IEA HPP Annex 28 – Uniform testing and seasonal performance calculation of combined operating heat pump systems

Carsten Wemhoener, Thomas Afjei and Ralf Dott

Institute of Energy in Building, University of Applied Sciences Northwestern Switzerland, Muttenz, Switzerland

Corresponding email: carsten.wemhoener@fhnw.ch

SUMMARY

Climate protection targets require the performance assessment of HVAC systems. As basis uniform component testing and subsequent transparent calculation of the seasonal performance factor is needed. Highly-integrated system layouts, however, are not covered by existing testing and calculation standards. Annex 28 in the heat pump program of the International Energy Agency delivered recommendations for extended testing and calculation of heat pumps with combined space heating and domestic hot water production. Test procedures are an extension of the current heat pump testing for space heating-only and domestic hot water-only mode. Calculation is performed by an extended temperature class approach (bin method). Validation of the calculation method with field monitoring results show a deviation of the seasonal performance factor in the range of ±6%, approving the feasibility of the approach. Implementation of the results in European and national standards has begun in the frame of the EU Building Directive EPBD.

INTRODUCTION

Market boundary conditions

Since the mid of the Nineties of the last century, building directives set tighter limits for the energy consumption of the building leading to the development of low energy buildings with significantly reduced space heating (SH) energy needs, e.g. down to dwellings, which must not require more than 15 kWh/m²a for space heating according to the German passive house standard. This enables to provide the space heating need by reheating of the ventilation air. Domestic hot water (DHW) energy needs reach fractions up to 50% of the total heat energy need. On the other hand, reduced temperature requirements of the heating system lead to new adapted system layouts, and environmentally sound technologies like heat pumps, solar and wood systems have been (re)introduced in the market and have increasing market shares. These developments lead to a generally higher system integration to multifunctional systems, which cover different building needs, in common layout space heating and DHW, often amended by the ventilation function. Currently, additional cooling and space conditioning functions are integrated due to extended comfort requirements. However, these new system developments are often not covered by existing test procedures and calculation methods. Due to the changing system markets, different stakeholders have strong interest in guidelines to compare the performance of systems under different boundary conditions:

- Manufacturers need regulations for providing precise and uniform technical data of their components derived from standard testing.
• **Designers** need methods to enable a comparison of different heating systems or system layouts in the design process.
• **Consumers** need a clear indication of environmental impact and energy costs as a guideline for their purchase decision, e.g. by transparent labelling.
• **Consultants and policy makers** need uniform values to set targets in regulations and directives on the background of climate protection policies. The resulting energy labels or building standards may be based upon the Seasonal Performance Factor (SPF) or primary energy as well as CO₂-emissions, which can easily be concluded from the SPF.

**Standarisation work**
These needs are addressed by the EU-Directive on the Energy Performance of Buildings (EPBD) [1], which has the target to introduce a Building Energy Certificate, which is displayed in the building and contains the energy consumption of the building and the installed system technologies in terms of primary energy consumption and CO₂-emissions. Moreover, measures to improve the energy efficiency of the building and the system technology are included in the assessment.

As common basis for the building energy certificate the EU has mandated the revision and extension of the current building and system technology standards. Under Mandate 343 a set of standards for the building and the system calculation is currently elaborated in the European standardisation organisation CEN. Most of the standards are almost finished and currently in the final enquiry called formal vote. The introduction of the standards on the national level will probably start by 2008.

With regard to the required component data test standards for domestic hot water appliances are currently to be harmonised based on the EU Labelling Directive. Under the EU Mandate M/324 [2] test standards of household appliances for DHW production are revised. For the harmonisation of the testing common EU reference tapping profiles have been defined in the mandate.

**METHODS**

The scope of the IEA HPP Annex 28 was the development of test procedure and subsequent SPF calculation method for combined operating heat pump systems for SH and DHW. The nine countries AT, CA, CH, DE, FR, JP, NO, SE, USA participated in IEA HPP Annex 28. Systems found on the market can be distinguished in alternate and simultaneous operating systems. In alternate operating systems the heat pump is switched to either the space heating or the DHW operation. In simultaneous operating systems space heating and DHW energy is delivered at the same time. Most common methods for simultaneous operation are refrigerant desuperheating and condensate subcooling as well as cascade cycle layout. Examples of alternate and simultaneous combined operating systems are shown in Figure 1.

![Figure 1. Alternate (left) and simultaneous (right) combined operating system layouts [13]](image-url)
Ventilation compact units with exhaust air heat pumps have been treated, as well, since they have become very common in low energy dwellings. The accomplished work in Annex 28 comprises the testing of the systems according to existing and extended standards, calculation of the systems and field testing for the validation of the calculation results and to gain experience with the functionality for system optimisation. The following basic definitions have been made for the testing and calculation inline with the ongoing standardisation activities.

**Test procedure**
In order to uniformly cover the different system configurations on the market, a black box testing is applied, where only the values at the system boundary are used for the calculation, i.e. values, that can be measured outside the unit. This approach enables to abstract from the internal system configuration, which is difficult to consider since it varies a lot from one system to the other. The black box approach is depicted in Figure 2.

![Figure 2. Black box testing as basic principle for the test procedure](image)

**Calculation method**
Due to the common system testing (generator and storage) and common bivalent system layouts for heat pump systems (heat pump and back-up) the system boundary has been chosen to comprise the generator part with attached storages (both for space heating or domestic hot water) and eventually installed back-up generators. The system boundary in the calculation scheme of the EPBD is depicted in Figure 3.

![Figure 3. System boundary of Annex 28 in the calculation scheme of prEN 15316-1](image)
RESULTS

Survey of heat pump markets and state in standardisation (state 2003)
As starting point a market survey of systems and the state-of-the-art in standardisation has been carried out.
Concerning combined operating heat pump systems, markets are different for Europe, North America and Japan. While Europe has mostly alternate combined operating systems on the market, North America mainly uses simultaneous systems with desuperheating for domestic hot water production, sometimes in combination with combined cooling/air conditioning and domestic hot water production, as well. In Japan, a combined alternate system was recently introduced in the market, where a CO₂ heat pump supplies hot water to a storage, which provides water at different temperature levels for floor heating, higher-temperature radiator heating and domestic hot water use.
In all participating countries, standards for the testing of the SH-only and DHW-only operation modes exist. In Japan, the DHW testing refers to the CO₂ heat pump water heaters, so called Eco–Cute systems, which have become very popular since their market introduction in 2002. However, testing for combined operating systems is missing except in the American standards ASHRAE 137 [4] treating the specific case of air-to-air heat pumps with DHW production by desuperheating, which is a common system configuration in the USA and Canada. Concerning the SPF calculation, no common standard for combined operating systems exists, either. For the SH-only mode, temperature class approaches (bin methods) are used in the USA and in some national guidelines in Europe, e.g. ASHRAE 116 [5] and VDI 2067-6 [6].

Evaluation of current European heat pump testing standards

Space heating-only operation
EN 14511 [7] performs steady state testing of the SH-only operation replaced the former standard EN 255-2 [8]. Comparison of the standards showed that resulting COP values according to EN 14511 are in the same range as EN 255, but approx. 4-5% lower due to the changes in the determination of the mass flow rate, which used to be manufacturer given in EN 255-2 and is now determined by a fixed temperature difference in the so-called standard rating point.

DHW-only operation
In contrast to steady-state of EN 14511, EN 255-3 [9] for the test of the DHW operation evaluates a tapping cycle, thus COP-value is derived by averaged evaluation of the energy balance for the tapping. For the determination of the COP DHW tappings of half of the storage volume are repeated, until the energy amount of the tapped hot water is within a 10% range. EN 255-3 is currently under revision in CEN/TC 113/WG 10.
Although comfortable to use, the major draw-back is a very long testing time of about 4 days for a single test point, mainly due to the testing of storage stand-by losses.
Further shortcomings of the EN 255-3, in particular with regard to combined operation, have been identified:
- EN 255-3 does not deliver a DHW output capacity, which is useful to evaluated running time in combined operation.
- EN 255-3 does only deliver one test point for the entire range of possible source and sink temperatures.
- EN 255-3 does not define a DHW outlet temperature, but uses manufacturer controller settings. Consequently, a direct comparison of tested heat pumps is not possible due to differing DHW temperatures.
On the basis of this analysis, modifications are recommended by the IEA HPP Annex 28 to be implemented during the revision of the EN 255-3.
Storage stand-by losses are not necessary for the COP determination, as the change is about 4% and thereby in the range of the measurement exactness [10].

Thus, if a heat loss value of the storage is known, testing of storage stand-by losses can be omitted. This can reduce the testing time significantly. If no information on the storage is available, i.e. in highly-integrated systems, the entire EN 255-3 cycle can be performed once, while the COP shall be evaluated for more test points.

Using the period of the cycle applied for the determination of the COP, an average output capacity can be calculated.

**EU tapping patterns for DHW testing**

Delivered COP values for EN 255-3 tests using the European tapping profile according to mandate M/324 tend to be lower due to a higher mean temperature in the condenser. Despite partly small mass flows (EU reference pattern 1), the reproducibility of COP-values is in the acceptable range of 5%, even though it may be problematic to secure the exactness of these small mass flows. Moreover, it is doubtful, if a set of 23 tappings give a more realistic result considering the differences in user behaviour.

**Extension of the testing for combined operating heat pumps**

Testing of alternate combined operating heat pumps approved that the overall SPF can be calculated based on the test results of the SH-only and DHW-only mode. Therefore, for alternate operating systems, no further testing is required.

For simultaneous combined operating systems, additional testing is to be performed, since the heat pump characteristic may change significantly compared to the SH-only and DHW-only operation. Therefore, the simultaneous combined operation is tested by performing the DHW tapping cycle during the space heating operation. Due to the black box testing, however, only the total electrical energy input to the heat pump can be monitored, so the allocation of the electrical energy to the operation modes is not possible. So the combined operation is evaluated as own operation mode, since in the end, the overall seasonal performance is the relevant characteristic number.

**Calculation method**

The calculation method is built on an existing temperature class approach (bin method) already introduced in national standards. The principle of the bin method is depicted in Figure 4.

The cumulative annual frequency of the outdoor air temperature is divided into temperature classes (temperature bins). In the centre of each bin, an operating point is evaluated with regard to the heat pump operation at these specific ambient conditions, which is determined by the respective standard component testing, e.g. for SH according to EN 14511 and for DHW according to EN 255-3. The operating point is considered to characterise the heat pump operation of the whole bin. The areas of each bin correspond to heating degree hours based on the meteo data of the site and characterises the energy consumption in the bin. Thus, a weighting of the operating conditions with this energy fraction of the bin and a subsequent summation of all bins delivers the seasonal performance factor. Electrical back-up heaters can also be considered by an evaluation of the respective area in the cumulative frequency diagram, in Figure 4 the area BU.

The overall seasonal performance can be calculated by weighting the single seasonal performance factors with the annual energy needs in SH- and DHW-operation, respectively. Thus, the alternate combined operation can be covered based on existing test standards.
In simultaneous combined operation, however, the heat pump characteristic may change significantly. Thus, a third operation mode, the combined operation has been introduced based on the test procedure described above. The estimation, how much combined operation takes place in the bin is done by an evaluation of the running time of each mode, which is determined by the respective heating capacity of the heat pump and the energy requirement in the bin.

The overall seasonal performance can be calculated by the weighting of three operation modes, i.e. SH-only, DHW-only and combined operation.

**DISCUSSION**

**Approximations of the calculation**

Obviously, the calculation method implies some simplifications in order to keep the calculation simple. One shortcoming with regard to low and ultra-low energy house may be the re-distribution of the energy requirement to the bins, that is only dependent on the heating degree hours and thereby on the outside temperature, while in low-energy dwellings the solar gains may have a higher impact on the energy distribution. This can be considered by an adjustment of the upper temperature limit for heating based on the quantity solar and internal gains as depicted in Figure 4.

Moreover, a shortcoming is that controller layout and controller setting can only be partly taken into account. In particular the energy production in combined operation may also depend on the controller settings for some system layouts. Controller settings for auxiliary components like pumps are often not known in detail and standard situation have to be evaluated. These effects can be taking into account by correction factors for typical control situations depending on the system configuration.
Comparison of calculated values to field monitoring results
To validate the calculation method with real data, field monitoring of pilot plants with combined operating heat pump systems were launched in the framework of the IEA HPP Annex 28. Even though not all types of system configuration could be monitored in field operation, the results of the comparison give a first impression of the exactness of the method. Three direct expansion ground source heat pumps were evaluated for the SH-only operation. A ventilation compact unit with air-source heat pump and a ground source brine-to-water heat pump with alternate combined operation have been evaluated for the space heating and DHW operation. Differences between the calculation and the measured values are in the range of ±6% for the seasonal performance factor. Considering the simplifications in the approach these values are satisfactory and show the applicability of the method.

Implementation of results
Results of IEA HPP Annex 28 of have been continuously transferred to the respective standardisation working groups of the European standardisation committee CEN. The calculation approach has been implemented in the European draft standard prEN 15316-4.2 [11], which is part of the heat generator calculation standards used in the European Building Directive (EPBD) [1]. The SPF delivered by the calculation method is a basis for primary energy consumption or CO2 emissions, respectively, which are displayed on the building energy certificate and determine the energy rating of the building.
For the implementation of the EPBD on the national level, Germany has introduced the method on a monthly basis in the pre-standard DIN V 18599 [12]. Results and recommendations for the test procedure are currently implemented in the CEN working group CEN/TC 113/WG 10 for the revision of the DHW test standard for heat pump EN 255-3. A working group committed to heat pump compact units incorporating also the ventilation is currently in constitution as a joint working group the ventilation CEN/TC 113 (Technical committee for heat pump testing) and CEN/TC 156 (ventilation systems). This gives the perspective that uniform testing of the heat pump and ventilation part of integrated ventilation compact units with heat pump can be achieved.
Concerning the international standardisation, the calculation approaches are quite similar, since the bin calculation is also introduced in ANSI/ASHRAE standards, but testing is still different due to different predominating system configurations on the market. Hence, to introduce internationally common standards, mainly the testing standards have to be further unified, i.e. on ISO level.

Information on IEA HPP Annex 28

ACKNOWLEDGEMENT
The authors would like to thank the Swiss Federal Office of Energy (SFOE) for funding and supporting the project. It has to be emphasised that the IEA HPP Annex 28 is a team work and the results presented above are based on the effort and contribution of each member. Hence, respect and thanks are expressed to all participants of the IEA HPP Annex 28 for the valuable contributions and for the constructive discussion and co-operation.
REFERENCES


