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Evaluation and demonstration of actual energy efficiency of heat pump systems in buildings, IEA EBC Annex 88

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Abstract

International Energy Agency, Energy in Buildings and Communities (IEA EBC) Programme has launched its 88th R&D project entitled "Evaluation and Demonstration of Actual Energy Efficiency of Heat Pump Systems in Buildings" (Annex 88, July 2022 to June 2027). In collaboration with IEA Heat Pumping Technologies (HPT) Programme and its Task Force, Annex 88 aims to establish the scientific basis for more accurate estimation of the energy efficiency of heat pumps when used in buildings and for more reliable and transparent design strategies for building applications of heat pump systems. When the energy efficiency of heat pump systems is evaluated, there are building-level evaluations and product-level evaluations. For the former evaluations, for example, the influence of sizing and consequent part load operation should be focused for each building, and a relationship between the part load ratio and energy efficiency of heat pumps is actually used in many relevant energy calculation methods. For the latter evaluations, the maximum load is assumed to be close to the full capacity of the product inevitably regardless of the buildings to be installed. As a basis for Annex 88 works, the state-of-the-art report was published by Subtask A in October 2024, and it reviews four focal areas to be studied in-depth during the rest of the working period. The focal areas are 1) load-based test methods of air-to-air and air-to-water heat pumps, 2) field monitoring methods and data, 3) methods of energy use calculation especially for building energy codes, and 4) design guidelines of heat pump systems for HVAC designers with quantitative information. This paper will focus especially on characteristics of load-based test methods and energy calculation methods for heat pump systems (air-to-air and air-to-water heat pump systems) to be used in total building energy use calculation methods for building energy codes.

Keywords: load-base test method; part load operation; equipment sizing; energy use calculation; building energy code

1. Introduction

This paper introduces an ongoing international collaborative work on heat pump systems in buildings [1].

Among the IEA Net-Zero by 2050's buildings milestones, the first milestone is "All countries targeted zero-carbon-ready (building energy) codes for new buildings by 2030". A milestone for heat pumps is also included as "Installation of 600 million heat pumps covering 20% of buildings heating needs by 2030" [2]. These two milestones are closely related to each other. Because the heat pump technology is an indispensable component for very energy efficient buildings, its contribution to saving energy has to be evaluated thoughtfully in the building energy codes. For example, the part load ratio for air-conditioners can often be below 50% in buildings, and its influence on energy efficiency has to be quantified in a very reliable way in energy calculation methods for the building energy codes.

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In Europe, as an example, energy for space heating is dominant compared with other energy uses (i.e., hot water supply, mechanical ventilation, lighting), but energy uses for other purposes should also be taken care of in a design stage. Such design and decision making can be supported by energy calculation tools and standards, which are used for building confirmations, energy certifications and performance labeling.

Energy calculation methods naturally need input data for characterising heat pump systems under consideration together with input data of the building side for estimating heat needs to be dealt with by the heat pump systems. That need originates another key question, what kind of test standards best fits the need of input data for the building energy calculation. In addition, monitoring data on the actual operation of heat pump systems in buildings is needed to verify correctness of testing methods providing input data and to validate the reliability of the building energy calculation.

2. Overview for the four focal areas reviewed in Annex 88

2.1. Energy use calculation methods for heat pump systems in buildings

It has been common for nations to parallelly implement product-level and building-level policies and standards for energy saving and decarbonisation. For example, EU has implemented ESPR [3] for products and EPBD [4] for buildings. The parallel policies are also applied to heat pump systems. In the building-level policies, overall energy use during building use or converted CO_2 emission is usually the evaluation index, and it has become common to most nations to have their own energy use calculation tools.

Based on the review of existing energy calculation methods for heat pump systems [5], there are the following three main basic modelling approaches.

a. With test performance data for very few conditions (in many cases, only one set for the rated condition) and default empirical functions, energy use by heat pump systems is calculated reflecting the influence of parameters including the outdoor temperature and the part load ratio. The effects of different parameters are assumed to be independent for inevitable simplification due to the present lack of useful test or monitoring data. This approach has been applied by most of national energy calculation tools [6-10].
b. Test results for several conditions with various part load ratios and outdoor temperature are pre-processed to identify a characteristic function that describes the efficiency of the heat pump products to be analysed. Then the characteristic function is used to evaluate the efficiency in operating conditions in the energy calculation. Examples of this approach are Path B of EN 15316-4-2 (heating) [11] and Method 1 of EN 16798-13 (cooling) [12]. These approaches originally intend to coordinate with EN 14825 [13], and the possibility to apply load-base test methods is being searched for in Subtask C of Annex 88.
c. The heating and cooling seasonal efficiencies are calculated as weighted averages of heat pump efficiencies for different part load ratios and outdoor temperature conditions based on EN 14825. Then, the seasonal efficiencies are used to convert heat needs to energy use by heat pumps.

For the approach (a), the default empirical functions (e.g., the relationship between the part load ratio and the COP under the rated outdoor temperature condition) are its key, but the protocol to obtain the functions is seldom disclosed in detail at present. One way to obtain the functions seems to be monitoring the relationship between focused parameters for plural representative products and identifying the average relationships as the functions. In addition, a clear definition of the test performance data is important, such as the test results for full-capacity conditions. The protocols need to be shared in detail and hopefully standardized in the near future. It can be said that this approach has been a compromise for the building-level evaluation due to very limited information on the actual behaviour of heat pumps especially during very low part load conditions.

For the approach (b), the background theories have already been standardized in above-mentioned European standards, and necessary test points (e.g., 6 testing points prescribed in EN 15316-4-2) have been identified. The existing hurdle seems to be the necessity of load-based test methods using products' native control (not the special control only for tests) to be integrated with EN 14825. It means that more attention should be paid to coordinate the approach (b) with product testing standards.

Tests of heat pumps for product-level evaluation may be carried out by each manufacturer of products, and the spot inspections by third-party organizations usually have to check the appropriateness for the same operating conditions. This seems to be a reason why the operating conditions need to be defined sharply by fixing the state of products during the tests. This need for current test standards unexpectedly deteriorates the applicability of test results for building-level evaluation. In field monitoring, operating points (i.e., average output and input in a period) always spread along rough relationships, which might be meaningful enough for building-level evaluation. This contrast between data for product-level and building-level evaluations should not be forgotten when trying to find appropriate test methods for each purpose.

2.2. *Current and newly developed testing standards and methodologies for heat pumps*

The review of current and newly developed testing methodologies and standards conducted was intended to recognise any potential convergences between the information extracted during product-level evaluations and necessary data for building-level evaluations such as by energy use calculations of heat pump systems [5].

On one hand, the product-level evaluation should provide values representing products' energy efficiency and are used to compare different products of the same kind not across different kinds. The product-level evaluation does not aim to characterise the performance of each heat pump system installed in a certain building, so it can be based on general assumptions for unpredictable parameters (e.g., a linear relationship between outdoor temperature and heat needs, a relationship between the maximum heat needs and the products' full capacities, etc.). That is almost inevitable. For product-level policies, future performance targets (e.g., five year later) or minimum performance requirements can be set based on a product-level evaluation index, such as SEER or SCOP for each category of heat pump products. Having said that, there must be examples of building-level standard, in which minimum performance requirements on the product-level are prescribed.

On the other hand, building-level evaluations must be applied to each building to be permit its construction or to be certified its performance presented in the market. The energy calculation tools including algorisms for heat pump systems need to have abilities to compare energy reductions across different kinds of energy-saving product, technologies and components. This ability is crucial to be reliable for users. For example, they can compare energy saving by heat pumps, LED lighting fixtures and increase of insulation for building envelope in a reasonable way. Additionally, designers' decisions related to equipment sizing are one of the main targets for the evaluation of the building energy performance, and this is the main reason why annual or seasonal efficiencies of product-level, which apply above-mentioned fixed assumptions, should not be used. Therefore, to increase the reliability of building-level evaluations, energy efficiency of heat pump systems under low part load ratios has become critical, mainly because the actual part load ratio for the equipment seems to be substantially smaller than the assumptions made in the product-level standards, and it is not unusual for designers to provide a room of capacity to avoid any shortage in heating/cooling capacity. For lower part load ratios, intermittent operation of compressors may occur more frequently than in higher part load ratios, and the situation should be reproduced in the tests without fixing the state of the compressor. The building-level policies are tightening the requirements such as toward the net-zero-energy building, and the improvement of energy calculation tools especially for very promising technologies like heat pumps is now being tackled.

The reviewed testing standards and methodologies for load-based test with native control of products are intended to: develop new product-level standards providing results with more representativeness of actual field operation, provide evidence for efficient equipment sizing and selection, support building-level evaluation by providing test results useful for energy modelling and calculation purposes, as well as develop more energy efficient design and control strategies. In most cases of load-based testing methodology, the same testing facilities and instrumentation as current standards is used, while revisiting the software elements of the testing facility control. It can be arguably stated that load-based tests might require more time for test convergence than current standards, but this may be related to the necessary learning curve needed for new procedures and could be quantitatively assessed during subsequent efforts of subtask B1 of Annex 88.

For air-to-air and air-to-water heat pumps, it seems that the frameworks of testing facility and software controlling the facility for the load-based tests have been almost ready for implementation at this time. Due to the native control, there must be a variation of state of tested products (e.g., a regular cyclic change of capacity and input energy), but a result with representativeness can be obtained after the appearance of the balance between a target load and an average capacity of the tested product. Most of the groups engaged in the load-based test methods are using algorisms (emulators) to control the reconditioning system of the test facility to treat the air or water supplied by the product and send it back to the product again so that the optimum delay of the change of retuning air or water conditions can be obtained (see Section 1.3.2, 1.3.3 and 1.3.5 of [5]). These methods for load-based tests seems to be proved of their potential to solve the hurdle of repeatability across different test facilities through their round-robin tests, and also to evaluate heat pumps taking building side and secondary side (e.g., hot water circuit) responses into consideration. However, when they are applied to product-level evaluations, any appropriate rules and specifications of the emulators and their parameters need to be determined, and the first step seems to be steady-state loads on heat pumps.

Another kind of load-base test method, which does not use the same testing equipment for airflow rate and humidity measurement as current standards and use the airflow rate measurement by rotation speed sensors for fans and humidity sensors attached to the outlet of air-conditioners, is also included among the reviewed methodologies. The thermal output from air-conditioners is immediately provided to the indoor-unit test room and mixed (see Section 1.3.4 of [5]). When any product needs to be certified of its higher energy efficiency than the default empirical function, this method is used to certify its own function between part load ratios and input energy under the rated outdoor temperature conditions for an energy calculation tool following the approach (a).

2.3. Further needs of field monitoring and dissemination of methodologies

Many field monitoring results for heat pumps in buildings have provided information on actual characteristics of heat pumps, especially under low part load conditions. It is obvious that trials of field monitoring need to be continued by a broader range of engineers interested in the heat pumps, including engineers engaged in manufacturing heat pumps. Monitoring can be planned not only in the field, but also in the testing facilities simulating actual building situations such as thermal loads.

Various methods for monitoring are reviewed in the report of Annex 88 [5]. Among them, the indoor side air enthalpy (ISAE) methods and the refrigerant specific enthalpy difference (RSED) methods (i.e., compressor energy conservation method, compressor performance curve method) were focused. For the ISAE, accuracy of the measurement of airflow rate and enthalpy needs to be maintained by carefully planning the methodologies without any attached hood and duct in the field. Sensors attached to the outlets of the indoor units must be as small as possible so that the airflow rate may not be affected. Measurement points of the enthalpy must be planned so that their average can represent the enthalpy of whole exhausted air. Figure 1 is an example of the field monitoring of room air conditioners by the ISAE method in a research-purpose detached house with mechanically simulated occupant behavior. The RSED method is being used by manufacturers of air conditioners to monitor their products in buildings, and the data provides fruitful information on the actual performance, when the data by the method can be shared by the manufacturers.

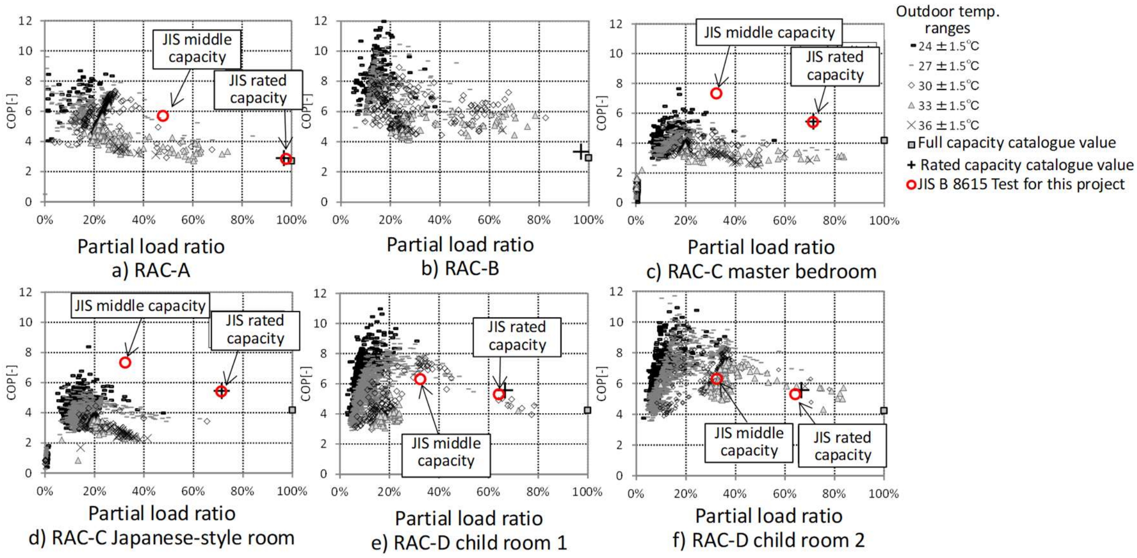

Figure 1. Relationship between partial load ratio and COP for different ranges of outdoor temperature for monitored five RACs (Cooling). Two (RAC-A, RAC-B operated in turn) in living room, four (two RAC-Cs in master bedroom and Japanese-style room, RAC-D in each child room) [5].

2.4. Insufficiency of design guidelines for heat pump application to buildings and perspectives

A review of existing guidelines reveals significant gaps in the release dates of guidelines, highlighting a divergence of approximately 10 to 15 years between certain recommendations [5]. This highlights the ongoing evolution of sizing guidelines within the industry. It emphasises the necessity for regular updates to align with technological advancements and methodological refinements. At this stage, implementation of load-based test methods has made it possible to generate information on the influence of part load operation on energy efficiency to grasp overall actual energy efficiency. In parallel, implementation of standards on *usual* building uses (e.g., internal heat gain, ventilation rate, schedule of HVAC operation, etc.) can be the basis for energy calculation of heat pump systems [14]. "*Usual*" means not the largest or smallest possible conditions, which have been applied for sizing, but the most probable average building use, which must be used for building energy calculations. Such updates of design guidelines are crucial for ensuring that sizing practices remain effective in accurately determining the capacity of heat pump systems relative to actual maximum loads. Ensuring the sizing according to an authorised procedure is the most important and effective way to improve the energy performance of buildings by using heat pump systems.

Needless to say, to address low part load conditions effectively, several countermeasures can be employed. These include adopting heat pumps designed for higher efficiency under low part load conditions (load-based tests must have a potential to differentiate such advantageous products), integrating multiple units or compressors operated according to the loads, utilising heat/cold thermal storage solutions for hydronic heat pump systems, and reviewing conditions and safety factors for sizing.

Quantitative examples using energy calculation methods play a crucial role in illustrating the impact of relevant factors on system efficiency. By demonstrating the energy use dynamics and efficiency variations of heat pump systems under different operational scenarios, these examples provide actionable insights for HVAC designers and stakeholders. They facilitate informed decision-making in system design and optimisation, ensuring that heat pump systems operate at peak or higher efficiency while meeting performance criteria outlined in technical standards and guidelines.

Hydronic (air-to-water) systems for space heating, alongside air-to-air heat pumps, like variable refrigerant flow systems, are prioritised in the design guidelines to be developed in Annex 88, because of their widespread applicability and energy efficiency potential. Manufacturers play a pivotal role in supporting HVAC designers with consistent, concrete, and quantitative technical information. This information is crucial for navigating the complexities of integrating heat pump systems into buildings. Clear step-by-step procedures provided by manufacturers enable designers to make informed decisions that optimise system performance and energy efficiency based on reliable data and the industry's best practices.

The development and refinement of guidelines for heat pump systems are instrumental in advancing energy-efficient practices within the HVAC industry. By addressing sizing methodologies, efficiency considerations, control strategies, and including diverse heat pump system types, these guidelines pave the way for standardised approaches that enhance system performance while reducing environmental impact. As technologies continue to evolve and global energy demands grow, the ongoing adaptation and implementation of these guidelines will play a pivotal role in shaping the future of sustainable building practices and energy management strategies. The structured approach provides a comprehensive overview of the topics outlined previously, ensuring each aspect is sufficiently explored within a coherent framework.

Representative monitoring results for heat pump systems will be included to show exemplified monitoring data to readers (contribution by Subtask B2) and to encourage readers to plan their own monitoring projects. With the description of available testing standards, guidance on which metrics, based on which testing standards, should be highlighted and included (contribution by Subtask B1). Also, a reliable energy calculation method should be introduced and utilised to provide the above-mentioned quantitative information (contribution by Subtask C).

Finally, easily understandable educational materials on how energy efficient heat pump systems can be designed should be provided with data based on the calculation methods as case studies. These materials should be tailored to specific segments like mechanical engineers designing large facilities and residential HVAC contractors for single-family houses.

3. Current overall understanding and near-future directions by Annex 88 as of January 2026

National and international approaches to establishing load-based test methods for heat pumps are on-going. Coordination among those approaches and with current test standards and rating schemes seem indispensable.

For building-level evaluation of design of heat pump systems in buildings, the basic modeling approach (a), which is rather statistical and empirical, seems to be most immediately effective for the next several years, but more theoretical and physically clear basic modeling approaches (b) need to be established for the second next stage. The approach (b) needs to be coordinated with test points by load-based test methods. Before the approach (b) and the coordination is developed, efforts to validate and, if necessary, to improve existing default empirical functions representing relationships between influential parameters and power consumption, etc. should be supported by monitoring data and/or laboratory tests by load-based test methods.

The requirements for higher performance of building envelopes have become usual and space heating and cooling loads tend to be dramatically reduced. Thanks to shared monitoring data for heat pump systems in buildings, it is not as difficult as before for HVAC designers to obtain information on the energy efficiency of heat pump systems under low part load conditions. They must have realised again the importance of sizing heat sources including heat pumps. It does not mean at all that they should take a risk of shortage of capacity. They should consider how lower energy efficiency under lower part load ratio can be avoided by better design of heat pump systems and by better heat pump products. It seems to be the best time to combine technical information on test methods, monitoring methods/data and energy calculation tools to develop load-based test standards and to prepare new design guidelines for HVAC designers and all relevant engineers.

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