A: an evaporator to produce chilled water, plant-side (44.1°F [6.7°C]);
- Exchanger B: a condenser to produce hot water, plant-side (120°F [48.9°C]); and
- Exchanger C: an exchanger that acts as either evaporator or condenser as required, source-side.

Whenever there is a simultaneous demand for heating and cooling, the unit’s heat reclaim mode kicks in so the unit manages the refrigerant fluid condensation (Exchanger B) and evaporation (Exchanger A), respectively, to produce the energy requested. Exchanger C links the unit to the external environment, changing its working principle (evaporator or condenser) according to the buildings’ load demand.

To prevent problems of corrosion inside Exchanger C, an intermediary heat plate exchanger, Exchanger D, is provided for each unit. It separates the elements in contact with seawater and those in the units. This requires the presence of auxiliaries, finalized to the handling of each fluid, and these elements contribute...
toward the amount of the global energy requirements and costs.

In the primary circuit, the intermediate heat exchanger interposition involves a temperature variance at Exchanger C input compared with seawater reference conditions.

**Comparison of Plant Solutions**

Loads and unit performance simulations must be carried out considering the outdoor relative humidity and air temperature tendency as independent variables. Moreover, the lack of connection between heating and cooling loads when they are simultaneous must also be taken into consideration. Therefore, it is not possible to carry out an accurate simulation by simplified method or as a function of singular parameters such as the outdoor air temperature.

To analyze the requirements and levels of performance, a dynamic model of the buildings was created using the TRNSYS-17 software. This model consists of real physical and structural parameters deduced from the project energy declaration (e.g., materials used, spatial orientation, actual size of single premises and their intended use). In this way we evaluated, hour by hour, the annual energy behavior of each room, starting from the set internal conditions, to be guaranteed throughout the day.

In cooperation with the Department of Industrial Engineering of the University of Padua, the annual requirements of the buildings were simulated and the energy demands for the conditioning of the premises were analyzed for every single shop and apartment. The designers considered the units’ performance as a function of the hourly load and the environmental parameter tendency. The designers took into account several variable values throughout the day such as outdoor air temperature, solar radiation parameters, and the internal loads.

The cooling and heating energy necessary to condition the rooms was associated with each of the premises, as were the requirements to produce the DHW and to handle the air renewal (AHU) for commercial rooms.

The aim is to simulate the behavior of smart, water-source heat pump units—installed in Livorno—compared to other possible solutions in the market that are able to provide the same amount of energy for producing hot and chilled water, but using different technology.

The designers compared the installed system to a combination of water-source chillers plus boiler, a combination of air-source chillers plus boiler, and finally smart, air-source heat pumps. All the aforementioned technologies used screw compressors and R-134a refrigerant gas, in line with smart water-source heat pump technologies actually installed in Livorno.

The air-source heat pumps have the same working principles and physical structure as the water-source ones. The only difference is that the source exchanger (Exchanger C) is a finned coil because of the outdoor air source considered.

Regarding the chillers, they have the same cold circuit (Exchanger A) as the heat pumps considered, with a finned coil or shell and tube source exchanger (Exchanger C), respectively, according to the source type adopted.

Finally, the traditional boiler is assumed to use natural gas as its power supply, and it is simulated through a seasonal generation efficiency.

For each source type, the heat pumps selected are the most suitable units available in the range for this specific project. To reach a choice for the traditional chillers, the designers carried out a preliminary financial analysis considering the most competitive solutions in terms of efficiency and price. Because of these prerequisites, the units that were eventually selected are not the most efficient ones available from Climaveneta (Table 2). The performance of these units is evaluated using the traditional parameters, COP, EER and TER, the last of which is defined as the ratio between the sum of the thermal and cooling capacity and the power input of the unit during the typical heat reclaim.

In particular, throughout the performed simulation, we compared different groups of units, each of which was sized to totally supply the cooling and heating load calculated. These groups are described below:

- **Air-source units:**
  - Two heat pumps; and
  - Two chillers + traditional boiler.

- **Water-source units:**
  - Two heat pumps + auxiliaries (intermediary heat plate exchangers); and
  - Two chillers + traditional boiler + auxiliaries (intermediary heat plate exchangers).

Finally, regarding the several primary energy consumption values, we assessed what was the most suitable solution from an energy point of view by comparing
Duct or hood mounted thermal dispersion airflow measurement probes
Use on thermostatically controlled systems with or without an airside economizer
Designed for smaller RTU’s (≤15 tons) and OA ducts to fan coils
Advanced DCV control capability
RS-485 BACnet network connection
No B.A.S. required
the various levels of primary energy consumption from the simulated operating of the different solutions considered. To further complete this study, we then carried out a financial analysis.

From the simulation of the annual energy requirements of the building, the global demands were as follows (Figure 4):

- Cooling load: 2,538 MBtu (744 MWh), (18.5 kBtu/ft² [59 kWh/m²]); and
- Heating load: 3,559 MBtu (1,043 MWh), (26 kBtu/ft² [82 kWh/m²]) of which 33.64% occurs in summer when the cooling load is also required.

Therefore, the design team confirm the advantageousness of the heat pump units chosen to be

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**TABLE 1**

<table>
<thead>
<tr>
<th>WATER-SOURCE</th>
<th>EVAPORATOR</th>
<th>CONDENSER</th>
<th>SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling</td>
<td>In 54°F/Out 44°F</td>
<td>–</td>
<td>In 85°F/Out 94.3°F</td>
</tr>
<tr>
<td>Heating</td>
<td>–</td>
<td>In 105°F/Out 120°F</td>
<td>T_{av} = 44°F</td>
</tr>
</tbody>
</table>

**AIR-SOURCE**

<table>
<thead>
<tr>
<th>EVAPORATOR</th>
<th>CONDENSER</th>
<th>SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling</td>
<td>In 54°F/Out 44°F</td>
<td>–</td>
</tr>
<tr>
<td>Heating</td>
<td>In 105°F/Out 120°F</td>
<td>47°F</td>
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</table>

**TABLE 2**

<table>
<thead>
<tr>
<th>COP</th>
<th>EER</th>
<th>TER</th>
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<tbody>
<tr>
<td>4.09</td>
<td>4.76</td>
<td>7.25</td>
</tr>
<tr>
<td>3.21</td>
<td>2.95</td>
<td>6.97</td>
</tr>
<tr>
<td>2.93</td>
<td>–</td>
<td>–</td>
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<tr>
<td>94%</td>
<td>–</td>
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**Figure 4** Air yearly simulation of the processed energy distribution by heat pump units.
installed in the Livorno buildings as they are able to successfully supply simultaneous demand for both heating and cooling whenever required.

Energy Analysis

Simulation results shown in Figure 5 consider primary energy demands evaluated in ton of oil equivalent (TOE). We compare local natural gas versus local electrical energy consumption adopting the following equivalence conversion factors: 0.82 TOE/Nm³ for natural gas and 0.23 TOE/MWh for electrical consumption.

Regarding water units, it can be observed that by adopting ones with smart heat pumps, a primary energy saving of approximately 36% can be achieved in comparison to using separate technologies to produce hot and chilled water. This advantage is realized thanks to the heat pumps’ operating principle for the combined production of hot and chilled water.

In Figure 4, the yellow area outlines how much thermal energy is provided during this typical operating system throughout summer. In fact, this amount of energy represents 80% of the global summer thermal energy to be provided and 27% of the annual thermal load.

By comparing the different solutions considered (Figure 5), it can be seen that, from the energy viewpoint, the heat pump units are always more economical than traditional systems such as chillers plus boiler.

Concerning air units, those with heat pumps guarantee a primary energy saving equal to 30%. This value rises to a considerable 36% for water units. Results show that heat pump water units are 6% more efficient than air-source units. These results are achievable as a consequence of the better performance of water-source units compared to air-source ones as the temperature variance of seawater is less than that of outdoor air, consequently with lower temperature differences between the source and the hot or chilled water released for use.

To further confirm these findings, the following data collected in Table 3 describe the mean performance parameters of the water-source heat pump units actually installed in Livorno compared to the results obtained from the air-source heat pump unit simulation. These mean parameters (COP, EER and TER) are obtained as the ratio between the sum of respective energy demand values and the sum of the absorbed energy both evaluated by yearly simulations.

It may be observed that the water-source units are more efficient than air-source ones for every kind of operating principle.

Financial Analysis

The designers considered:

- Installation costs related to each unit (referring to statistical averages from an inter-project database).
- Auxiliaries and plant costs, according to the solutions considered based on statistical company averages.
- Annual energy consumption for electric and methane supply. Once again, considering the Italian rates: $0.23/kWh as electric energy cost and $0.09/kWh as methane cost.
- Maintenance costs included in initial investments costs, since for the hypothesis, they are included in the purchase contract.

If we consider the use of air-source heat pump units against a traditional chiller plus boiler system for separate production of energy, we obtain a payback time of approximately six years and 10 months. This value decreases to two years and three months if we consider water-source heat pump units.

Then, we compare the air-source and water-source heat pump units. It is clear that the water-source solution is economically more advantageous immediately upon installation (Table 4).
These different results are mainly due to the greater cost involved with the finned coils compared to the shell and tube units, and to the better performance achievable with water-source systems.

**Impact of Heat Plate Exchanger D**

Using the Exchanger D prevents direct contact between seawater and Exchanger C. This solution, however, implies a reduction of the global system efficiency. This additional exchanger, combined with other measures, is necessary to counteract the main problems related to encrustation primarily due to salt, sand and microorganisms in the seawater.

Pipes and fittings installed are made of plastic materials to limit the effect of saline corrosion. Concrete settling chambers are built around the seawater intake to reduce the presence of suspended sand. The pipes for the seawater intake are perforated, reducing water turbulence near the inlet drills. Upstream of Exchanger D, the seawater flows through ultraviolet light sterilizers, ensuring an almost complete elimination of the presence of microorganisms, while during the plant shutdown period, this heat exchanger is further treated with a sodium hypochlorite solution.

However, in addition to these measures, there is also a periodic monitoring of Exchanger D to verify the working conditions and its physical and structural state. During these times, thanks to having two separate intake and generation systems, the continuity of plant operations is guaranteed and the need to install other heat exchangers in parallel is avoided.

In the final analysis, during the development of this study, it was observed that heat plate Exchanger D, used, as previously explained, to prevent seawater from coming into contact with Exchanger C and avoid corrosion, affects the global performance of water-source units. In particular, performance levels are lower because Exchanger C comes into contact with water at a different temperature compared to the effective seawater one. Some design choices were taken as a result of analysis and considerations with the purpose of obtaining working parameters as consistent as possible with the real working conditions.

During the winter, working as a heat pump, these assessments imply that Exchanger C should come into contact with a temperature that is approximately 9°F (5°C) lower than the actual seawater temperature, while in summer, and working to produce chilled water for users, the temperature is some 18°F (10°C) higher.

In both operating conditions, the temperature difference between the water for the user and the seawater source increases with a consequent reduction in the efficiency of the heat pump unit.

**Conclusions**

From yearly simulations, it is evident that for these kinds of loads, heat pump units using seawater are the better choice in Livorno when compared to units for the separate production of heating and cooling, both from an energy and an economic viewpoint. Concerning water-source units, smart heat pumps allow a 36% annual energy saving compared to traditional technologies analyzed. Furthermore, referring to a longer period, we obtain a payback time of only two years and three months. In conclusion, water-source heat pump units are more advantageous than air-source ones for this project, allowing higher performance at all load values and energy and economic savings immediately upon installation.

**References**


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**TABLE 4 Energy and economic performance comparison.**

<table>
<thead>
<tr>
<th></th>
<th>ANNUAL PRIMARY ENERGY SAVING (TOE) (FIGURE 5)</th>
<th>PAYBACK PERIOD SAVING AT 10 YEARS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air-Source Heat Pumps vs. Boiler + Air-Source Chillers</td>
<td>30%</td>
<td>Six Years and 10 Months $77,300</td>
</tr>
<tr>
<td>Water-Source Heat Pumps vs. Boiler + Water-Source Chillers</td>
<td>36%</td>
<td>Two Years and Three Months $305,400</td>
</tr>
<tr>
<td>Water-Source Heat Pumps vs. Air-Source Heat Pumps</td>
<td>6%</td>
<td>Immediately Upon Installation $164,300</td>
</tr>
</tbody>
</table>
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