Current and future energy calculation standards for heat pumps

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IEA Energy in Buildings and Communities TCP
Annex 88 Evaluation and Demonstration of Actual Energy Efficiency of Heat Pump Systems in Buildings
ANNEX 88 EBC Energy in Buildings and Communities Programme

Emerging concern: setting up requirements and displaying **buildings** energy performance.

To do this, you need :

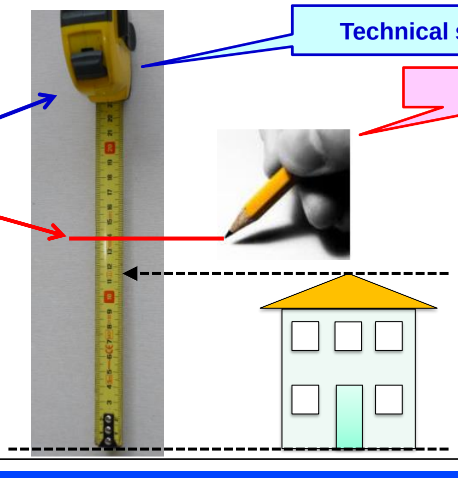
A meter
- **Calculation methods**
- **Common definitions**

A benchmark
- **Legal requirements**
- **Energy classes definition**

… but the purpose can also be how does the building and systems behave and perform as a whole

Technical standard

Regulation



If you change the meter, you are changing the legal requirements

You have to know the meter to set-up correct requirements

Sometimes the calculation method is included in the regulation

The context: building energy performance calculation methods

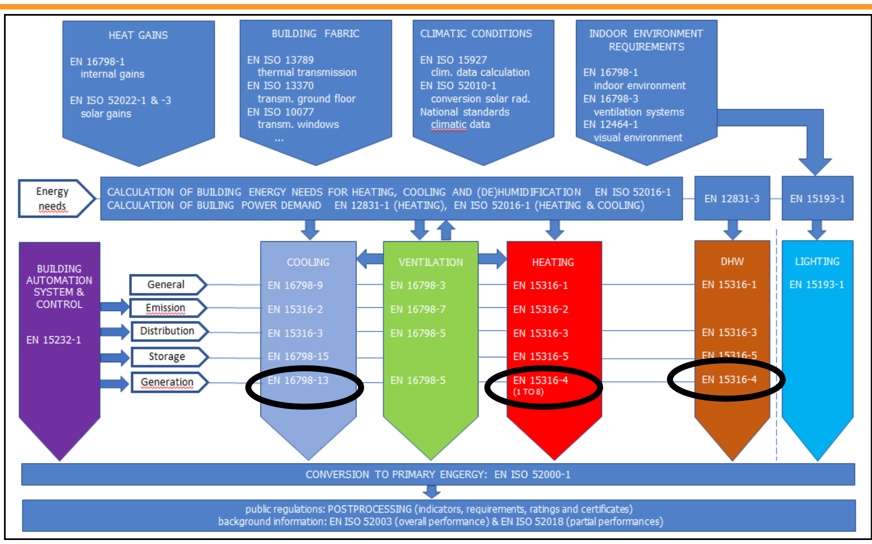
A set of calculation procedures that **take into account**:

- The **actual or specifically designed** **building envelope** geometry and properties
- The **actual or specifically designed** HVAC, domestic hot water and lighting **systems** (comfort technical systems) properties
- A **standardized** set of **climate** and **use** conditions of the building (or actual data for audits)

… and **calculates** the overall energy performance of the building («weighted energy use», such as non-renewable primary energy, renewable primary energy, CO_2 emission, etc.) and other so called "partial performance indicators" (e.g. average transmittance, system efficiencies).

This is done by «modules», that is specific parts on each considered aspect
→ the focus of this presentation is on the specific part that deals with the heat pump performance.

The heat pump shall be calculated according to the specific operating conditions in the actual assessed building.
This includes also any «wrong» situation (e.g. oversized machines, bad building insulation).



A sample modular organization of the overall building energy performance calculation

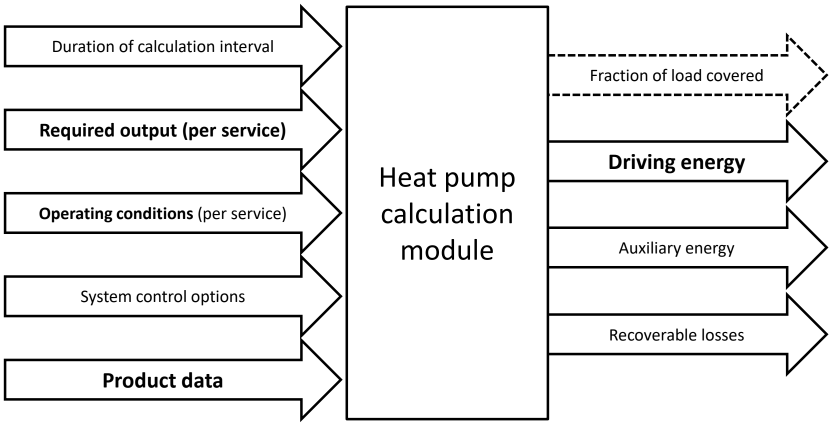
ISO reserved the 52000 series for EPB standards
EPB = Energy Performance of Buildings

The heat pump modules are highlighted

Work in progress in this field:

- Monthly versus hourly methods
- Detailed description of the variety of technical systems
- Building and systems zoning
- Building automation and control
- Interaction with the grid
- …

What should a «heat pump energy performance calculation module do…



The scope is the «calculation interval», that can be one month, one day, one hour, one bin, …

The possible combinations of input data can often be far from assumed average conditions and include several services.

Fraction of load covered is required when handling cascade generators and/or checking if the system can fulfill the load.

The big challenge: the sensitivity of heat pumps to operating conditions

Temperature of both sources

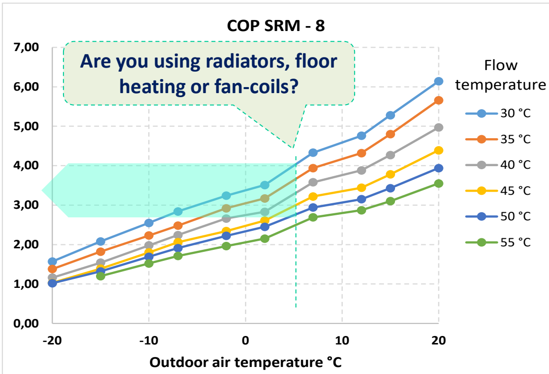
- **Calculation of cold source temperature**
  - External air temperature: hourly or bins for the monthly method
  - Surface/ground water temperature (heat exchanger approach?)
  - Ground heat exchanger outlet temperature (approach to ground? Ground temp drift?)
- **Calculation of hot source temperature**
  - Water based: calculation of required generator flow temperature (LWT)
  - Air based: indoor temperature or required duct air temperature (EAT)

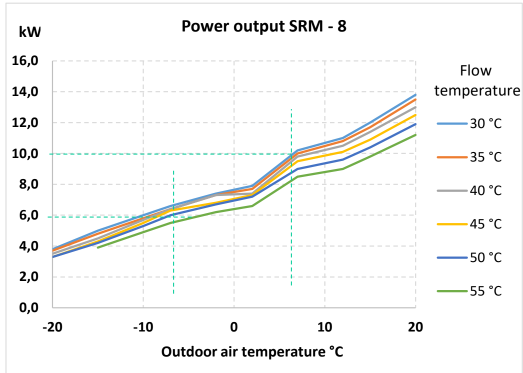
Part load operation

- Continuous operation at reduced power (inverter) → **maximum turndown**?
- ON-OFF operation on full load (ON-OFF control) or min load (inverter) → **cycling frequency**
- Control options → evaporator/condenser fan speed

Other influences

- Auxiliaries not included in the COP testing
  - Internal to the heat pump (absorption)
  - External (source pumps, etc.)
- Defrosting





COP range in practical application range: 1,5...6 = 1 to 4
Sensitivity on flow temperature at 7°C Air:
-40% / 25 °C = 1,6%/°C

Power output decreasing with temperature
High cost per kW installed
→ Sizing is critical, back-up may be required
→ Check if the heat pump can fulfill the load

The big challenge: the sensitivity of heat pumps to operating conditions

Condensing boiler performance: efficiency is in the range 0,94…1,06 = ± 6% *(on lower calorific value)*
Heat pump performance: 1,5…2,5 %/°C → COP range 2…6

Where do we find enough data to identify a reasonably accurate «performance map»?!

Some pitfalls:

- «Source» and «sink» temperature influence
  - Should be «evaporation» and «condensation» temperature
  - Reported: «air» and «water» temperature (can be leaving or entering temperature)
- **Part load:**
  - **What is «part load»?** Compressor speed? Actual power / Maximum power?
    No standard clearly defines "full load"…
  - Change of temperature difference on evaporator and condenser
- Other influences (defrosting, …)

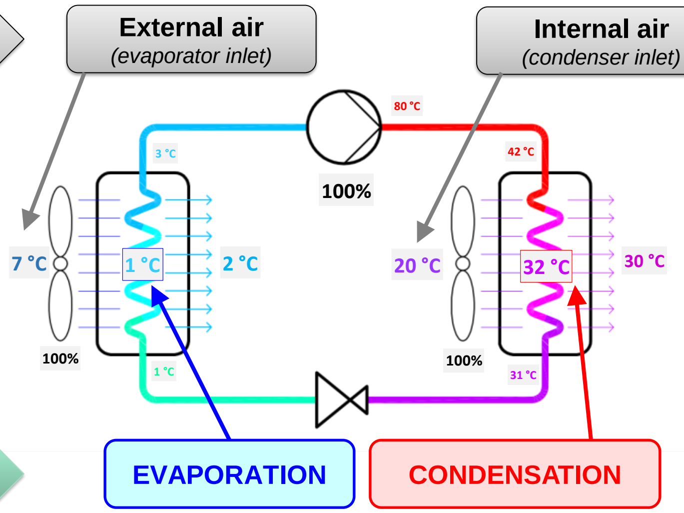
The heat pump performance is a non-linear function of at least three significant independent variables … + control options…

A7W35 or A7W35P60…

AVAILABLE

Example

Temperatures in an air to air heat pump

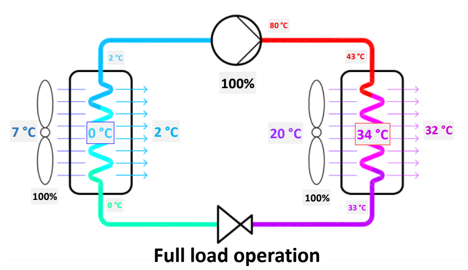


RELEVANT

Example of hidden additional complexity.

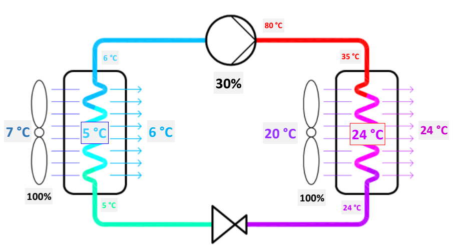
For practicality you refer to commonly and easily **available data** but the heat pump efficiency depends on **relevant data.**

Some calculation methods (EN) estimate relevant data for the purpose of applying corrections to COP

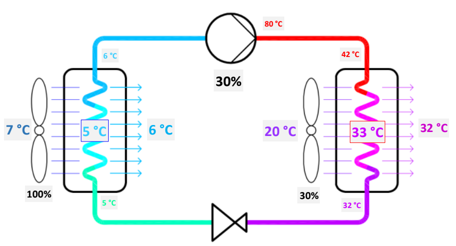


Full load operation

Part load operation: only the compressor modulates
Theoretical COP increase: 83%



Part load operation: both compressor and condenser fan modulate…
(“quiet mode”)
Theoretical COP increase: 21%



To be also taken into account: performance of air to air heat pumps is strongly dependent on evaporator and condenser fan control strategy.

Is the control strategy in day to day operation the same as in the testing procedure?

Is this considered in the EP calculation module?

Another challenge: heat pump type…

"EXTERNAL" CONNECTION

Air
- External air
- Exhaust air
- Solar assisted

Water
- Ground heat exchanger
- Ground water
- Surface water

✖

"INTERNAL" CONNECTION

Air (direct expansion or condensation)
- Indoor air (single/multi)
- Ducted air

Water
- Technical water
- Domestic hot water

✖

… and several are missing here …

"OTHER" THINGS…

Capacity control
- ON-OFF / Modulating / staged

Integrated appliances with other services
- Ventilation
- Domestic hot water

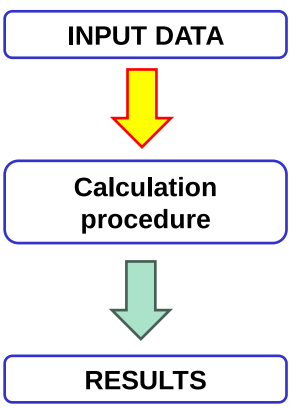
Operating principle
- Vapor compression / absorption

Simultaneous heating and cooling

Heat recovery (desuper-heater)

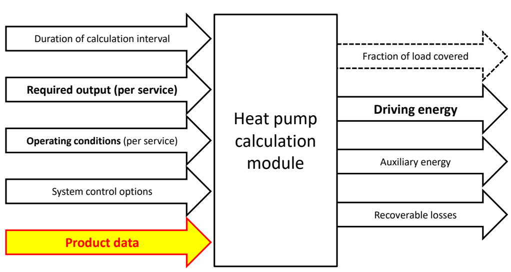
…

A pending issue: heat pump product data for building energy performance



Input data sets and calculation methods are interdependent.

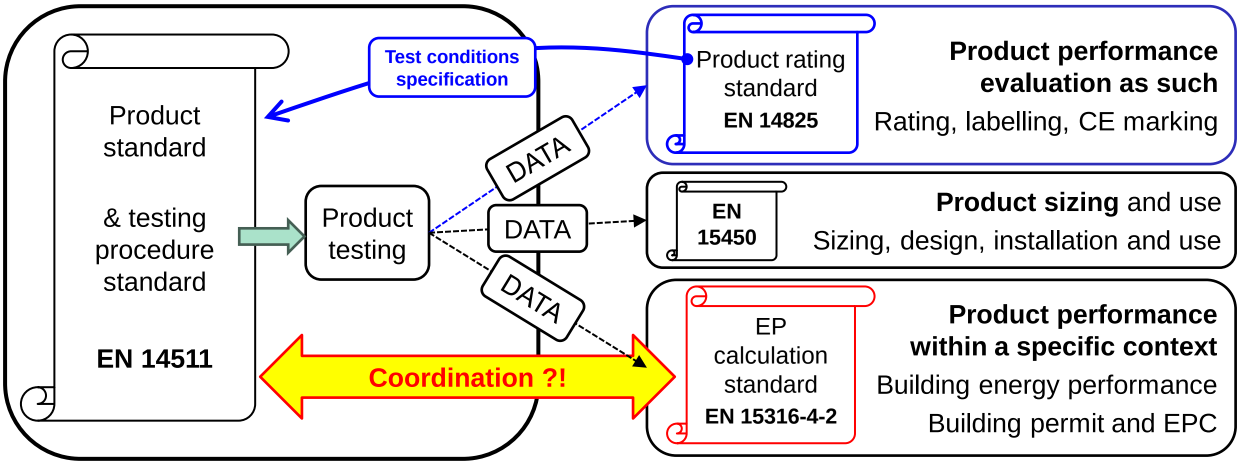
Any standardized calculation method should be developed **together** with the corresponding product standard that defines the data and the measurement procedure. This allows to balance and optimize costs (test and measurement) and benefits (accuracy and exhaustivity of the energy performance prediction)



It looks like this happened for product rating only…

Product data: SCOP, IPLV, …

A pending issue: heat pump product data for building energy performance (EP)



Building rating

- Gives access to **building market**: building permit, building on the market
- Looks for the performance of each product in **building specific and changing operating conditions**
- **Needs parameters** to assess the influence of each operating condition variable on the product performance
- Needs to distinguish between the effect of product characteristics and installation choices
- Has to foresee also the effect of bad products and wrong sizing, installation and operating conditions

EU EPBD Directive

Product rating

- Gives access to **product market**: product on the shelf
- Looks for the performance of all products in the **same operating conditions** (representative ?)
- Needs a **single performance indicator** to rate the product on a scale
- Representative installation conditions may be embedded in the testing
- No reference to possible wrong sizing, installation or operating conditions

EU Ecodesign + Ecolabeling Directives

Heat pump modules for building energy performance calculation
The current challenge :

- Calculating the performance of the heat pump in a single calculation interval, which is a non-linear function of at least 3 variables: source and sink temperature, load
- Additional factors: control strategy, impact of installation on cycling frequency, defrosting, transient operation during domestic hot water charge, ….
- **Using the currently available data**
  → several methods, approximations and default data to leverage the available data sets

Not satisfactory because of low accuracy and flattening of the evaluation of products within a building (you use the same defaults for all)

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Heat pump modules for building energy performance calculation
Common approaches

- Starting from declared performance value in a single or several reference operating conditions, apply **independent corrections** for each influencing factor
  → basic assumption: the effect of each influencing factor is independent of the effect of the others
- Preprocess test results form several operating conditions to identify a **characteristic function** that describes the efficiency of the heat pump. Then apply the characteristic function in actual operating conditions.
  → example: assume exergy efficiency is a function of required output capacity only
- The seasonal efficiency is assumed to be a **weighted average** of efficiency for a set of part loads.

Frequently used “additional” assumptions (for small adjustments and/or complementing)

- Constant exergy efficiency (heat pumps performance is a given fraction of Carnot theoretical maximum)
  This is used for interpolation and extrapolation when data for several testing points are available
- Approach of evaporator and condenser is a linear function of instantaneous capacity
  (to switch from available temperatures to relevant temperatures)
- …

Sample methods: EN 15316-4-2 (new draft, on-going review)

EN 15316-4-2 is structured as

- A main procedure, dealing with common issues like operating limits, priorities between services, required back-up, auxiliary energy, …
- Specific parts according to two main calculation options ("path A" and "path B") options, designed to connect to two different sources of data.
  - Path A: intended to use data from EN 14511 → capacity and COP at full load
  - Path B: intended to use data from EN 14825 → declared COP at various load and operating conditions

EN 15316-4-2

This is the **backbone** of the calculation procedure.

The steps in orange

- Assessing the available capacity
- Calculating the COP in the calculation interval

can be performed either with path A or path B depending on the heat pump type

1
- Get **product type** (source / sink / technology) → decide calculation path (A /B and variants)
- Get **product data**

2
- Get **required heat output for each service** (heating and domestic hot water)

3
- Calculate **source temperature** depending on **source type**
- Calculate **sink temperature** depending on **service**

4 A/B
- Get **maximum available power output** depending on operating conditions (**per service**)

5
- Handle **priority and load dispatch** within the calculation interval

6 A/B
- Correct **performance (COP) according to actual operating conditions**

7 A/B
- Calculate **main energy input**

8 A/B
- **Repeat for all priorities**

See next slides on Path A and Path B details

9
- Calculate **back-up energy** input and energy to be covered by next generator in the sequence

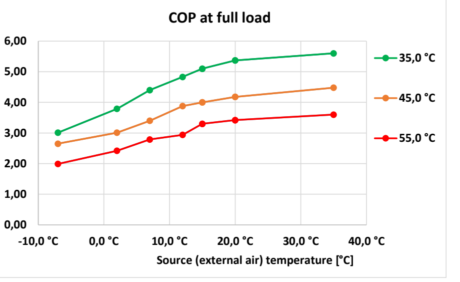
10
- Calculate **auxiliary energy** and recoverable losses

EN 15316-4-2

Path A basics (heating and cooling)

Step 1: determine full load capacity and COP performance map for a predefined set of sink and source temperatures.
This can be either done by declaration by the manufacturer or extrapolation from a single (nominal) declared data point.

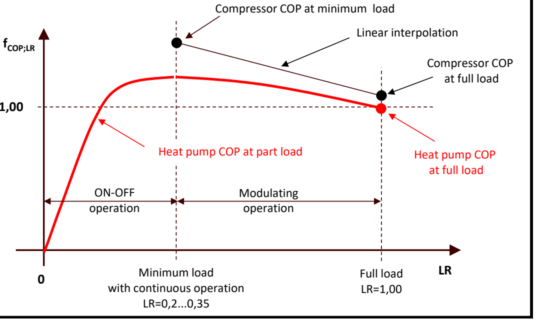
Step 2: interpolate full load capacity and COP to actual source and sink temperature



Step 3 (for COP only): correct COP according to part load factor LR, ratio of actual required output to full load capacity for the given source and sink temperature.

There are several options provided for this step.

Other influence factor should be embedded in the declared performance

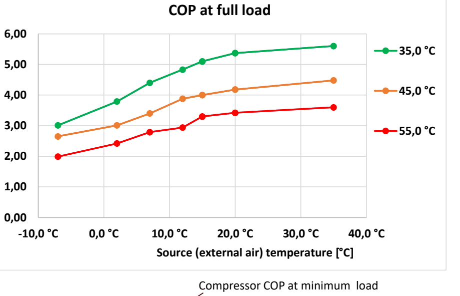


EN 15316-4-2

Path A basics (heating and cooling)

Step 1 + Step 2

$$COP_{100\%,ci} = f(\theta_{source,ci};\theta_{sink,ci})$$

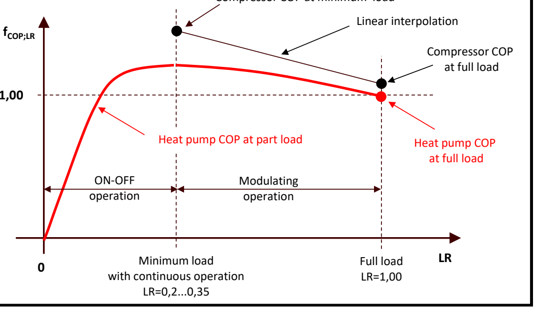


Step 3

$$COP_{ci} = COP_{100\%,ci} \cdot f_{corr;COP}(LR)$$

or

$$COP_{100\%,ci} = COP_{100\%,ci} + \Delta_{COP}(LR)$$



EN 15316-4-2

Path B basics (heating and cooling)

Intended use: based on 4 data points from EN 14825.

Issues: from points A to D all parameters are changing, no information on the influence of one parameter

Turn around: assume that the exergetic efficiency of the heat pump is only a function of the capacity

1. Get heat pump performance in **conditions A, B, C, D (and E, F, G)** according to EN 14825
   NOTES: EN 14825 test points allows all operating parameters (part load, hot and cold source temperatures) to vary simultaneously. E=TOL, F=BIV may duplicate A. G only for cold climate
2. Estimate **evaporation and condensation temperature** (linear ΔT according to power output) at conditions A, B, C and D and calculate exergetic efficiency according to evaporation and condensation temperature and COP
3. Determine the **correlation between exergetic efficiency and output power** based on these 4 points
4. Determine the **exergetic efficiency based on actual power output**
5. Calculate **evaporation and condensation temperature at actual operating conditions** (actual source and sink temperature + linear DT on evaporator and condenser)
6. Calculate **COP based on exergetic efficiency** and actual evaporation and condensation temperatures

Steps 1 to 3 is the preprocessing, needed only once

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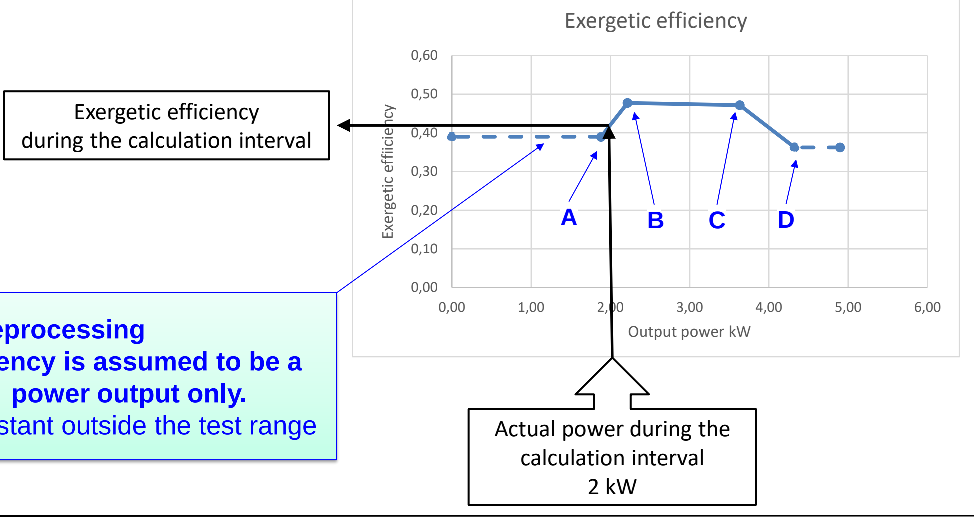
EN 15316-4-2

Path B basics



Preprocessing
Exergetic efficiency is assumed to be a function of power output only.
It is assumed constant outside the test range

EN 15316-4-2

Path B basics

The source of the data is EN 14825.

Test points are selected assuming a perfect sizing o the heat pump and a strong flow temperature reset according to outdoor temperature or load.

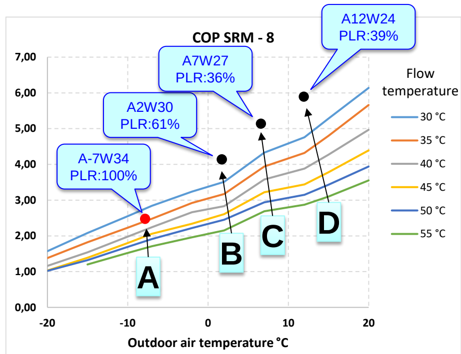
Coverage of the performance range is limited.

Ongoing development: using data for several temperature levels and interpolating.

Test point	T_{aria}	Average climate		
		PLR	LWT «35»	LWT «55»
	°C		°C	°C
A	**-7**	**0,88**	**34**	52
B	**2**	**0,54**	**30**	42
C	**7**	**0,35**	**27**	36
D	**12**	**0,15**	**24**	30

Definition of testing points according to EN 14825 for average climate and 2 temperature levels.

Part load test are static tests.
Test load is P_{design} x PLR



Comparison between testing points according to EN 14825 for average climate and 35 °C and a full performance map of a heat pump

UNI-TS 11300

Italy

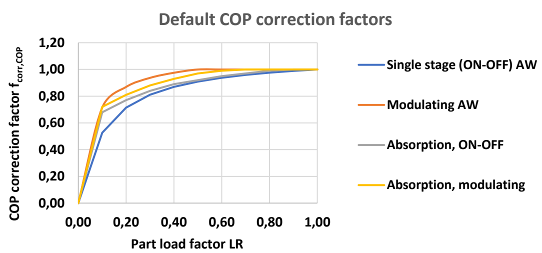
Same method as path A of EN 15316-4-2.

Correction according to part load is based on a simple default curve.

Required data point are listed in a table that includes summer air temperature because of domestic hot water production.

Not satisfactory with air to air het pumps and domestic hot water heaters.

Type of source	Reference source temperatures $\theta_{src;ref,j}$				Reference sink temperatures, $\theta_{snk;ref,i}$					
					Air	Water			Domestic hot water	
External air	-7	2	7	12						
Surface water and ground water		5	10	15	20	35	45	55	45	55
Ground heat exchanger	-5	0	5	10						
Domestic hot water heaters, air source only	7	15	20	35	Not applicable				45	55



RE 2020

France

Same method as path A of EN 15316-4-2.

The full load performance map is generated from one single value according to default multipliers to fill in the grid.

COP is interpolated according to actual source and sink temperature then the correction according to part load is applied

COP_{LR100}		θ_{src} -15	-7	2	**7**	20	$f_{COP;snk}$	
θ_{snk}	25	1,94	2,42	3,87	4,84	6,05	*1,10*	W35 to W25
	35	1,76	2,20	3,52	**4,40**	5,50		
	45	1,41	1,76	2,82	3,52	4,40	*0,80*	W35 to W45
	55	1,13	1,41	2,25	2,82	3,52	*0,80*	W45 to W55
	65	0,90	1,13	1,80	2,25	2,82	*0,80*	W55 to W65
$f_{COP;src}$		*0,80* A-7 to A-15	*0,625* A2 to A-7	*0,80* A7 to A2		*1,25* A7 to A20		

Default multipliers

A set of default multipliers is defined for each type of heat pump (AA / AW / …)

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SAP 10.2

United Kingdom

For each product, manufacturer shall perform an hourly calculation to determine a seasonal SCOP that will be uploaded to an official data-base for use by assessors.

The seasonal SCOP is calculated for a number of heat emitters and for a range of relative sizing of the heat pump compared to the building needs (PSR = Plant sizing ratio)

PSR (Plant Size Ratio)	0,2	0,5	0,8	1,0	1,2	1,5	2,0
Floor heating							
Heating SPF	3,855	3,926	4,173	4,217	4,241	4,191	4,108
Running hours	4925	2716	1770	1447	1231	1016	800
Radiators							
Heating SPF	3.502	3.413	3.607	3.665	3.698	3.657	3.585
Running hours	4699	2516	1643	1345	1146	947	749
Convectors							
Heating SPF	3.930	3.89	4.133	4.186	4.215	4.166	4.081
Running hours	4776	2577	1682	1376	1172	968	764

ENERGY PLUS

The method is similar to Path A of EN 15316-4-2

There is an independent corrections for each influence factor.

The correction functions are given as polynoms.

Default values were given for some types of chillers several years ago

$$\boldsymbol{P_{input}} = \frac{\boldsymbol{P_{out,ref}}}{\boldsymbol{COP_{ref}}} \times \boldsymbol{CFT} \times \boldsymbol{EIRFT} \times \boldsymbol{EIRPLR} \times \boldsymbol{CCR}$$

$$\boldsymbol{CFT} = a_1 + a_2(T_{cw,ls}) + a_3(T_{cw,ls})^2 + a_4(T_{cond,e}) + a_5(T_{cond,e})^2 + a_6(T_{cw,ls})(T_{cond,e})$$

$$\boldsymbol{EIRFT} = b_1 + b_2(T_{cw,ls}) + b_3(T_{cw,ls})^2 + b_4(T_{cond,e}) + b_5(T_{cond,e})^2 + b_6(T_{cw,ls})(T_{cond,e})$$

$$\boldsymbol{EIRPLR} = c_1 + c_2(PLR) + c_3(PLR)^2$$

$$CCR = \min\left(\frac{PLR}{PLR_{min}}, 1.0\right)$$

Sample equations for a chiller. (biquadratic)

Each manufacturer should provide the performance curve for its machines …

… or you have to perform curve fitting …

NECB (Canada)

The method is similar to Energy plus

An example of default performance curve for air source heat pump is shown here

NOTE: there is no correction based on the leaving water temperature level. A correlation with outdoor dry bulb temperature is assumed.

$$\boldsymbol{Q_{available}} = \boldsymbol{Q_{rated}} \times CAP\_FT_{EAS}$$

$$\boldsymbol{CAP\_FT_{EAS}} = a + (b \times t_{odb}) + (c \times t_{odb}^2) + (d \times t_{odb}^3)$$

a = 0.2536714 c = -0.0001861
b = 0.0104351 d = 0.0000015

t_{odb} = outdoor dry bulb temperature in °F

$$\boldsymbol{P_{operating}} = \boldsymbol{P_{rated}} \times EIR\_FPLR \times EIR\_FT \times CAP\_FT_{EAS}$$

$$\boldsymbol{EIR\_FPLR} = a + (b \times PLR) + (c \times PLR^2) + (d \times PLR^3)$$

a = 0.0856522 c = -0.1834361
b = 0.9388137 d = 0.1589702

PLR = part load ratio based on available capacity

$$\boldsymbol{EIR\_FT} = a + (b \times t_{odb}) + (c \times t_{odb}^2) + (d \times t_{odb}^3)$$

a = 2.4600298 c = 0.0008800
b = - 0.0622539 d = -0.0000046

t_{odb} = outdoor dry bulb temperature in °F

Conclusion

- **Heat pumps are damn sensitive to operating conditions**: 3 and non linear with a result in the range 1 to 3
- There is a **huge variety of heat pumps typologies** depending on source type, sink type, control options, combination with other products and services, etc.
- The product **standardization** has **focused** mainly **on the product rating**
- Countries have different prevailing needs (heating versus cooling) and different type of prevailing systems (air based versus water based)
- **Building energy performance calculation** requires the coverage of **very various situations**, often far away from the assumptions used e.g. in product rating.
- Given the variety of heat pump types and in the absence of well defined product data intended for energy performance calculation, all sorts of calculation methods have developed, none comprehensive and fully satisfactory
- **Input data and methods are interdependent**: much more **collaboration is needed** between heat pump experts and building energy performance experts to find a good compromise between the required effort (testing several operating conditions to map the performance of the heat pump) and the benefit (exhaustive and accurate prediction of the heat pump performance in all foreseeable operating conditions)
- **New typologies** are emerging, VRV/VRF, desuperheating, simultaneous heating and cooling, integration with ventilation…
- **Huge work in progress…**

Current Design Guidelines of Heat Pumps in Buildings and Challenges

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Acknowledgements

"We recognise the importance of our relationship to the traditional owners of the land. I pay my respects to the traditional custodians of the land and extend that respect to other indigenous people."

Authors, Reviewers, and Editors: State of the Art Report

Dr Maria Kapsalaki, International Network for Information on Ventilation and Energy Performance

INIVE

Existing guidelines

European	EN 15450:2007 – Heating systems in buildings – Design of heat pump heating systems
	VDI 4645:2023-07 – Heating systems with heat pumps in single and multi-family houses – Planning, construction, operation
	The standards applied in Denmark: EN14511, EN14825, EN16147, and EN12102.
Canadian	CSA C273.5:11 (R2020) "Installation of air source heat pumps and air conditioners"
	CAN/CSA-C448 SERIES-13 "Design and installation of earth energy systems"
	CSA SPE-17:23 – HVAC guide for Part 9 homes
US	Air Conditioning Contractors of America (ACCA) manuals Manual J – load calculations, Manual S – Equipment selection
	The Northeast Energy Efficiency Partnership (NEEP) sizing and installation guidance
ISO 13153:2012 & Japanese	Design Guidelines for Low Energy Housing with Validated Effectiveness' (LEHVE)

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Characteristics of current guidelines

Guideline	Year	HP Type
EN 15450:2007	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
VDI 4645:2023-04	2023	Air-to-water
CSA SPE-17:23	2023	Air-to-air, air-to-water, geothermal water-to-air, geothermal water-to-water, gas-fired HP
ACCA Manual J	2016	Air to air and ground-source air-to-water
ACCA Manual S	2014 (new version 2023)	Almost all types of residential HVAC equipment
NEEP	2017 and 2018	Air source heat pumps - guidance
ISO 13153:2012	2012	Air-to-air, air-to-water
LEHVE	Mild climate: 2005, 2015 (2nd edition) Hot humid climate: 2010, 2012 (English edition) Cold climate: 2012	Air-to-air, air-to-water

Current guidelines and target application

Guideline	Applications
EN 15450:2007	Space heating, DHW
VDI 4645:2023-04	Space heating and DHW
CSA SPE-17:23	HVAC
ACCA Manual J	Heating and cooling building load calculation
ACCA Manual S	To select appropriate heating and cooling equipment at design conditions.
NEEP	Residential homes are targeted. Air-to-air ductless and ducted
ISO 13153:2012	Space heating and cooling, DHW
LEHVE	Space heating and cooling, DHW

Challenges

- Significant gaps in the ages (10-15 years) of current guidelines,
- Ongoing evolution of sizing guidelines within the industry,
- Necessity for regular updates of design guidelines to align with technological advancements and methodological refinements,
- Efficient operation under varying load conditions is crucial
  - 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.
- Effective control of HP systems is essential for maximising their performance
- Clear and logically prescribed technical documentation detailing control strategies is required.
- Identifying targeted HP system types early in guideline development is foundational.
- Priorities
  - Hydronic HP systems for space heating and domestic hot water,
  - Air conditioners like variable refrigerant flow systems.

Future focal points

1. The sizing procedure of heat pumps,
2. Countermeasures to avoid operation under low partial load conditions and to improve energy efficiency under the low partial load condition by selecting products (referring to the load-based test methods and provided performance indices),
3. Emphasising the critical role of controlling the systems together with a transparent specification of the control logics,
4. Quantitative information on the energy use by different specifications and product selections in coordination with energy use calculation methods.

Many thanks!

The end.