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Heat pumps in refurbishment of existing buildings

This article analyses the opportunities of heat pump applications in the refurbishment of existing buildings. The first issue is the temperatures in the heating system. The high original design temperature for the radiator system, mostly incompatible with the heat pump operations, is mainly due to poorly insulated buildings. The improvement of the building envelope insulation during the refurbishment makes it possible to reduce the radiators supply water temperature and improve the COP of heat pump.

The second problem is the production of domestic hot water (DHW). While the boiler selection can be driven by the instantaneous need of domestic hot water, thus to higher heating capacity than that required for space heating, the heat pump selection – given the higher capacity cost, since the higher technology level of the product – should be conducted more carefully. First of all the heat pump requires a hot water storage with an adequate sizing of the heat exchanger and of the DHW set point. The risk is that the heat pump cannot supply its heating capacity to the storage, particularly when in summer its capacity is higher due to the favorable source temperature: the heat pump would then be heavily modulated, requiring a long time to satisfy the DHW demand.

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Effect of temperatures on performance

Heat pumps can result in a great advantage even in the refurbishment of buildings, providing that its different behavior from a traditional boiler is carefully considered.

First of all a heat pump requires a heat source: availability and thermal level of the source strongly influence the performance both in capacity and efficiency. Whereas the thermal level of the produced heat little modifies a boiler performance, it changes strongly the heat pump efficiency, and even less, its capacity.

The usual upper thermal limit for a heat pump is around 60°C: this creates problems with the most widespread heat distributing devices in the existing buildings, the radiators, and other questions regarding to the DHW (Domestic Hot Water) production.

The first cost of a heat pump is much more dependent on its capacity than boiler capacity. Thus a higher capacity device has a higher cost; moreover when the heat pump is electrically driven a more expensive power engagement with the utilities is due.

Then the selection of the heat pump capacity is of paramount importance. The capacity is generally lower than the design load. This is particularly true for air source heat pump, as an outdoor air temperature reduction faces a heat pump capacity reduction just when the load is increasing.

If the heat pump capacity is selected after the design load, apart the costs just reminded, the heat pump almost always operates at part load with potential performance reductions.

Figure 1 better explains: it represents winter and summer loads of a building, considering that they are essentially dependent on the outdoor air temperature. Loads are given by two straight lines with opposite slope, rising from zero to the left (winter) and to the right (summer). The figure shows the heat pump capacity both in winter and summer, the former increasing and the latter decreasing with the outdoor air temperature. The intersection between the heat pump heating capacity and the load is referred to as the balance point, in the figure just little below 0°C. For higher temperatures the heat pump fully satisfies the loads, whereas at lower temperatures an auxiliary heating is needed such as a small gas boiler or electrical resistance heating. The optimal selection of the balance point is probably one of the most critical elements of the design.

The main data requested for the heat pump application in a refurbishment are:

- Cumulative curve of the heating (and cooling) building demand as a function of the outdoor temperature in a given location;
- Heating distributing devices characteristics;
- Assumed trend and amount of DHW demand;
- Electricity and natural gas tariffs, present and likely future;
- Availability and properties of the heat source for the heat pump.

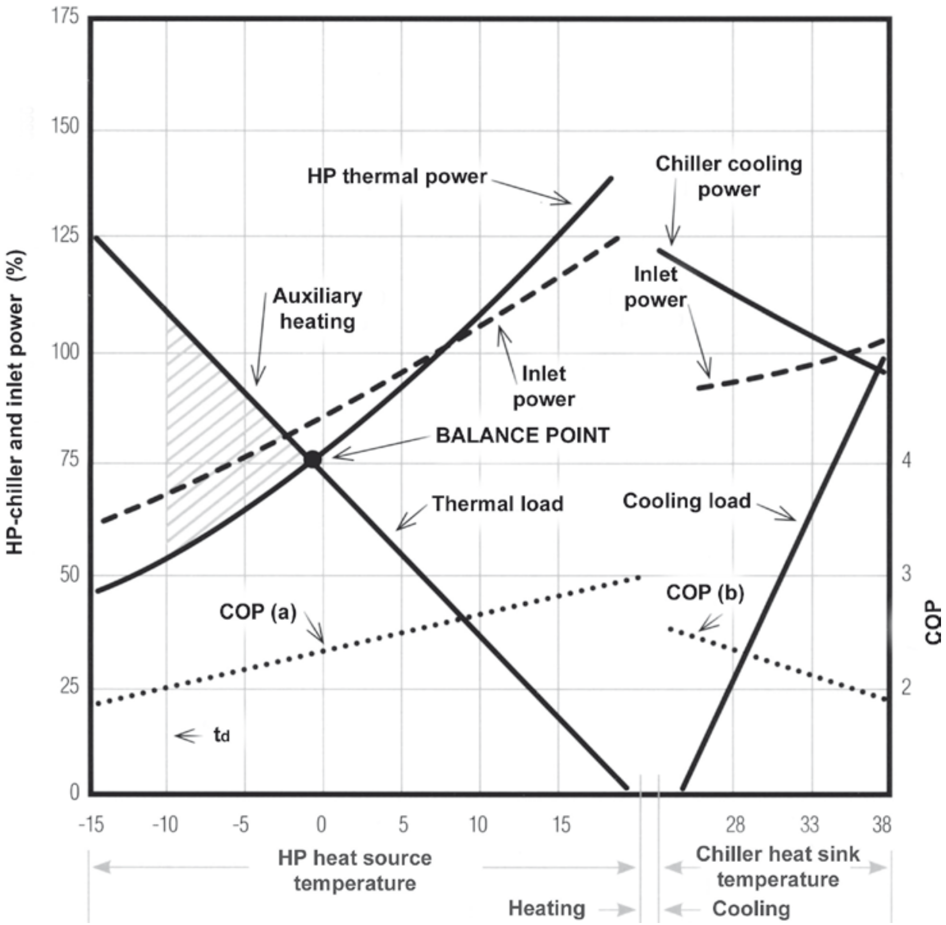

Figure 1. Thermal-cooling power produced, electrical power supplied to the heat pumps both in heating and cooling mode, COP and thermal and cooling loads of the building as a function of outdoor air temperature.

The most relevant elements in the refurbishment are discussed in the next chapters.

Heat pump types

A first important classification is between electrical and gas driven heat pumps. The latter can be absorption or motor driven. Another important classification regards the heat pump source, frequently outdoor air for the easy availability, but also surface or well water or the ground. Outdoor air is the most common source in refurbishment as drilling is often prevented by the existing buildings and infrastructure. If a mechanical ventilation system is provided, then a suitable source can be the recover on the exhausted air. The selection of the heat pump type is in some way connected to the possible source. In fact electrical heat pumps are particularly sensitive to the temperature difference between the heat source and the thermal useful effect. A typical example is illustrated in **Figure 2** where for a low source temperature (air at 2°C) COP and PER (Primary Energy Ratio for an electricity conversion factor of 0.45) are evaluated as a function of the hot water temperature. In the interval from 30°C to 60°C COP and PER are almost halved.

Absorption heat pumps are less sensitive and motor driven heat pumps are intermediate. An absorption heat pump PER is represented in the temperature field from 45 to 65°C in **Figure 3**: at lower supply temperature the behavior is a little less favorable, but surely better at higher temperature, particularly starting from 50°C.

The selection of the most suitable heat pump type is fundamental in refurbishment. The most important elements to be considered are:

1) The temperature differences, as already mentioned;
2) The availability (and the relative cost) of electricity and natural gas;
3) The possibility of an eventual easy exhaust of the combustion gases;
4) The availability of a suitable heat source;
5) The ratio between winter and summer loads.

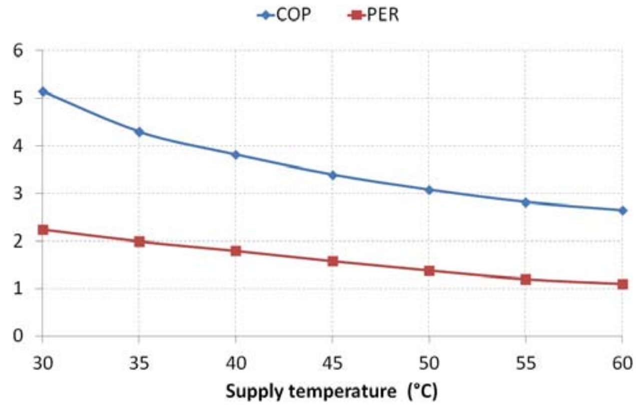

Figure 2. Coefficient of Performance (COP) and Primary Energy Ratio (PER) of a typical electric heat pump depending on the supply temperature in a water based heating system (outdoor air temperature 2°C).

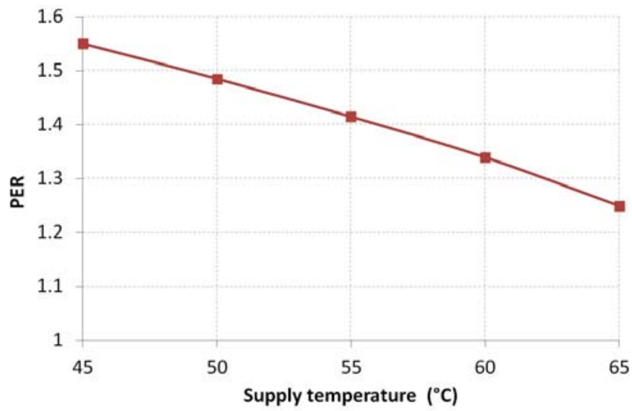

Figure 3. Primary Energy Ratio of a typical absorption heat pump as a function of supply temperature.

Heat distribution

In residential buildings the most common heating devices are hot water radiators. Low temperature radiant emitters are recently more widespread than radiant floors or ceilings. A recent study in Germany reports that radiators represent 53% of the heat emitters in existing buildings, while combined systems 20%, and floor heating systems only 2%.

It is really unlikely that even the heat distributing devices are replaced during a refurbishment as it would mean to let out the inhabitants for a period of at least 15 days. Then the radiators are kept usually intervening on the insulation and on the central heating plant. The radiators sizing is usually based on a supply temperature of 80°C and a return at 60°C in design conditions. Thus nominal thermal emission is obtained with a temperature difference of 50°C (difference between the average temperature of the radiator, 70°C, and the room temperature of 20°C).

In spite of its name a radiator exchanges heat mainly by convection (about 70-80%) and the thermal emission can be evaluated as the product of the nominal emission and the ratio of the two temperature differences (the actual and the nominal calculated by EN442 standard) raised to an exponent n, usually around 1.3:

$$P_{eff} = P_{EN\,442}\left(\frac{\Delta t_{eff}}{50}\right)^{n}.$$

Figure 4 illustrates the emission reduction as a function of the inlet temperature (a 5°C lower temperature is considered at the outlet). A supply temperature of 55°C, consistent with the heat pump utilization, gives an emission slightly less than 60% of the nominal value. For a design temperature of –5°C the corresponding load could be for an outdoor condition of 5°C. It could be also the design load for a refurbishment providing good insulation even only on windows.

Besides, as reminded above, the heat pump heating capacity should not be selected according to the design

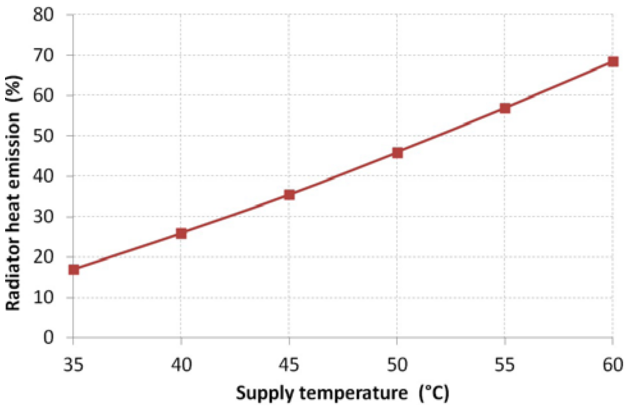

Figure 4. Radiator heat emissions as a function of supply water temperature.

conditions as for a boiler: the cost would be high and the heat pump would be almost always operating at part load. Even a heat pump equipped with an inverter for a continuous capacity control would not always be the best solution as the control seldom arrives below 30% of the nominal capacity. Instead, selecting correctly a balance point, the heat pump satisfies completely the load at higher temperatures, whereas at lower temperatures an auxiliary heating is provided, normally a boiler in the refurbishments. A boiler can easily provide the higher temperatures requested by the radiators in case of very cold weather.

Production of domestic hot water

A building refurbishment usually allows a significant reduction of the loads, but DHW demand remains the same or it is even increasing.

A DHW storage must be provided as the heat pump does not allow the instantaneous production. When storage already exists with built-in heat exchanger, sized for a gas boiler, it must absolutely be replaced with a storage equipped with a much higher capacity heat exchanger.

The DHW set point is to be determined considering the heat pump temperature limits. If the highest temperature supply of the heat pump is of 60°C, setting the storage temperature only some degrees below that value makes the heat pump to operate at part load for hours, as the bottle neck is just the heat exchange that is proportional to the temperature difference. Thus, besides the long time requested to storage charging at low efficiency, the building heating is not assured meanwhile. Provided a minimum value of at least 5°C in the temperature difference, sizing and quality of the heat exchanger is of paramount importance.

The most critical operation for DHW production is not, as one might think, at a low temperature of the heat source, but at higher temperatures when the heat pump capacity increases. Let us consider a heat pump that gives 18 kW for 7°C heat source (outdoor air) reference temperature. When the air temperature is 35°C, this heat pump capacity arrives at 28 kW. A gas boiler sized built-in heat exchanger is able to exchange around 20-30 kW for 80°C inlet temperature and 20°C temperature difference. The heat pump should operate with 5°C temperature difference, that means 4 times lower heat exchange. If the heat pump gives 28 kW, while only 6 kW can be exchanged, the machine operates at part load with frequent ON-OFFs. Even a heat pump equipped with an inverter and variable speed compressor cannot be a solution, because the speed reduction goes seldom below 1/3 of the top speed (typically the inverter frequency field is from 30 to 90 Hz). Moreover, the capacity reduction is not proportional to the compressor speed. In fact when the refrigerant flow is reduced, also pressure drop at inlet/outlet of compressor and friction are lowered. Consequently the refrigerant density is higher, so that a volumetric flow reduction of 50% produces a capacity reduction of about 30%. Such a coupling of heat pump and heat exchanger does not work satisfactory even in winter. In fact for a 15 kW heating capacity, a 6 kW heat exchanging ability obliges the heat pump to produce DHW for 2.5 longer time than it would be necessary. During this period no ambient heating is provided.

The solution is a generously sized built-in or external heat exchanger. A selection of a heat exchanger able to exchange 100 kW for the classical 20°C temperature difference solves the just described problems, as it can exchange 25 kW for 5°C temperature difference.

Heat pump in the refurbishment of apartment buildings

Most of heat pump applications in residential buildings are actually for single-family houses, both because builders of apartment buildings tend to the cheapest solutions on the market for the heating plant and for tariff problems.

However, the most suitable heat pump application is just on apartment buildings (**Figure 5**). Here a short list of advantages:

- Significant economy of scale. The unitary capacity cost lowers with the heat pump capacity.

- Fewer problems regarding DHW production as the simultaneous load of all the apartments is unlike. A well sized storage can equipped with a timer for nocturnal charging at lower electricity tariffs.
- The plant can be used for summer cooling.
- Higher capacity heat pumps often operate at some percent higher COP.
- The overall engaged power is lower than the sum of the requested power of many single apartment heat pumps.

A thorough analysis is presented in the full paper version, considering a comparison of heat pumps vs. condensing boiler in apartment buildings located in the three cities of Athens, Strasbourg and Helsinki.

Conclusions

The heat pump can be an excellent solution in refurbishment of existing buildings. The selection of type and capacity must be carefully considering the heating system and its operating temperatures, the insulation provided to the building and the availability of a suitable heat source. The right selection of the balance point as a function also of the load cumulative curve is particularly sensitive.

Temperature levels for the heat emitters, climatic conditions for an outdoor air source and electricity and gas tariffs lead to the choice between electrically or gas driven heat pumps.

Figure 5. A centralized heat pump in an apartment building. [Courtesy of Robur]

The use of the heat pump in apartment buildings is normally very favorable. Economic evaluations suggest simple payback periods of around 5 years for a suitable heat source with the further advantage of summer cooling allowed by the reverse cycle heat pump.

References

See the complete list of references of the article in the html-version at www.rehva.eu -> REHVA European HVAC Journal.