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A Taranto's Hotel Application of Sea Water-Air Heat Pump

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Abstract: - A reduction of the fossil fuel and the carbon dioxide emissions can be obtained by improving thermal plant efficiency. Both in heating and cooling, stated the high temperature and low temperature respectively, the other temperatures would be closer as possible to the stated one. So in order to increase the efficiency of the heat pump cycle, the use of seawater instead of outside air allows to exchange thermal energy within a smaller range of temperatures.
In this paper is proposed a yearly simulation analysis of the behaviour of a heat pump thermal plant for heating and cooling need of a hotel located in Taranto, South Italy.
Using the characteristic efficiency-temperatures curves of a actual heat pump, several simulations are carried out in order to evaluate the heat pump and the whole thermal plant efficiencies.

Key-Words: - Seawater heat pump, energy plant simulation, energy saving.

1 Introduction

This project provides for carrying out, in the actual environmental themes about sustainable development, a low cost conditioning system in order to improve the hotel's management of energetic sources.
Energy consumption creates large quantities of waste, particularly from the nuclear industry which provides electricity. Energy consumption increases air pollution and adds to global warming.
A reduction of the fossil fuel and the carbon dioxide emissions (Kyoto objectives) can be obtained by improving thermal plant efficiency. This improvement in the heat pump plant can be obtained by using seawater instead of external air as thermal source/well for heating/cooling. Both in summer and in winter, the sea water temperature is closer to the exercise temperature than the air temperature. In fact, sea water is colder than air in summer and hotter in winter. For this reason, the C.O.P. (Coefficient Of Performance) of heat pump increases.
In this work is proposed a yearly simulation analysis of the behaviour of a hotel's heat pump thermal plant. The considered hotel is in Taranto, a coastal town in Mar Piccolo (Fig. 1).
In the simulation, it was compared the actual operating energy, the C.O.P. and the energy performance of a seawater heat pump with traditional air source heat pump.

Sea water is an excellent heat source under certain conditions, and it can be mainly used for medium or large size heat pump installations. At a depth of 25-50 meters, the sea temperature is constant (about 5-8 °C), and ice formation is generally no problem (freezing point -1°C to -2°C).
In a country as Italy, with 7500 km of coastline and 30% of coastal urban settlements, the intensive use of sea water as thermal source of heat pumps can notably reduce gas emissions produced by traditional heating and cooling plants. Besides, the sea is a big energy reserve that is able to maintain the average temperatures superior to the winter average air temperature, the very contrary is the summer case [2]. In this conditions, the sea water heat pumps have high performances and they result economically and environmentally better than traditional systems based on oil combustion.
The hotel's theoretical energy consumption was calculated on the bases of the hotel's specific characteristics (if the hotel is air-conditioned, if it has a restaurant, etc.).
The actual paper is fundamentally composed by two main part: the first part contains theoretical considerations, including conceptual analysis, with special emphasis on thermal parameters for plan efficiency, i.e. the influence of seawater temperature on heat pump's effectiveness; in the second part, it is explained the empirical projected system and the innovative analytical reflections and conclusions.

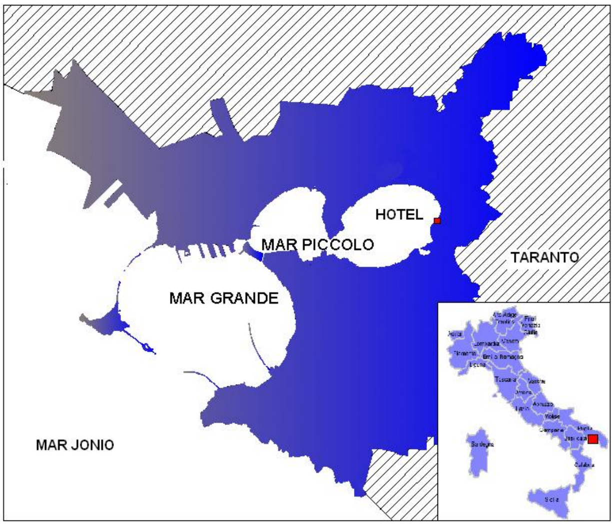

Fig. 1 – *The blue colour represents the Taranto's frontier, the white represents the sea*.

2 Hotel's Energy Consumption

Three type of energy are normally used in hotels, or rather electricity, gas and heating oil. Electricity is used to power all building engineering systems, as HVAC, lighting, etc., and it is seldom used for hot water heating. Gas is used primarily for cooking, but may also be used for domestic hot water heating. Heating oil and also gas are used as fuel for boiler plants to generate steam for hot water heating in radiators.

Energy consumption in a South Italy hotel accommodation comprises energy directly and indirectly consumed in running the accommodation building. A hotel is normally operate for 24 h, all year around, and the occupancy levels vary notably during specific seasons in a year. However, in many hotels, air conditioning will still be provided to prevent odors or discomfort, even when a guestroom is not occupied. For this reason, hotel occupancy level does not directly influence the energy performance of a hotel building.

2.1 Energy Analysis

According to several studies ([12], [14], [15], [16]) about the control of buildings' energy consumption, it is possible to evaluate hotel's energy performances.

Energy performance in individual hotels can be evaluated in terms of Energy Use Index (EUI), [2], [4] defined as the site energy consumption per unit of gross floor area. This index allows to calculate the energy consumption per unit floor area through the actual total gross floor area, class of hotel, occupancy level, hotel age, number of guest rooms, number of restaurants.

An evaluation algorithms is available [13] in order to calculate a hotel's *theoretical energy consumption* based on values representing the hotel's characteristics, i.e. air-conditioned plan, electronic facilities, presence of restaurants and the climate zone.

The temperature levels influence the energy consumption amount, higher the temperature, lower the efficiency and exergetic losses.

Typical operative temperatures of the thermal plant and buildings are shown in Fig. 2.

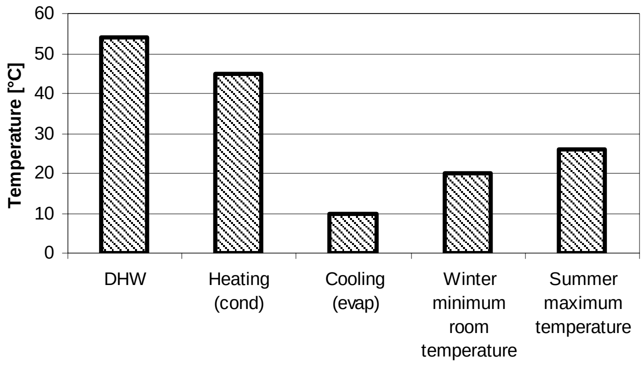

Fig. 2 – *Temperatures of the thermal plant and building.*

3 Methodology and Proposed System

The heat pump is one of the most diffuse machine, with a consolidated technology [7]. Domestic and industrial refrigerators and summer cooling and winter heating plans work as heat pumps. Their performances are usually very sensible to the temperatures of operation: heating source temperatures. Heat pumps work by extracting thermal energy from a low temperature (T_L) source and upgrading it to a higher temperature (T_H) for space or water heating. This is the reason why sources, that are different from the outside air, are welcome.

Heat pumps function by moving (or pumping) heat from one place to another [8], and it is necessary, for this aim, that a certain amount of work should be done on the system.

Like a standard air-conditioner, a heat pump takes heat from inside a building and dumps it outside. The difference is that a heat pump can be reversed to take heat from a source outside and pumps it inside.

Heat pumps use electricity to operate pumps that alternately evaporate and condense a refrigerant fluid to move that heat. In the heating mode, heat pumps are far more "efficient" at converting electricity into usable heat because the electricity is used to move heat, not to generate it.

The most common type of heat pump is air source heat pump, that uses outside cold air as heat source in winter period, and the hot air, during refrigeration. Water source heat pumps works at the same way, except if the heat source/sink is the sea water.

The water source heat pump's efficiency (C.O.P.) is significantly higher than an air source heat pump's, because the heat source is warmer during the heating season and the heat sink is cooler during the cooling season.

Water-source heat pumps are environmentally attractive because they deliver so much heating or cooling energy per unit of electricity consumed. The COP's values are usually 3 or higher. The best water source heat pumps are more efficient than a high-efficiency gas combustion, even when the source efficiency of the electricity is taken into account [9].

The parameter normally used to compare heat pumps efficiency is the Coefficient Of Performance (COP_{HP}), (1), that measures the ratio between the heat output (Q_{out}) and the energy used to drive the machine (E_m):

$$COP_{HP} = \frac{Q_{out}}{E_m} \qquad (1)$$

The COP_{HP} may also is expressed by means of the following theoretical expression, (2), based on Carnot cycle, that is function of heat pump's operating temperatures:

$$(COP_{HP})_{Carnot} = \frac{T_H}{(T_H - T_L)} \qquad (2)$$

It shows that, for a fixed temperature T_H, the value of the COP_{HP} increases as the lower temperature T_L increases. This means that the value of the COP is established by the evaporator inlet temperature as reported in equation (2).

For real machines, the relevant technical I/O characteristic curves, factory provided, show the relationship among the evaporator inlet temperature, the condenser inlet temperature and the value of COP [10].

In this paper is proposed to use seawater to exchange heat to evaporator instead of the external air.

In this way, higher temperatures allow higher efficiency of the heat pump. The thermal plant is designed to supply energy to an hotel located on the Jonio sea close Taranto city with a total floor area of 15,000 m^2. It is a four star coastal hotel and there are over 150 guestrooms with 370 total beds. The hotel caters for both business and leisure travelers.

In Fig. 3 is shown the trend of Taranto's sea water average monthly temperatures at a depth of 8 meters [1], compared to average monthly external air temperatures, obtained by TRNSYS software simulation.

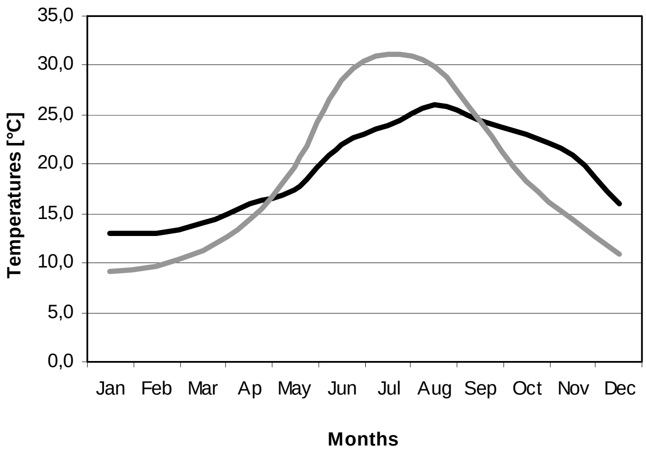

Fig. 3 - *Seawater (black line) and external air (grey line)* average *monthly temperatures.*

It's interesting to note that, in winner period, if an heat pump is adopted as heating system, sea water source temperature is closer to ideal room temperature (20-22 °C), than external air. While, in summer season, seawater is cooler than external air and closer to the room temperature (that is less than 26 °C).

This situation makes seawater-heat pump economically and energetically competitive with traditionally heating thermal plan.

Using the heat pump's characteristic curves, factory provided [11], it was been possible to find the equation of COP_{HP} as a logarithmic function of T_L, in the case of heat pump's heating function. The choice of the heating system, as fan coil and radiator determines the temperature of water supplied by heat pump. It is usually used in Italian hotels' fan coil to heating or cooling. So, for a fixed temperature T_H of about 45 °C, in winter period, the logarithmic COP_{HP} equation is expressed as follows, (3):

$$COP_{HP} = 0{,}9472 \cdot \ln(T_L) + 2{,}6995 \qquad (3)$$

For domestic hot water, the high temperature T_H will be 60 °C, so it is necessary to use another heat pump with a lower COP_{HP}, which has the following equation, (4):

$$COP_{HP} = 0{,}6616 \cdot \ln(T_L) + 1{,}9423 \qquad (4)$$

In cooling period, the value of T_L is fixed to 10°C, because heat pump functions as refrigerator, so the COP_{HP}'s equation will be function of T_H, (5).

$$COP_{HP} = -1{,}2212 \cdot \ln(T_H) + 5{,}2508 \qquad (5)$$

In order to increase the effectiveness of the heat pump, the proposed thermal system uses sea water source. In this way, the inlet temperature of evaporator, T_L, i.e. the heating power, Q_{out}, increases, improving the system effectiveness.
The seawater heat pump, considered in this work is a single-stage liquid source heat pump with an optional desuperheater. The heat pump conditions a moist air stream by rejecting energy to cooling mode or absorbing energy from heating mode a liquid stream. In cooling mode, the desuperheater relieves the liquid stream of some of the burden of rejecting energy. However, in heating mode, the desuperheater requires the liquid stream to absorb more energy than that is just required for space heating.
The hotel's simulated conditioning system consists also of a seawater circulation pump, that takes water from the sea and sends it to seawater heat pump; a building circulation pump; several plan pipes and building fan coils. In Fig. 4 a schematic of thermal conditioning plan is represented.

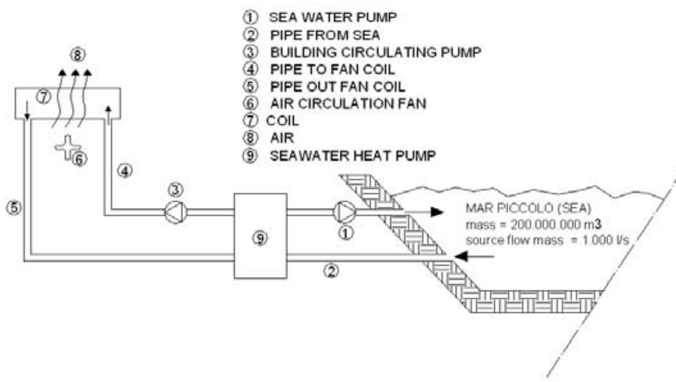

Fig. 4 – *Studied system.*

4 Simulation

In order to design the test system, several extensive simulation studies (over a full year) have been carried out. The performances of the energy supply plant have been investigated by means of a dynamic simulation code, realised with the software TRNSYS [5]. It simulates the hourly performances by means of several FORTRAN subroutines, called *types*, which are linked together in order to model a thermal system. Each subroutine calculates the heat and the mass flow interactions.
Simulations performed using Taranto's average climatic data [3], that are the input of weather subroutine, type 54a.
The TRNSYS component that models the thermal behavior of the coastal hotel is the type 56. In order to use this component, a separate pre-processing program must first be executed: PREBID program.
The type 504 (water source heat pump) represents seawater heat pump and it is based on user-supplied data files containing catalog data for the capacity (both total and sensible in cooling mode), and power, based on the entering water temperature to the heat pump, the entering water flow rate and the air flow rate. Other curve fits are used to modify the capacities and power based on off-design indoor air temperatures. The data files which must be used with this model have to contain the data in a specialized format in order to be read in by the TRNSYS program.

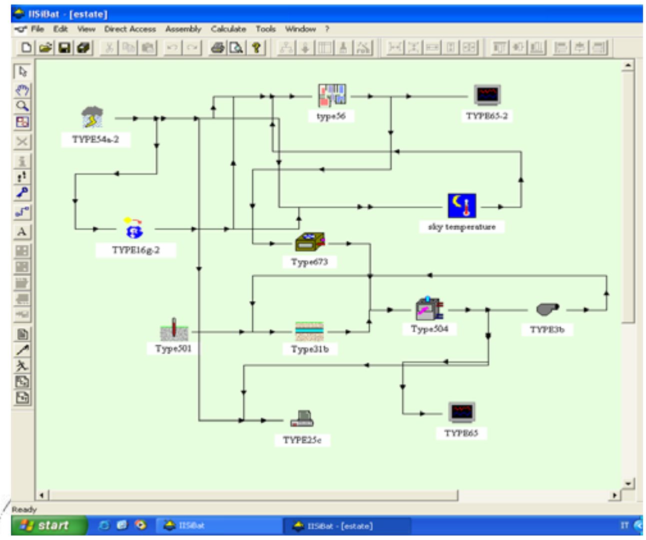

Fig. 5 - *TRNSYS simulation scheme of hotel conditioning system.*

The component chosen for the simulation of fan coil is the type 673; while it was used the type501 for the simulation of seawater temperature data, as input to seawater heat pump.
The online graphics component, type 65, is used to display the seawater heat pump's COP at specified intervals of time (hourly) while the simulation is processing.
The printer component, type 25, is used to output (or print) selected system variables (as for example energy hotel demand) at specified intervals of time.
Moreover, in summer period, it was considered in the simulation an average Taranto's sea water source

temperature, respectively in summer and winter season, of about 22°C and 16°C, [1].
The value of hotel's rooms temperature is supposed constant at 20-22 °C, as imposed by Italian issue [4].
Figures 6 and 7 show the seawater heat pump's simulated COP, obtained respectively, in winter (from 15 November to 30 March) and in summer (i.e. from May to September).

5 Discussion of Results

The characteristics of Mar Piccolo are a little depth, of about 8 meters, a surface of 9 millions of m^2, a flow mass of about 200 millions of m^3 and a water flow mass change of 1,000 liters/second [1]. For these characteristics, the Taranto's sea water temperatures are conditioned by environmental climate data and for these reasons simulation gives us as results, in summer period, values of seawater heat pump's C.O.P. close to air source heat pump's.
Heat pump has a better behaviors in winter period, in fact the C.O.P. is about 5.5, because heat source has a temperature of about 16 °C, that is near to 20°C, hotel rooms temperature. Both in summer and in winter period, seawater heat pump is better than a traditional air source heat pump.
In the heating the seawater exchanges heat with evaporator else in the cooling the seawater exchange heat with condenser, the two temperature are close, so COP increases.
This graphics show how isn't it suitable using air source heat pump for winter heating. In fact, if external temperature is less than 5°C (January case), the C.O.P. will fall down to 2. This means that giving 2 units of heat from air to ambient, that should be heated, it is necessary to pay 1 unit of electric power, or rather 3 units of combustion heat.
A worst situation there is if heat source temperature is near or less than 0°C. Instead, if the thermal heat source has a higher temperature, as 16-20 °C (spring period), the C.O.P. will increase up to 5. This means that to produce 1 electric unit it is necessary to consume 3 units of combustion heat but, at the end, 5 heating units were obtained as heating power.
The energetic, environmental and economic [9] advantage is about of 40% in spite of direct combustion [2].
In summer period, it is evident that the conditioning system that uses sea water as thermal source is better than air source heat pump, even if both thermal plans have low effectiveness values.
The results in Fig. 8 show also that it is indifferent to use in summer period air source or seawater heat pump in heating domestic hot water. But, during a whole year, it is suitable to use seawater heat pump for domestic hot water heating because its COP value does not fall under 3.5, and it has an almost constant yearly value.

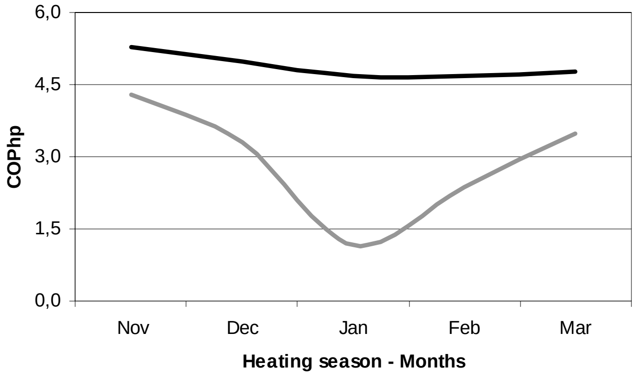

Fig. 6 - *C.O.P. of air source, grey line, and sea water, back line, heat pump in heating season.*

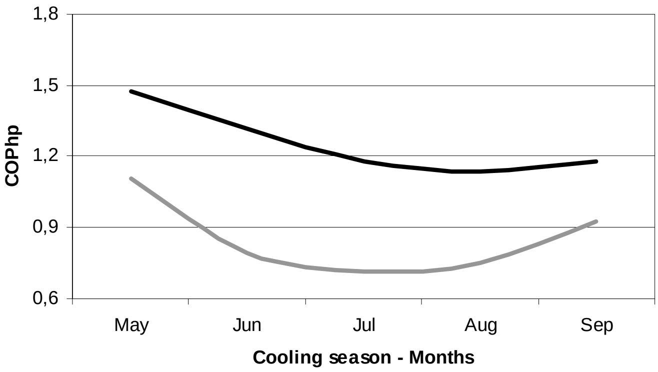

Fig. 7 - *C.O.P. of air source, grey line, and sea water, back line, heat pump in cooling season.*

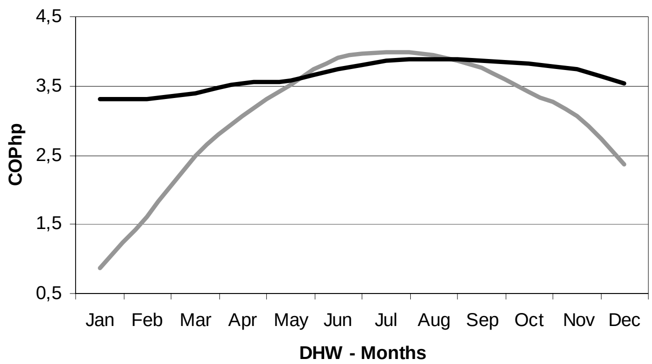

Fig. 8 - *C.O.P. of air source, grey line, and sea water, back line, heat pump in DHW heating.*

Energy hotel's consumption profiles of monthly electricity, heating oil and gas use are shown in Fig. 9.

The calculated total energy consumption of the examined hotel is about 420 kWh/m^2 and its respective theoretical energy consumption is 305 kWh/m^2. This means that the considered hotel's energy consumption is bad-controlled, in fact the hotel has a surplus of about 43% in energy use. It is necessary to make an energy saving plan with new proposal ideas, for this reason it was been proposed the present plan system.

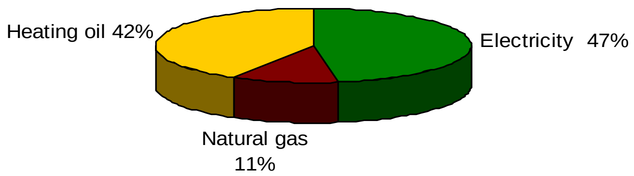

Fig. 9 – *Shares of energy required in hotel's consumptions.*

6 Conclusions

The development and the characterization of an innovative heating system with high performances in terms of efficiency, has been proposed. The main parameters influencing the efficiency of the system have been identified in the temperature of heat source, T_H, considered.

The proposed paper underlines as sea water heat pump could be a very favourable technology not only in Italy, by also in the other Mediterranean coastlines. The main aspects that make suitable seawater heat pump are: the presence of good thermal levels undersea, with excellent characteristics of heat exchange, and the possible use of sea as a suitable summer thermal sink.

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