Heat pumps: *lost in standards…*

The different EU directives and regulations have been and are the main driver for the development of CEN standards on Heat Pumps, from basic product standards towards system standards.

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Introduction

EU is pushing energy conservation and emissions reduction with a set of directives, which already underwent amendments and recast.

EPBD, Energy performance of Buildings Directive, targets efficiency in buildings and related technical systems. The objective is making any building habitable to a standard comfort level using the least possible amount of non-renewable primary energy and/or greenhouse gas emissions. Minimum requirements and building labels are based on the actual building description with the standard climate of the actual location and a standard use. This directive includes both minimum requirements and a display mode (the EPCs) to make users aware of energy performance.

ErP and Ecolabeling directives[**1**] target efficiency of products. They extend minimum requirements to access EU market to the energy efficiency of products. The objective is having only efficient products on the market. Ecodesign EU regulations define what are "efficient products" and "Ecolabeling" regulations define how to display the efficiency level of products so that consumers can recognise their added value. Minimum requirements of products are based on their behaviour in a standardised average condition of use.

The Energy Efficiency Directive, targets the total final uses of energy of EU countries. Since comfort in buildings and products are already subject to specific directives, it complements with requirements to other energy consuming sectors, such as industry, by e.g. compulsory energy audits.

After energy use has been reduced, **RES, Renewable Energy Sources, Directive** asks to cover the energy use with renewable resources, so that we will not deplete non-renewable sources and energy will be always available in the future.

All these directives aim to the same goal. However, they were developed in parallel and the coordination between them is not perfect. There are some overlaps and the groups of people and stakeholders interested in each directive are not the same and they do not always coordinate optimally. Currently, there is an effort to make them consistent to cover rationally the entire topic of energy use in Europe.

The need for coordination is also emerging in the supporting EN standards for directives EPBD and ERP.

EPBD and ErP share the same starting point, the products, and in both cases you need a calculation based on product properties but the approach is quite different.

ErP directive approach

The intent of ErP directive is to ban inefficient products from the EU common market. Ecodesign sets minimum requirements on products and Ecolabeling displays products efficiency to encourage EU citizens to select and buy the best performing ones. This is fine for "off the shelf" products, where the citizen is alone in making the decision of which product to buy and then use.

To apply ErP directive, you have to define a method, based on product tests and some calculations, to determine the "efficiency" of each product and label it. EU regulations have been issued for "lots" of products: they define the testing conditions and the calculation method to simulate an average use of the product and rate the product efficiency as a stand-alone item.

To have a fair rating, it shall be based on a representative mix of operating conditions. Obviously, this shall be the same for all products and provide one single rating figure for the product. For the testing and/or calculation method, EU regulations may refer to "harmonised" EN standards. In that case, the so called "annex Z" defines how to use the harmonised EN standard for EU regulation compliance purpose. ErP application is strictly the same all across Europe since it's a common market issue and part of the CE marking.

ErP compliance is a key concern of manufacturers. They have to achieve a minimum rating to be able to sell the products (that's a survival issue for them!) and possibly a good rating to sell many products.

Table 1. *Overview of CEN standards on heat pumps.*

Context	Standard	
Basic product standard	EN 14511	Air conditioners, liquid chilling packages and heat pumps for space heating and cooling and process chillers, with electrically driven compressors Part 1: Terms and definitions Part 2: Test conditions Part 3: Test methods Part 4: Requirements
	EN 16247	Heat pumps with electrically driven compressors - Testing, performance rating and requirements for marking of domestic hot water units
	EN 15879	Testing and rating of direct exchange ground coupled heat pumps with electrically driven compressors for space heating and/or cooling – Part 1: Direct exchange-to-water heat pumps Part 2: Water(brine)-to-direct exchange and direct exchange-to-direct exchange heat pumps (draft)
	EN 12309	Gas-fired sorption appliances for heating and/or cooling with a net heat input not exceeding 70 kW Part 1: Terms and definitions (under review) Part 2: Safety Part 3: Test conditions Part 4: Test methods Part 5: Requirements Part 7: Specific provisions for hybrid appliances
	EN 16905	Gas-fired endothermic engine driven heat pumps Part 1: Terms and definitions Part 2: Safety (under review) Part 3: Test conditions Part 4: Test methods (under review)
EPBD application	EN 15346-4-2	Energy performance of buildings - Method for calculation of system energy requirements and system efficiencies Part 4-2: Space heating generation systems, heat pump systems, Module M3-8-2, M8-8-2
ErP (Ecodesign) and Ecolabeling	EN 14825	Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling, commercial and process cooling - Testing and rating at part load conditions and calculation of seasonal performance
	EN 16247	Heat pumps with electrically driven compressors - Testing, performance rating and requirements for marking of domestic hot water units
	EN 12309	Gas-fired sorption appliances for heating and/or cooling with a net heat input not exceeding 70 kW Part 6: Calculation of seasonal performances
	EN 16905	Gas-fired endothermic engine driven heat pumps Part 5: Calculation of seasonal performances in heating and cooling mode
System design	EN 15450	Heating systems in buildings - Design of heat pump heating systems

EPBD directive approach

The intent of EPBD directive is:

- to have only efficient new buildings, hence all new buildings shall be NZEB;
- to push efficient renovation of existing buildings, hence requirements when renovating envelope and/or technical systems;
- to increase the market value of efficient buildings, hence provide an EPC before selling and renting.

A calculation method of the "energy performance of the building" is required. This has to take into account the performance of the products incorporated in the building and its technical systems in the specific operating conditions required by the building, system set and climate. EPBD directive does not specify the calculation method, it only requires that a number of features are taken into account and that the actual method enforced by the MSs be described in terms of equivalent options of the EN overarching standards. A full set of EN standards has been developed indeed, to support a uniform EPBD directive application throughout EU, i.e. to calculate the energy performance of the building.

EPBD compliance and rating is a key concern of building owners and building designers.

Heat pump technology

The "generation sub-system" is that part of the technical systems that uses an energy carrier delivered from outside the building (i.e "delivered energy) to provide the type of energy that you need inside the building (e.g. heat, heat extraction, light). The most obvious example is a combustion boiler that converts the chemical energy of the delivered fuel into heat. Likewise, a lamp is a "light generator" as well as a fan is an "air flow rate generator".

In the last decades the market of heating generators for buildings has been dominated by combustion boilers. It's a mature product, simple, easy to use, powerful, cheap per kW. There are other alternative generation techniques but they are limited in availability (example: district heating), complicated to use at building level (cogeneration, which requires simultaneous electrical and thermal loads) or unable to provide a full year-round service (thermal solar). Of course, you may find exceptions but have a look around you and you will see quite few popular alternatives.

Heat pump technology has been always used for cooling but now there is a strong push for its massive use for heating, as well. Well insulated buildings and low temperature emitters allow to overcome the inherent limitations of this technology which are the still high cost per kW installed, the need for a source of free heat and the drop in efficiency when asking for a high temperature difference between the source and the sink (the heated object).

It's no doubt that taking heat from a cold source where it can be extracted for free and pumping it into the heated fluid (or directly into the heated space) can be a much more efficient process than obtaining the same amount of heat by converting an equivalent amount of chemical energy in a combustion boiler. This makes heat pump technology a serious competitor menacing the boiler supremacy.

"Heat pump" is a wide and complex world:

- there are several heat pumping technologies: the most popular is gas compression cycle driven by an electric motor (internal combustion engines are used as well), then there is absorption, adsorption, Peltier cells, … even a thermocouple could be used;

- there are several types of heat sources being used:
  - air, probably the most available and used but it makes the performance of the heat pump strongly dependent on climate conditions;
  - ground, makes it less dependent on climatic conditions but needs an extensive and expensive heat exchanger (vertical bore hole or horizontal network);
  - ground water, needs pumping energy;
  - surface water, only where available;

- there are several heat sinks in use
  - indoor air;
  - technical water, e.g. water circulating in the system;
  - domestic hot water, for domestic hot water heaters;

- the main energy carrier can be electricity, a fuel, waste heat…

and then the heat pump can be single stage, staged, modulating, splitted, etc.

No surprise if it takes some time to "normalise" this multi-faceted world.

Heat pump performance

The performance of a heat pump is extremely sensitive to operating conditions. A typical heat pump may have a COP from 2 to 6 within the winter operating range. The dependency of efficiency on operating conditions is typically non-linear and there are several factors to take into account:

- source and sink temperatures: one single degree less or more in temperature difference between sink and source means 2…3% change in efficiency;
- part load operation;
- defrosting cycles, when outdoor air is used as a source.

This makes it difficult to represent accurately the whole performance map with only few test points.

An example of the dependency of COP and maximum power output on source and sink temperature is given in figures 1 and 2, that refer to an air to water heat pump. **Figure 1** shows the wide range of the COP and its dependency on both source and sink temperature. **Figure 2** shows the dependency of maximum output power on the evaporator (source) temperature. Recent inverter heat pumps have limitations in output power at high external temperature because it is unlikely that a high power be required in these conditions.

An example of the potential effect of part load (at constant source and sink temperature) is shown in **Figure 3** which shows some correction curves of full load efficiency that are adopted in several standards. For inverter heat pumps you may expect some increase of the COP with a moderate part load, up to a maximum, and then the COP decreases significantly with intermittent operation. When the part load goes below 20% the correction is quite significant. Often this happens for low loads so it is somewhat masked. Furthermore, a heat storage may help reducing this issue.

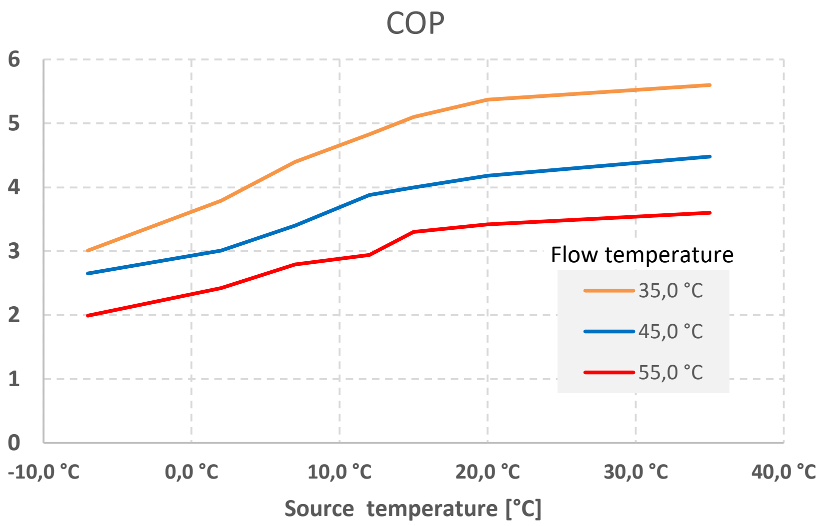

Figure 1. Typical AW heat pump COP.

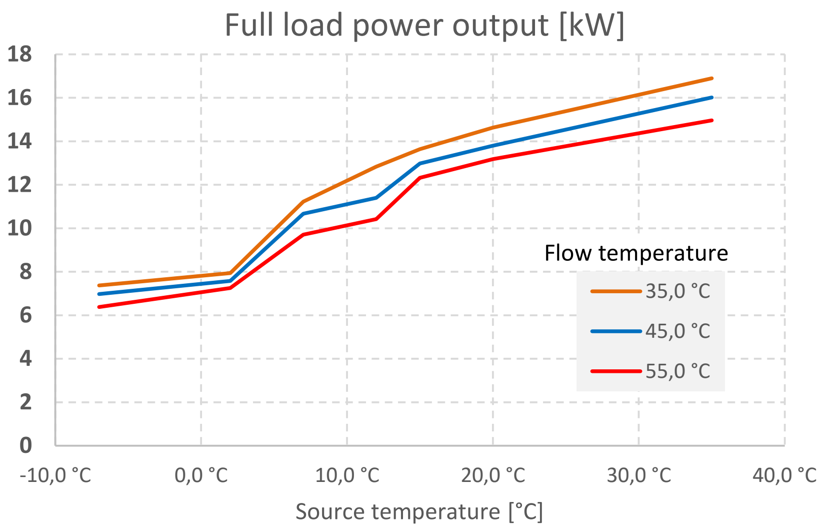

Figure 2. Typical AW heat pump maximum output.

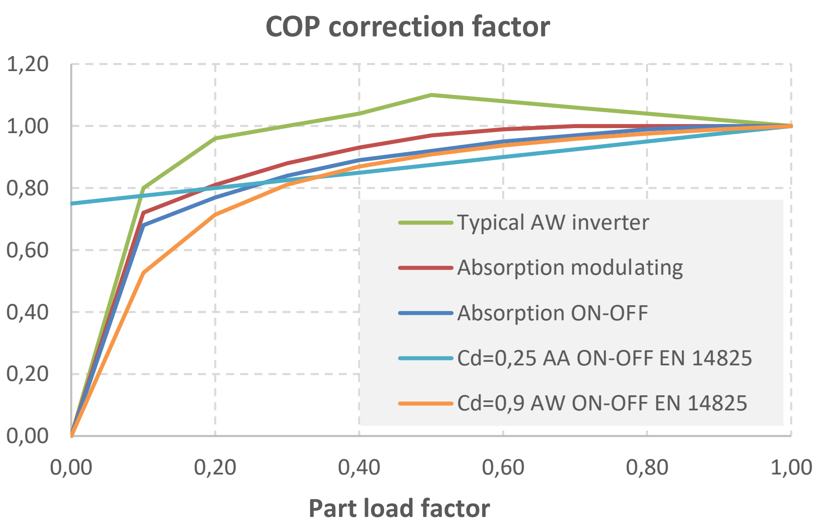

Figure 3. Typical part load correction factors of COP.

For ON-OFF heat pumps, each start-up means that the compressor has to pressurise again the condenser and when stopping the pressure will be equalised and some work done by the compressor is wasted.

For modulating and staged heat pumps, some part load can be beneficial for the compressor efficiency.

The COP depends on the pressure difference seen by the compressor, which in turn depend on condensation and evaporation temperatures. Performances of heat pumps are not displayed as condensation and evaporation temperature but on air and/or water temperature.

Source temperature, for both air and water heat pumps, is the entering temperature in the evaporator. The evaporation temperature is lower due to the temperature drop of air or water across the evaporator (typically 5…7°C), plus the approach of the evaporator. At low load the approach is reduced and this increases the COP. The temperature drop of air or water is reduced as well but this is true only if their flow rate is maintained, which means increased relative auxiliary energy use and noise.

When using water, the sink temperature is the leaving water temperature. The difference with condensation temperature is only given by the approach of the condenser, which is usually 2…3 degrees. The effect of part load is small here. When using air, the sink temperature is the inlet temperature to the condenser. To get to the condensing temperature you have to add both the temperature increase of the heated air and the approach of the condenser. In this case part-load is very beneficial because both the heated air temperature increase is reduced and the approach. However, this is really true only if the air flow rate across the condenser is kept constant when modulating down. To get a quieter operation, the condenser fan speed is often reduced at low load and the increase in air temperature may stay constant. In other words, you may trade-off between comfort (quiet operation) and efficiency (fan at full speed, which means draft in the heated space). This should be taken into account when dealing with part load efficiency of air-to-air heat pumps.

Since part load operation is a concern, the conventional way to express operating conditions when declaring performance data of heat pump, such as A7W35 should be extended to include the information on part load factor during the test, with any of following: $A7W35_{100}$, $A7W35_{50}$, $A7W35_{FL}$, $A7W35_{MIN}$…

Even part load definition is tricky with heat pumps. Since the maximum power output strongly depends on operating conditions it should be the ratio between actual output power and maximum output power for the same source and sink temperature (maximum compressor speed). Sometimes the maximum compressor speed is limited electronically depending on source and sink temperature for a number of good reasons. In that case the apparent maximum output is already a part load. This should be taken into account as well.

EN Standards on heat pumps

EN 14511

The basic product standard on heat pumps is EN 14511. It deals with electric heat pumps and it defines the testing procedures and a set of testing points depending on the type of source and sink. The first published version dates back to 2004.

Product tests concern the maximum power output (heating capacity) and COP at full load depending on the source and sink temperature. There is no specific testing for part load operation mentioned in EN 14511.

EN 14825

EN 14825 is intended to support the application of Eco-design and Ecolabeling directive. It provides a method to calculate a "seasonal" performance (SCOP and SEER) with an assumed operating condition. It complements EN 14511 in defining part load test conditions suitable to provide the data for the calculation of the SCOP and SEER.

The $SCOP_{ON}$ is a weighted average of the part load COP measured for 4 operating conditions, labelled A to D, plus an extra point G for cold climate. Then other components of auxiliary energy (stan-by, crankcase heating,…) are taken into account to get $SCOP_{NET}$.

The weighting factors are given by a simulated bin calculation assuming that the required power output increases linearly from design power P_{des} at the design outdoor temperature (T_{des} = –22°C, –10°C and +2°C depending on the reference climate) to zero at 16°C external temperature. For each bin, the COP is determined by linear interpolation according to external temperature between the values of COP measured at conditions A, B, C and D and possibly point E.

The test conditions are tailored for the purpose and expressed as special variants to test conditions defined by EN 14511 which is still the basic test standard. If the heat pump should cycle on-off in a given test point (single stage machines or power request below minimum modulation), then the test is performed indeed at the minimum capacity and then the result is corrected by a given function with a default correction parameter Cd. The manufacturer may provide a tested value of the correction parameter.

The procedure makes sense to test and label a product. A simple linear model is used to simulate the heating demand and it is assumed that all conditions vary linearly between the 4 tested points.

It shall be noted that the weighting can be somewhat "optimised" by the manufacturer: by declaring a bivalent temperature $T_{BIV} < T_{DES}$, an electric heater is taken into account to compensate for the missing energy in the colder bins but the part load factor in conditions B, C and D improves and may compensate the loss at A (or G).

It has to be noted that in the 4 (or 5) tests all the operating conditions are varying simultaneously: source temperature, sink temperature and required power output. Sink temperature is kept constant for fixed flow temperature units, which are quite an exception.

A point of attention when reading EN 14825 is the difference between PLR (part load ratio) and CR (capacity ratio).

The PLR (part load ratio) is a descriptor of the load model: it is the ratio between the load at a given outdoor temperature and the load at design temperature. The range is 0 to 1 and the value is the same for all heat pumps at a given test point and temperature.

The CR (capacity ratio) is a descriptor of the heat pump loading: it is the ratio between the load at a given outdoor temperature and the maximum capacity of the heat pump at that given outdoor temperature. It is not the same as PLR because the maximum capacity of the heat pump $\Phi_{hp;out;max}$ depends on the temperature (see **Figure 5**).

Then the IR (intermittency ratio) should be introduced to complete the description of the behaviour of modulating heat pumps. As the required output power decreases, it will drop below the minimum continuous operation capacity of the heat pump. Then, the heat pump will start to cycle ON-OFF, ideally at the minimum power. The IR should be defined as the ratio between the load at a given outdoor temperature and the minimum continuous operation capacity of the heat pump at that given outdoor temperature. If we call CR_{min} the value of CR, then $IR = CR/CR_{min}$.

For a single stage heat pump, the minimum capacity is the same as the maximum, hence IR = CR.

For a modulating heat pump, IR = 1 (continuous operation) until $CR>CR_{min}$ and then $IR = CR/CR_{min}$.

EN 14825:2018 fails to identify explicitly IR, which is essential for the correct application of the degradation coefficient to modulating heat pumps.

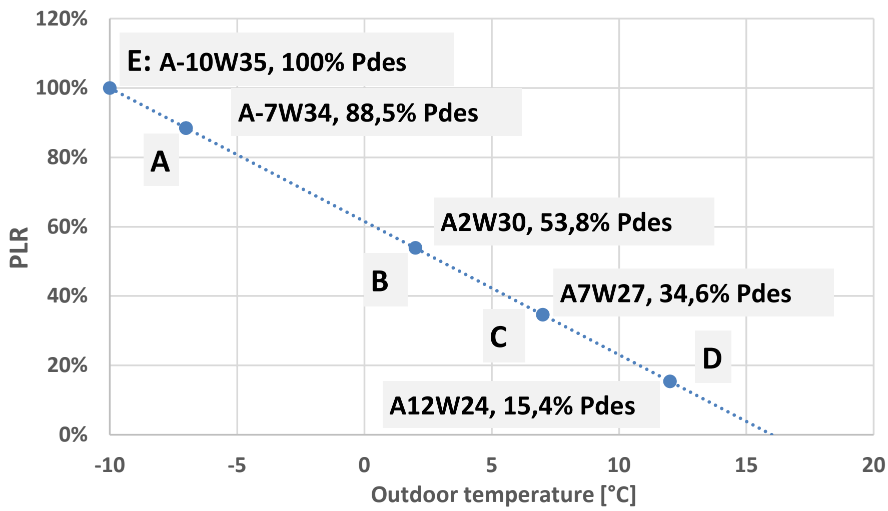

Figure 4. Diagram with test conditions for AW heat pumps.

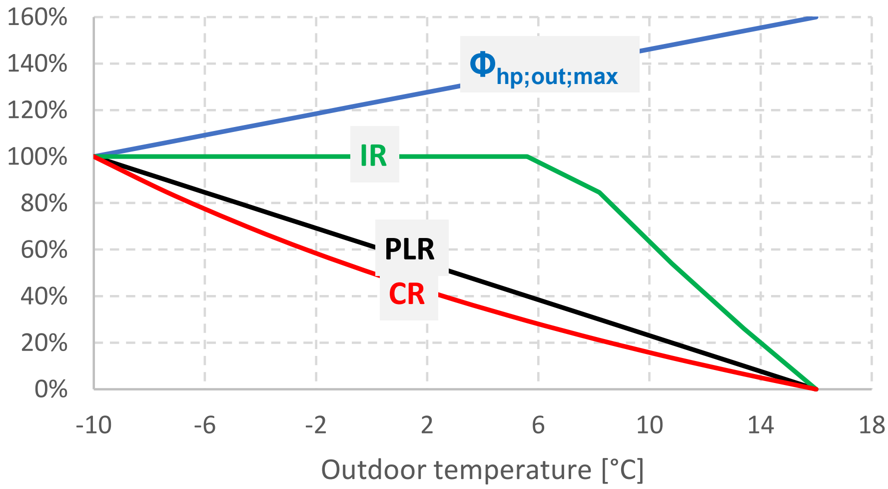

Figure 5. Relationship between PLR, IR and CR for a modulating heat pump.

EN 15316-4-2

EN 15316-4-2 is part of the CEN-EPB package of standards. This package was first drafted according to a mandate of the EU Commission in 2006 to support the implementation of EPBD directive. The first published version dates back to 2008.

The aim of this standard is to assess the energy performance of the heat pump taking into account the operating conditions according to the actual building needs, technical system configuration and control options.

For each calculation interval, which can be monthly, hourly or bin, the other modules of the calculation determine the required power output and flow temperature. EN 15316-4-2 module has to determine:

- if the heat pump can fulfil the whole load or only part of it;
- the required energy input, main for compressor, auxiliary and integrated back-up.

The new draft of this standard [**2**] has a common calculation frame which allows to select one of two calculation paths depending on the type of heat pump and the available data to take fully into account all relevant operating conditions.

When using the so called "path A", first the full load COP and available output power are determined according to EN 14511 test data (or other relevant product data like EN 12309 and EN 16905). Then a part load correction factor is applied to full load COP to take into account the actual part load operation CR in the calculation interval. The difficulty is that there several ways available to do that, also depending on the heat pump type. The underlying assumption is that the correction factor or method doesn't depend on the sink and source temperature. Some examples of correction factors are given in **Figure 4**.

The intent of the so called "path B" is to leverage test data measured according to EN 14825. The difficulty is that the 4 measuring points have been selected based on an assumed linear load pattern and all influence variables are changing from one test point to another. It is therefore impossible to extract the influence of only one parameter from EN 14825 data set. To overcome this difficulty, this calculation path assumes that the II principle efficiency [**3**] of the heat pump be a function only of the required output power. This correlation is extracted once for all from the test data according to EN 14825. So the procedure is: calculate II principle efficiency dependency on the required output power, then calculate COP based on source and sink temperature. One limitation is that data on the maximum output power is available only for on-off heat pumps. For modulating heat pumps it is assumed that the maximum power is that at TOL. The increase in available power is not taken into account. This makes it difficult to handle situations with multiple generators, where one has to determine the contribution of each one based on their capacity.

Another limitation of path B is that no specific data is given for the domestic hot water production.

The two calculation paths coexist and there is an ongoing discussion about their use.

Figure 6 shows a calculated distribution of COP as a function of outdoor temperature for a correctly sized heat pump (continuous operation). The effect of part load is quite visible for the higher temperatures where the load is reduced.

However, only little energy is supplied in the range where the part load correction factor drops dramatically. **Figure 7** shows the distribution of energy output according to the part load correction factor, for the same calculation: only 10% of the energy is supplied

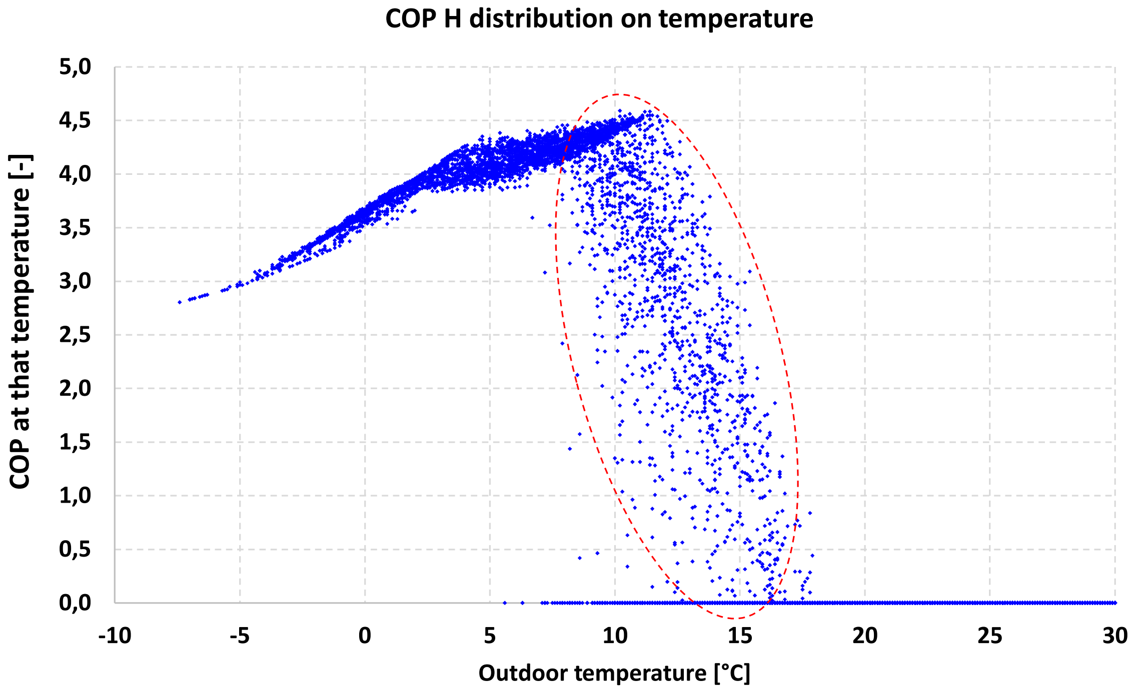

Figure 6. Sample COP as a function of outdoor temperature.

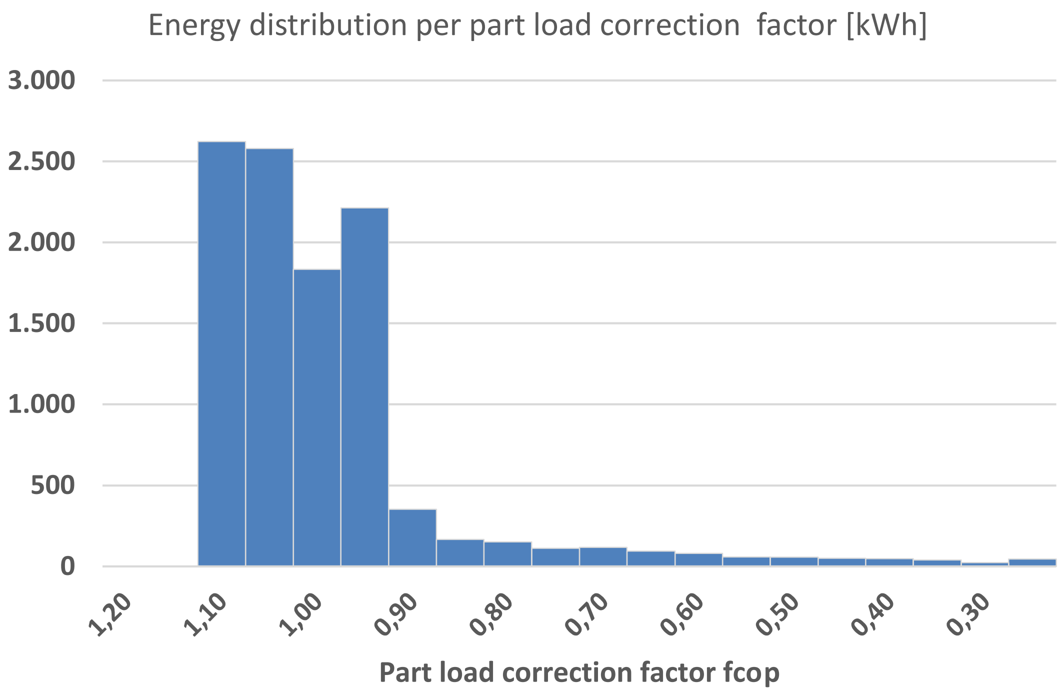

Figure 7. Distribution of supplied energy according to part load correction factor.

with a correction factor which is less than 0,85. So, the main influencing factors are still the source and sink temperatures except for badly oversized heat pumps. This is another reason to size them tight.

To identify correctly heat pump performance, some more product data will be required. In principle, to be able to isolate the influence of each parameter, only one of them should change from one test point to another one. This is already the case for data according to EN 14511, where source and sink temperature change one at a time in a set of values. A series of test at several CR for one condition of source and sink temperature may suffice to identify the COP correction factor.

A suggestion can be to test a modulating heat pump at:

- CR= 1, this is already done according to EN 14511
- CR = 0,6, this is a likely point of maximum increase of COP for AW inverter type heat pumps and indeed nearly half-way to minimum compressor speed.
- $CR=CR_{min}$ at minimum compressor speed, so that it is defined and then intermittency

For constant speed (ON-OFF) heat pump, part load effect is always decreasing the efficiency. The CD and CC equations are used in this case. It should be noted that an appropriate storage volume may reduce the effect of intermittent operation by limiting the number of on off-cycles. This is not yet mentioned in the current standards.

Domestic hot water

EN 16247 establishes test methods and calculation for heat pump domestic hot water heaters.

Modelling is simpler here because the only variable is outdoor temperature.

The heat pump providing heating can also be used to heat a domestic hot water store. This requires extra data that are not included in the standard: operation as a heat pump with outdoor temperature up to 35°C at least. An extrapolation of data from 12 to 35°C is not likely to be very accurate. This range of outdoor temperature should be used when a heat pump is intended for domestic hot water use.

Absorption and combustion engine driven heat pumps

There are two specific standards dealing with these typologies: EN 12309 and EN 16905.

These standards were developed after EN 14511 and EN 14825. So, they already cover all the issues of the basic EN 14511 and EN 14825, e.g. providing test data and a method to rate the product.

Design of heat pump systems.

EN 14150 complements EN 12828 with special provisions for the design of heat pumps systems. This standard is currently under revision.

Conclusion

Standardisation on heat pumps is far from complete. Heat pumps are both subject to Ecodesign and a key product for EPBD purpose.

The focus of the standardisation effort has been on ErP in the last years, since this is an obvious top priority for manufacturers. The focus has been on specific products, one at a time as they were included in lots and in a simple well defined operating condition.

EPBD supporting standards have a much wider scope. They have to deal with any product on the field and they have to describe all operating conditions, even the wrong ones. Actually, it is a must because the reliable demonstration of the potential gains with new products or improved operating conditions is needed to support recommendations in general and within an EPC. ■

References

[1] DIRECTIVE 2009/125/EC of 21 October 2009, establishing a framework for the setting of ecodesign requirements for energy-related products; COMMISSION REGULATION (EU) 2016/2281 of 30 November 2016 implementing Directive 2009/125/EC establishing a framework for the setting of ecodesign requirements for energy-related products, with regard to ecodesign requirements for air heating products, cooling products, high temperature process chillers and fan coil units

[2] The enquiry of this new prEN 15316-4-2 : 2021 is expected in a few months

[3] The "II principle efficiency" of a heat pump is the ratio between it's COP in a given operating condition and the maximum theoretical COP with the same source and sink temperature.