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Modular heat pumps: Energy performance

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Heat pumps are ever more frequently being used as single generators in heating systems without being coupled to an emergency boiler. Reliability becomes a primary requirement to achieve without limiting energy efficiency. The best solution is represented by modular systems that are able to maximise seasonal energy indices, both with summer and winter operation, thus assuring the same reliability of a system with multiple generators.

Keywords: heat pumps, modular heat pumps, energy efficiency, renewable energies.

Heat pumps are generators more complex than boilers or traditional cooling units without cycle inversion. The complex nature is not to be considered a defect, if you are able to manage it, nor is it synonymous with poor reliability.

However, the spread of heat pumps in heating systems is very low compared to boilers, and the number of technicians able to intervene rapidly on any malfunction, even the most trivial, is still relatively limited. To assure the unit operating in any situation many designers choose double cooling circuit heat pumps, each equipped with an individual compressor in order to provide sufficient redundancy. It is unfortunately a poor solution, which is explained in more detail in the following paragraphs, since you can only ensure complete reliability in every situation by increasing the number of generators.

HP requirements in heating systems

The widespread distribution of heat pumps as single generators in heating systems has mainly been in new, rather isolated buildings, thus having limited unit loads. This has enabled the use of low temperature terminals such as fan coil units and, especially, radiant systems. However, in order to extend the use of these types of generators and benefit from their energy efficiency to reach the targets of 20-20-20, it is also compulsory to work with radiators, which were the most commonly used terminals in heating systems in the past.

New buildings and buildings to restore

There are tens of thousands of buildings to restore in Europe, the majority of which are residential. The energy challenge of the future will be in renovating existing buildings, and the winner will be the one who proposes system-engineering technologies that can be installed with minimal interventions. Therefore, if you really want to promote the technology of heat pumps, they must be designed to also work with radiators.

Terminal power supply temperature

A floor radiating system requires water input temperatures between 35°C and 40°C, a radiator system built in the 70s was designed with input temperatures higher than 70°C. The question is, how much can the supply temperature of the radiators be lowered, whilst keeping their same size, in order to use the existing terminals. Acting both increasing the building performances and introducing a VMC system a reduction in requested power is obtained and this permits to reduce the water temperature sent to the plant. The water input temperature in terminals with both a floor radiating system and a radiator system can reduce the thermal load according to the change in outdoor air temperature, as shown in **Figure 1**.

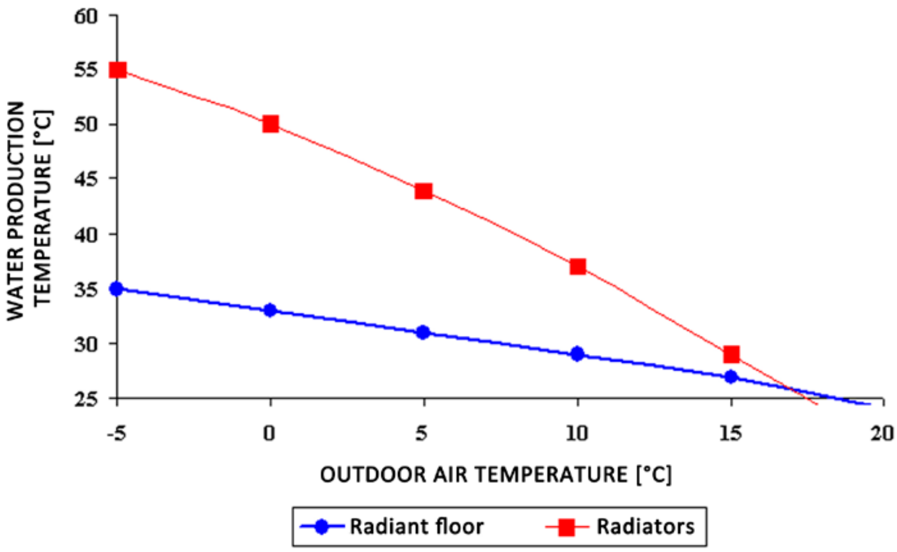

Figure 1. Floor radiating system (blue line) and radiator performance (red line) of water supply production temperature according to outdoor air temperature.

Performance of heat pumps in accordance with the temperature of thermal sources

Figure 2 shows the winter performance of a full load air hydronic heat pump in accordance with the temperature of thermal sources, or according to the change in outdoor air temperature and the produced water temperature. The produced water temperature affects COP, however, it is practically insignificant with regard to the power capacity.

From a viewpoint of machine size, it is advantageous since heat pump power is also essentially guaranteed by the requested production temperature of DHW, and to the lowest outdoor air temperature for radiator systems. On the other hand, COP deterioration requires proper management of the production temperature in accordance with the load and outdoor air temperature so as not to penalise seasonal efficiency too much.

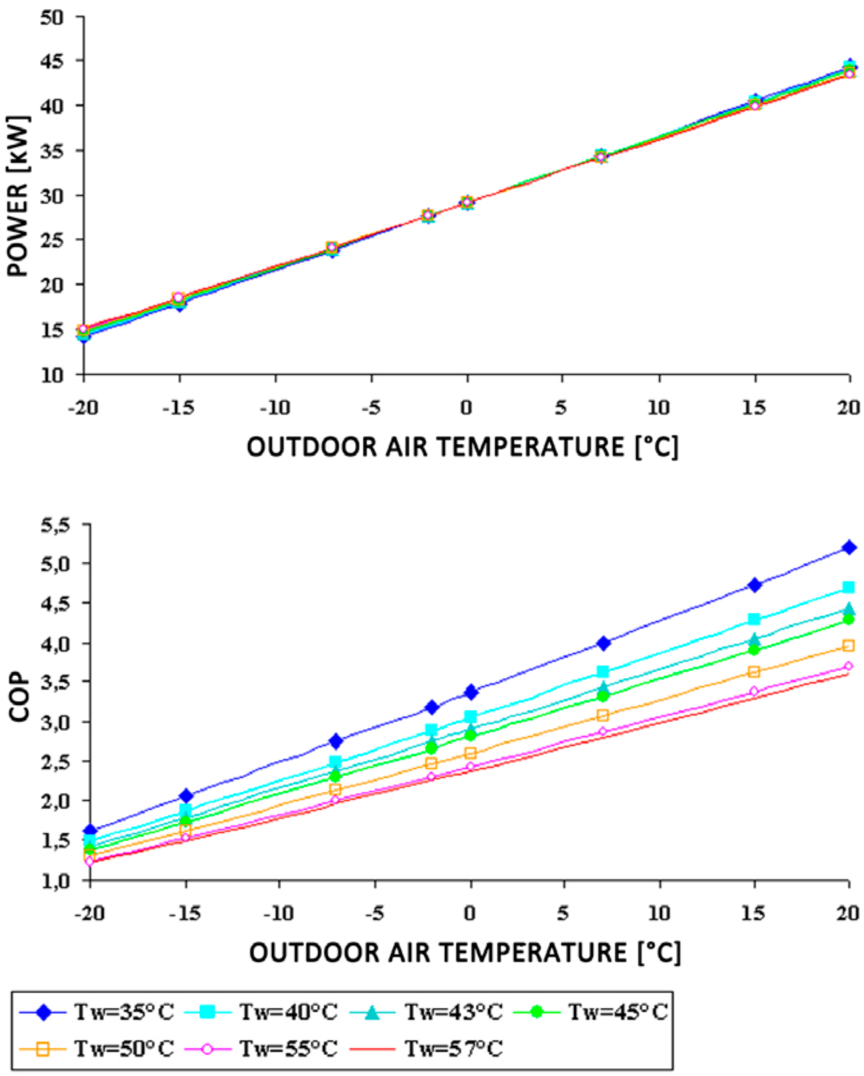

Figure 2. Full load winter performance of a heat pump with scroll compressors.

Search for energy reliability and efficiency

If the heat pump is the only generator supplying the heating and DHW system, it must be totally reliable. Choosing models with many refrigerant circuits clashes on the one hand with energy efficiency, and, on the other hand, with the presence of a single electrical panel and a single microprocessor that if breaks, it completely blocks the entire heat pump. **Figure 3** shows instead the increase obtained in the heat pump COP if the produced water temperature decreases according to the curve in **Figure 1**, instead of being constant at the maximum value (35°C for floor radiating systems and 55°C with radiators). This can be done with the predictive advanced software Adaptive Function Plus (AFP) patented by Rhoss, which enables the cooling unit to adapt itself to the actual load of the building (Albieri et al, 2007).

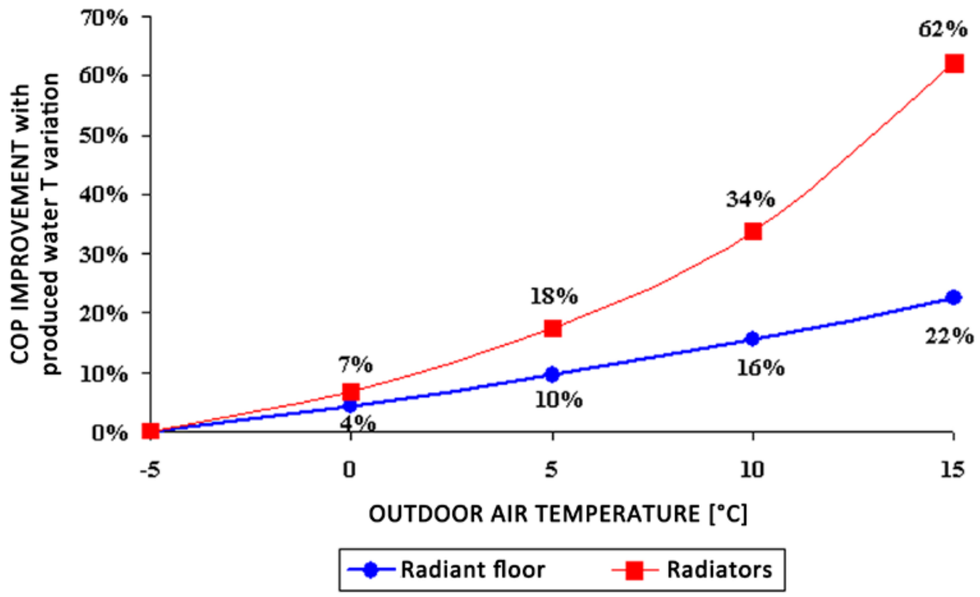

Figure 3. COP heat pump improvement if the production temperature follows the curve in Figure 1 instead of remaining constant.

Partialisation energy efficiency

Heat pump works at full load for short periods of time, while most of the time it works reducing its power so it's important to consider the average seasonal performances. The efficiency of the units is influenced by the number of steps per cooling circuit, the system water content, the defrost cycles (see **Figure 4**).

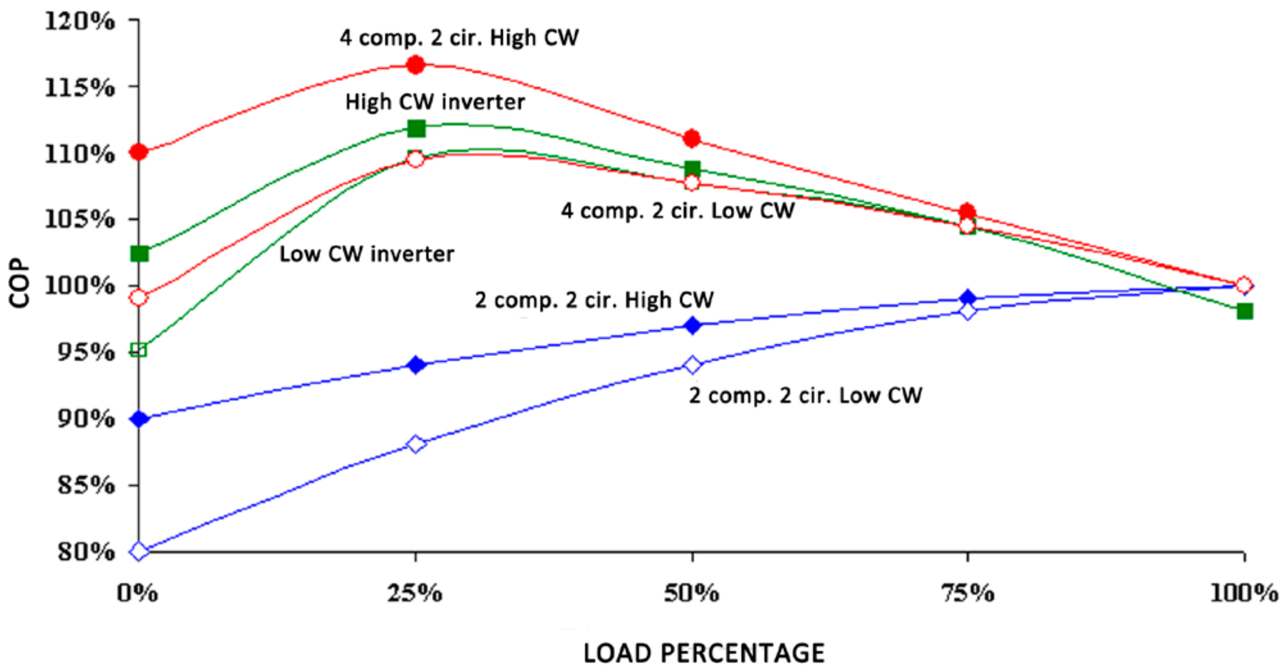

Figure 4. COP variation on percentage variation of the load (outdoor air temperature 7°C, produced water temperature 45°C), depending on the cooling circuit partialisation and the content of water (CW).

Total performance of COP during winter months

Figure 5 summarises what has been reported up to this point, since it shows the performance of different types of heat pumps considering the presence, or otherwise, of software able to adjust the produced water temperature required by the terminals, both with regard to the outdoor air temperature and the defrost cycles (highlighted by the discontinuity of the curves). The content of water in the system was considered high and humidity of outdoor air was always considered equivalent to 80%. In any case, the best performance is always obtained by modular systems described in the following paragraph 4.

EER performance during the summer season

Performance of the EER energy efficiency index during the summer season is very similar to that described for winter operation (Bacigalupo et al, 2000; Vio, 2006).

Advantage of modular systems

The best solution is represented by modular systems that are able to maximise seasonal energy indices, both with summer and winter operation, thus assuring the same reliability of a system with multiple generators.

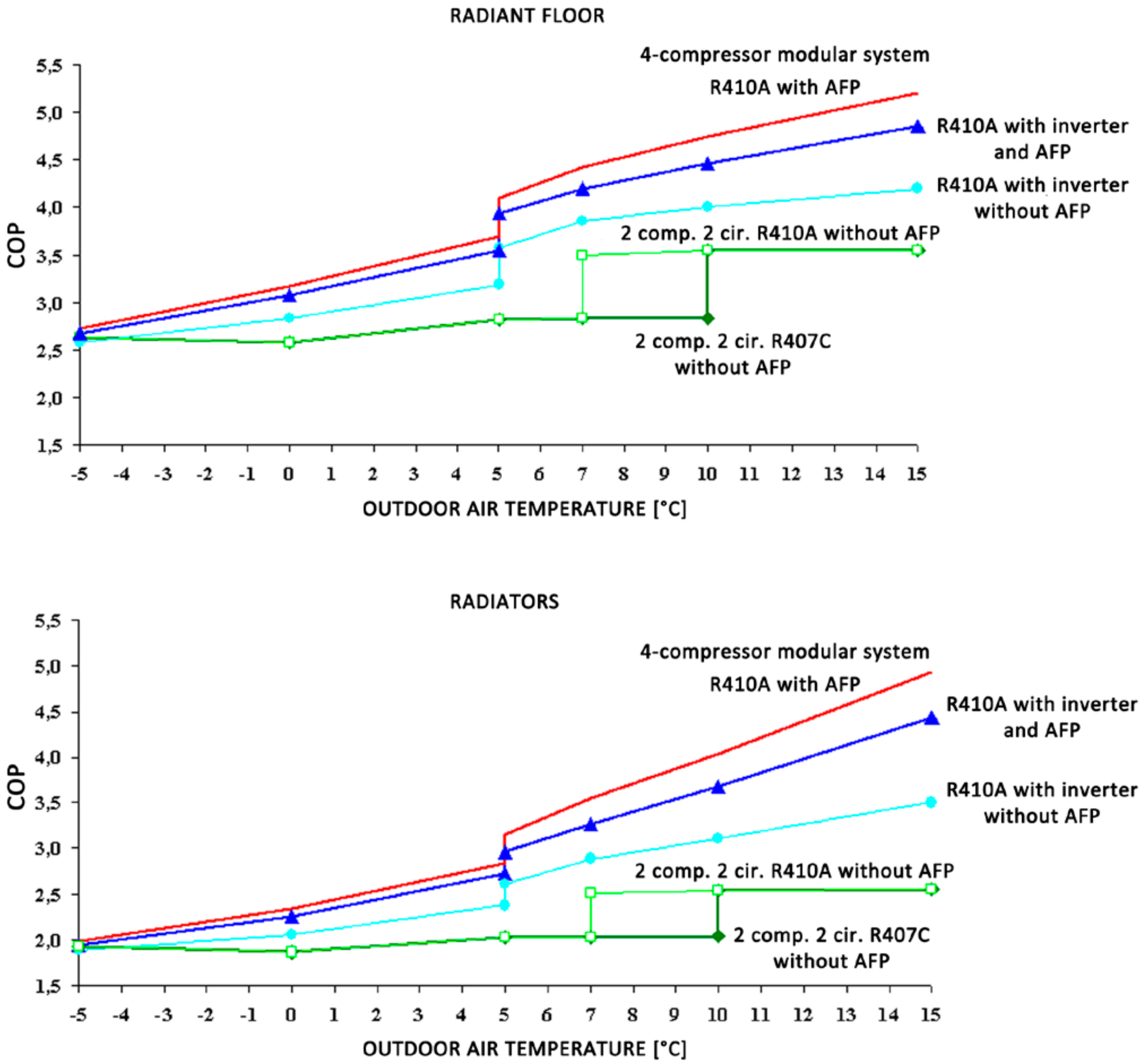

Figure 5. Total winter performance of different types of heat pumps.

The Poker modular system

Poker is an innovative line of modular heat pumps that are able to combine main features such as noiselessness, flexibility, and energy efficiency. Poker consists in independent 34 kW thermal modules, which, connected to, each other, generate an overall power of 137 kW. Each individual module is an air-water reversible heat pump equipped with a scroll compressor with tandem configuration and R410A refrigerant. The units are easy to install, both from a hydraulic and electrical viewpoint.

System configuration

The modular system is able to produce hot/cold water for the system and DHW with different configurations (3-way diverter valve or heat recovery).

It gives also many advantages:

- Partialisation energy advantages
- Energy advantages due to the patented adjustment logic Adaptive Function Plus
- Energy advantages due to the presence of partial recovery
- Total redundancy of components
- Reduction of the amount of refrigerant per individual circuit

Energy and economic analysis: a few practical cases

Hereunder is a report of data obtained regarding three similar buildings situated in three different Italian locations with very different climates: Milan, Rome, and Catania. The analysis was carried out using Energy Plus software. **Table 1** shows the energy requirements in the buildings taken as an example.

Table 1. energy requirements in the buildings taken as an example (kWh).

	Milan	Rome	Catania
Heating Requirements	58,025	46,555	33,998
DHW Requirements	21,827	21,827	21,827
Cooling Requirements	15,062	25,155	25,352

Table 2. Seasonal energy efficiency in the cases taken into consideration.

		HP 2 compressors 2 circuits without AFP	HP 2 compressors 2 circuits with an inverter without AFP	Modular system 2 modules 4 compressors 2 circuits with AFP
SCOP	MILAN radiators	2.20	2.51	3.42
	MILAN floor	3.71	4.24	4.74
	ROME radiators	2.33	2.70	4.23
	ROME floor	3.93	4.40	5.00
	CATANIA radiators	2.59	2.85	4.69
	CATANIA floor	4.35	4.79	5.55
SEER	MILAN	3.32	3.68	4.17
	ROME	3.17	3.51	3.91
	CATANIA	3.30	3.67	4.14

Five different generators were compared, each one applied to two types of heating systems (floor radiating and radiators), while summer cooling was taken into consideration in all cases with a fan coil system.

Table 2 shows the seasonal efficiency values obtained from the various types of heat pumps. The observation

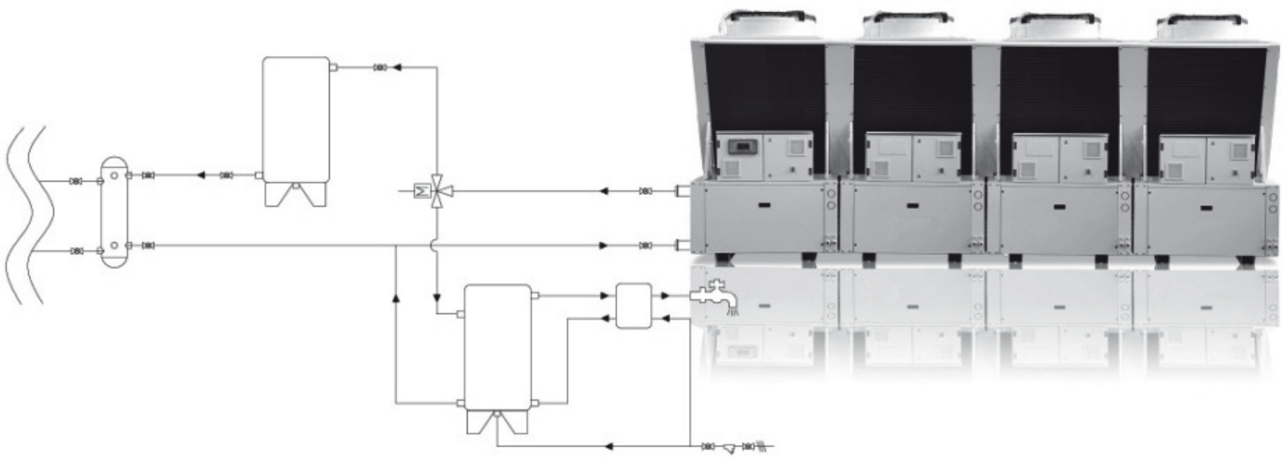

Figure 6. Example of separate production of domestic hot water and hot/cold water for the system.

Table 3. Work costs (€) in the considered cases (cost of methane 0.80 €/m^3, cost of EE 0.20 €/kWh).

		Methane boiler	HP 2 com 2 circ no AFP	HP 2 com 2 circ inverter no AFP	Poker system 2 modules	Poker system 2 heat recovery modules
MILAN	Radiator Heating + DHW	6,856	6,941	6,293	5,034	4,932
	Floor Heating + DHW	6,626	4,794	4,403	4,089	3,987
	Cooling		907	818	722	722
ROME	Radiator Heating + DHW	5,901	5,601	5,056	3,800	3,637
	Floor Heating + DHW	5,716	3,974	3,720	3,461	3,298
	Cooling		1,587	1,431	1,287	1,287
CATANIA	Radiator Heating + DHW	4,854	4,157	3,918	2,966	2,782
	Floor Heating + DHW	4,719	3,095	2,952	2,741	2,558
	Cooling		1,536	1,372	1,225	1,225

of **Table 2** helps us to understand the energy advantages of a modular system compared to the other types of heat pumps.

The energy advantages are also translated into economic advantages, as shown in **Table 3**. As we can note, economic savings are always very high with radiator systems, especially thanks to the ability of modular systems to produce water at the precise requested temperature of the system.

It is interesting to point out how modular systems in Rome and Catania, which are applied to radiator systems, obtain better economic results compared to heat pumps without logic adjustment AFP (also with inverters) connected to radiant systems.

This shows that it is possible to save energy and money without substantial initial investments, especially when considering that the cost of a modular system is in line with that of a monobloc unit having the same power, thus leaving the existing system unchanged or, at most, changing them with new radiators.

Conclusions

The diffusion of heat pumps in heating systems has just begun and may be successful if the products proposed by manufacturers can be also fitted onto traditional radiator systems. Memory has shown how important it is to work on energy efficiency, especially by optimising performance of heat pumps in partialisation and using software that is able to reduce the temperature of water production according to actual system requirements. Similarly, if the heat pump is to be the only generator present, it must be completely reliable under any operating condition: modular systems are the best solution to fulfil these requirements. ■

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