4. State of the art on design guidelines for heat pump systems in buildings

4.1 Background

Heat pump systems play a crucial role in buildings by significantly reducing greenhouse gas emissions. They achieve this by efficiently transferring heat from one location to another. Heat pumps are versatile systems that can provide cooling and heating, making them suitable for various climates and seasons. Heat pumps extract heat from indoor spaces and reject it to the outdoor air, water bodies, or the ground in cooling applications. Heat pumps upgrade the freely available ambient energy from outdoor air, water sources, or the ground in heating applications. This utilisation of ambient energy results in lower energy consumption and higher energy efficiency compared to traditional heating and cooling systems. Heat pumps can be powered by renewable electricity sources, such as solar PV panels or wind turbines.

Design guidelines are crucial in achieving energy-efficient designs, guaranteeing occupant comfort, minimising environmental impact, and adhering to applicable building codes and regulations. These guidelines should aid in the design, installation, and maintenance of heat pump systems within buildings. As modern technologies and research continue to emerge, these guidelines continuously evolve. The aim of Chapter 4 is to present current design guidelines for heat pump systems in buildings and suggest potential future advancements.

In Section 4.2, the current guidelines are briefly presented and discussed; they are as follows:

- EN 15450:2007 – Heating systems in buildings – Design of heat pump heating systems (CEN - Comité Européen de Normalisation, 2007).
- VDI 4645:2023-07 – Heating systems with heat pumps in single and multi-family houses – Planning, construction, operation (VDI - Verein Deutscher Ingenieure, 2023).
- The standards applied in Denmark: EN14511, EN14825, EN16147, and EN12102.
- CSA SPE-17:23 – HVAC guide for Part 9 homes (CSA - Canadian Standards Association Group, 2023).
- ACCA Manuals.
    - Manual J – Residential Load Calculation (ACCA, 2016, 8th Ed, Full).
    - Manual S – Residential Equipment Selection (ACCA, 2023, 3rd Ed, V 1.01)].
- NEEP Sizing and Installation Guidance – Developed by the Northeast Energy Efficiency Partnership (NEEP, 2020a, b).
- ISO 13153:2012 – Framework of the design process for energy-saving single-family residential and small commercial buildings (ISO, 2012).
- Design Guidelines for Low Energy Housing with Validated Effectiveness (LEHVE) – Developed by the Building Research Institute in Japan (BRI Japan, 2010)

Section 4.3 summarises the characteristics of existing guidelines and presents perspectives on developing design guidelines for heat pump systems in Annex 88.

4.2 Existing guidelines for designers and installers of heat pump systems in buildings

4.2.1 European guidelines

For a decade, designers and installers are facing a new task in Europe (eventually maybe everywhere in the world), urged by new regulations: the use of heat pumps instead of fossil fuel combustion boilers as the basic heat generation device. In several EU countries fossil fuel boilers are already banned from new buildings, either explicitly (no natural gas connection allowed for new buildings, as e.g., in the Netherlands) or implicitly (you cannot meet energy performance requirements for new buildings with fossil fuel boilers in Italy). The new EPBD Directive 2024/1275/EU (published on the 8th of May 2024) bans combustion of fossil fuels:

- in all new buildings, starting from 2030;
- in all existing buildings (with few exceptions), starting from 2050.

Heat pumps are already in use for a long time for cooling air conditioning, but this is mostly:

- simple split or multi-split room air conditioners in individual dwellings.
  This is a large market, especially in southern Europe, but the installation is simple and straightforward and requires low expertise of installers and no regular design activity (meaning that design decisions are simple and taken by the installer without the help of a professional designer);
- cooling systems in non-residential buildings.
  Expertise is required from designers and installers, but it is a small market as the number of professionals involved.

Also, most of Europe does not require serious cooling.
Most installers and designers were used to boilers only, which are easy and inexpensive to install. Modern boilers are powerful devices, capable of operation at high temperature, highly modulating, little sensitive to operating conditions. Commissioning activity requires knowledge of combustion technology.

Now installers and designers must switch to heat pumps also for heating. This means:

- changing the basic technology: every installer and designer shall become a refrigeration engineer;
- dealing with sizing a still expensive machine (cost per kW installed), with little modulation, low power and extremely sensitive to operating conditions;
- dealing with a machine that requires a low flow temperature, which is often tough to achieve on existing buildings (may require insulation, continuous operation, replacement of heat emission terminals);
- facing additional technical (and bureaucratic) challenges because of environmental and safety aspects of refrigerants, which have already changed several times in the last few years;
- finding room for the heat pump and the domestic hot water storage in existing buildings where the boiler was incorporated in the kitchen furniture and domestic hot water preparation was instantaneous, with no space consuming storage;

and more, especially for existing buildings.

This is a cultural shift that should occur quickly, in a shorter time than is required for a new generation of installers and designers to appear on the market.

In this context, information, training, guidelines, and new standards provide essential support, but they all follow a similar evolution and require experience to be effectively developed. Installers and designer associations are aware of that and for a decade there have been plenty of organisations producing independent documentation, guidelines, checklists to support heat pumps installation and design. Some trends can be identified in this production.

- The first concern is the sizing of the heat pump for heating. Boilers were sized according to "heat load" calculated according to EN 12831 (CEN, 2017a). This means neglecting any gains and assuming all heat losses (e.g., ventilation) in worst-case conditions. The result was oversizing, which is no or little harm for boilers but has severe consequences on heat pumps.
  It must be noted that this is a topic centred on building enclosure characteristics.
  New sizing techniques appear based on energy performance calculation (monthly or hourly and dynamic) and on measured energy performance (for renovation of existing buildings). Manufacturers are already using extensively tools based on past energy used to advise designers and installers on heat pump sizing.
- The sizing for domestic hot water storage could be simplified in the past because of the high capacity of combustion boilers. New dynamic sizing techniques appear for non-residential applications.
- The operating temperature of the system shall be designed (new buildings) or checked (renovation of existing buildings). This requires additional calculations involving the required heat output of terminals, their sizing, the type of hydraulic circuits (both distribution and generator connection) and their control.
- Selection and handling of refrigerants is strictly regulated and is increasingly a practical (and bureaucratic) concern. Unfortunately, environmentally friendly refrigerants are toxic or explosive or require special operating conditions.

All these aspects are being dealt in more and more detail in the guidelines and standards. Most publications deal with specific aspects, but when you must design and install a heat pump system, you must consider them all simultaneously. Newly published guidelines are also getting increasingly comprehensive.

An example of this evolution is the European standard EN 15450 which is described in the next clause. Starting from a simple standard replicating most of the concepts already in use for boilers (like using heat load for sizing) it is evolving into a comprehensive guideline covering the whole design process of a heat pump installation, including aspects like using special sizing techniques, designing the operating temperature, taking care of environmental and safety aspects.

4.2.1.1 EN 15450 Heating system in buildings – Design of heat pump heating systems

4.2.1.1.1 Introduction and status of the standard

EN 15450 is the European standard dedicated to the design of heat pump systems. It complements EN 12828 (CEN, 2014) which is about the design of space heating and domestic hot water systems, with specific provisions concerning the use of heat pumps.

EN 15450 was first published in 2007 and is now (year 2024) undergoing a major revision. A new draft for public review is expected within the end of 2024. Since the revision will introduce several improvements and new concepts, the anticipated revision is also covered in the following discussion.

In the European context, water-based heating systems are by far the most common. Air based heating systems have an increasing share but are still a minority. Therefore, even if air-based systems are within its declared scope, the focus of EN 15450 is mainly on water-based systems.

4.2.1.1.2 Structure and contents of the current version of EN 15450:2007

The scope of the current version includes heat pumps for space heating and domestic water heating with all popular combinations of sources (heat extraction) and sinks (heat rejection).

The following objectives of the heat pump design process are considered:

- maximising the seasonal efficiency calculated according to EN 15316-4-2, which is the European module about the energy performance of heat pumps generation systems; minimum values and target values, depending on source and sink type, are given in informative annex C to EN 15450;
- limiting the cycling frequency during part load operation;
- minimising the environmental impact (e.g. ozone depletion, global warming, noise).

The sizing of the heat pump for the space heating service is based on the heat load ΦHL calculated according to EN 12831 (CEN, 2017a). This value can be slightly corrected by a “design factor” according to EN 12828 (CEN, 2014), which allows a reduction in the sizing up to 10%, depending on the specific heat capacity of the building in Wh $m^{-3} \cdot K^{-1}$. This is a critical issue because the sizing according to heat load is often excessive, because it neglects the contribution of internal gains and the limited number of hours during the heating season that are at or near the design outdoor temperature.

Two possibilities are given for the sizing of the domestic hot water storage volume:

- accumulation, where the volume is set as twice the average domestic hot water daily volume need;
- semi accumulation, where the volume is set as equal to the average domestic hot water daily volume need.

The additional design power for domestic hot water of the heat pump depends on the previous choice:

- for accumulation systems, the additional power required is equal to the average power required to heat the average daily volume of domestic hot water;
- for semi accumulation systems, a check is required that the heat pump can reload the storage in between critical draw-offs.

Minimal information is given for domestic hot water service sizing (25 litres per person and per day at 60 °C), and it is specific for residential context.

Informative annexes provide complementary information about topics such as:

- using special sources, like ground water and ground;
- typical hydraulic circuits (a collection of basic functional diagrams);
- definition and scope of performance factors;
- seasonal performance factor (SPF) recommended targets;
- noise limits;
- domestic hot water tapping (draw) patterns;
- basic definitions of capacity control.

The contents of this standard are basic and often incomplete. Also, there is no specific requirement and/or advice about the connection with heating terminals and their specific sizing that might be required for use with heat pumps. The standard needed a revision, and this work started in 2022.

The following clause describes the new draft. The standard is being also revised because of the extension of the scope of CEN-TC 228 (CEN, 2017d), which now also includes water-based cooling. The new EN 15450 will be about water-based and direct condensation and expansion heating and cooling systems.

4.2.1.1.3 Structure and contents of the new standard

The ongoing revision of EN 15450 has several objectives:

- extending the standard to water-based cooling systems;
- identifying all the concerns when designing a heat pump system;
- dealing with the specific issues of the building renovation and of the replacement of combustion boilers by heat pumps;
- introducing a two step-procedure for existing buildings: start with a preliminary design and then decide if to proceed with a final design of a heat pump system;
- defining a procedure which is more aligned with the design workflow practice.

The introductory part covers heat pump nomenclature, system boundaries and definitions of efficiencies. The intent is to clarify the scope of COP when specifying design energy performance requirements. The design objective is not limited to the heat pump: it includes the so called “external auxiliaries”, that is electricity use for heat source and heat rejection systems that are required for system operation.

The main design objective is identified as achieving the highest seasonal performance given the design constraints and expected operating conditions.

The issues that must be considered and solved when designing a heat pump system are identified and potential consequences highlighted. No solution is provided at this stage, since providing solutions for the specific case will be the task of the design process. The following issues are identified.

- Optimising source and sink temperature, by selecting the type of source and sink and, if possible, acting on its operating conditions. This includes (e.g.) sizing the heating terminals and/or insulating the building to reduce the required fluid temperature. Each one °C is worth between 2 and 3% of efficiency.
- Heat pump sizing: Over-sizing is detrimental for investment cost, efficiency, and expected lifespan.
- Provision of a sufficient flow rate in the primary loop to avoid unintended mixing.
- Provision of a sufficient available water volume, to limit cycling frequency at low loads and to allow defrosting.
- Environmental impacts, such as noise, use of toxic chemicals, refrigerant issues (e.g. GWP, Global Warming Potential), risk of ground and groundwater contamination (for ground coupled heat pumps)
- Service specific issues that arise in connection with the provision of one specific service (e.g. space heating, domestic water heating) or a combination thereof. Example: if two levels of temperature are required (most common: low temperature space heating and higher temperature domestic water heating), consider either alternate operation modes or the use of separate, dedicated heat pumps.
- Safety aspects, including fire hazards and toxicity because of refrigerant properties. Referring to EN 378-1 for this topic.

A checklist is proposed to confirm that the design covers all relevant issues (quality check).

Information collection is the first step in the design workflow and it details design objectives and boundary conditions. This includes required services (space heating, cooling, domestic water heating) and their level, user requirements and expectations, applicable regulations and legal constraints, performance objectives, site characteristics, available resources (heat source and driving energy).

The next phase of the proposed design workflow, the preliminary design, is the provision of a so called “design concept”, that is the rationale to fulfil the design objectives. The design concept should include at least the following:

- a functional diagram as shown in Figure 4.2.1-1 (a collection of basic functional diagrams is provided in an annex to the standard so that the designer can adapt them for the specific project);
- a draft system layout, showing the possible location of the required equipment;
- a system operation sequence (operation and control rationale);
- an estimation of the expected system performance and cost.

The design concept shall:

- confirm that the designed system can be realised;
- confirm that the energy performance targets can be achieved;
- provide a cost estimation of the project;
- support a go/no-go decision to proceed with the detailed design.

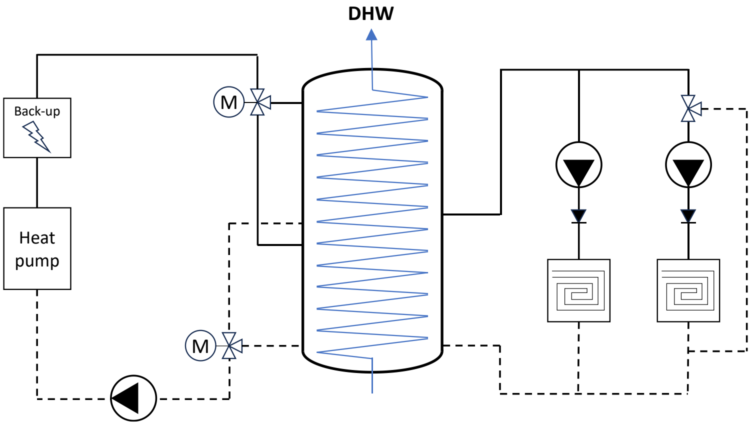


Figure 4.2.1-1. Sample basic functional diagram

The preliminary design is an important step for renovations, where a combustion boiler is replaced by a heat pump, which is expected to be the most common case in the coming years. Heat pumps do not provide a simple one-to-one replacement for boilers: upgrades of existing building enclosures and/or terminal emitters may be needed to install a heat pump successfully.

If the design concept is approved, then the design workflow continues with the detailed design, where all design issues are addressed systematically.

Sometimes, several sizing procedure alternatives are presented because of the variety of possible boundary conditions and design approaches across Europe. An example is the sizing of the heat pump itself, that requires considering at least three issues, with possible alternatives in their evaluation (see Figure 4.2.1-2):

- The starting point is the required power output under design conditions, that is the building enclosure requirement. Several alternatives are proposed:
  - heat load, which is the traditional approach to sizing heating systems but leads to oversizing;
  - new approaches, based on energy performance calculation (either monthly or hourly) or measured energy use for existing buildings. This provides a more accurate tailored sizing.
- The next step is considering the availability and intended use of a back-up generator. Here, too, several alternatives are provided. The sizing criterion can be either a desired bivalence temperature or a desired energy needs coverage, and the control option can be alternate or simultaneous operation.
- Finally, the allowed daily operation time and schedule may be considered.
- Hourly methods based on EN ISO 52016-1 (CEN, 2017c) applied on a design day or week are also proposed. They allow to deal simultaneously with all previously mentioned issues and options.

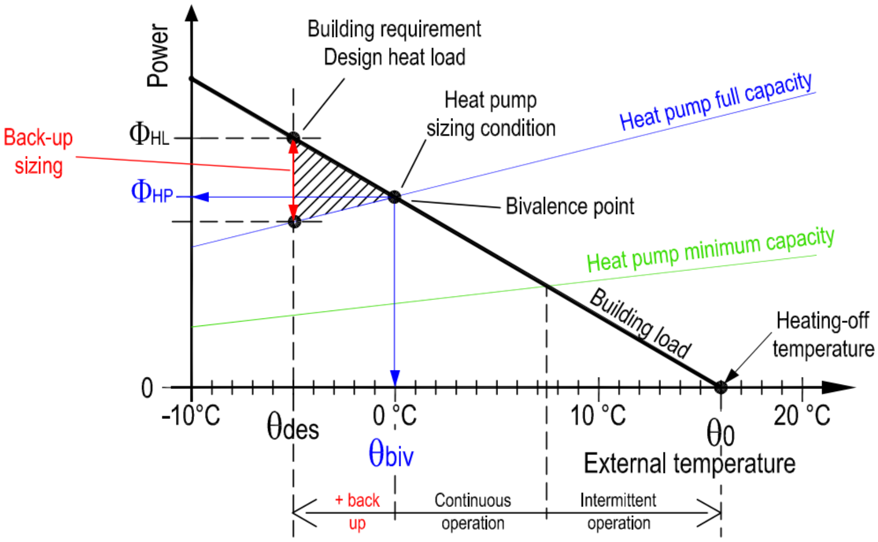


Figure 4.2.1-2. Graphical example of the bivalence point concept.

A new feature worth mentioning is the sizing of the domestic hot water storage volume, which is a basic concern, because of the limited available power of the heat pump and the intrinsically high power / low energy demand for domestic hot water service. There are two methods proposed (see Figure 4.2.1-3):

- a simple rough method based on the domestic hot water daily needs, similar to that in the accumulation method of the current standard: have a storage volume twice the average daily volume needs;
- a detailed method based on a design load curve according to EN 12831-3:2017 (CEN, 2017a), which is a comparison between the cumulated energy required during the day with a one-minute time interval and the system performance curve.

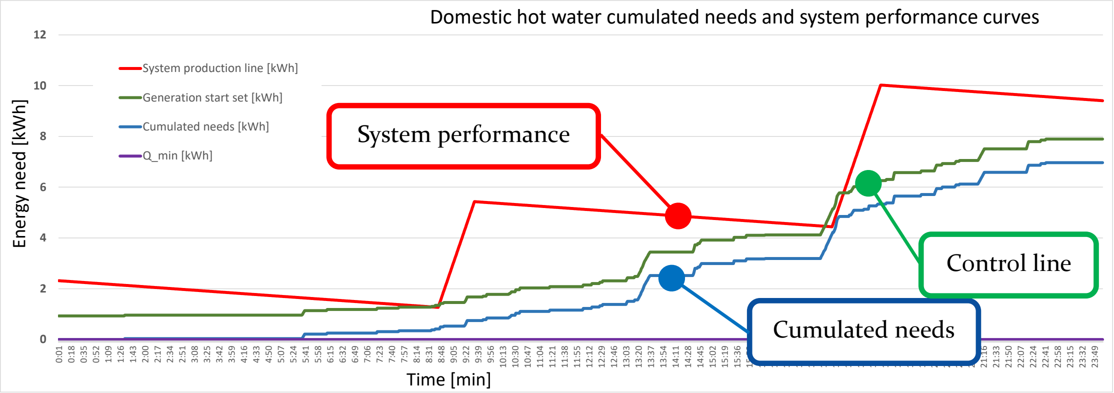


Figure 4.2.1-3. Comparison between load requirements and system capacity

The detailed procedure may provide a useful tool to size heat pump systems for domestic hot water in demanding non-residential contexts such as hotels. The sizing of a heat pump for space cooling is a new topic introduced in this revision. Until now, it has not been a routine task in northern and central Europe, whilst in southern Europe, cooling system sizing practices and methods still vary substantially. A basic simplified method taken from a Danish standard is presented to calculate the instantaneous peak cooling load. Gains at peak conditions are summed and the effect of heat accumulation in the internal structures is considered as a reduction in cooling load. This method needs localised climatic data about solar radiation depending on façade orientation. Other methods are mentioned, such as the hourly method presented in EN ISO 52016-1 (CEN, 2017c), clause 6.5.4.5, which is also applies to cooling system sizing.

4.2.1.1.4 Foreseen development

The new draft is under development and should be ready to undergo public review at the end of year 2024. Then one more year will be necessary for handling comments and to complete the formal vote procedure. If the process is smooth, the revised EN 15450 should be available at the end of 2025 or early 2026

4.2.1.2 VDI 4645 Heating systems with heat pumps in single and multi-family houses - Planning, construction, operation

VDI 4645 (VDI, 2023) deals with the steps necessary for the planning of heat pump systems in single and small multi-family (mainly two-family) residential buildings from the preliminary examination/concept preparation to the detailed planning. The scope includes only hydronic space heating and domestic hot water heating.

It is described that to achieve a high efficiency of the heat pump, the flow temperature in the space heating operation must be kept as low as possible. In the 4-pipe system, each primary circuit is operated at a system temperature required for the application. For this reason, it is said that different buffer storage systems are required for the space heating and the domestic hot water heating system, as shown in Figure 4.2.1-4. A figure showing the relationship between flow temperature and coefficient of performance (approximately linear relationship) is given.

The ways of sizing the storage tank volume for domestic hot water and for space heating water are described in 9.5.1.2 of VDI 4645 (VDI, 2023). For the sizing of the storage tank for domestic hot water, average tapping (draw) profiles for one-member, two-member and three member families are included in Annex J of VDI 4645.

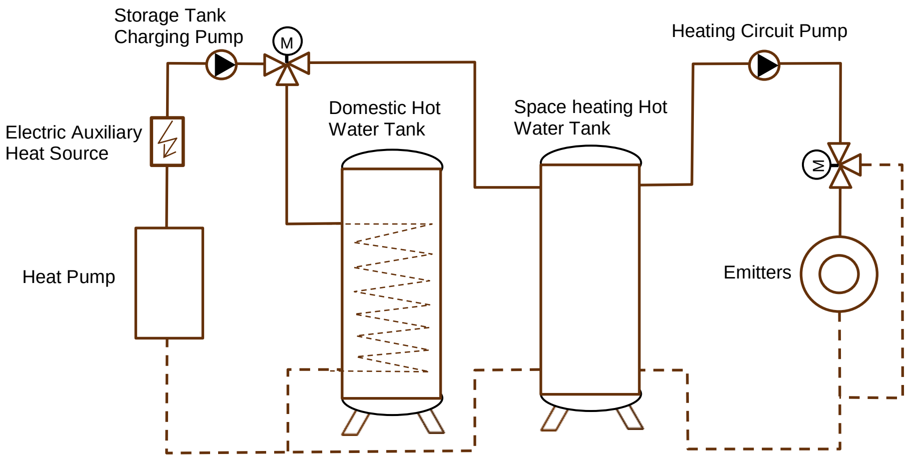


Figure 4.2.1-4 Typical configuration of heat pump systems for a detached house or two-family houses

Sizing of the heat pump is also described, taking into consideration the option of a supplemental heating source, such as an electric heater or a fossil fuel boiler.

Efficiency assessment of heat pumps is included in Annex G, where methods to calculate the seasonal coefficient of performance of the heat pump in bivalent heating operation (COPH) and the seasonal COP of the bivalent heat pump in the domestic hot water heating system are described (Annex G). A method of cost estimation is by using the COPH and the COPW only (Annex H).

In Chapter 2, some guidance is provided on commissioning and how to set the control system. In this chapter, documentation and instruction for the user are also described. Items that are covered include:

Switching the system on and off, switching the heating circuits and domestic hot water heating on and off, changes in temperature, changes of time windows, and explanation of the indicators (controller and device displays, pressure and temperature indications).
Annex D is the overall checklist for concept and detailed planning of heat pump systems.

4.2.1.3 National application of European design guidelines in Denmark

4.2.1.3.1 National application of European design guidelines in Denmark

Scandinavia has always been at the forefront of renewable energy. Indeed, it was in Denmark and Sweden during the 1980s that the initial standards for heat pumps were established. In these early Nordic standards, the focus was on the requirements for the declaration of heat pumps, and a set of test requirements for the products were laid out. Today, these standards are crafted by a technical committee (TC) under the European Committee for Standardization (CEN), which represents shared European interests. Over recent years, standards have been developed that provide an accurate representation of the efficiency of heat pumps.

4.2.1.3.2 Relevant standards as a basis for Danish design guidelines

In Denmark, heat pumps must adhere to several standards, including EN14511, EN14825, EN16147, and EN12102.

1) EN14511 “Air conditioners, liquid chilling packages and heat pumps for space heating and cooling and process chillers, with electrically driven compressors (CEN - Comité Européen de Normalisation, 2018). It has four parts: 1) Terms and definitions, 2) Test conditions, 3) Test methods, 4) Requirements.
Heat pumps are becoming increasingly important in the context of sustainable and renewable energy solutions. Standards like EN14511 ensure these technologies deliver their promised performance and maintain safety, reliability, and environmental responsibility. As the demand for efficient heating and cooling solutions grows, adherence to such standards becomes crucial for manufacturers, installers, and end-users alike.
Key Aspects of EN14511:
Scope: The standard applies to both air-to-air and liquid-to-air air conditioners and heat pumps, liquid chilling packages, and dehumidifiers. It encompasses both factory-made products and those assembled on-site.
Performance Ratings: One of the primary objectives of the EN14511 (CEN, 2018) is to define the performance rating of these devices in terms of capacity and efficiency under various operating conditions. This aids in benchmarking and ensuring the product's capability matches its specifications.
Testing Requirements: The standard lays down specific testing methodologies and conditions for ensuring consistent and reliable results. These methodologies measure the efficiency and performance of heat pumps in a range of conditions – for instance, different temperatures and pressures.
Safety and Environmental Concerns: While the focus is on performance, the standard also touches upon certain safety and environmental concerns, ensuring that the heat pumps do not pose risks to users and are environmentally friendly.
Interoperability and Integration: Given the diverse applications of heat pumps – from domestic settings to larger commercial environments – the EN14511 (CEN, 2018) ensures products can be integrated seamlessly into various systems and infrastructures.

2) EN14825 “Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling - Testing and rating at part load conditions and calculation of seasonal performance”

In an era where energy efficiency and sustainability are paramount, the EN14825 (BSI, 2022) standard is crucial. It ensures that heat pumps and related products are not just efficient under lab conditions but deliver consistent performance throughout their operational life, reflecting the actual European climate conditions. Manufacturers and consumers alike benefit from this standard, which provides a clear benchmark for product performance and efficiency.

Key Aspects of EN14825:

Scope: The EN14825 standard applies to all types of air conditioners, heat pumps, and chillers, including both the ducted and ductless varieties, regardless of their source of energy or the type of energy used (e.g., electricity or gas).

Seasonal Performance Metrics: One of the standout features of EN14825 is its emphasis on seasonal performance. Instead of merely evaluating a device's performance under standardised test conditions, it considers variations in climatic conditions throughout the year. This provides a measure of the unit's efficiency and effectiveness over the entire heating or cooling season.

EN 14825 is intended to support the application of the European Eco-design and Eco-labelling directive. It provides a method for calculating a “seasonal” performance (SCOP and SEER) under an assumed operating condition. It complements EN 14511 (CEN, 2018) in defining part load test conditions suitable for providing the data for the calculation of the SCOP and SEER.

Testing Protocols: EN14825 details the test methods to determine and verify the seasonal performance coefficients, ensuring that manufacturers and testers have clear and consistent guidelines to follow.

Classification and Ratings: The standard provides a basis for classifying and rating the efficiency of devices. This classification helps consumers, installers, and policymakers make informed decisions about the products in terms of their environmental impact and potential energy savings.

Supporting Information: Apart from technical specifications and testing methodologies, EN14825 also requires that supplementary information, like user manuals and product labels, be provided with the products. These details help users understand the optimal usage conditions and maintenance requirements.

Integration with Other Standards: EN14825 works in conjunction with other standards, such as EN14511, to provide a comprehensive view of the performance of heat pumps and related devices.

3) EN16147 (CEN, 2022).

As domestic hot water production is a significant contributor to household energy consumption, heat pumps in this category can play a vital role in enhancing energy efficiency. The EN16147 standard is thus essential as it ensures that these heat pumps are effective in their primary function and energy-efficient, safe, and environmentally responsible. Adherence to this standard is crucial for manufacturers, ensuring their products meet high-quality benchmarks, and it provides consumers with a reliable measure of a product's performance and safety.

Key Aspects of EN16147: “Heat pumps with electrical driven compressors- testing. Performance rating and requirements for marking of domestic hot water units”

This standard specifies methods for testing, rating of performance and calculation of water heating energy efficiency of air/water, brine/water, water/water and direct exchange/water heat pump water heaters and heat pump combination heaters with electrically driven compressors and connected to or including a domestic hot water storage tank for domestic hot water production. This standard includes only the testing procedure for the domestic hot water production of the heat pump system. This document only applies to water heaters which are supplied in a package of heat pump and a storage tank.

Scope: EN16147 is specifically geared towards heat pumps designed for producing domestic hot water. This includes units that are monobloc, split, or with multiple compressors and can be either factory-made or assembled on-site.
Performance Metrics: The primary aim of this standard is to set the performance rating of the heat pumps in terms of their capacity and efficiency. It evaluates the coefficient of performance (COP) and energy efficiency, ensuring the product meets its specified performance metrics.
Testing Conditions: EN16147 establishes standardised testing conditions, which include specific ambient and load conditions. This ensures that all products are tested under consistent conditions, allowing for accurate comparisons between different units.
Safety and Environmental Factors: Beyond performance metrics, the standard also addresses certain safety and environmental considerations, ensuring that the heat pumps are safe to operate and do not harm the environment. This can include factors like refrigerant type and emissions.
Product Information: Manufacturers are required to provide specific information about their products, ensuring transparency for the end-users. This can include data about the product's performance, its optimal operating conditions, maintenance requirements, and more.
Interoperability: Given the various configurations and applications of heat pumps for domestic hot water production, EN16147 ensures such products can be integrated smoothly into different domestic setups without hindrance

4) EN12102
EN12102 (CEN, 2020) plays a critical role in ensuring that the acoustic emissions of heat pumps and related devices are within acceptable limits, promoting user comfort and environmental well-being. This standard is invaluable for manufacturers aiming to design quieter, more efficient devices, and for consumers seeking products that will not disrupt their living or working environments.
Key Aspects of DS/EN12102:
Standardised Procedure: The standard provides a uniform procedure for accurately determining the sound power levels of the specified devices. Such standardisation ensures that all measurements are consistent and comparable across different devices and manufacturers.
Importance of Acoustic Measurements: Sound power levels are crucial for assessing the potential noise pollution a device might cause. Noise can affect the comfort and well-being of inhabitants and neighbours. For commercial applications, excessive noise can also impact worker productivity and comfort.
Testing Conditions: The standard will probably stipulate the conditions under which the measurements should be taken, including ambient conditions, device operational state, and the environment in which the test is conducted.
Reporting and Declaration: Manufacturers are expected to report their findings according to this standard, providing potential buyers and users with a clear understanding of the acoustic profile of the product.
Supporting Sustainable Design: As more emphasis is placed on creating sustainable and comfortable living and working environments, the noise emitted by essential HVAC equipment becomes a pivotal consideration. EN12102 supports this by providing clear metrics for airborne noise evaluation.

4.2.1.3.3 General Heat Pump Design Guidelines for Danish Buildings

The general design guidelines for heat pump systems in buildings, considering Denmark's context:

1. Selection of Heat Pump Type: Depending on the source of heat available, there are different types of heat pumps to choose from:
    - Air-to-Water/Air-to-Air Heat Pumps: These extract heat from the ambient air.
    - Ground Source Heat Pumps (GSHP): These use heat from the ground via boreholes or

horizontal loops.

  - Water Source Heat Pumps: Extract heat from nearby water sources, like lakes or rivers.
2. Sizing of Heat Pump: The heat pump should be correctly sized according to the heating demand of the building. Over-sizing can lead to more frequent start-stops, reducing the efficiency and life of the heat pump.
3. Integration with Existing Systems: In many renovation cases in Denmark, heat pumps are integrated with existing heating systems, such as district heating or gas boilers, to ensure maximum efficiency and reliability.
4. Temperature Levels: Heat pumps are most efficient when supplying low-temperature heating systems, such as underfloor heating. For older buildings with radiators designed for higher temperature supply, ensure that the radiators are large enough or consider integrating with other systems.
5. Insulation: Ensure the building envelope is properly insulated to reduce the heating demand. This is important in Denmark's cold climate to ensure the efficiency of the heat pump system.
6. Controls and Monitoring: Intelligent controls can adapt the operation of the heat pump based on the outdoor temperature, occupancy patterns, and other variables to ensure maximum efficiency.
7. Maintenance: Regular maintenance and monitoring can ensure the system operates efficiently over its lifespan.
8. Integration with Renewables: Given Denmark's focus on wind energy, integrating heat pumps with renewable sources like wind or solar PV can further reduce carbon footprints.
9. Legislation and Incentives: Keep in mind any governmental regulations, incentives, or grants that are available to encourage the adoption of heat pumps. Denmark has often offered incentives for sustainable building practices and renewable energy installations.
10. Noise and Aesthetics: Especially for air-source heat pumps, consider the noise levels and aesthetics, ensuring they do not pose disturbances to inhabitants or neighbours.
11. Hybrid Systems: Consider hybrid systems that combine heat pumps with boilers or other heating systems to ensure continuous heating during extreme cold spells when the efficiency of heat pumps might decrease.
12. Training and Awareness: Make sure that the occupants and building managers understand the operation of the heat pump system, which can be crucial for its optimal functioning.

For the most up-to-date guidelines and specific standards related to Denmark, it would be best to refer to the Danish Energy Agency or relevant local building codes. Also, professional associations related to HVAC and building systems in Denmark might have detailed, updated guidelines and best practices for the design and installation of heat pump systems.
In Denmark, the installation and design of heat pump systems in buildings are regulated and guided by specific national standards (European standards published by CEN and according to CEN rules taken over by Danish Standards) and building codes. The primary standards and regulations relating to heat pump installations in Denmark are:

1. EN 15450: Heating systems in buildings - Design of heat pump heating systems. This standard specifies the requirements for the design of heat pump heating systems in buildings (BRI Japan, 2010).
2. EN 14825: Air conditioners, liquid chilling packages and heat pumps for space heating and cooling and process chillers, with electrically driven compressors - Testing and rating at part load conditions and calculation of seasonal performance.
3. Building Regulations (BR23): These are the general building regulations in Denmark which, among other things, include requirements for the energy performance of buildings, which heat pumps can play a role in achieving.
4. Danish Energy Agency Guidelines (Danish Energy Agency, 2018): The Danish Energy Agency

provides guidelines and requirements for various energy technologies, including heat pumps, to ensure efficient and sustainable use.

Besides the national standards and regulations, various industry associations in Denmark, such as the Danish Heat Pump Association (DHPA), may offer additional guidelines and best practices.

1. EN 15450 - Heating systems in buildings - Design of heat pump heating systems:
    - Scope: This standard is specific to heat pump heating systems in buildings. It sets the requirements for the design, dimensioning, installation, and control of heating systems with heat pumps, in combination with any other heat source if used.
    - Key Elements:
        - Determination of building heat losses to size the heat pump accurately.
        - Guidelines for the selection of the heat source (air, water, or ground) and the related necessary components.
        - Provisions for integrating with other heating systems.
        - Control and regulation guidelines for maintaining user comfort and achieving high energy efficiency.
        - Considerations for domestic hot water production using heat pumps.
2. EN 14825 - Air conditioners, liquid chilling packages and heat pumps for space heating and cooling and process chillers, with electrically driven compressors:
    - Scope: This standard deals with the testing and rating of air conditioners, liquid chilling packages, and heat pumps used for both space heating and cooling.
    - Key Elements:
        - Specifies test conditions for full load and part-load performance and seasonal performance.
        - Provides methods for determining the capacity, power consumption, and efficiency of these systems.
        - Sets forth standard rating conditions to make a comparison between different products easier for consumers.
        - Addresses different climate conditions, ensuring that the systems are tested for diverse operational challenges.
3. Building Regulations (BR23):
    - Scope: The Building Regulations cover all aspects of building construction in Denmark, from energy to indoor climate and fire safety. The energy provisions in BR23 ("Danish building regulations - codes (BR23)," 2023) are relevant for heat pumps.
    - Key Elements:
        - Specifies minimum energy performance requirements for new buildings and renovations.
        - Provides methodologies for calculating a building's energy needs.
        - Promotes energy-efficient technologies and solutions, such as heat pumps.
        - Emphasises the integration of renewable energy sources, which includes the operation of heat pumps in tandem with renewable energy.
        - Addresses ventilation, insulation, and airtightness standards that impact the heating and cooling demands and thus influence the design and operation of heat pump systems.
4. Danish Energy Agency Guidelines:
    - Scope: The Danish Energy Agency offers various guidelines related to energy use, including those concerning heat pumps.
    - Key Elements:

  - Promotion of efficient and sustainable energy technologies.
  - Information on subsidies or incentives for installing heat pumps and other renewable technologies.
  - Best practice guidelines and case studies for efficient implementation.
  - Reporting and documentation requirements for different energy solutions.

The details provided above give a broad overview, but the actual standards provide specific technical criteria, methodologies, and guidelines that need to be followed for compliance.

4.2.2 Canadian codes and practices

Heat pump installation practices are taught in Canada through the provincial and federally recognised "Red Seal" program's refrigeration and air conditioning mechanic designation (Red Seal Program, 2024). Design practices are taught through the Heating, Refrigeration and Air Conditioning Institute's (HRAI) courses, with the Residential Air Systems Design (RASD) course and Residential Heat Loss and Heat Gain (RHLHG) courses being directly relevant to heat pump equipment sizing and selection. Regional associations such as the Thermal Environment Comfort Association (TECA) in British Columbia, Home Performance Stakeholders Council (HPSC) in British Columbia as well as others also have regional teaching workshops and teaching materials.

Relevant codes and standards related to heat pump installation and design would include:

- For air source heat pumps: CSA C273.5:11 (R2020) "Installation of air source heat pumps and air conditioners"
- For ground source heat pumps: CAN/CSA-C448 SERIES-13 "Design and installation of earth energy systems"

Additionally, the federal government of Canada undertakes industry design and installation support training through Natural Resources Canada, CanmetENERGY Local Energy Efficiency Partnerships (LEEP) program. A series of videos aimed at contractors and the design community specific to residential heat pump retrofits are hosted on the LEEP website (Government of Canada, 2024a).

Natural Resources Canada's CanmetENERGY also produced and maintains an Air Source Heat Pump Sizing and Selection Toolkit (Government of Canada 2024b) aimed at heat pump distributors, contractors and designers, comprising a Step-by-Step Sizing and Selection procedure (the Guide), an Addendum of worked examples, training video, an Excel-based Tool and forthcoming online App.

Building code adoption, installation and design practices are released federally in Canada by the National Research Council of Canada and adopted as is, or with modifications, at the discretion of provinces within Canada. Codes overseen by the National Research Council of relevance to heat pump design and installation include:

- The National Building Code of Canada (Government of Canada 2020a)
- The National Energy Code of Canada for Buildings (Government of Canada 2020b)
- The National Plumbing Code of Canada (Government of Canada 2020c)

Provisions within the National Electrical Code also have implications on the design and installation of heat pumps. The Canadian Electrical Code (CSA Group 2024a) is overseen by the Canadian Standards Association.

4.2.2.1 Toolkit for air source heat pump sizing and selection

Background

Natural Resources Canada developed a package of materials for air source heat pump (ASHP) sizing and selection (Government of Canada 2024b), intended for use by mechanical system designers and renovation contractors. The materials were designed to assist these individuals with sizing and selecting ASHPs for Canadian climates in both new and existing (retrofit) residential applications.

Scope

The Toolkit focuses on air source heat pumps (ASHPs) for space heating and/or cooling applications. The Toolkit covers the following applications of ASHPs:

- New home (or major new addition) installations.
- Full heating system replacement where existing HVAC equipment is removed.
- Add-on ASHP applications to displace heating energy or provide supplemental heating where existing heating equipment remains functional.

This Toolkit covers the following technologies:

- Ducted and ductless ASHPs
- Single-zone and multi-zone centrally ducted ASHPs
- Single-zone and multi-zone ductless mini-split ASHPs
- Single-zone and multi-zone ducted mini-split ASHPs
- Single-stage ASHPs
- Staged and variable-capacity ASHPs
- Cold-climate ASHPs.

Exclusions:

- Installation best practices and requirements are outside the scope of this guide.

Overview of the Air-Source Heat Pump Sizing and Selection Process

An overview of the ASHP sizing and selection process is shown graphically in Figure 4.2.2-1.

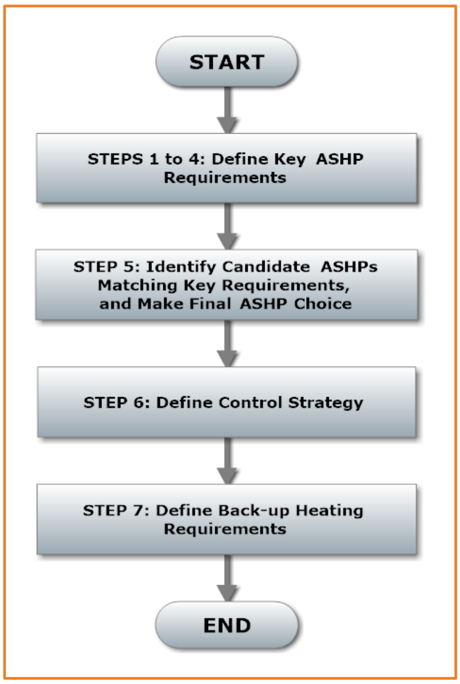


Figure 4.2.2-1. Overview of the ASHP Selection and Sizing Process

The process comprises seven steps, which can be grouped into four major parts:

I. Define key ASHP requirements (STEPS 1 to 4);
  - Define ASHP Configuration.
  - If required, choose mini-split indoor unit types.
  - Determine heating and cooling loads.
  - Determine sizing approach and ASHP target capacity requirements.

II. Identify candidate ASHPs matching key requirements and make final ASHP choice (STEP5);

III. Define system control strategy (STEP 6); and,

IV. Define backup heating requirements (STEP 7).

Components of the Toolkit

The Toolkit comprises:

- ASHP Sizing and Selection Guide (referred to as “the Guide”) and ASHP Key Specifications Summary Worksheet (included in the Guide as Appendix B, see Figure 4.2.2-1 & 4.2.2-2);
- ASHP Sizing and Selection Tool: an electronic representation of the ASHP Sizing and Selection Guide. The tool interactively guides users in applying the step-by-step process described in the Guide while providing additional charting and performance analysis features;
- Addendum of worked examples provides case studies of the Guide used to select centrally ducted or ductless mini-split ASHPs for various installation scenarios.

Users can complete the guide process using one or more of these components. Short descriptions of each are provided below.

ASHP Sizing and Selection Guide

This seven-step guide provides sizing and selection instructions, and information on various options for both centrally-ducted and mini-split ASHPs.

- Complete each step of the guide in the order shown to size and select an ASHP for a specific application.
    - Each STEP provides the user with 3 to 4 options.
    - Short descriptions of each option help users select which “best fits” specific application requirements.
    - Chosen options are recorded on the ASHP Key Specifications Summary Worksheet (see Figure 4.2.2-2).
- Use the information recorded in Steps 1 to 4 to identify a short list of commercially available ASHP models suitable for the specific application.
- Final ASHP selection can be based on such items as:
    - Staging or modulation capabilities,
    - Efficiency ratings,
    - Noise ratings, and
    - Equipment cost.
- In the final two steps, define:
    - The ASHP system control strategy, and
    - The backup heating requirements.

ASHP Key Specifications Summary Worksheet

The **ASHP Key Specifications Summary Worksheet** can be used in one of two ways:

- Together with the **ASHP Guide** as a summary sheet that records decisions made while working through the seven steps using the full Guide documentation; or,
- As a stand-alone worksheet, experienced users can complete sizing and select an ASHP, referring to the full guide documentation only when additional information is required.

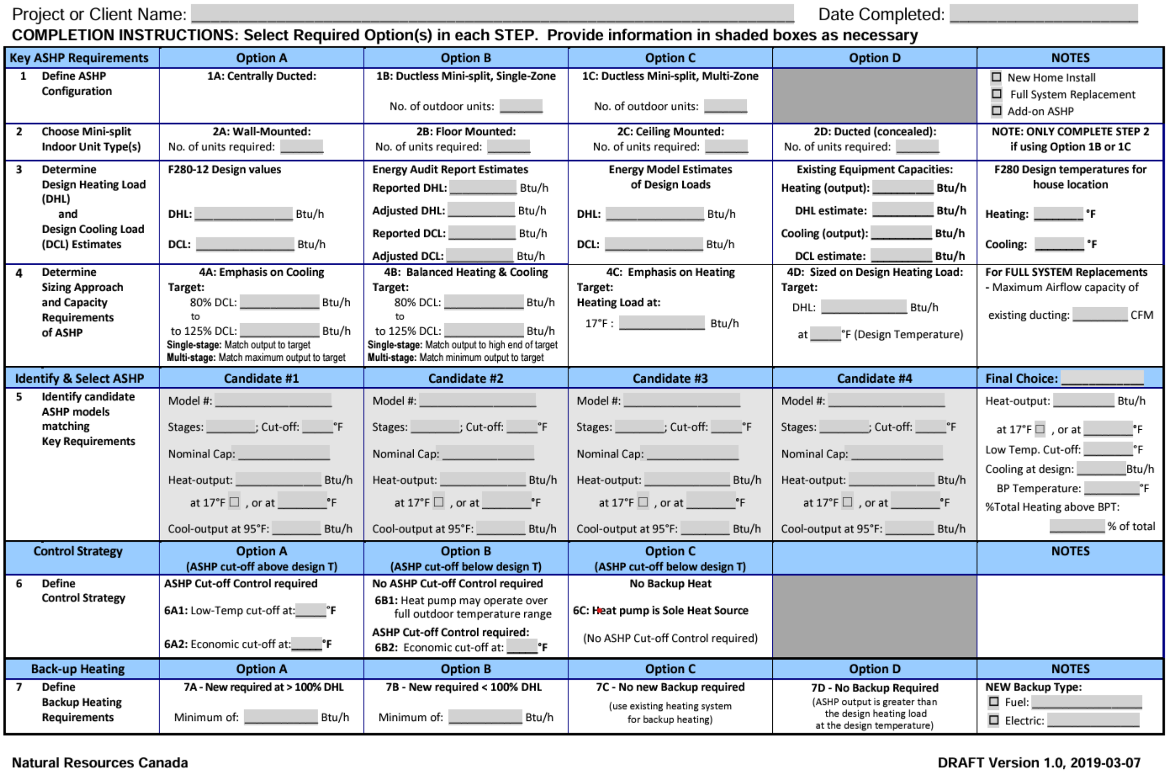
ASHP Sizing and Selection Tool

This Excel-based tool examines the Guide steps to assist designers or contractors in sizing and selecting air-source heat pumps (ASHP) in Canadian climates.

The ASHP sizing and selection tool will perform various calculations and charting functions that can help size and select ASHPs. These include, among others:

- Plotting of heating load lines and estimating the target output capacity of ASHP equipment needed for an application based on:
    - load values entered, and
    - sizing approach selected.
- Plotting of ASHP output characteristics versus outdoor temperature and estimating thermal balance point temperatures (t-BPTs) for up to four candidate ASHPs for an application.
- Estimating the annual fraction of total space heating load provided by the different candidate

ASHPs above their t-BPTs to help with the final selection.
- Calculating the minimum backup heating requirement for the application.
- For dual-fuel ("hybrid") applications, calculating the "economic cut-off temperature" for the ASHP based on:
    - local cost of electricity and fuel, and
    - the efficiency characteristics of the ASHP and the backup heating system.



Project or Client Name: ____ Date Completed: ____

COMPLETION INSTRUCTIONS: Select Required Option(s) in each STEP. Provide information in shaded boxes as necessary

Key ASHP Requirements	Option A	Option B	Option C	Option D	NOTES
1 Define ASHP Configuration	**1A: Centrally Ducted:**	**1B: Ductless Mini-split, Single-Zone** No. of outdoor units: ____	**1C: Ductless Mini-split, Multi-Zone** No. of outdoor units: ____		☐ New Home Install ☐ Full System Replacement ☐ Add-on ASHP
2 Choose Mini-split Indoor Unit Type(s)	**2A: Wall-Mounted:** No. of units required: ____	**2B: Floor Mounted:** No. of units required: ____	**2C: Ceiling Mounted:** No. of units required: ____	**2D: Ducted (concealed):** No. of units required: ____	**NOTE: ONLY COMPLETE STEP 2 if using Option 1B or 1C**
3 Determine Design Heating Load (DHL) and Design Cooling Load (DCL) Estimates	**F280-12 Design values** **DHL:** ____ Btu/h **DCL:** ____ Btu/h	**Energy Audit Report Estimates** **Reported DHL:** ____ Btu/h **Adjusted DHL:** ____ Btu/h **Reported DCL:** ____ Btu/h **Adjusted DCL:** ____ Btu/h	**Energy Model Estimates of Design Loads** **DHL:** ____ Btu/h **DCL:** ____ Btu/h	**Existing Equipment Capacities:** **Heating (output):** ____ Btu/h **DHL estimate:** ____ Btu/h **Cooling (output):** ____ Btu/h **DCL estimate:** ____ Btu/h	**F280 Design temperatures for house location** **Heating:** ____ °F **Cooling:** ____ °F
4 Determine Sizing Approach and Capacity Requirements of ASHP	**4A: Emphasis on Cooling** **Target:** 80% DCL: ____ Btu/h to to 125% DCL: ____ Btu/h **Single-stage:** Match output to target **Multi-stage:** Match maximum output to target	**4B: Balanced Heating & Cooling** **Target:** 80% DCL: ____ Btu/h to to 125% DCL: ____ Btu/h **Single-stage:** Match output to high end of target **Multi-stage:** Match minimum output to target	**4C: Emphasis on Heating** **Target:** **Heating Load at:** 17°F : ____ Btu/h	**4D: Sized on Design Heating Load:** **Target:** DHL: ____ Btu/h at ____°F (Design Temperature)	**For FULL SYSTEM Replacements** - Maximum Airflow capacity of existing ducting: ____ CFM
Identify & Select ASHP	**Candidate #1**	**Candidate #2**	**Candidate #3**	**Candidate #4**	**Final Choice:** ____
5 Identify candidate ASHP models matching Key Requirements	Model #: ____ Stages: ____; Cut-off: ____°F Nominal Cap: ____ Heat-output: ____ Btu/h at 17°F ☐ , or at ____°F Cool-output at 95°F: ____ Btu/h	Model #: ____ Stages: ____; Cut-off: ____°F Nominal Cap: ____ Heat-output: ____ Btu/h at 17°F ☐ , or at ____°F Cool-output at 95°F: ____ Btu/h	Model #: ____ Stages: ____; Cut-off: ____°F Nominal Cap: ____ Heat-output: ____ Btu/h at 17°F ☐ , or at ____°F Cool-output at 95°F: ____ Btu/h	Model #: ____ Stages: ____; Cut-off: ____°F Nominal Cap: ____ Heat-output: ____ Btu/h at 17°F ☐ , or at ____°F Cool-output at 95°F: ____ Btu/h	Heat-output: ____ Btu/h at 17°F ☐ , or at ____°F Low Temp. Cut-off: ____°F Cooling at design: ____Btu/h BP Temperature: ____°F %Total Heating above BPT: ____ % of total
Control Strategy	**Option A (ASHP cut-off above design T)**	**Option B (ASHP cut-off below design T)**	**Option C (ASHP cut-off below design T)**		**NOTES**
6 Define Control Strategy	**ASHP Cut-off Control required** **6A1:** Low-Temp cut-off at: ____°F **6A2:** Economic cut-off at: ____°F	**No ASHP Cut-off Control required** **6B1:** Heat pump may operate over full outdoor temperature range **ASHP Cut-off Control required:** **6B2:** Economic cut-off at: ____°F	**No Backup Heat** **6C: Heat pump is Sole Heat Source** (No ASHP Cut-off Control required)		
Back-up Heating	**Option A**	**Option B**	**Option C**	**Option D**	**NOTES**
7 Define Backup Heating Requirements	**7A - New required at > 100% DHL** Minimum of: ____ Btu/h	**7B - New required < 100% DHL** Minimum of: ____ Btu/h	**7C - No new Backup required** (use existing heating system for backup heating)	**7D - No Backup Required** (ASHP output is greater than the design heating load at the design temperature)	**NEW Backup Type:** ☐ Fuel: ____ ☐ Electric: ____

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Figure 4.2.2-2. ASHP key specification summary worksheet

Addendum to the ASHP Guide of Worked Examples

Worked examples have been completed for both centrally-ducted and ductless mini-split ASHPs using various sizing and selection scenarios. These example cases illustrate how the guide process works and have been prepared to help users better understand the various decision steps when selecting ASHPs for different applications.

4.2.2.2 CSA SPE-17:23 HVAC guide for Part 9 homes

With the permission of Canadian Standards Association, (operating as "CSA Group"), the material described below is reproduced from CSA Group standard CSA SPE-17:23, HVAC guide for Part 9 homes (CSA, 2023). This material is not the complete and official position of CSA Group on the referenced subject, which is represented solely by the Standard in its entirety. While use of the material has been authorised, CSA Group is not responsible for the way the data is presented, nor for any representations and interpretations. No further reproduction is permitted. For more information or to purchase standard(s) from CSA Group see (CSA, 2024b).

Background

The ultimate performance of the heating, ventilation, and air conditioning (HVAC) system in a residential Part 9 home depends upon proper design, installation, and commissioning, with each of these components being equally critical to delivering the designed efficiency of the equipment itself.

In new construction, adequate planning and upfront integrated design of HVAC systems in new, low-rise residential buildings is not common practice, resulting in systems not being fully optimised for performance.

Research published by the American Council for an Energy-Efficient Economy (ACEEE) shows that 50 to 70% of HVAC systems are improperly installed, causing them to be 10 to 50% less efficient than if they received quality design, specification, and installation (Mowris and Jones, 2008).

HVAC has been the single largest source of new home complaints by their owners. Design, poor quality systems, and inadequate installations have all been found to be the problem in different parts of Canada (see (Canadians for Properly Built Homes, 2024) for further information).

Expanding on this, Canada's Part 9 residential building industry is going through a significant period of change where builders, architects/designers, engineers, trades, manufacturers, authority having jurisdictions (AHJ), and other industry stakeholders are adapting to increasing market demand for enhanced performance in homes. This is characterised by a transition to performance-based energy codes or standards like the BC Energy Step Code (Energy StepCode, 2018), Zero Carbon Step Code (Energy StepCode, 2020), or the Passive House standard, as well as a growing regulatory focus on decarbonisation.

The combination of market and regulatory conditions and rapidly evolving technologies creates an opportunity for the residential design and construction community to improve significantly overall indoor comfort, improve home performance, and enhanced resiliency and health outcomes at the same time. The risk is that an integrated sequence of HVAC design, sizing, installation, and commissioning could be overlooked, or not fully considered, as residential buildings seek to achieve low-energy/low-carbon performance targets, resulting in the following:

a) Increased costs — Improperly sized equipment costs more to install and operate. It increases maintenance and repairs and shortens the life cycle of equipment.

b) Poor comfort — Inadequate approaches to equipment selection, HVAC design, and installation results in HVAC "short-cycling" and poor performance (e.g., uneven temperatures, equipment noise).

c) Performance liabilities — Incorrectly designed HVAC systems are more likely to undermine a homeowners' sense of satisfaction and tarnish builder reputations while also creating potential liabilities and warranty claims.

d) Home aesthetics — Larger or poorly designed HVAC systems can incorporate equipment and duct requirements that compromise living spaces with larger than needed bulkheads and chases.

To address these issues, a more sophisticated approach is needed to deal with the knowledge gap in mechanical HVAC systems for new Part 9 buildings, helping to ensure that both functional and performance-based objectives and targets are met.

Current practices

Within current building industry practices, there is a lack of design stage planning for the HVAC systems, which limits design strategies and equipment choices, creating increased costs and poor operational performance. Inadequate consideration of proper design and installation of mechanical systems is characterised by:

a) "rule of thumb" approach to heat loss and heat gain calculations;

b) lack of upfront coordination with builder and architect in the design phase of the building design process.

c) absence of HVAC designs to guide installations or numerous opinions that vary on the HVAC design, none of which are supported by calculations and technical engineering;

d) lack of consistent and verifiable standards of practice within the HVAC industry; and

e) incomplete performance verification through commissioning to test the installed systems and document that HVAC equipment is operating to the design intent and meeting performance targets.

Enhanced practices

A better approach starts with integrated and coordinated design between builders, architects, building designers, HVAC designers, and contractors, focusing specifically on optimising overall HVAC system performance. Collaboration between designers, builders, and trades, as well as use of CSA F280 load calculations, are foundational elements of this approach. These practices help builders respond to increased energy and greenhouse gas (GHG) emission performance objectives, integrated with housing form, style, and construction methods. Enhanced practices include these essential elements:

a) CSA F280 compliant load calculations to inform equipment sizing and selection;

b) pre-construction integrated Design Process, coordinating with builders, architects, and clients to establish an HVAC strategy and design;

c) a clearly articulated expectation of installation standards of practice; and

d) performance verification, including on-site review, once the equipment is installed with commissioning results documented and verified to demonstrate optimised performance.

Evolving practices

Going forward, adaptation and change will be a constant for the construction industry, particularly with energy performance requirements in national and provincial building codes, eventually moving toward a net zero-ready standard. To meet these requirements, evolving HVAC industry practices may include:

a) improved compliance and verification through more standardised permitting requirements by the AHJ (Authority Having Jurisdiction);

b) additional inspection processes for consumer protection that verify HVAC system performance intentions are being met; and

c) increased trade coordination and wider adoption of performance testing methodologies to confirm design/construction objectives are achieved (e.g., mid-stage blower door testing to confirm air tightness metrics).

Objectives

CSA SPE-17:23 (CSA, 2023) assists the building industry with identification of standards of practice that are designed to deliver HVAC systems that provide enhanced comfort, improved energy-efficiency, and ultimately achieve the performance expectations of builders, architect/designers, and homeowners alike. Overall objectives for CSA SPE-17:23 are:

a) increasing building industry awareness on how an integrated/coordinated design process can help deliver efficient HVAC systems and better home performance;

b) presenting best practices for HVAC design, equipment sizing, selection, installation, and performance verification of HVAC systems that can be readily applied by builders.

c) communicating the options, opportunities, and limitations of various HVAC equipment in a fuel-neutral manner, to meet performance-based code requirements and support decarbonisation objectives; and

d) building familiarity and confidence in more sophisticated building practices and HVAC technologies.

Audience

Audiences for CSA SPE-17:23 include:

a) builders and developers;

b) architect/designers;

c) building officials;

d) HVAC designers and HVAC contractors;

e) energy advisors;

f) utilities; and

g) homeowners.

Scope

CSA SPE-17:23 highlights the benefits of best practices in proper design, sizing, installation, and commissioning for HVAC systems with a focus on practical information for building industry practitioners to apply knowledge from the Guide to support new construction and major renovation projects. CSA SPE-17:23 also provides useful industry resources, supporting tools, and technical information.

CSA SPE-17:23 may be used as a technical reference document for Part 9 new residential buildings, incorporating illustrations, resources, and tools to assist with knowledge transfer and application. It has also guided collaboration between the builders, designers, tradespersons, and suppliers with respect to integration of sizing, design, installation, and performance verification.

4.2.3 US

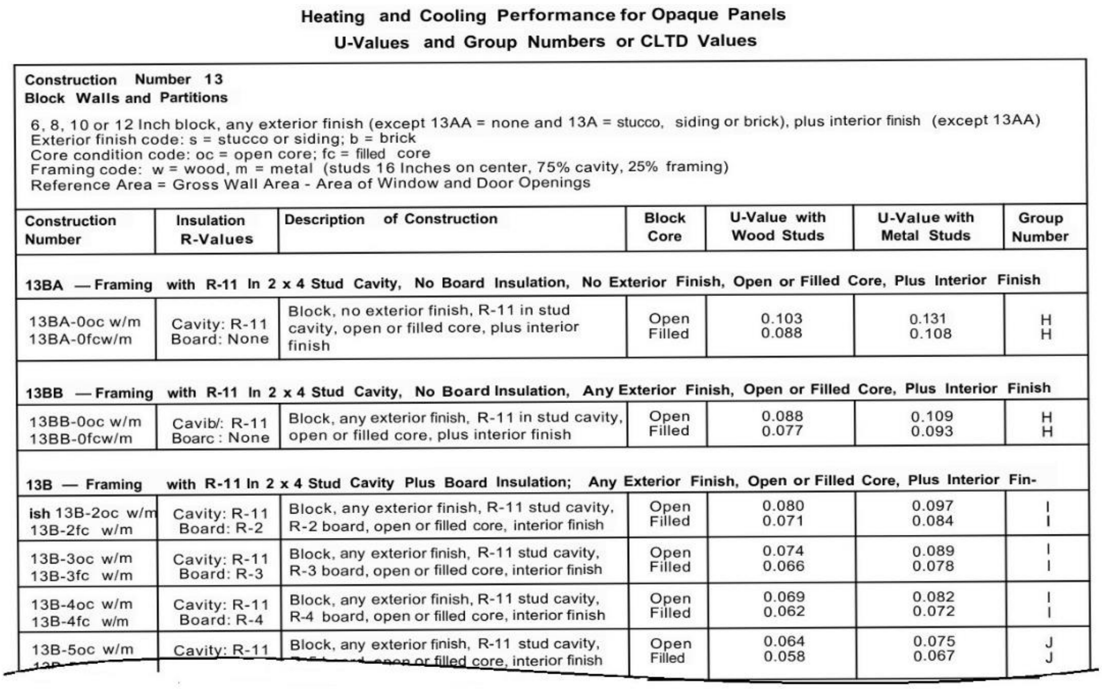
4.2.3.1 ACCA manuals

4.2.3.1.1 Background

The Air Conditioning Contractors of America (ACCA) is an HVAC industry association that has published accredited and non-accredited procedures for residential and commercial HVAC equipment design and installation, and related services, since the 1970s. The design manuals for heat pumps include ANSI/ACCA 2 Manual J (2016) - Residential Load Calculation (8th Edition), ANSI/ACCA 3 Manual S (2014) - Residential Equipment Selection, and ANSI/ACCA 1 Manual D (2016) - Residential Duct Systems (where applicable, when ducted air distribution systems are used). Several other guides focus on specific skills and services related to residential HVAC).

4.2.3.1.2 Manual J – load calculations

Manual J is a procedure for calculating heating and cooling building and room loads under outdoor design conditions, and Manual S is a procedure for selecting appropriate heating and cooling equipment for a building, based on the results of Manual J calculations. Manual J and Manual S are the most frequently used and are both cited by reference in residential codes (model codes by the International Codes Council, which are adopted into regulation individually by most of US states and some cities or other jurisdictions) for many years as a code requirement for residential building construction. Neither Manual J, Manual S, nor Manual D is specific to heat pumps, but each includes general requirements for the most common types of residential cooling and heating systems.



Heating and Cooling Performance for Opaque Panels
U-Values and Group Numbers or CLTD Values

Construction Number 13
Block Walls and Partitions

6, 8, 10 or 12 Inch block, any exterior finish (except 13AA = none and 13A = stucco, siding or brick), plus interior finish (except 13AA)
Exterior finish code: s = stucco or siding; b = brick
Core condition code: oc = open core; fc = filled core
Framing code: w = wood, m = metal (studs 16 Inches on center, 75% cavity, 25% framing)
Reference Area = Gross Wall Area - Area of Window and Door Openings

Construction Number	Insulation R-Values	Description of Construction	Block Core	U-Value with Wood Studs	U-Value with Metal Studs	Group Number
13BA — Framing with R-11 In 2 x 4 Stud Cavity, No Board Insulation, No Exterior Finish, Open or Filled Core, Plus Interior Finish						
13BA-0oc w/m 13BA-0fcw/m	Cavity: R-11 Board: None	Block, no exterior finish, R-11 in stud cavity, open or filled core, plus interior finish	Open Filled	0.103 0.088	0.131 0.108	H H
13BB — Framing with R-11 In 2 x 4 Stud Cavity, No Board Insulation, Any Exterior Finish, Open or Filled Core, Plus Interior Finish						
13BB-0oc w/m 13BB-0fcw/m	Cavib/: R-11 Boarc : None	Block, any exterior finish, R-11 in stud cavity, open or filled core, plus interior finish	Open Filled	0.088 0.077	0.109 0.093	H H
13B — Framing with R-11 In 2 x 4 Stud Cavity Plus Board Insulation; Any Exterior Finish, Open or Filled Core, Plus Interior Fin-						
ish 13B-2oc w/m 13B-2fc w/m	Cavity: R-11 Board: R-2	Block, any exterior finish, R-11 stud cavity, R-2 board, open or filled core, interior finish	Open Filled	0.080 0.071	0.097 0.084	I I
13B-3oc w/m 13B-3fc w/m	Cavity: R-11 Board: R-3	Block, any exterior finish, R-11 stud cavity, R-3 board, open or filled core, interior finish	Open Filled	0.074 0.066	0.089 0.078	I I
13B-4oc w/m 13B-4fc w/m	Cavity: R-11 Board: R-4	Block, any exterior finish, R-11 stud cavity, R-4 board, open or filled core, interior finish	Open Filled	0.069 0.062	0.082 0.072	I I
13B-5oc w/m	Cavity: R-11	Block, any exterior finish, R-11 stud cavity, or filled core, interior finish	Open Filled	0.064 0.058	0.075 0.067	J J

Figure 4.2.3-1. Example of construction type and thermal properties table from Manual J

Manual J provides detailed instructions on collecting thermal performance data and building dimensions, selecting appropriate indoor and outdoor design conditions, addressing air infiltration and solar gains, and includes extensive tables showing thermal performance values to use for building surfaces such as walls, windows, roofs, floors, etc. that use a wide range of construction and insulation approaches. An example is shown in Figure 4.2.3-1 (the standard includes nearly 200 pages of such tables). It also includes procedures to calculate the impacts of ventilation systems and duct losses and gains that may apply to existing or new buildings. Most users of Manual J use software, rather than manual calculations, to conduct the procedure, and ACCA has a process for approving software as being 'compliant' with the standard. The result is a report by room, by zone(s) if used, and for a whole building or dwelling, that states the heating, sensible cooling, and latent cooling loads at design conditions, that may be used for sizing and selecting equipment. The full edition of Manual J also includes large informative sections with examples, clarifying illustrations and commentary.

4.2.3.1.3 Manual S – Equipment selection

Manual S has detailed procedures for choosing based on capacity and other factors. The scope encompasses almost all types of residential HVAC equipment, including air conditioners, furnaces, boilers, most of which are not of interest in this report. However, a new version of Manual S has been approved by ANSI and is about to be published (at the time of this writing, it has yet to be available); the most notable changes are in how the procedure handles heat pump design.

Previous editions of Manual S (including 2014 cited above) only provided pathways for heat pump selection based on cooling capacity – with the limits of 90-115% of design cooling load for single - speed units, while allowing slightly larger over-sizing for cooling (120% to 130%) for other types of equipment, such as 2-speed, variable-capacity, or ground-source units. The focus is on avoiding oversizing so that humidity control is not compromised (and in very dry summer climates, a different approach is allowed). In this case, if the heating capacity is not adequate to meet the heating load under design conditions, then auxiliary heat (typically electric resistance) is specified. Figure 4.2.3-2 shows an example of this; in this case, the heat pump would have inadequate capacity at outdoor temperatures below about -1 °C, and at the design condition of -10 °C a minimum of 4 kW of backup heat would be needed to meet the heating load.

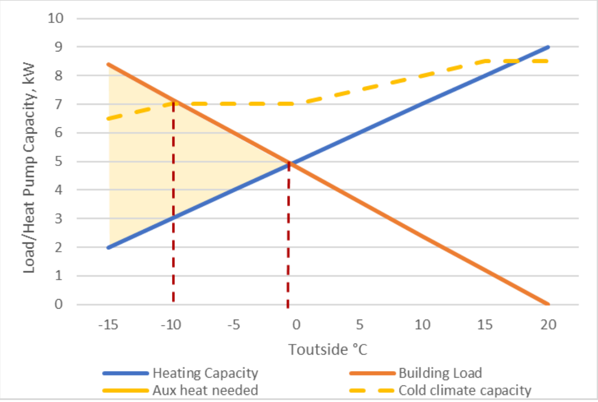


Figure 4.2.3-2. Traditional handling of low heating capacity using auxiliary heat, and cold-climate comparison

Many parts of the northern United States and most of Canada have heating design temperatures ranging from -15 °C to -25°C and, in some cases, even colder. The rapidly increasing interest in heat pumps for reducing carbon emissions, even in very cold climates, and the desire to reduce or eliminate the electric grid impact of resistance heating elements has led to a new alternative approach. There is now common availability of variable-speed systems with high heating capacities at cold temperatures (for example, the yellow dotted line in Figure 4.2.3-2), that may not require auxiliary heating at all. However, in cold and very cold climates, it is still quite common for cooling design loads to be significantly smaller than heating design loads, resulting in a conflict for designers who want to size heat pumps for full-load heating without violating the sizing requirements of Manual S and the building code.

The new edition of Manual S, *Residential Equipment Selection (3rd Edition, Version 1.01) (ACCA - Air Conditioning Contractors of America, 2023),* addresses these concerns by offering several explicit pathways to size heat pumps to meet 100% of the heating design load, while still maintaining control of summer humidity in climates where that is relevant. Table 4.2.3-1 summarises the most important requirements for two-speed and variable-speed units. Two-speed heat pumps allow more flexibility for sizing to heating loads, but still focus on maximum total cooling capacity with the expectation that supplemental heat will often be needed. All three variable-speed options specify explicitly that the unit meets 100% of the heating load, while addressing cooling and humidity control in various ways that can include dedicated dehumidification equipment or active dehumidification function built into the heat pump. Both two-speed and variable have limits to avoid unneeded oversizing, and all the variable-speed options explicitly negate the need for supplemental heat. Though supplemental heat is still allowed (for example, in a case where it may be needed for defrost operation), it is limited to a maximum of 5 kW.

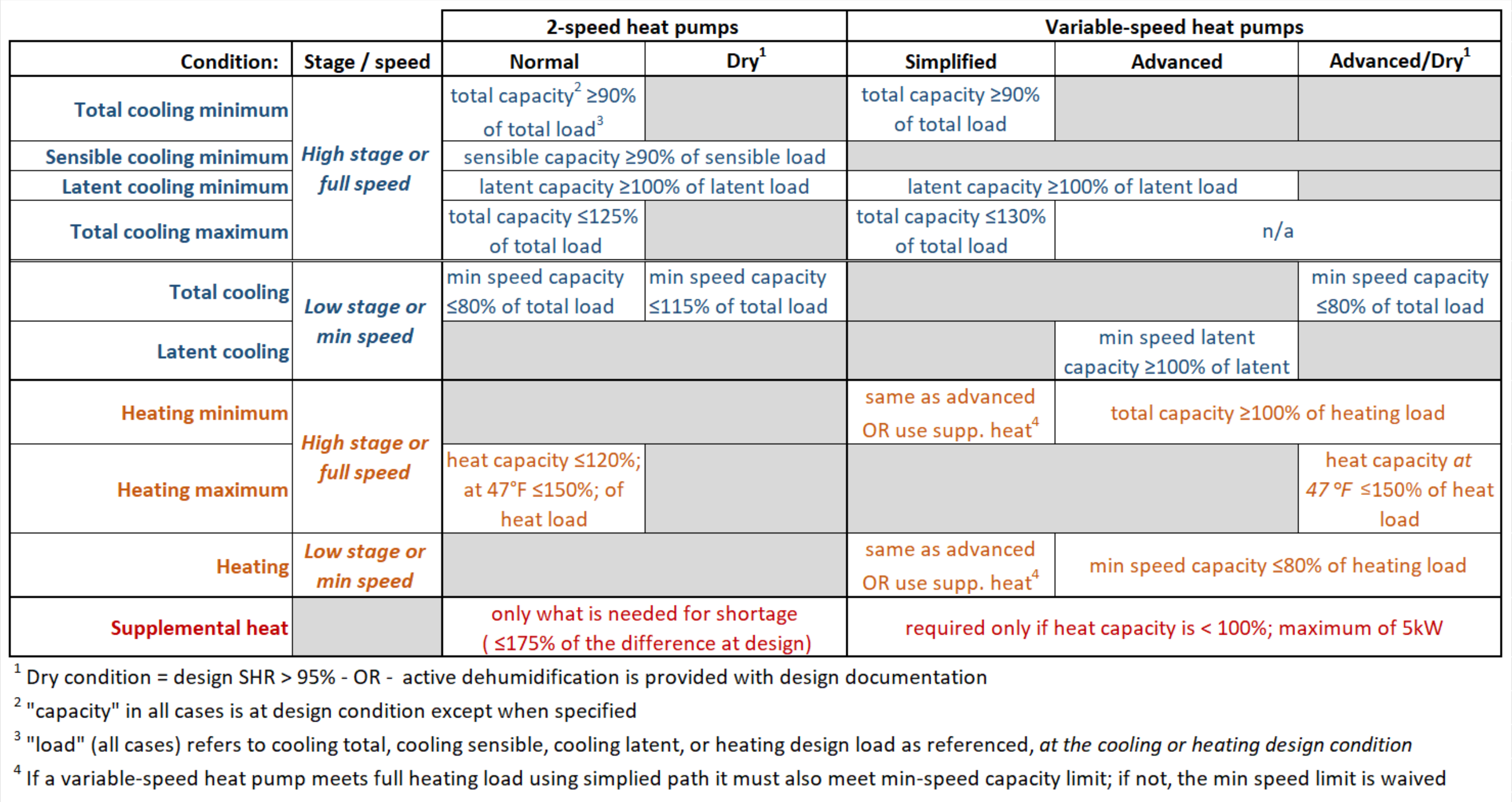
Pros and cons

It is useful to have a consistent industry standard for load calculations to ensure accurate results and help promote and support proper equipment selection. And for sizing, it is a dramatic improvement to have a mechanism to allow for full heating load sizing in cold climates, which has been done in thousands if not tens of thousands of homes, but technically did not comply with building codes.

The most significant drawback of the load calculation procedure, Manual J is that most residential proposals are made by salespeople, and most often they either do not bother with the calculations or do not trust the results. Despite the clear statements in Manual J to take credit aggressively for all energy efficiency features, there are strong tendencies for users to increase the calculated loads to represent what they expect in advance will be needed. Further, within any of the approved software packages, it is very easy to allow the use of defaults that are too conservative: generic windows, losses and gains attributed to ductwork, and similar features that increase the stated design loads. This is especially true for the most efficient houses, that often use building components and levels of insulation that are so efficient that they are not recognised by the Manual J tables. In many cases, to follow the procedure properly, users must understand these limitations and override the software’s default values, but there is little or no guidance to suggest that this is necessary. Even then, when the user has a result, they will still size the equipment even larger ‘just in case’. In the end, absent requirements by incentive programs that include a review of the design process (which is rare), many (or perhaps most) residential contractors do not bother with the calculations because they conclude it gives them the answer they expect. All this results in oversizing equipment, which is not bad if it is within the guidelines but can be so extreme as to impact the operating efficiency seriously. It also makes the sizing procedures somewhat irrelevant if they are based on faulty load calculations.

The updated/proposed edition of Manual S is a significant improvement, but it is rather complex to understand and put into practice, which may be a large challenge for users who already have trouble understanding the simpler existing procedures. The biggest limitation on its use in the near term is that the methods available for two-speed and variable-speed systems also require knowing the total and/or latent capacities of the equipment at the lowest operating speed. Engineering data on low-speed capacity is rarely available for variable speed systems, which would make those pathways impossible to use until such data is regularly available. Also, the simplified approach for variable-speed has a limitation of high-speed total cooling capacity at 130% of the design cooling load, so it cannot account for lower-speed cooling operation and will be impossible to use in cases where the design heating load is significantly larger than the design cooling load. The other options require information about low-speed capacity.

Table 4.2.3-1. New edition of Manual S (preliminary) sizing condition summary for 2-speed and variable heat pumps



		2-speed heat pumps		Variable-speed heat pumps		
Condition:	**Stage / speed**	**Normal**	**Dry[1]**	**Simplified**	**Advanced**	**Advanced/Dry[1]**
Total cooling minimum	***High stage or full speed***	total capacity[2] ≥90% of total load[3]		total capacity ≥90% of total load		
Sensible cooling minimum		sensible capacity ≥90% of sensible load				
Latent cooling minimum		latent capacity ≥100% of latent load		latent capacity ≥100% of latent load		
Total cooling maximum		total capacity ≤125% of total load		total capacity ≤130% of total load	n/a	
Total cooling	***Low stage or min speed***	min speed capacity ≤80% of total load	min speed capacity ≤115% of total load			min speed capacity ≤80% of total load
Latent cooling					min speed latent capacity ≥100% of latent	
Heating minimum	***High stage or full speed***			same as advanced OR use supp. heat[4]	total capacity ≥100% of heating load	
Heating maximum		heat capacity ≤120%; at 47°F ≤150%; of heat load				heat capacity *at 47 °F* ≤150% of heat load
Heating	***Low stage or min speed***			same as advanced OR use supp. heat[4]	min speed capacity ≤80% of heating load	
Supplemental heat		only what is needed for shortage (≤175% of the difference at design)		required only if heat capacity is < 100%; maximum of 5kW		

[1] Dry condition = design SHR > 95% - OR - active dehumidification is provided with design documentation

[2] "capacity" in all cases is at design condition except when specified

[3] "load" (all cases) refers to cooling total, cooling sensible, cooling latent, or heating design load as referenced, *at the cooling or heating design condition*

[4] If a variable-speed heat pump meets full heating load using simplied path it must also meet min-speed capacity limit; if not, the min speed limit is waived

The updated/proposed edition of Manual S is a significant improvement, but it is rather complex to understand and put into practice, which may be a large challenge for users who already have trouble understanding the simpler existing procedures. The biggest limitation on its use in the near term is that the methods available for two-speed and variable-speed systems also require knowing the total and/or latent capacities of the equipment at the lowest operating speed. Engineering data on low-speed capacity is rarely available for variable speed systems, which would make those pathways impossible to use until such data is regularly available. Also, the simplified approach for variable-speed has a limitation of high-speed total cooling capacity at 130% of the design cooling load, so it cannot account for lower-speed cooling operation and will be impossible to use in cases where the design heating load is significantly larger than the design cooling load. The other options require information about low-speed capacity.

4.2.3.2 The Northeast Energy Efficiency Partnership (NEEP) sizing and installation guidance

NEEP is a non-profit regional organisation in the U.S. that promotes energy efficiency and decarbonisation/electrification. In 2017 and 2018, with support from the US Department of Energy they developed two downloadable guides to assist designers and contractors in sizing, selecting, and installing air-source heat pumps for residential homes in cold climates. They can be downloaded here neep.org/ashpinstallerresources, and there are companion videos on the same web page.

The guides are not detailed design procedures, but each is more of an overview that covers at a fairly high level the things that residential HVAC professionals should pay attention to what to look out for along the way. It points them to the full design procedures (Manual J and S) for details but focuses on how to choose appropriate applications based on the house characteristics and client needs: designing a smaller system to strategically displace as much existing heat as possible; full heating replacement for a house; individual zone; and new construction or gut renovation. Once an approach is chosen, there is a page to guide users on the steps appropriate to further refine that application and explain possible risks to watch out for.

There are numerous other regional and local guides that are published and promoted by utility companies, state (provincial) agencies, or regional groups, but not sanctioned by government or required by regulation. The NEEP guides are one example of this type of resource that is well known and used widely.

4.2.4 ISO 13153:2012 and Japanese design guidelines for low energy housing with validated effectiveness

4.2.4.1 Short history of LEHVE and ISO 13153

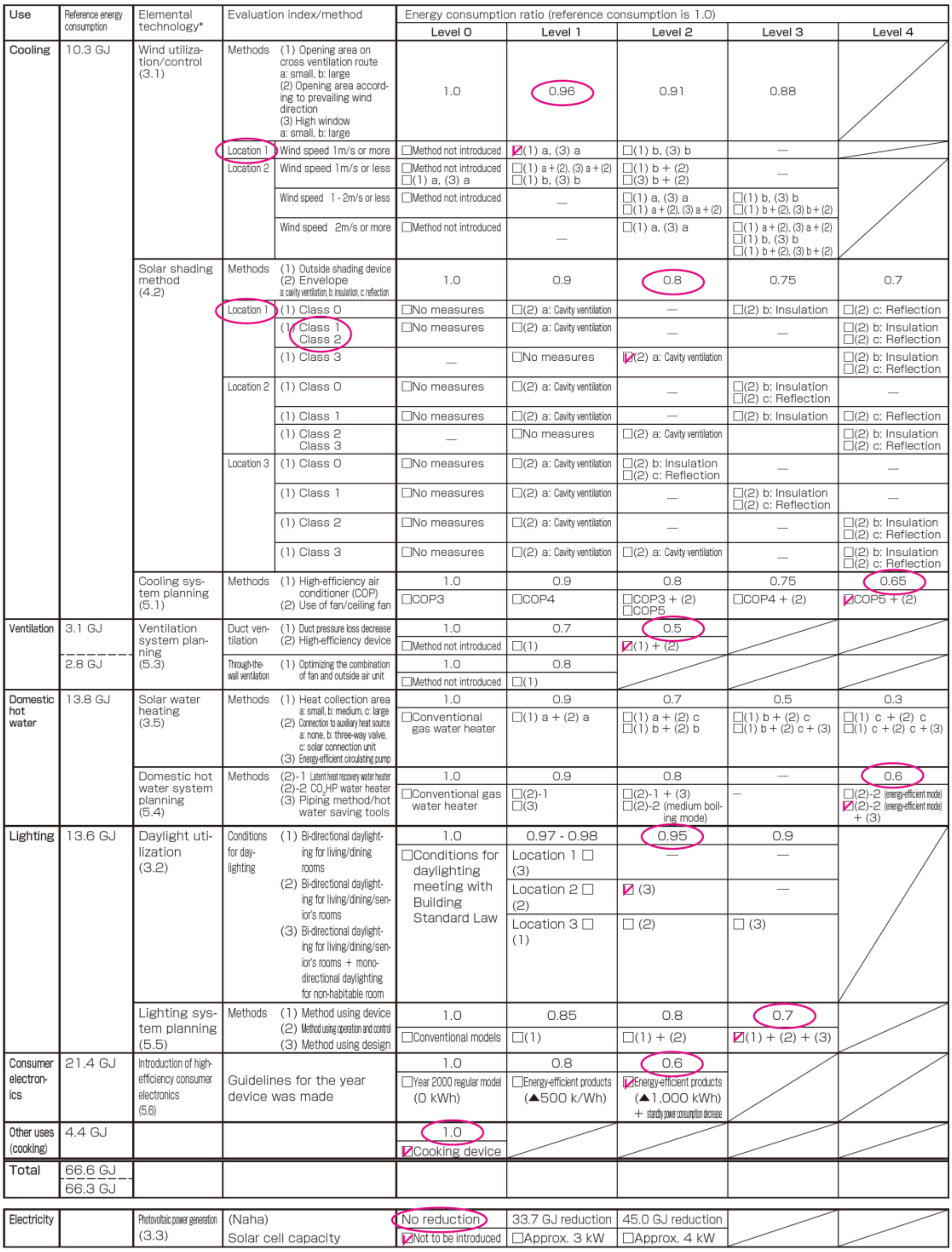
In 2005, ‘Design Guidelines for Low Energy Housing with Validated Effectiveness’ (LEHVE) was developed based on the outputs from 4-year (2001-2004) national R&D project by national research institutes including Building Research Institute (BRI, 2013). The R&D project was funded by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) (IBECs, 2024).

Before the project, the effectiveness of a building enclosure on energy-saving was mainly focused on practice and in the national building energy standard, which was not mandatory. It was partly because there was a lack of quantitative technical information on how much energy can be saved by choosing energy-efficient equipment for space heating, and the gain of such kind of knowledge was the main objective of the project. To tackle this issue, various experiments and monitorings were conducted to validate the effectiveness of major kinds of promising technology and equipment for residential buildings. Heat pump system had been one of the promising technologies dealt with in the project. Some experiments and monitorings are reviewed in Chapter 2 of this report (Section 2.4.3). There are three LEHVEs for three different climatic conditions, namely mild climate, cold climate, and hot humid climate. Only the LEHVE for hot humid climate was translated into English and is publicly available (Building Research Institute, 2010). The theories and experimental methods used for LEHVEs were further developed and finally have been utilised for web-based programs to calculate primary energy use for Japanese Building Energy Conservation Standard (BECS) (Building Research Institute/National Institute for Land and Infrastructure Management, 2013). The contents of the LEHVE and requirements for core quantitative information in the design guidelines for building design practitioners was standardised as ISO 13153:2013 ‘Framework of the design process for energy-saving single-family residential and small commercial buildings (ISO, 2012; Sawachi, 2013). LEHVE design guidelines have been presented at seminars. Over 24,000 practitioners have attended the seminars organised by an institute engaged in dissemination of energy saving technologies as of January 2024 (IBECs, 2024). More importantly, as mentioned before, technical knowledge for developing LEHVE has been utilised also for the BECS, in which not only documenting design but also online programs are provided for applicants, who are going to get certifications for various incentives and will try to get building permits after April 2025. The BECS will be mandatory after April 2025, even for detached houses newly built.

4.2.4.2 Core structure of information provided by LEHVE

Table 4.2.4-1 and Table 4.2.4-2 show the framework of design guidelines, by which LEHVEs are made and prescribed in ISO 13153 (ISO - International Organization for Standardization, 2012). Energy use comprises six uses for space cooling, ventilation (outdoor intake), domestic hot water, lighting, consumer electronics and other uses. There is no heating because this table is for houses in a hot humid climate, but there is, of course, space heating in cold and mild climate versions. Four-member family and a model building are assumed for energy calculation. The reference total annual primary energy use is 66.6 GJ/annum for houses with a ducted ventilation system. It takes time to understand Table 4.2.4-1, but it covers all technologies recommended to be considered in the design process with quantitative information on how much energy can be saved by applying each technology and each specification. For reducing cooling energy, three elemental technologies, namely 1) wind utilisation to dissipate internal heat (natural ventilation), 2) solar shading for roof and openings, and 3) cooling system (room air conditioners/fans), are highlighted, because it was the conclusion that influences of other elemental technologies were not clear when the guidelines were developed. An energy efficient cooling system can be designed not only for energy efficient air conditioners but also for ceiling fans. However, only information dealt with in the guidelines for air conditioners and heat pump water heaters shall be reviewed.

Table 4.2.4-1. Table of energy consumption ratios for different levels of each elemental technology for energy-saving (detached house in hot humid climate) with red ellipses showing selections of levels.



Use	Reference energy consumption	Elemental technology*	Evaluation index/method		Energy consumption ratio (reference consumption is 1.0)				
					Level 0	Level 1	Level 2	Level 3	Level 4
Cooling	10.3 GJ	Wind utilization/control (3.1)	Methods	(1) Opening area on cross ventilation route a: small, b: large (2) Opening area according to prevailing wind direction (3) High window a: small, b: large	1.0	[✓ 0.96]	0.91	0.88	
			[✓ Location 1]	Wind speed 1m/s or more	☐Method not introduced	☑(1) a, (3) a	☐(1) b, (3) b	—	
			Location 2	Wind speed 1m/s or less	☐Method not introduced ☐(1) a, (3) a	☐(1) a + (2), (3) a + (2) ☐(1) b, (3) b	☐(1) b + (2) ☐(3) b + (2)	—	
				Wind speed 1 - 2m/s or less	☐Method not introduced	—	☐(1) a, (3) a ☐(1) a + (2), (3) a + (2)	☐(1) b, (3) b ☐(1) b + (2), (3) b + (2)	
				Wind speed 2m/s or more	☐Method not introduced	—	☐(1) a, (3) a	☐(1) a + (2), (3) a + (2) ☐(1) b, (3) b ☐(1) b + (2), (3) b + (2)	
		Solar shading method (4.2)	Methods	(1) Outside shading device (2) Envelope a: cavity ventilation, b: insulation, c: reflection	1.0	0.9	[✓ 0.8]	0.75	0.7
			[✓ Location 1]	(1) Class 0	☐No measures	☐(2) a: Cavity ventilation	—	☐(2) b: Insulation	☐(2) c: Reflection
				(1) [✓ Class 1 Class 2]	☐No measures	☐(2) a: Cavity ventilation	—	—	☐(2) b: Insulation ☐(2) c: Reflection
				(1) Class 3	—	☐No measures	☑(2) a: Cavity ventilation		☐(2) b: Insulation ☐(2) c: Reflection
			Location 2	(1) Class 0	☐No measures	☐(2) a: Cavity ventilation	—	☐(2) b: Insulation ☐(2) c: Reflection	—
				(1) Class 1	☐No measures	☐(2) a: Cavity ventilation	—	☐(2) b: Insulation	☐(2) c: Reflection
				(1) Class 2 Class 3	—	☐No measures	☐(2) a: Cavity ventilation		☐(2) b: Insulation ☐(2) c: Reflection
			Location 3	(1) Class 0	☐No measures	☐(2) a: Cavity ventilation	☐(2) b: Insulation ☐(2) c: Reflection	—	—
				(1) Class 1	☐No measures	☐(2) a: Cavity ventilation	—	☐(2) b: Insulation ☐(2) c: Reflection	—
				(1) Class 2	☐No measures	☐(2) a: Cavity ventilation	—	—	☐(2) b: Insulation ☐(2) c: Reflection
				(1) Class 3	☐No measures	☐(2) a: Cavity ventilation	☐(2) a: Cavity ventilation	—	☐(2) b: Insulation ☐(2) c: Reflection
		Cooling system planning (5.1)	Methods	(1) High-efficiency air conditioner (COP) (2) Use of fan/ceiling fan	1.0	0.9	0.8	0.75	[✓ 0.65]
					☐COP3	☐COP4	☐COP3 + (2) ☐COP5	☐COP4 + (2)	☑COP5 + (2)
Ventilation	3.1 GJ	Ventilation system planning (5.3)	Duct ventilation	(1) Duct pressure loss decrease (2) High-efficiency device	1.0	0.7	[✓ 0.5]		
					☐Method not introduced	☐(1)	☑(1) + (2)		
	2.8 GJ		Through-the-wall ventilation	(1) Optimizing the combination of fan and outside air unit	1.0	0.8			
					☐Method not introduced	☐(1)			
Domestic hot water	13.8 GJ	Solar water heating (3.5)	Methods	(1) Heat collection area a: small, b: medium, c: large (2) Connection to auxiliary heat source a: none, b: three-way valve, c: solar connection unit (3) Energy-efficient circulating pump	1.0	0.9	0.7	0.5	0.3
					☐Conventional gas water heater	☐(1) a + (2) a	☐(1) a + (2) c ☐(1) b + (2) b	☐(1) b + (2) c ☐(1) b + (2) c + (3)	☐(1) c + (2) c ☐(1) c + (2) c + (3)
		Domestic hot water system planning (5.4)	Methods	(2)-1 Latent heat recovery water heater (2)-2 CO_2HP water heater (3) Piping method/hot water saving tools	1.0	0.9	0.8	—	[✓ 0.6]
					☐Conventional gas water heater	☐(2)-1 ☐(3)	☐(2)-1 + (3) ☐(2)-2 (medium boiling mode)	—	☐(2)-2 (energy-efficient mode) ☑(2)-2 (energy-efficient mode) + (3)
Lighting	13.6 GJ	Daylight utilization (3.2)	Conditions for daylighting	(1) Bi-directional daylighting for living/dining rooms (2) Bi-directional daylighting for living/dining/senior's rooms (3) Bi-directional daylighting for living/dining/senior's rooms + mono-directional daylighting for non-habitable room	1.0	0.97 - 0.98	[✓ 0.95]	0.9	
					☐Conditions for daylighting meeting with Building Standard Law	Location 1 ☐ (3)	—	—	
						Location 2 ☐ (2)	☑ (3)	—	
						Location 3 ☐ (1)	☐ (2)	☐ (3)	
		Lighting system planning (5.5)	Methods	(1) Method using device (2) Method using operation and control (3) Method using design	1.0	0.85	0.8	[✓ 0.7]	
					☐Conventional models	☐(1)	☐(1) + (2)	☑(1) + (2) + (3)	
Consumer electronics	21.4 GJ	Introduction of high-efficiency consumer electronics (5.6)	Guidelines for the year device was made		1.0	0.8	[✓ 0.6]		
					☐Year 2000 regular model (0 kWh)	☐Energy-efficient products (▲500 k/Wh)	☑Energy-efficient products (▲1,000 kWh) + standby power consumption decrease		
Other uses (cooking)	4.4 GJ				[✓ 1.0]				
					☑Cooking device				
Total	66.6 GJ 66.3 GJ								

Electricity		Photovoltaic power generation (3.3)	(Naha) Solar cell capacity	[✓ No reduction]	33.7 GJ reduction	45.0 GJ reduction		
				☑Not to be introduced	☐Approx. 3 kW	☐Approx. 4 kW		

* Numbers in parentheses under each elemental technology indicate which section of Chapter 3, 4 or 5 describes it.

Note: by numbers and symbols (e.g., (1)a, (2)) in the table, specification of each LEVEL of elemental technologies can be identified in the main body of the LEHVE (Building Research Institute, 2010).

Table 4.2.4-2 Energy consumption calculation table by using energy consumption ratios of chosen levels of elemental technologies (Building Research Institute, 2010)

Table 4.2.4-2. An example of energy consumption calculation, where elemental technologies and their levels are selected as shown by red ellipses in Table 4.2.4-1 (Building Research Institute, 2010)

Use	Calculation formulas	Design value	Reference value	Reduction rate
Cooling	10.3 × (☐×☐×☐)	GJ	10.3J	
Ventilation	3.1 × ☐ (2.8)	GJ	3.1GJ (2.8GJ)	
Domestic hot water	13.8 × ☐ (Solar water heating or Domestic hot water system planning)	GJ	13.8GJ	
Lighting	13.6 × (☐×☐)	GJ	13.6GJ	
Consumer electronics	21.4 × ☐	GJ	21.4GJ	
Other uses (cooking)	4.4 × ☐	GJ	4.4GJ	
Subtotal		GJ	66.6GJ (66.3GJ)	
Electricity (reduction amount)	Power generation with solar cell (☐ 0.0 GJ ☐ 33.7 GJ ☐ 45.0 GJ)	▲ GJ		
Total		GJ	66.6GJ (66.3GJ)	

Table 4.2.4-3. An example of energy consumption calculation, where elemental technologies and their levels are selected as shown by red ellipses in Table 4.2.4-1

Use	Calculation formulas	Design value	Reference value	Reduction rate
Cooling	10.3 × (0.96 × 0.8 × 0.65)	5.14GJ	10.3GJ	50.1%
Ventilation	3.1 × 0.5	1.55GJ	3.1GJ	50.0%
Domestic hot water	13.8 × 0.5 (Solar water heating or Domestic hot water system planning)	6.9GJ	13.8GJ	50.0%
Lighting	13.6 × (0.95 × 0.7)	9.04GJ	13.6GJ	33.5%
Consumer electronics	21.4 × 0.6	12.84GJ	21.4GJ	40.0%
Other uses (cooking)	4.4 × 1.0	4.4GJ	4.4GJ	0.0%
Subtotal		39.9GJ	66.6GJ	40.1%
Electricity (reduction amount)	Power generation with solar cell (☑ 0.0 GJ ☐ 33.7 GJ ☐ 45.0 GJ)	▲ 0.0GJ		
Total		39.9GJ	66.6GJ	40.1%

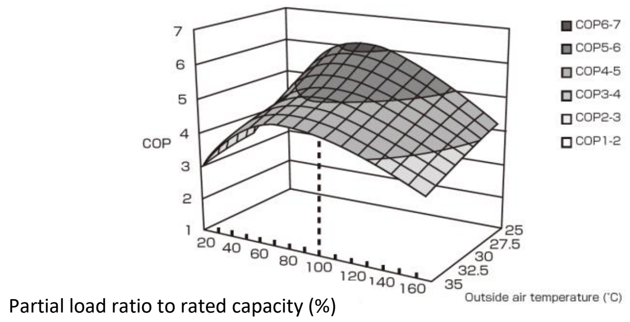


Figure 4.2.4-1. Relationship between outdoor temperature, partial load ratio and COP for cooling (Building Research Institute, 2010)

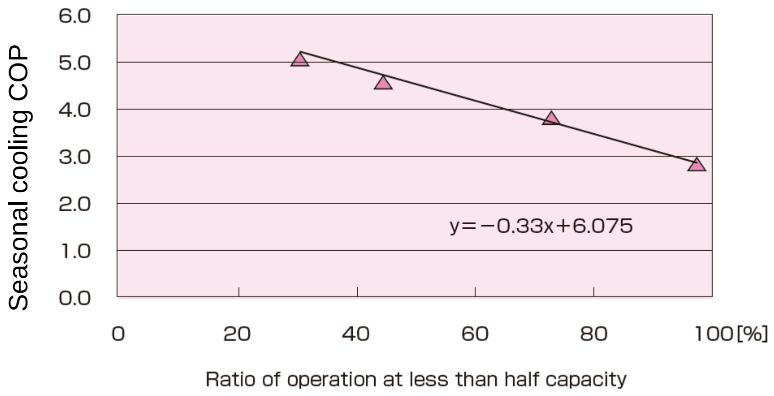


Figure 4.2.4-2. Effect of ratio of low partial load operation on seasonal average cooling COP (Building Research Institute, 2010)

Table 4.2.4-4. Recommended maximum cooling capacity (kW) as a guideline for selecting air conditioner for different levels of solar shading conditions represented by M value, which is defined in the guidelines (Building Research Institute, 2010)

Level of solar shading method	M value Summer solar gain coefficient that factors in the effect of adjacent buildings		6 *tatami* mats ($10\ m^2$)	8 *tatami* mats ($13\ m^2$)	10 *tatami* mats ($16\ m^2$)	14 *tatami* mats ($22\ m^2$)
	Insulation or vented cavity	Solar reflection				
Level 0	Exceeds 0.135	Exceeds 0.150	3.7	4.9	6.1	8.6
Level 1	0.135	0.150	3.1	4.1	5.1	7.1
Level 2	0.10	0.125	2.6	3.4	4.3	6.0
Level 3	0.08	0.115	2.1	2.8	3.5	5.3
Level 4	0.065~0.04	0.105~0.092	1.9~1.6	2.6~2.1	3.2~2.7	4.9~4.0

4.2.4.3 Contents for room air conditioners in LEHVE for hot humid climate

According to the guidelines, ‘Level 0’ for the cooling system is accomplished by using room air conditioners with the rated COP of 3.0, and ‘Level 2’ is accomplished by using those with the rated COP of 5.0. The latter condition (design) is evaluated to save cooling energy by approximately 20%, that is equal to 2 GJ/annum.

The influence of partial load ratio on the energy efficiency of room air conditioners is introduced by Figure 4.2.4-1 and Figure 4.2.4-2. Because appropriate capacity of room air conditioner for a room is important, Table 4.2.4-3 is provided to show appropriate maximum capacity of room air conditioners for different levels of solar shading (building enclosure and distance from adjacent buildings) and area of the room.

4.2.4.4 Contents for heat pump water heaters in LEHVE

Before introducing the contents for heat pump water heaters in LEHVE, an overall recommended strategy to save energy for domestic hot water (DHW) is introduced as follows. There are two elemental technologies to save energy for DHW, namely 1) solar water heating and 2)

DHW system planning (i.e., choosing energy efficient equipment for DHW and design), as shown in Table 4.2.4-4.
Energy saving for each specification (combination of methods in Table 4.2.4-4) is quantified, as shown in Table 4.2.4-5. In Table 4.2.4-6, ‘electric water heater with a natural refrigerant heat pump (CO_2 HP)’ is evaluated as a 40% reduction rate if it is used by ‘energy-efficient mode’. CO_2 HPs in the Japanese market are standardised by JIS C 9220 ‘Residential heat pump water heaters’ (JSA Group, 2018). Their common configuration and secondary energy flow can be represented by Figure 4.2.4-3.

Table 4.2.4-5. Method alternatives for energy saving DHW systems (BRI Japan, 2010)

Method	Description of method		Energy saving effect (Domestic hot water energy reduction rate)
Method 1	Using solar heat (adopting solar water heater or solar system)		
Method 2	Using high-efficiency water heater	Latent heat recovery gas/oil water heater	Approx. 15%
		Electric water heater with a natural refrigerant heat pump (CO_2 HP)* Only when boiling mode serves as “energy-efficient” mode	Approx. 35% (Zone V) Approx. 40% (Zone VI)
Method 3	Considering energy-efficient design/construction for each component of domestic hot water system (thermal insulation of piping/bathtub, hot water saving devices, etc.)		Approx. 10%

Note: Energy saving effect by using solar heat is between 10 to 70%, which is described in the chapter on solar water heating in LEHVE guidelines.

The most important message to practitioners for CO_2 HPs is that they have approximately 40% or more energy-saving potential as described in Table 4.2.4-5. But it is indispensable for users to use them with ‘energy-efficient mode’ by selecting appropriate modes at their controllers. If they selected ‘maximum heat storage only during night’, energy use would increase 10% or more compared with conventional instant gas boilers, as shown in Figure 4.2.4-4.

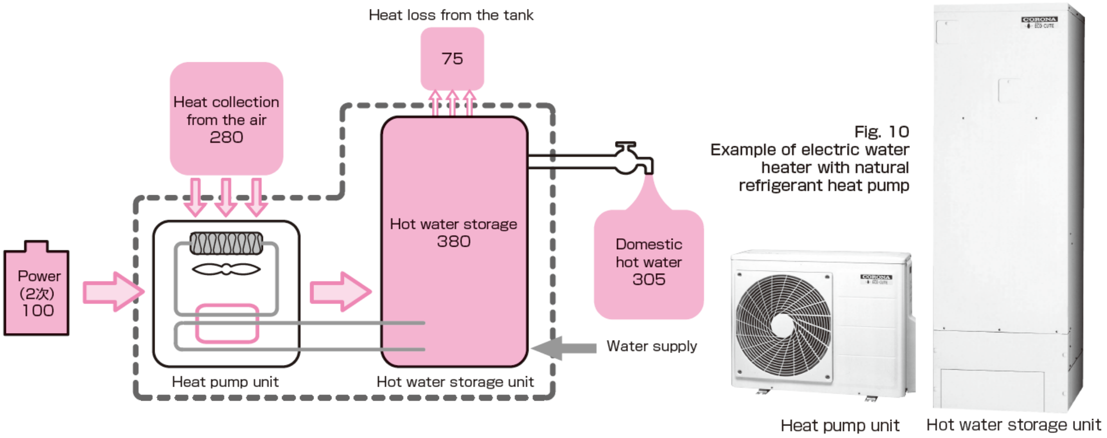


Figure 4.2.4-3. Secondary energy flow (numbers in normalised energy unit) of electric water heater with natural refrigerant heat pump (estimated annual average based on 2005 model of ‘Energy-efficient mode’ by manufacturer A) (BRI Japan, 2010)

Table 4.2.4-6. Target levels for DHW system planning and how to achieve them by combinations of method alternatives (Building Research Institute, 2010)

Target level	Energy saving effect (Domestic hot water energy reduction rate)	Application of method
Level −1	Increase of 10% or more	**Method 2** (CO_2 HP used for “Maximum boiling mode” and “Maximum late-night only mode”)
Level 0	0	Uses a conventional domestic hot water system device only and does not apply any energy saving methods.
		Method 2 (CO_2 HP used for “Medium late-night only mode”)
Level 1	10% or more	**Method 2** (latent heat recovery gas/oil water heater)
		Method 2 (CO_2 HP used for “Medium boiling mode (Zone V))
		Method 3
Level 2	20% or more	**Method 2** (latent heat recovery gas/oil water heater) + **Method 3**
		Method 2 (CO_2 HP used for “Medium boiling mode” (Zone VI))
Level 3	30% or more	**Method 2** (CO_2 HP used for “Energy efficient mode” (Zone V))
Level 4	40% or more	**Method 1**
		Method 2 (CO_2 HP used for “Energy-efficient mode” (Zone VI))
		Method 2 (CO_2 HP used for “energy-efficient mode”) + **Method 3**

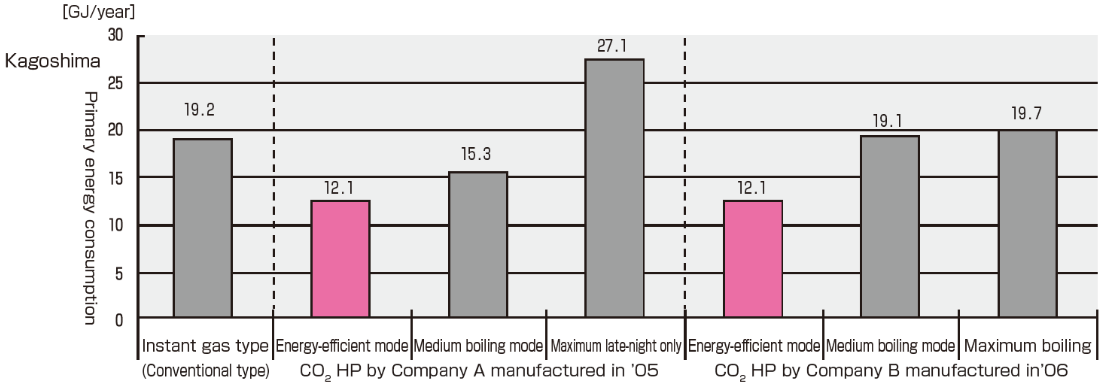


Figure 4.2.4-4. Changes in annual primary energy consumption using CO2 HPs at various modes

4.3 Perspectives of developing design guidelines for heat pump systems in Annex 88

The characteristics of existing guidelines presented in this chapter are summarised in Table 4.3.1-1. It reveals significant gaps in the ages of guidelines presented, highlighting a divergence of approximately 10 to 15 years between certain recommendations. 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. Such updates are crucial for ensuring that sizing practices remain effective in accurately determining the capacity of heat pump (HP) systems relative to actual maximum loads. This continuous evolution not only reflects industry progress but also reinforces the importance of adapting guidelines to optimise system efficiency and energy conservation efforts.

Efficient operation under varying load conditions is pivotal for HP systems in maintaining energy efficiency. To address low partial load conditions effectively, several countermeasures can be employed. These include adopting HP models designed for higher efficiency under partial loads, integrating multiple staged HP systems for larger total loads, and utilising heat/cold thermal storage solutions. By implementing these strategies, energy wastage during periods of reduced demand can be minimised, enhancing overall system performance. This approach not only optimises energy use but also aligns with sustainability objectives by reducing environmental impact through improved energy management practices.

Effective control of HP systems is essential for maximising their performance and energy efficiency. Clear and logically prescribed technical documentation detailing control strategies is required. Quantitative examples play a crucial role in illustrating the impact of these controls on system efficiency. By demonstrating the energy use dynamics and efficiency variations of HP 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 HP systems operate at peak efficiency while meeting performance criteria outlined in technical standards and guidelines.

Identifying targeted HP system types early in guideline development is foundational. Hydronic HP systems for space heating and domestic hot water, alongside air conditioners like variable refrigerant flow systems, are prioritised 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 HP 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 industry best practices.

While comprehensive, the guideline under development in Subtask D acknowledges its limitations in covering all types of HP systems. Air-source heat pumps (ASHP) are the primary focus because of their extensive global application, whereas air-to-water systems dominate in European contexts. Proposals for including both air-to-air and air-to-water HP systems in Annex 88's design guidelines recognise their relevance across diverse geographical and climatic conditions. This inclusive approach ensures that the guidelines cater to a broad spectrum of HP applications, fostering standardised practices that promote energy efficiency and sustainability in HVAC systems worldwide.

The development and refinement of guidelines for HP systems are instrumental in advancing energy-efficient practices within the HVAC industry. By addressing sizing methodologies, efficiency considerations, control strategies, and including diverse HP 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 those HP systems to be included to show exemplified monitoring data of HP systems to readers (need contribution by Subtask B2). With the explanation of characteristics of current testing standards for HP systems, guidance on which metrics, based on which testing standards, should be highlighted should be included (need contribution by Subtask B1). Also, a reliable energy calculation method should be introduced and utilised to provide quantitative information on influences of design parameters on the system energy performance (need contribution by Subtask C). Finally, easily understood educational materials on how they can design energy efficient HP systems should be provided with the data based on the calculation methods. These materials should be tailored to specific segments: e.g., mechanical engineers designing large facilities will have a different level of knowledge, and need very different type of details, then residential HVAC contractors for single-family or larger multifamily housing; required concerns and knowledge vary with different climates, etc.

Table 4.3.1-1. Characteristics of current guidelines

Guideline	HP Type	Applications	Year	Note
EN 15450:2007	Air-to-air, air-to-water, water-to-water, water-to-air, geothermal water-to-air, geothermal water-to-water, geothermal refrigerant-to-water, geothermal refrigerant-to-refrigerant	Space heating, DHW	2007	Capacity less than 1 MW
VDI 4645:2023-04	Air-to-water	Space heating and DHW	2023	-
CSA SPE-17:23	Air-to-air, air-to-water, geothermal water-to-air, geothermal water-to-water, gas-fired HP	HVAC	2023	-
ACCA Manual J	Air to air and ground-source air-to-water	Heating and cooling building load calculation	2016	-
ACCA Manual S	Almost all types of residential HVAC equipment	To select appropriate heating and cooling equipment at design conditions.	2014 (new version 2023)	New version is recently published. It will better support heat pump space heating.
NEEP	Air source heat pumps - guidance	Residential homes are targeted. Air-to-air ductless and ducted	2017 and 2018	Not detailed. Pointing readers to Manual J and S by ACCA
ISO 13153:2012	Air-to-air, air-to-water	Space heating and cooling, DHW	2012	A framework of guidelines for energy efficient housing is prescribed.
LEHVE	Air-to-air, air-to-water	Space heating and cooling, DHW	Mild climate: 2005, 2015 (2nd edition) Hot humid climate: 2010, 2012 (English edition) Cold climate: 2012	-
Note that the scope of this list is limited to determining building loads (e.g., heating and cooling design and necessary operating conditions) and selecting appropriate equipment to meet those loads. In reality, whenever possible good design practice should include, or may be required to include further items that are outside the scope of this list. Integrated design that accounts for mechanical system and building enclosure design (for example, thermal properties of insulation and windows, comfort requirements) and other systems (for example, solar PV array) together with the heat pump(s) to better optimise the entire system and increase energy efficiency and indoor environmental quality as well as reduce capital cost. In addition, there may be further design requirements for heat pumps defined by (for example) indoor air quality and fire safety requirements in case of mass refrigerant leakage, or other similar statutory or best practice design guidelines.				

4.4 References

ACCA - Air Conditioning Contractors of America. (2016). Manual J Residential Load Calculation (8th Edn - Full).

ACCA - Air Conditioning Contractors of America. (2023). Manual S - Residential Equipment Selection (3rd Edn, Version 1.01).

BRI - Building Research Institute Incorporated Administrative Agency Japan. (2010). Design Guidelines for Low Energy Housing with Validated Effectiveness (LEHVE).

BRI - Building Research Institute, Japan. (2010). Design Guidelines for Low Energy Housing with Validated Effectiveness: Hot Humid Region Edition, 397 pages https://www.kenken.go.jp/english/contents/publications/paper/149/index.html.

BSI – British Standard Institution (2022). BS EN 14825:2022: Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling, commer-cial and process cooling. Testing and rating at part load conditions and calculation of seasonal performance.

BRI/NILIM -Building Research Institute/National Institute for Land and Infrastructure Management. (2013). Technical Information regarding energy consumption performance of buildings, since 2013, https://www.kenken.go.jp/becc/index.html.

Canadians for Properly Built Homes (2024) https://canadiansforproperlybuilthomes.com/

CEN - Comité Européen de Normalisation. (2014). EN 12828:2012+A1:2014 Heating systems in buildings. Design for water-based heating systems.

CEN - Comité Européen de Normalisation. (2017a). EN 12831-1:2017 Energy performance of buildings. Method for calculation of the design heat load Space heating load, Module M3-3.

CEN - Comité Européen de Normalisation. (2017b). EN 12831-3:2017 Energy performance of buildings. Method for calculation of the design heat load Domestic hot water systems heat load and characterisation of needs, Module M8-2, M8-3.

CEN - Comité Européen de Normalisation. (2017c). EN ISO 52016-1:2017 Energy performance of buildings. Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads Calculation procedures.

CEN - Comité Européen de Normalisation. (2017d). CEN/TC 228/WG 4 - Calculation methods and system performance and evaluation.

CEN - Comité Européen de Normalisation. (2018). EN 14511-2:2018 - Test methods and standards for air conditioners, liquid chilling packages and heat pumps.

CEN - Comité Européen de Normalisation. (2020). EN 12102-2:2020 Air conditioners, liquid chilling packages, heat pumps, process chillers and dehumidifiers with electrically driven compressors - Determination of the sound power level - Part 2: Heat pump water heaters.

CEN - Comité Européen de Normalisation. (2022). EN 16147:2017+A1:2022 Heat pumps with electrically driven compressors. Testing, performance rating and requirements for marking of domestic hot water units.

CSA - Canadian Standards Association Group. (2023). CSA SPE-17:23 HVAC guide for Part 9 homes.

CSA Group (2024a). Canadian Electrical Code Products, https://www.csagroup.org/store/canadian-electrical-code-products/

CSA Group (2024b). https://www.csagroup.org/store/, Tel: 1-800-463-6727, 178 Rexdale Blvd., Toronto, ON, M9W 1R3.

Danish Energy Agency, Danish building regulations - codes (BR23). (2023).

Energy StepCode, (2018). How the BC Energy Step Code works, https://energystepcode.ca/how-it-works/

Energy StepCode, (2021). Zero Carbon Step Code, https://energystepcode.ca/zero-carbon/

Government of Canada (2020a). National Building Code of Canada 2020, https://nrc.canada.ca/en/certifications-evaluations-standards/codes-canada/codes-canada-publications/national-building-code-canada-2020

Government of Canada (2020b). National Energy Code of Canada for Buildings 2020, https://nrc.canada.ca/en/certifications-evaluations-standards/codes-canada/codes-canada-publications/national-energy-code-canada-buildings-2020

Government of Canada (2024a). Local Energy Efficiency Partnerships (LEEP), https://natural-resources.canada.ca/energy-efficiency/homes/local-energy-efficiency-partnerships-leep/17338

Government of Canada (2024b). Toolkit for air source heat pump sizing and selection, https://natural-resources.canada.ca/maps-tools-and-publications/tools/modelling-tools/toolkit-for-air-source-heat-pump-sizing-and-selection/23558

IBECs - The Housing and Building SDGs Promotion Center, Institute for Built Environment and Carbon Neutral for SDGs. (2024). Home page for LEHVE design guidelines, Design guidelines for self-reliant and recycling-oriented housing. https://www.jjj-design.org/jjj/jjj-guideline.html

ISO - International Organization for Standardization. (2012). ISO 13153:2012 Framework of the design process for energy-saving single-family residential and small commercial buildings.

JSA Group - Japanese Standards Association Group. (2018). JIS C 9220:2018 Residential heat pump water heaters.

Mowris, R., & Jones, E. (2008, August 17-22). Peak Demand and Energy Savings from Properly Sized and Matched Air Conditioners the 14th biennial ACEEE conference on Energy Efficiency in Buildings, Asilomar Conference Center, Pacific Grove CA.

NEEP - Northeast Energy Efficiency Partnerships. (2020a). Guide to Installing Air-Source Heat Pumps in Cold Climates.

NEEP - Northeast Energy Efficiency Partnerships. (2020b). Guide To Sizing & Selecting Air-Source Heat Pumps in Cold Climates.

Red Seal Program (2024). Refrigeration and Air Conditioning Mechanic, https://www.red-seal.ca/eng/trades/r.1cm.shtml

Sawachi, T. (2013). Towards the ultra-efficient home – ISO standard supports the development of energy efficient homes. ISO Focus+, 4(1), 19-22.

VDI - Verein Deutscher Ingenieure. (2023). VDI 4645 Berichtigung:2023-07 Heating systems with heat pumps in single and multi-family houses - Planning, construction, operation.