High temperature multifunctional heat pump system for better over all energy efficiency

Recent years are characterized by important changes in the energy sector, which mean more efficient integrated projects focusing on innovative technologies. Current laws show that the main objectives are the reduction of energy consumption and greenhouse gases emissions and the use of renewable energy sources. The design approach has also changed: buildings should be viewed as a set, fully balanced, identifying not efficient elements, reducing heat loss, unnecessary consumption and increasing efficiency of the equipment. Manufacturers, consultant and customers plan to reduce energy consumption and reducing pollutant emissions. The climate sector moves towards the application of electrical and electronic technologies since they are: eco-sustainable products with high energy efficiency and integration with renewable energy with low CO_2 emissions and opportunity to eliminate the use of non-renewable energies.

Challenges and opportunities for heat pump technology

The possible solution to work towards eco-sustainable products with high energy efficiency and integration with renewable energy is the replacement of boilers for heating and hot sanitary water production by heat pumps.

The advantages are obvious:

- Possibility of exploitation of renewable energies (air, water, geothermal);
- High efficiency (COP ever higher);
- Increase of the energy efficiency rating of buildings (A+);
- Reduction of CO_2 emissions (best performance even compared with condensing boilers);
- Reduced use of primary energy;
- Versatility of use: seasonal employment winter / summer;
- Economic benefits from taxation;
- Using where natural gas networks does not exist;
- They do not need chimneys;
- No need for places where the demands of fire fighting;
- They do not need gas supply contracts;
- Possibility to use special power rates.

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But using traditional heat pumps we face, at times, a number of problems. While functioning satisfactorily in summer, have some problems, well known, in the winter:

- Reduction of heating capacity when outdoor temperature decreases;
- The need for over sizing the project;
- The high mechanical stress in case of high temperature of water with low air temperatures (increase of compression ratio with the drastic decrease in isentropic efficiency);

- Time required to eliminate the risk of legionella is greater as lower the water temperature;
- Almost always installations with standard heat pumps are complemented by traditional energy sources (boilers, electric heaters) to reach the limits of power and temperature;
- For hot sanitary water it is required a three-way valve with an additional heater in the tank (double exchange) which causes a significant loss of efficiency (performance decreases of about 7%);
- Impossibility to obtain the hot sanitary water temperature above 55°C;
- The need for buffer tank for hot water high-volume to meet the need in the morning.

By reversing the cycle on the water evaporator/condenser it is possible to supply the air conditioning users; at the same time the unit can produce hot water for sanitary use with an additional dedicated water exchanger.

The operating modes of a multifunctional unit during the whole annual period are:

- During WINTER:
  - □ Only Heat pump mode (Hot water production for heating);
  - □ Heat pump + sanitary mode (Hot water production for heating or for sanitary use with priority on sanitary circuit);
- During MIDDLE SEASONS:
  - □ Heat pump mode for hot sanitary water production;
- During SUMMER:
  - □ Only Chiller mode (Cold water production for air conditioning);
  - □ Chiller + sanitary mode (Cold water production for air conditioning and simultaneous free hot water for sanitary use).

The main advantages of the use of a multifunctional unit in place of a standard heat pump are:

- High energy efficiency;
- Dedicated exchanger for hot sanitary water production;
- No integration of electrical heater;
- Elimination of double water / water exchange;
- Free hot sanitary water during summer cycle.

Two stage multifunctional unit

In some applications high temperature hot water is required. However with the simple cycle system is not possible to reach temperatures above 65°C as reaching the outlet water temperature at 80°C would require theoretically a compression ratio of about 7 and the coolant temperature (R134a) of 140°C.

The above mentioned operating conditions is not feasible with components developed and designed so far, besides it would bring additional negative effects, such as lubrication problems, abnormal stress of the components, very low efficiency, etc.

In order to overcome these problems the only feasible solution is to split the temperature difference in a cascade of two cycles. The use of two different refrigerants allows to exploit the best performance of each refrigerant combining a wide scale of advantages.

Figure 1 represents a patented cascade cycle applied in Thermocold DUO unit.

The low-pressure cycle operates with R410a and the high-pressure cycle with R134a. The choice is optimized for winter heating application, since the R410A is a well performing with low outdoor temperature while the R134A is the refrigerant perfectly designed for high pressure and temperatures.

By a simple comparison and considering operating temperature between 55°C for condensation and –5°C for evaporation, a standard single cycle need a compression

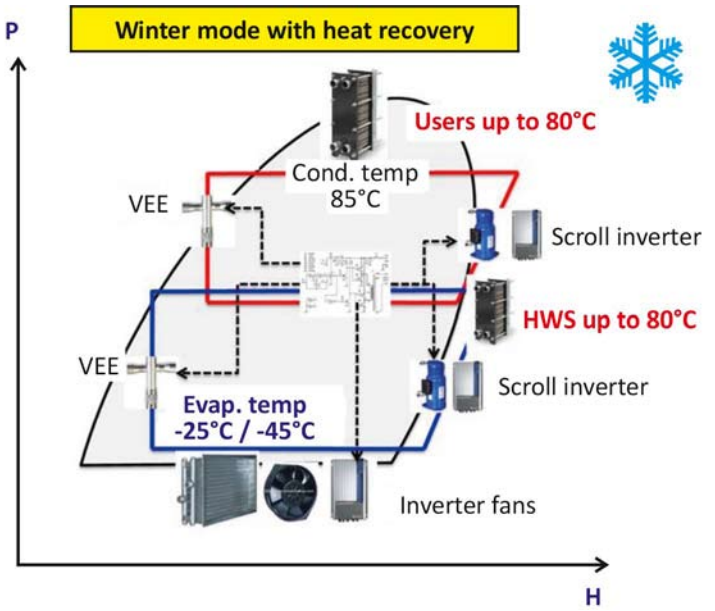

Figure 1. Thermodynamic cycle cascade cycle heat pump in pressure – enthalpy diagram.

ration about 7, while the double cycle will have a low and an high pressure cycle with a ratio between 2.5 and 3.2.

Therefore provided that all the scroll compressor exploit the highest isentropic efficiency in this range of compression ratio (2.5 – 3.5), the case of DUO® the isentropic efficiency is becoming maximum.

Furthermore mechanical stresses are directly proportional to the compression ratio. Dividing the compression into two-stages, it is possible to reduce by half the compression ratio of each of the compressors. According to the data provided by manufacturers of compressors the average lifetime of compressors operating in the "normal" conditions is 40 000 hours. The average lifetime in the double-cycle units is 60 000 hours, thus increasing the useful life of about 50% because they work better and avoiding the mechanical stress.

By considering what stated above, the combination of a cascade compression cycle with the multifunctional technology will offer an optimal solution for the actual market requirements.

High heating capacity even at low outdoor temperatures

DUO® overcomes the limitations of traditional heat pumps (strong decrease in performance with low outdoor temperature) in addition to providing winter heating, summer cooling and hot sanitary water (HOT SANITARY WATER) up to 80°C retaining a **constant heating capacity** at different outdoor temperatures down to –20°C.

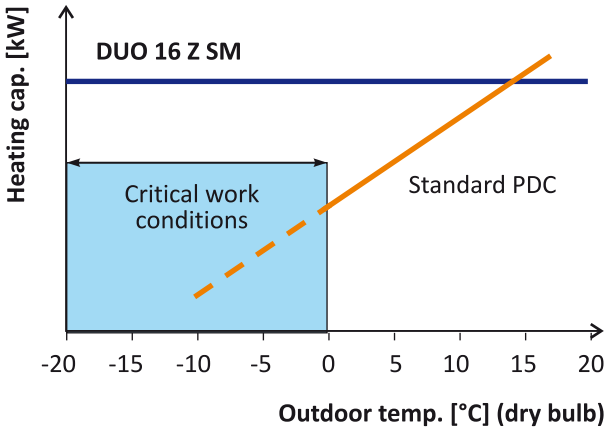

Figure 2. Constant heating capacity of DUO® heat pump system.

DUO® is a multifunctional unit where the key of this innovation is the advanced electronic system that allows to manage complex refrigeration cycles in an interactive way through a **full inverter technology** allowing to set up **different and completely independent set points** for HOT SANITARY WATER, winter heating, summer cooling and also managing with absolute fluidity the Digital Defrost System (intelligent digital technology defrost).

The use of primary energy of DUO® is both substantially lower than a methane condensing boiler and a last generation heat pump.

The two-stage DUO® units are equipped with **Full Inverter technology** to ensure maximum efficiency, much higher than traditional heat pumps. Both compressors of low and high pressure, such as fans and circulation pumps are with inverter in combination with electronic expansion valves and high-performance heat exchangers.

The two-stages next generation units are completed by the new technological defrost system: with this function, the electronic control system minimizes the number of reversing cycle in the heating mode while the unit is operating in cooling mode.

The **Digital Defrost**, used in these units, is a digital self-adaptive defrosting system able to prevent the production of frost and only allows the defrost cycle in case of real presence of frost on the coils fins.

Modulating the frequency of the inverter compressor according to the outdoor temperature keeps the evaporation temperature above the boundary conditions of frost formation, thereby reducing the number of defrost cycles, so much negative as required, in standard heat pumps.

To achieve the best possible conditions of comfort and above all for maximum energy savings, the control system has been equipped with the function of DSP (**Dynamic Set Point**), allowing temporary change of set point according to the change of outdoor temperature. With this system it can be maintained the temperature difference between indoor and outdoor by varying the set point, reducing consumption and preventing thermal shock. On the other hand it allows to decrease the set point when the thermal load increases on time.

The possibility to produce hot water at 80°C with two-cycle units offers another important advantage about the problem of Legionella. The *Legionella* bacteria reaches its maximum growth at water temperatures between 25 and 40°C. Having the opportunity to have water temperature of 80°C, it can be performed automatic cycles of sanitation, eliminating harmful bacteria, even when working with lower water temperatures.

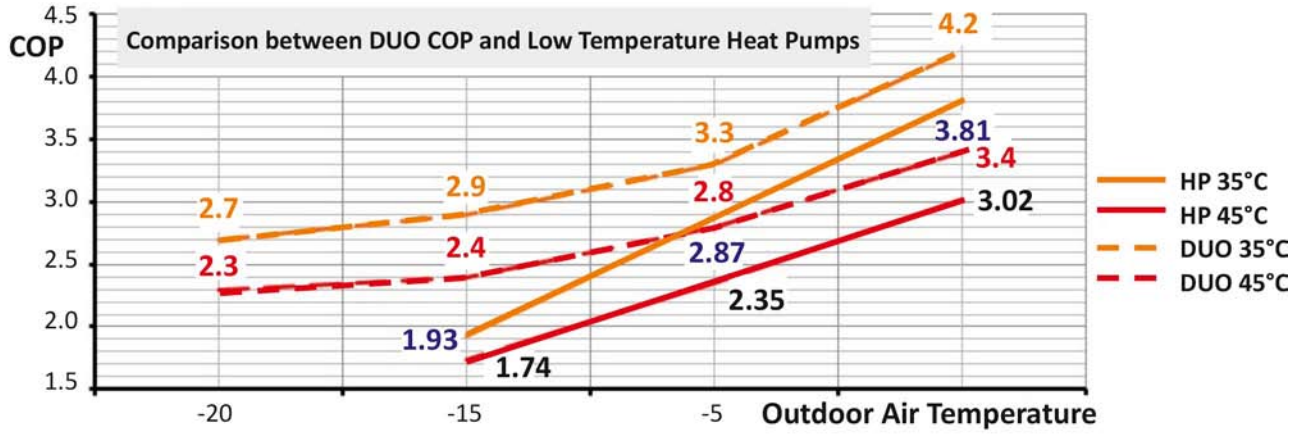

Figure 3. Comparison of COP between DUO® and standard heat pumps.

Figure 4. Split version of DUO® DUO® heat pump system.

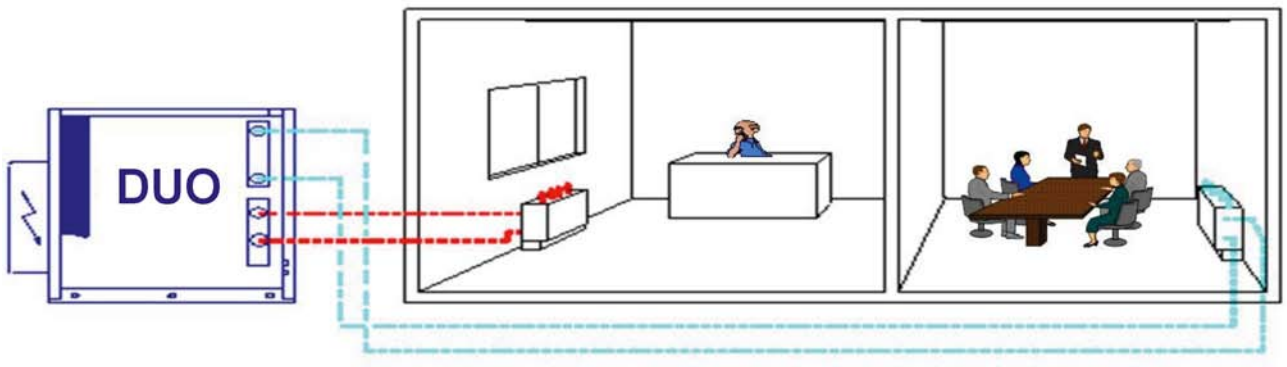

Figure 5. Four-pipe solution of double cycle DUO® heat pump system.

Multifunctional unit DUO® is available into packaged or split versions

In facilities with split versions it can be eliminated glycol regardless of outdoor temperature if the high-pressure unit is installed inside the building and the interconnection with the low pressure unit is made through refrigerant lines.

The versatility of the multifunctional units with dual thermodynamic cycle allows simultaneous heating and cooling in four-pipes solutions with the additional advantages that this system involves rationalization of energy when the thermal load is very erratic.

In conclusion energy saving is the most clean and affordable form of energy and the use of heat pump allows the achievement of targets for primary energy savings, increase of renewable energy and reduction of CO_2 emissions.

Therefore the heat pump can be regarded as a technology able to make a tangible contribution to the environmental strategies of the European Community.

The double cycle multifunctional unit DUO® combines and enhances all the merits of the traditional heat pumps (in terms of energy, reduction of pollutants, safety, availability of the fuel, etc.), without being penalized by the limits (minimum capacities at low outside temperatures, low outlet hot water temperatures, high stress on the components in extreme conditions, etc.).

The use of DUO® unit in place of a traditional plant with a boiler combined with a chiller unit, allows a considerable simplification of the plant itself and consequently an increase in reliability of the system given by the presence of a smaller number of components.

DUO® applied in residential buildings, allows to produce free hot water during the summer to all homes, allowing a large energy recovery.

Ultimately, thanks to the constancy of the thermal performance, the large choice of design flow temperature, even at very low outdoor temperatures, combined with the reliability of components not subjected to high mechanical stress, DUO® allows to overcome the prejudice that has so far accompanied the use of heat pumps as the only element of the production of hot or chilled water.