IEA HPP ANNEX 28—A UNIFORM ENERGY-RELATED CHARACTERISATION OF HEAT PUMP SYSTEMS

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ABSTRACT

Which heating system is performing best? This question is still not easy to answer, since standardised calculation methods for the comparison of different heating systems hardly exist. Annex 28 of the Heat Pump Programme (HPP) of the International Energy Agency (IEA) has been initiated to deliver calculation methods for the Seasonal Performance Factor (SPF) and the necessary comprehensive test procedures of combined operating heat pump systems. The results of this research are continuously transferred to the standardisation committees. Nine countries are participating in the IEA HPP Annex 28.

New system developments are often not covered by existing standard testing or calculation methods. Thus, the application of the test procedures and the calculation methods developed in the framework of IEA HPP Annex 28 is manifold: Manufacturers have regulations for providing precise and uniform technical data. On the other hand, system layouts can be compared in the planning process. Moreover, energy labels or building standards can be based upon the SPF. Hence, a uniform testing and calculation is necessary to overcome trade barriers and enhance consumer confidence.

Key Words*: heat pump, standardisation, test procedure, seasonal performance.*

1 INTRODUCTION

In this chapter the background both in product development as in standardisation is given as motivation for the work carried out in the framework of IEA HPP Annex 28.

1.1 Product Developments

Due to a restriction of the energy consumption of newly-built residential buildings in national directives or building regulations during the Nineties, the share of the heat energy requirement for domestic hot water production in relation to the overall heat energy requirement of the building is growing continuously. In Germany, for example, ultra-low energy houses according to the "passive house standard" must not require more than 15 kWh/(m^2a) for space heating. Therefore, the domestic hot water heat requirement can reach up to 50% of the total heat requirement. Thus, heat pump systems which can produce both space heating and domestic hot water with the same heat pump in combined operation are becoming more and more interesting.

New system developments using an enhanced internal heat pump cycle layout with internal heat exchange or heat decoupling at different temperature levels are usually not covered by existing standard testing or calculation methods. However, in the context described above, a combined generation of space heating and domestic hot water with the same heat pump is attractive, as efficiency gains are expected by the coupling. So, integrated systems providing different building services like space heating, domestic hot water production, ventilation or cooling are currently introduced in the market.

For the characterisation of these new systems testing and calculation is required for different fields of application:

- Manufacturers need guidelines, how to test their components in compliance with other systems and which data have to be provided.
- Planning engineers need reliable efficiency data as an input for a seasonal performance comparison of systems, which is the basis for further cost analysis and assessment of environmental impact.
- Product labelling is presently changing to make product rating no longer dependent on instantaneous efficiency values but on seasonal performance values, which seem to be a better metric for energy saving potentials and environmentally sound technologies.
- Consumers are interested in the performance and quality of the product with an emphasis on energy costs and on environmental issues, e.g. expressed in primary energy consumptions.
- Policy makers and consultants need adequate key figures to define target values in regulations and directives.

Summarising, comprehensive and uniform test procedures and consecutive calculation methods are needed by various users to compare different heating systems and enable a fair and transparent competition of systems on the market.

1.2 European Standardisation

European standardisation in the field of heating and domestic hot water systems is presently driven by the implementation of two directives, which are shortly described in the following paragraphs.

Directive on the Energy Performance of Buildings

In December 2002 the European council published a Directive on the Energy Performance of Buildings (EPBD 2002), often shortly entitled as Energy Performance Building Directive (EPBD). The general objective of the EPBD is to transfer best practise examples found in the building sector of single countries of the European Union (EU) to the other member countries of the EU. Thereby methods to keep climate protection objectives in terms of a reduction of CO_2-emission as laid down the Kyoto Protocol shall be spread over the entire EU.

The instruments outlined in the directive to achieve this objective are threefold:

- Energy performance requirements for new buildings and major renovations
- Introduction of a building energy performance certificate, often referred to as building energy passport, where both the performance of the building and the installed building technology is assessed and displayed, similar to other product labels already in operation in the EU.
- Guidelines and directives for heating system inspections and maintenance

The implementation of the directive comprises a revision of existing European buildings standards like the calculation of the building energy requirement according to EN ISO 13790 (ISO 2003), which is updated to include a cooling requirement as well as a set of updated or new standards covering the building technologies. Implementing the EPBD would enable a uniform comparison of different heating systems covering solar energy, biomass, heat pumps, boilers and cogeneration. The outline of the standardisation work is given in an umbrella document (CEN 2004) of the European standardisation organisation CEN. The standards in the framework of the EPBD are to come into operation by January 2006. Moreover, standards for the design of heating and domestic hot water systems are in preparation. However, these are not directly covered by the EPBD.

1.2.2 Mandate M/324 on Water Heating Systems

The mandate M/324 (EC 2002) to CEN aims to elaborate and adopt measurement standards for household domestic hot water appliances in order to derive comparable testing results for labelling purposes, i.e. testing standards for different hot water producing systems including heat pumps are to be harmonised. Therefore, European tapping profiles have been defined and are included in the mandate.

Hence, a general revision of testing standards has started. The working group committed to the revision of the European heat pump standard for domestic hot water systems EN 255-3 (CEN 1997b) is in constitution.

2 SCOPE AND PROJECT STRUCTURE OF IEA HPP ANNEX 28

2.1 Objectives and Project Structure

On this background IEA HPP Annex 28 (Zogg et al. 2003) has started in January 2003 with nine countries participating: AT, CA, CH, DE, FR, JP, NO, SE, USA. The project management (Operating Agent) has been mandated from the Swiss Federal Office of Energy (SFOE) to the Institute of Energy (IfE) of the University of Applied Sciences Basel (FHBB) in Muttenz, Switzerland. The objective of the IEA HPP Annex 28 is to deliver

- comprehensive test procedures with a minimum of testing expenses
- subsequent easy-to-use calculation methods

Results are intended as recommendations for the respective international standardisation organisations to be implemented in common standards.

The project is structured in three tasks:

- Task 1 is a market and literature survey to deliver the state of the art in system development and in international standardisation. Results of the survey are the missing items for combined operating heat pump systems.
- Task 2 is to deliver the test procedure and Task 3 the aligned calculation methods. Since the tested efficiency values of the system components are the basis for the subsequent seasonal performance calculation, the two tasks are strongly linked and worked out in parallel.

2.2 Scope, System Boundaries and System Layout

The scope of the IEA HPP Annex 28 is combined operating heat pump systems. The system boundary comprises the generator part with attached storages (both for space heating or domestic hot water (DHW)) and back-up generators. Additional pumping energy input is considered, as well. The system boundary of the IEA HPP Annex 28 is depicted in the calculation scheme of the European provisional standard prEN 14335 (CEN 2001) of the EPBD in Fig. 1.

Combined operation for space heating and domestic hot water can be performed either by alternate combined operation, where the heat pump is switched and operates either on the space heating or domestic hot water operation, or simultaneous combined operation, where space heating and domestic hot water heating are produced at the same time.

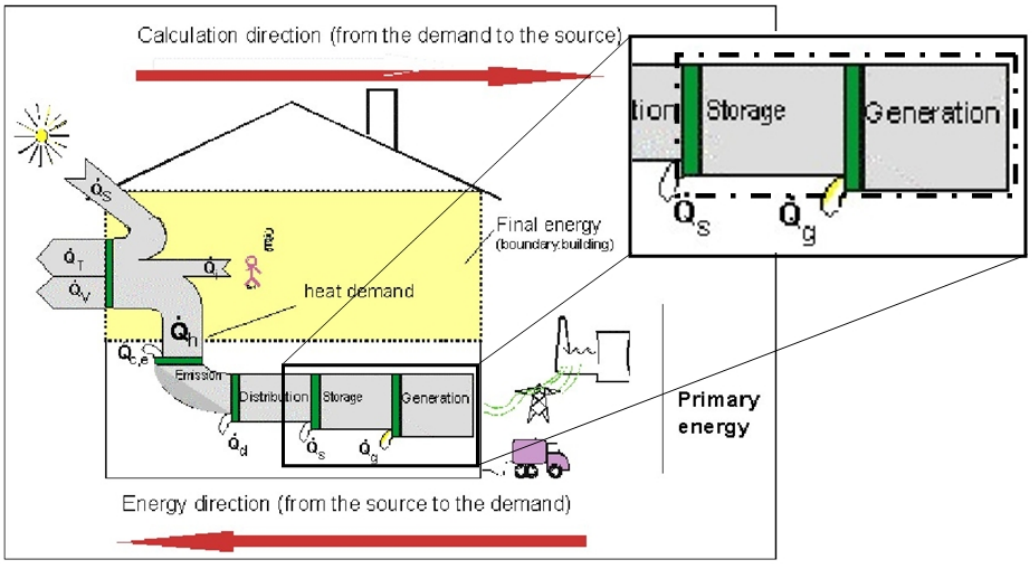


Fig. 1. System boundary of IEA HPP Annex 28 in the calculation scheme of prEN 14335 (source: CEN 2001)

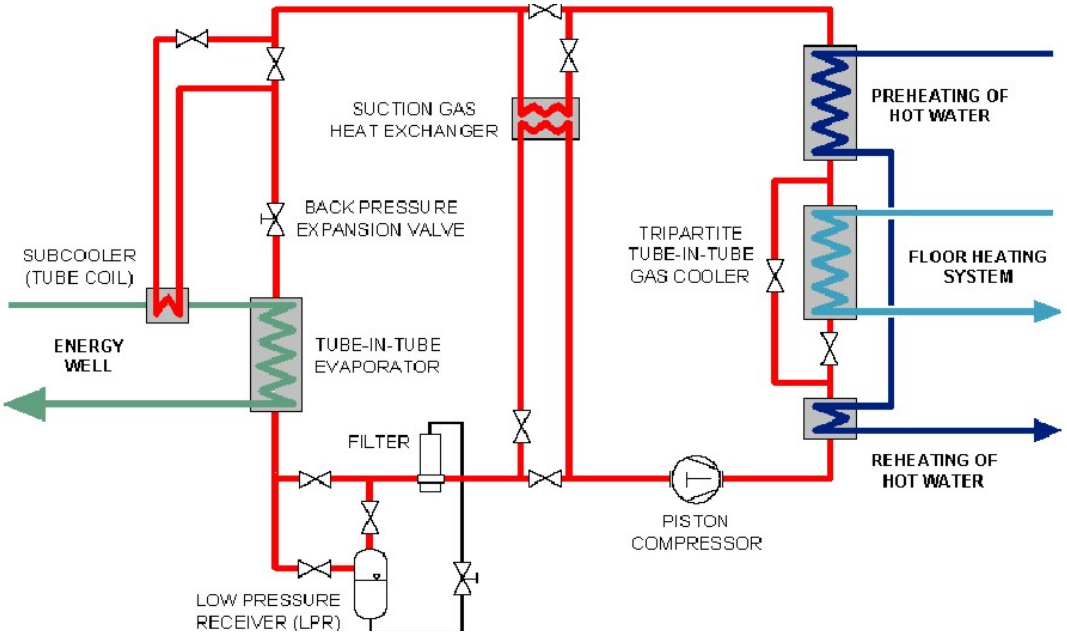


Fig. 2. Simultaneous combined operating heat pump system using desuperheating and condensate subcooling (source: Stene 2004)

For simultaneous operation basically the mechanisms of internal heat exchange are applied as well as temperature-related heat decoupling in the form of desuperheating of the compressed refrigerant and condensate subcooling. An example of a simultaneous operating system is given in Fig. 2.

3 RESULTS OF TASK 1 (MARKET AND STANDARDISATION SURVEY)

Task 1 has been concluded with an interim report delivered to the Executive Committee of the IEA Heat Pump Program in March 2004 (Wemhöner, Afjei 2004), yielding the following basic results.

3.1 Market Analysis

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 CO_2 heat pump supplies hot water to a storage, which provides water at different temperature levels for floor heating, high-temperature heating and domestic hot water use.

3.2 International Standardisation

3.21 Testing

In Europe heat pumps are tested separately for the space heating and the domestic hot water mode. Testing for combined operation does not exist.

In North America standards for the testing of the single operation modes are available, as well. Moreover, for the case of air-to-air heat pumps a test procedure for the simultaneous combined operation for both simultaneous space heating/DHW production and simultaneous space cooling/ DHW production with desuperheater is described in ASHRAE 137 (ASHRAE 2001).

The situation in Japan resembles the one in Europe. The single operation modes are tested, but for the combined operation, no standards are available.

3.2.2 Calculation

In Europe different calculation methods are available on the national level in some European countries, mainly for the single heating mode. On the European level of CEN standardisation a calculation method for heat pump systems is in preparation as prEN 14335 (CEN 2005) in the framework of the above described EPBD. The standard is presently prepared for a six-month period of commenting called public enquiry, which will start in April 2005.

In North America the calculation of single modes for space heating and DHW production is covered by ASHRAE standards. ASHRAE 137 (ASHRAE 2001) extends these calculation methods for the above mentioned system configuration for the simultaneous combined operation.

In Japan single operation modes are calculated using the respective ASHRAE standards. However, no calculation method for the combined operation is available.

3.3 Assessment and Conclusions from the Results of Task 1

In Europe, alternate combined operation can be covered by combining the results from the separate heating and DHW testing of the heat pump. However, the simultaneous combined operation is not covered by the existing standardisation. Moreover, missing items, in particular of the DHW testing, have to be elaborated in Task 2 (e.g. output capacity of the heat pump in DHW mode) and testing time is to be reduced.

In North America the testing and calculation of the alternate combined operation can be covered in the same way by combining the test results of the single mode. The treatment of the simultaneous combined operation is restricted to the special case of air-to-air heat pump in desuperheater configuration.

In Japan no testing/calculation of the combined operation is possible, either.

In conclusion, the following decisions were made:

3.3.1 Testing

- Testing of simultaneous combined operation shall be treated by extending the existing standards
- All testing shall follow a black-box approach, i.e. only results, that could be measured from outside the system shall be required.
- Highly integrated systems, which are sold as a unit, shall be tested as system. In case of the combination of different components to a combined operating system, component-based results shall be used.

3.3.2 Calculation

- Calculation shall be based on a so-called bin method (see description below), which is already contained in several national European calculation methods and the American standardisation. The bin approach seems to be the best compromise between and easy-to-use hand calculation method and the exactness of the results.

4 RESULTS OF TASK 2 (TESTING) AND TASK 3 (CALCULATION)

The following presentation of the results on testing and calculation are preliminary, since the final results will be discussed and harmonised on the 4th working meeting in March 2005. Therefore, differ n approaches under discussion are outlined. The definite results will be presented on a workshop in the frame of the 8th International Heat Pump Conference 2005 in Las Vegas.

4.1 Evaluation concerning actual and proposed European Standards

In this paragraph, results of the evaluation of the existing and proposed European testing standards are presented. Moreover, results from part load testing of an air-to-water heat pump are stated. Feedback on the application of American standard has not been available at the time of writing, but will be included in the final report.

4.1.1 EN 14511 vs. EN 255-2

EN 14511 (CEN 2004b) is the European standard for the testing of heat pumps in single heating or cooling mode and replaced the former standards EN 255-2 (CEN 1997a). The testing is performed as steady state testing at defined testing points. COP values contain the pumping electricity to overcome internal pressure drop in the evaporator and condenser as well as additional electrical expenses for control. The determination of the test mass flow has changed. While formerly manufacturer given mass flow was used, it is now determined by a given temperature difference over the evaporator/condenser respectively at a standard rating point, and this determined mass flow is used for the other so-called application rating points, too. Comparison of the two standards was performed by the Swedish team. Resulting COP values according to EN 14511 are in the same range as EN 255, but a bit lower due to the changes in the determination of the mass flow rate.

However, EN 255-2 sometimes led to unrealistic temperature conditions at the condenser, so EN 14511 delivers more realistic values as EN 255-2 (Axéll et al. 2004).

4.1.2 European Tapping Profiles Defined in Mandate M/324

Mandate M/324 on the harmonisation of testing standards contains 5 reference tapping cycles over 24 hours for household appliances with differing total amount of tapped hot water. COP values delivered by the tapping profile according to mandate M/324 tend to be lower, probably due to stratification effects in the storage leading 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. (Axéll et al. 2004) (Hantz, Arzano-Daurelle 2005)

Therefore, it is to be discussed, if measurements with tapping patterns containing 23 draw-offs are necessary. While one opinion is that the tapping profiles will deliver more realistic values (Hantz, Arzano-Daurelle 2005), the other opinion is that user behaviour varies a lot in reality anyway, so probably a simplification could be applied.

4.1.3 EN 255-3

The European standard of the DHW-mode of heat pumps uses a black-box system testing including the heat pump, the DHW storage, the storage loading pump as well as the pumping energy for internal friction losses of the source heat exchanger. In contrast to steady-state of EN 255-2, EN 255-3 evaluates a cycle, thus COP-value is derived by averaged evaluation of the energy balance for the tapping. For the determination of the COP hot water draw-offs of half the storage volume are repeated, until the energy amount of the tapped hot water is within a 10% range.

Although comfortable to use, the major draw-back is a very long testing time of at least 4 days for a single testing 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 testing 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 outlet temperatures.
- EN 255-3 does not provide testing for variable speed units.

On the basis of this analysis, modifications are proposed by the IEA HPP Annex 28 to be implemented during a 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 (Hantz, Arzano-Daurelle 2005).
- Thus, if a heat loss value of the storage is known, testing of storage stand-by losses can be omitted. If no information on the storage is available, i.e. in highly-integrated system, the entire EN 255-3 cycle should be performed once at average operation conditions concerning the operation range, while testing of COP shall be performed for more testing points.
- Using the period of the cycle applied for the determination of the COP, an average output capacity is calculated.

4.1.4 Part Load Operation

In France extensive testing of a heat pump in heating and cooling mode was carried out to quantify cyclic effects. The results shows, that cycling effect are negligible. Declination of the heat pump effi-

ciency is due to increasing impact of stand-by power and defrosting losses. Correcting for these effects, COP-values do not decline over the whole range of loads. Surprisingly, capacity of the heat distribution system and the setting of the hysteresis of the controller do not have an impact, either (Hantz, Arzano-Daurelle 2005). Based on these results, it is sufficient for the calculation method to take stand-by power consumption into account.

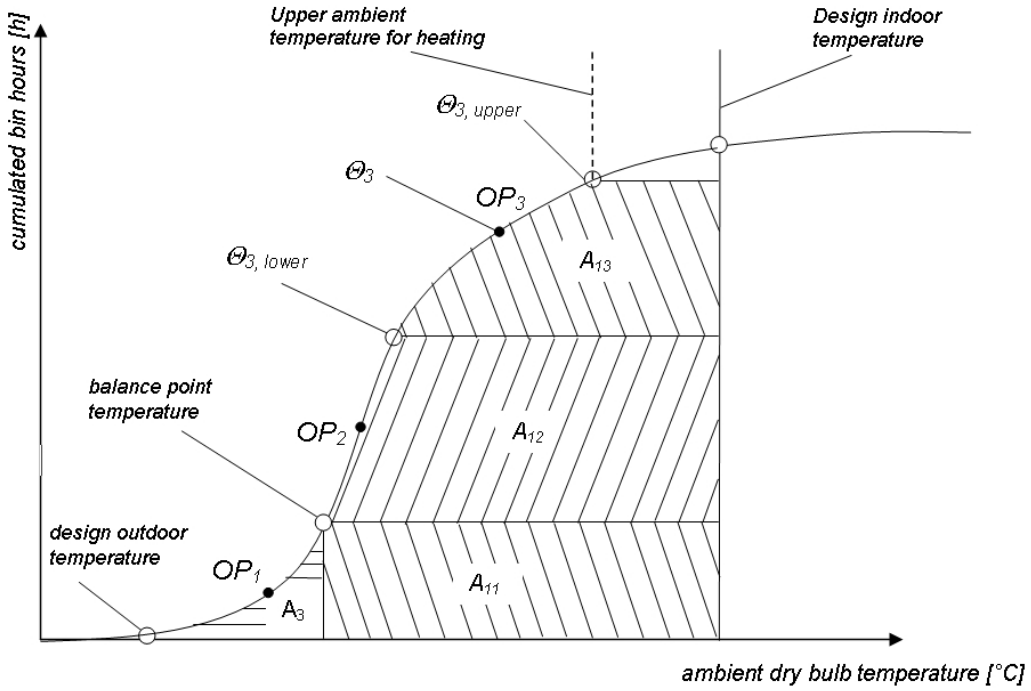
4.2 Proposal of Calculation Method

Since the testing in accomplished to deliver the needed characteristics to perform the calculation, testing has to be coherent to the calculation method. Therefore, in this paragraph, the calculation approaches are described first, and the proposal for the respective test procedure in the next paragraph.

The basic situation for the operation of heat pumps is the strong dependency of the output capacity and the coefficient of performance (COP) on the source and sink temperatures which are both changing constantly over the operation period. The testing can deliver this characteristic of the heat pump for defined testing points.

The bin methodology is based on the cumulative annual frequency of the outside temperature which has the major impact on the space heating energy requirement. A typical cumulative annual frequency is depicted in Fig. 3.

Fig. 3. Principle of bin-methodology on the basis of cumulative annual frequency of the site



As only discrete points of the heat pump characteristic are known by testing, the cumulative annual frequency is divided into temperature classes called “bins”. Bins are defined by an upper and lower temperature Θ. It is assumed that the operating conditions of the heat pump correspond to the conditions of a so-called operating point (OP) in the centre of the bin. Areas A in Fig. 3 are defined by the product of the outside and inside temperature difference and the cumulative time in the respective bin and thus correspond to heating degree hours. Hence, the building energy requirement can be evaluated by the ratio of the bin area to the total area up to the heating limit. In conclusion, the fraction of the total energy requirement characterised by the areas A is covered by the efficiency conditions defined by the respective operating point. Consequently, the seasonal performance is delivered by a weighted summation of all bins. The DHW operation can be treated in an analogue way.

Different operation modes for only-heating, only-DHW and combined operation can be considered by a weighting of the performance with the respective energy requirement to derive the overall seasonal performance.

In the national projects, different variations of the bin method to integrate the combined operation have been proposed:

- Separation of operation modes for space heating and domestic hot water
  The single operation modes are treated independently of each other, i.e. the only-heating operation is characterised by the test results of the heating mode and the only-DHW operation is characterised by the heat pump characteristic in DHW. Simultaneous combined operation is treated as an own operation mode using the test results of the combined testing. The fraction the respective operation modes is evaluated by the required running time, which is determined by the energy requirement divided by the output capacity of the heat pump. Running time enables an evaluation of additional auxiliary energy requirement that is not considered in the standard testing, too. (Wemhöner, Afjei 2003)
- Evaluation of typical days for the bin
  The division of the total operation time is not made due to the ambient temperature, but ambient conditions are evaluated with regard to certain seasonal classes, i.e. winter conditions, summer conditions, transition. For each season typical days concerning temperature as well as demand profiles are fixed, which correspond to the testing of the unit. By evaluating the sum of such typical days for the whole year, the seasonal performance is calculated (Hihara, Ida 2005)
- Evaluation of combined operation with regard to the ratio space heating/DHW demand
  Different operation modes are no longer separated, but the heat pump characteristic is interpolated concerning the ratio of space heating/DHW in line with a respective evaluation of the testing results based on the standards EN 14511 and EN 255-3 (Axéll et al. 2004). Consequently, neither a splitting up of heating and DHW operation is necessary nor an evaluation of the running time.

4.3 Proposal of Test Procedure

As described above, single operation modes can be tested by existing standards. To cover the alternate combined operation, these testing results are sufficient, as well, as the system operates either in heating or in domestic hot water mode. Combined testing of the alternate combined operation yields negligible difference in the COP-values compared to calculated weighting of single operation modes (Axéll et al 2004).

To treat the simultaneous combined operation testing according to the standards for heating and domestic hot water is performed at the same time, i.e. the hot water draw-offs according to the DHW test procedure are performed during the heating operation. The test procedure and the testing points should thus be oriented at the single operation modes.

Referring to a black box configuration an essential problem occurs for the evaluation: only the total consumption of electricity can be measured, but this total electricity input can hardly be allocated to the single services space heating and domestic hot water. Two possibilities arise to deal with this situation:

- Assumptions can made to redistribute the total electricity consumption which do not necessarily reflect the real physical conditions, but are reasonable to derive key figures for a comparison of different systems.
- On the other hand, the key figure for the comparison is the overall seasonal performance. Thus, the combined operation can be treated as own operation mode, and for the calculation, three different operation modes (only-heating, only-DHW, combined heating-DHW) instead of two are considered.

The latter solution is the simpler and the more pragmatic one and thus is favoured by the participants of IEA HPP Annex 28. The above described experiences with the application of the DHW standards shall be considered and shortcomings are to be improved. The definition and evaluation of testing points is determined by the calculation method chosen.

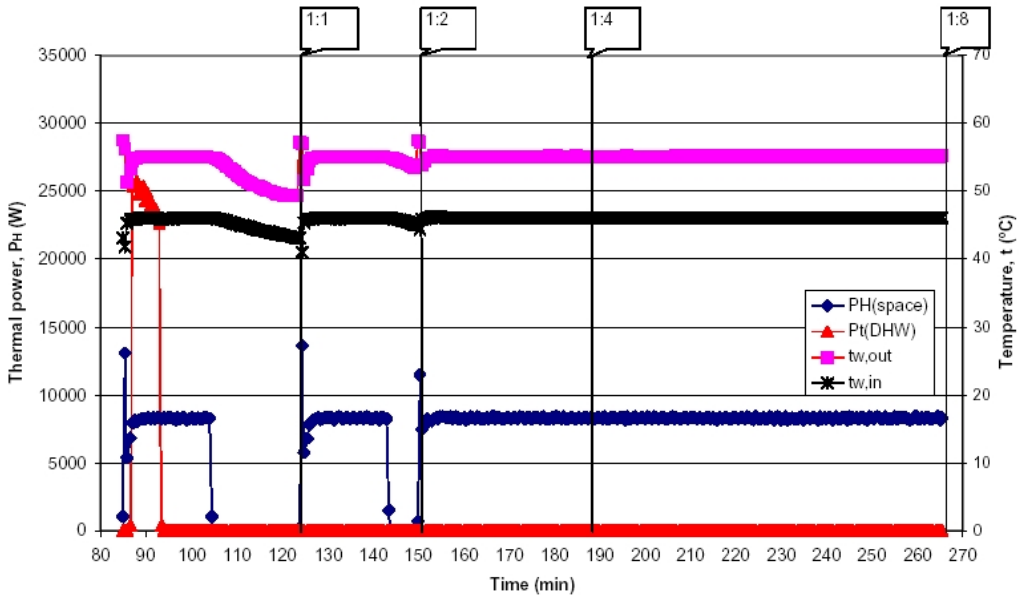


Fig. 4. Testing cycle for simultaneous operation with evaluation of ratio DHW/ space heating (source: Axéll et al 2004)

- Separation of space heating and domestic hot water operation
  If the calculation is performed implying the separation of space heating and domestic hot water mode, additional testing comprises simultaneous application of the standards for the single operation modes, i.e. hot water draw-off scheme during heating operation regardless of the ratio of space heating/ DHW consumption. The derived characteristic can be combined to a seasonal performance evaluating running times in the respective operation modes in the single bins.

- Evaluation of characteristic days
  If this calculation method is applied, the respective test conditions (temperature, profiles etc.) are defined by the characteristic of the day.

- Evaluation of combined operation with regard to the ratio space heating/DHW demand
  In this case testing has to cover different ratios of the demand for heating and domestic hot water at each of the respective testing points. To reduce testing time the test procedure depicted in Fig. 4 is proposed (Axéll et al. 2004). Testing is performed continuously and the different ratios of DHW to space heating consumption, indicated by the flags in Fig. 4 are evaluated afterwards. However, total testing time depends on the energy content of the hot water, possibly depending on the storage size.

4.4 Further Research Work not covered by IEA HPP Annex 28

A key feature of the calculation method and the respective test procedure is a comparison of the calculated result with measured data to get an idea of the exactness of the results. This validation on the basis of the field measurements is in progress. However, not all cases are measured and can consequently be covered in the remaining time of the IEA HPP Annex 28.

Moreover, the following topics will not be entirely covered by IEA HPP Annex 28

- Testing for variable speed units, two step control as well as multi-compressor configuration.
- Combined cooling/DHW operation, which is to be covered by the EPBD, too.
- Special testing requirements of natural refrigerants, e.g. CO_2.

5 IMPLEMENTATION OF THE RESULTS

The results of the IEA HPP Annex 28 are intended to be implemented in the respective standards published by the international standardisation committees as the European CEN, US-American ASHRAE or on ISO level.

Thus, external liaisons have already been established with the respective technical committees of CEN, the TC 113 for the heat pump testing and the TC 228 for the calculation method of heating systems. As presently testing and calculation standards are under revision in Europe as described in chapter 0, there is an opportunity of directly introducing the results in the standardisation process.

While the working group for the revision of the heat pump testing standards is currently in constitution, the calculation proposal has been introduced in the heat pump part of the above described standard prEN 14335 in the framework of the EPBD. Updated results from the IEA HPP Annex 28 can be transferred in the six-month commenting period called public enquiry. As soon as the testing working group will start working, results will be presented in this working group, too.

In the course of the revision of their national energy directives, Germany has implemented a monthly-based bin methodology which is in line with the IEA HPP Annex 28 approach.

6 CONCLUSION

IEA HPP Annex 28 has the objective of enabling the assessment of seasonal energy-performance of different heating system solutions for fulfilling the requirements for space heating and domestic hot water. Actually, there is a variety of different heating systems on the market, but a lack of standardised internationally uniform methods to compare energy performance to reward and promote environmentally sound technologies on the background of climate protection.

Thus, IEA HPP Annex 28 is to deliver easy-to-use calculation methods and the necessary test procedures to deliver the required input of the product characteristics for the calculation. The scope are heat pump systems with alternate or simultaneous combined production of space heating and domestic hot water, which are becoming more and more interesting due to actual trends to highly insulated buildings and low-temperature heating systems.

The Annex started with an analysis of the status quo of the systems on the market and the standardisation, concluding that the combined operation should be covered by an extension of existing standards. Thus, the testing for simultaneous operation shall be accomplished by performing the respective domestic hot water cycle during the operation of the heating system. Further modifications of the existing standards, in particular the DHW part due to experiences of the national projects, are proposed.

Calculation is based on an extension of the bin-methodology, which turned out to be the best compromise between expense for the calculation and exactness of the results without extensive computer programming. In addition, it is already established in several national calculation methods.

IEA HPP Annex 28 is currently being completed. The final results of the national projects are to be discussed and harmonised on a working meeting in March 2005, and the final report is slated for May 2005. Final results will be presented to the public on a workshop in the frame of the 8th International Heat Pump Conference in Las Vegas on May, 30 2005.

Continuously updated information on the IEA HPP Annex 28 and related topics can be found on the IEA HPP Annex 28 homepage at the URL: http://www.annex28.net

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