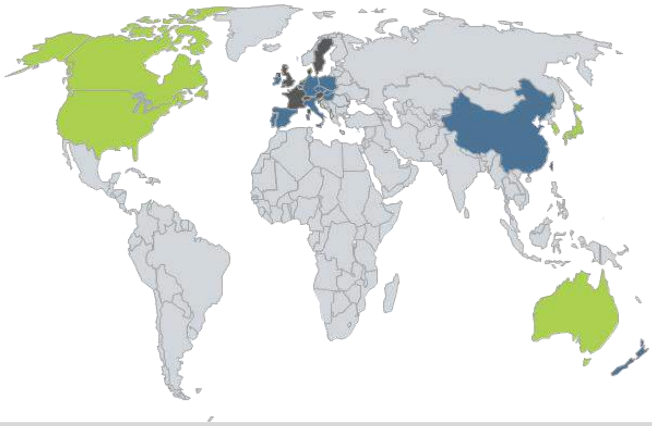
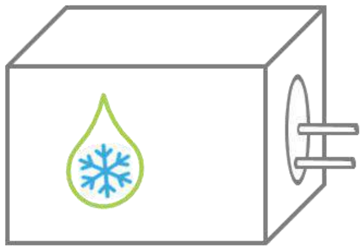
Benchmarking Document

Technology: Packaged Liquid Chillers





Participating countries:
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Policy benchmarking for Packaged Liquid Chillers and evaluating the lack of comparability between economies

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For further information refer to http://mappingandbenchmarking.iea-4e.org/matrix

1 Executive Summary

This report, commissioned by the IEA 4E implementing agreement, aims to compare standards for packaged liquid chillers as far as practicable at present, and indicates possible pathways towards better comparability in future, both for market average performance and to enable comparison of the stringency of regulations between economies.

The report follows initial research in 2014 which concluded that conventional IEA 4E mapping and benchmarking analysis of standard full load efficiency for packaged liquid chillers would be of little relevance to new policy (i.e. if based on coefficient of performance (COP) and energy efficiency ratio (EER)). This is because new policy is focused, more appropriately, on seasonal and part load performance. It was also observed that the integrated part load value metric (IPLV) of the US and the seasonal energy efficiency ratio (SEER) of the EU are not at all comparable, which would limit the amount of analysis that could be done. Hence, this analysis compares standards within those constraints. The analysis also examines the apparent rationale for the development of the different metrics and the barriers to, and advantages of, harmonisation for this product group.

The focus of the analysis is on product policy standards, rather than building codes that generally deal with the wider HVAC system – even though some building codes also set standards for components (such as ASHRAE 90.1). Under this analysis, packaged liquid chillers are defined as factory-built units for cooling water or brine by means of a vapour compression refrigeration system. This analysis is focused on electric chillers for use in comfort cooling applications (although some reference to process chillers is also made).

US standards amongst the first and widely adopted by other economies

The US test method AHRI 550/590 was one of the early major standards to address chiller performance and has been adopted by many regions of the world. Standards in Canada, Australia & New Zealand and China are closely based on the US standards; Japan has developed some climate-related adjustments to them. Conversely, the EU has developed its own standard EN 14511. Some information has been collated on standards in Chinese Taipei but it was not possible to determine comparability for this; comparability for China has been inferred from published papers.

Policies in place

For packaged chillers, mandatory policies in the US, Canada, Australia/New Zealand and the EU use only minimum energy performance standards (MEPS), and China has MEPS plus an additional comparative label; an industry association in the EU runs a voluntary energy label scheme for chillers. The requirements apply to air-cooled and water-cooled chillers of all capacities except in Canada and New Zealand, which have a limited scope by capacity in kW. Some of these requirements are linked to building codes (USA, France, Australia /New Zealand and UK) and for the EU, regulation applies directly to products as placed on the market.

Policy first on full load efficiency

At first, policy addressed only full load efficiency of chillers, expressed as COP or EER, and whilst some differences between full load tests exist, the differences in measured efficiency are of the order of 5% to 8% for most types and sizes of chiller (though the actual differences seen can vary significantly depending on particular configurations and capacities and can, for example, extend up to 30% and over). But in broad terms, full load COP and EER performance thresholds and market average performance can be compared with caution for policy purposes across the regions considered.

Regarding air-cooled chillers for comfort cooling, the MEPS in the economies reviewed have a relatively narrow range between only 2.5 and 3.0 EER, with the most ambitious MEPS for full load efficiency at 3.0 EER for screw chillers in China and then 2.8 EER for USA and Canada, as shown in Figure S1.

The range of MEPs for water-cooled chillers for comfort cooling is much wider, from 3.0 up to 6.1 (USA and Canada), as shown in Figure S2, with Canada's MEPS for centrifugal chillers being the most stringent in current use at 5.55 and 6.10 at the higher capacity range; and the US for centrifugal the most stringent below 528 kW, at 5.50 EER.

Figure S1. Comparing existing MEPS for air-cooled chillers that are based on full load efficiency (COP or EER).

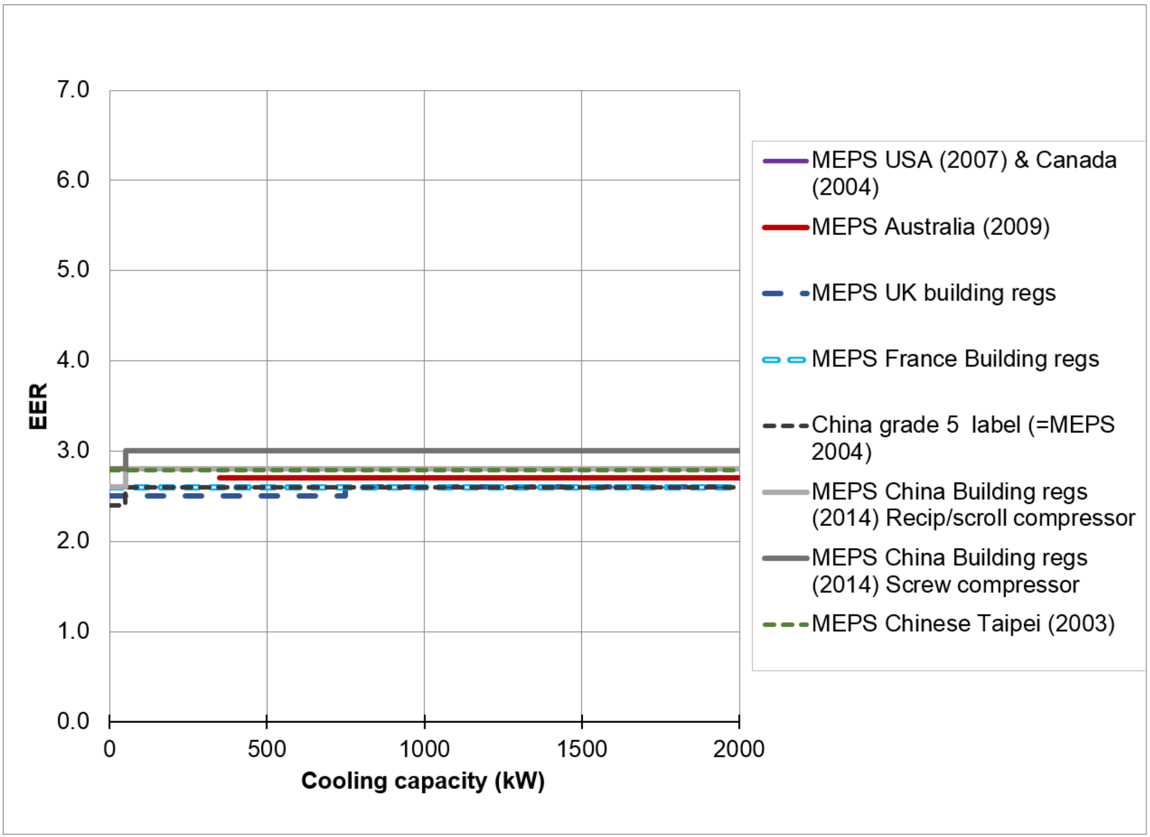
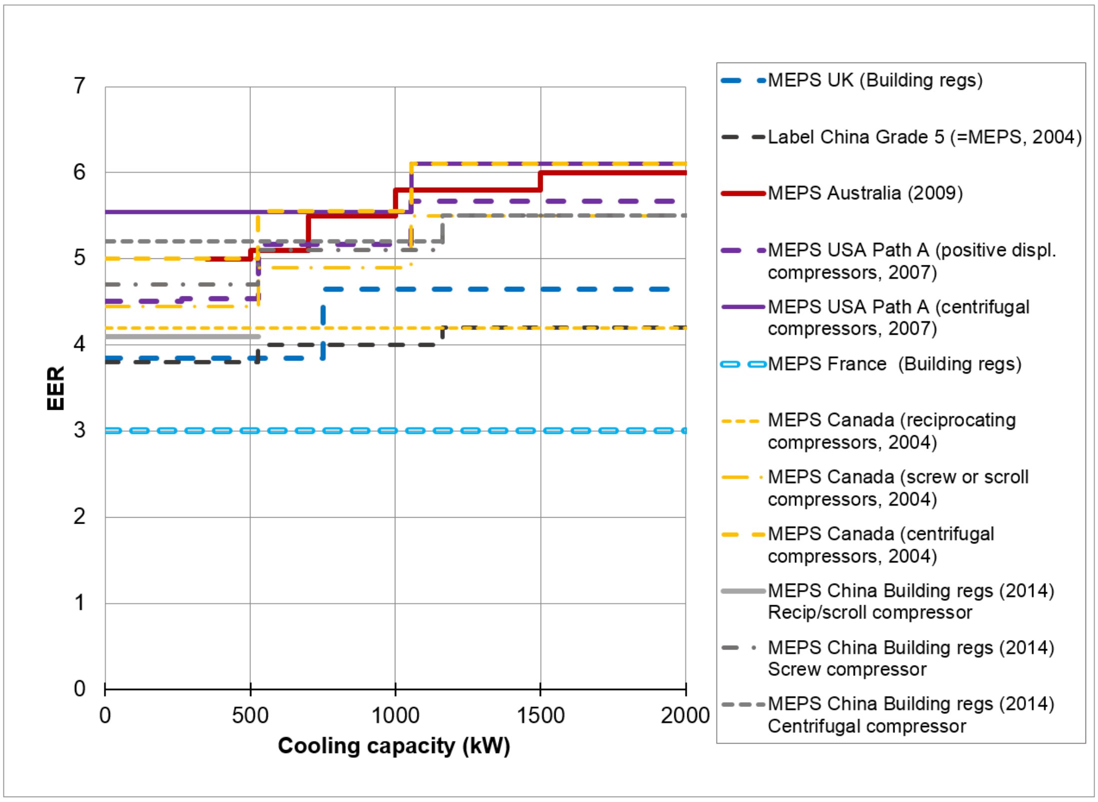


Figure S2. Comparing existing MEPS for water-cooled chillers for comfort cooling applications that are based on full load efficiency (COP or EER).



Policy using seasonal efficiency metrics and divergence of the EU

Full load efficiency does not, however, reflect accurately the efficiency levels generally experienced by users as most chillers, especially in comfort cooling applications, spend much of the year working at part load.

Australia, USA, Canada and China have already adopted MEPS based on the seasonal performance index Integrated Part Load Value or IPLV (Figure S3 and Figure S4). Europe, however, is diverging from other economies and plans to publish standards based on its own, quite different, seasonal energy efficiency ratio or SEER (Figure S5 and Figure S6), which is further differentiated in the regulation as it is expressed as a percentage efficiency in primary energy terms (seasonal primary energy ratio or SPER). The move to standards based on seasonal efficiency is an important trend as this enables comparison of product performance in a way that simulates performance in the field much better than with full load rating standards alone.

But IPLV and SEER or SPER cannot be directly compared (as explained below) and the IPLV of Japan also has different rating conditions compared with the IPLV of other economies. Hence it is only possible to compare US-based IPLV standards:

As shown in Figure S4, air-cooled chiller MEPS range from 3.0 to 4.1, with Australia setting the most stringent requirements. Once again, the range for water-cooled chiller MEPs is much wider, from 4.9 up to 8.8 and centrifugal chiller requirements in the US are by far the most stringent.

The proposed EU requirements are measured using a completely different and non-comparable metric and are shown in Figure S5 for air-cooled and in Figure S6 for water-cooled chillers.

Figure S3. Comparing existing MEPS for air-cooled chillers that are based on seasonal efficiency IPLV.

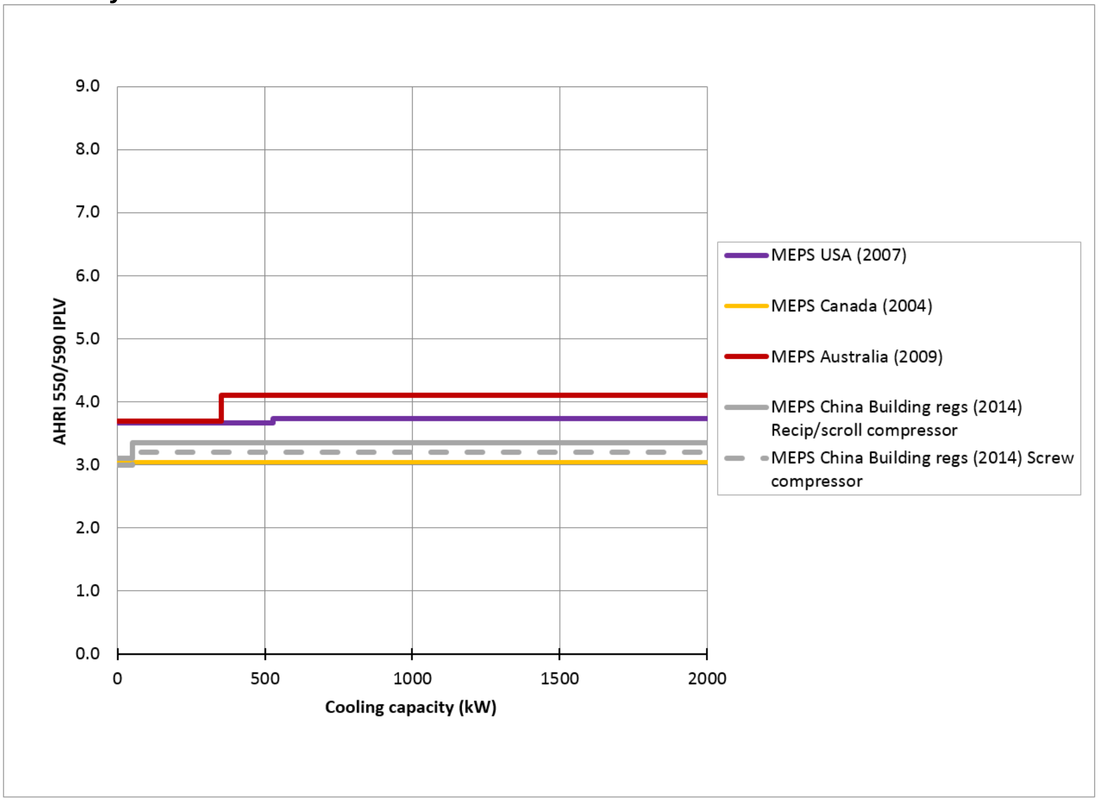


Figure S4. Comparing existing MEPS for water-cooled chillers that are based on seasonal efficiency IPLV for comfort cooling applications.

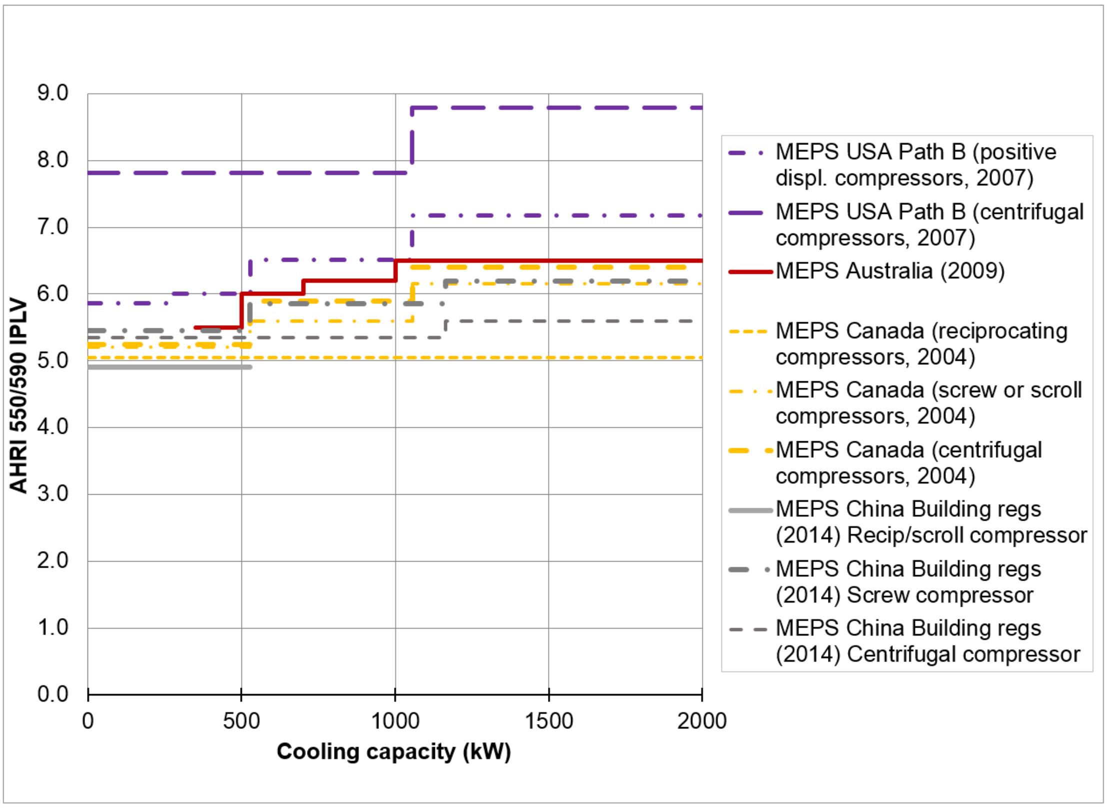


Figure S5. Proposed MEPS for EU air-cooled chillers, seasonal efficiency SEER (expressed as percentage useful cooling efficiency). GWP is the global warming potential of the refrigerant used in the chiller.

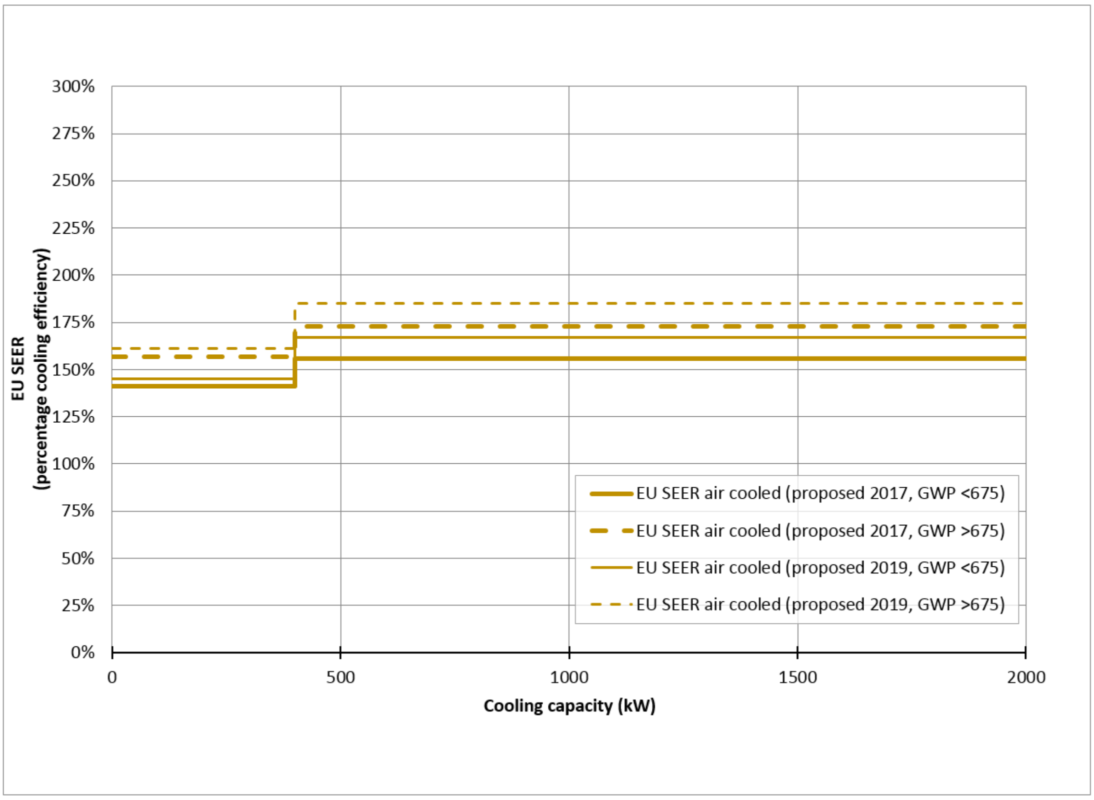
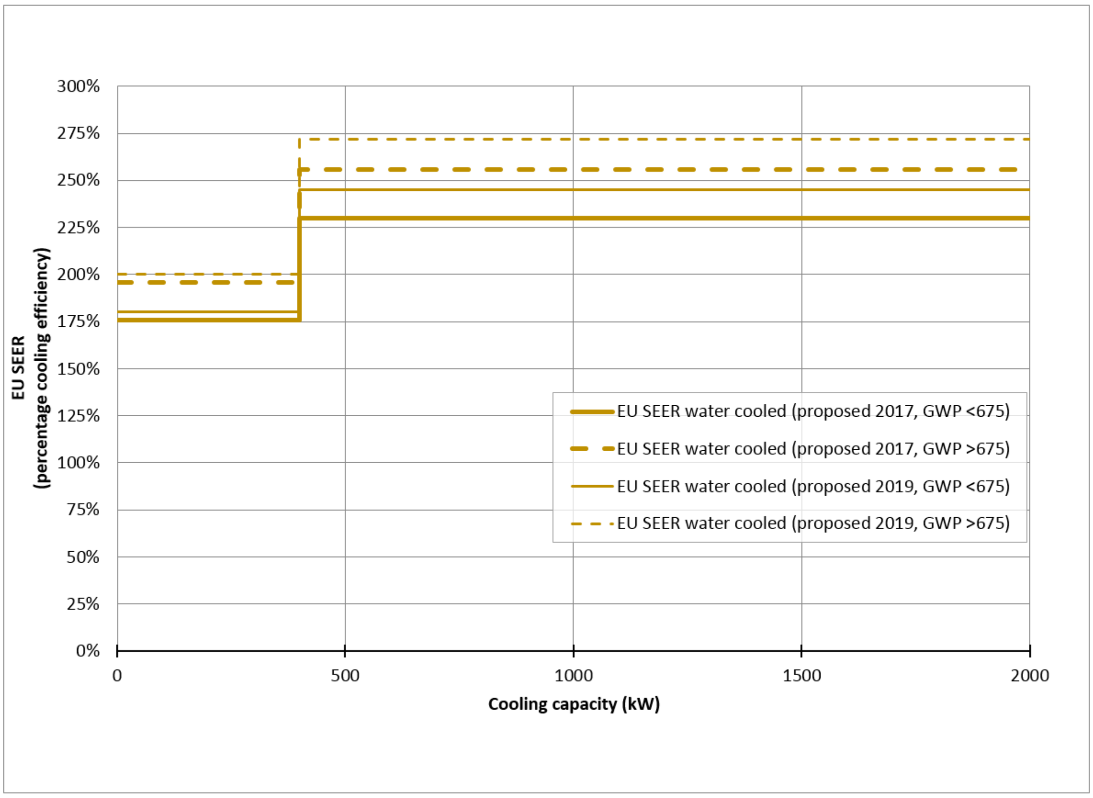


Figure S6. Proposed MEPS for EU water-cooled chillers, seasonal efficiency SEER (expressed as percentage useful cooling efficiency). GWP is the global warming potential of the refrigerant used in the chiller.



Why the EU approach is different to that of the US

In terms of chiller metrics and standards, the EU is now significantly out of line with the rest of the world, which has largely adopted the US approach. Thus, issues regarding the lack of harmonisation revolve mainly around those two economies: the EU and US.

The reasons for the EU metrics diverging from the US and most other economies on seasonal efficiency metrics are complex but rational, given the circumstances. Firstly, there are significant **policy and market-related reasons**:

- Perhaps most fundamentally in policy terms, the SEER metric is one component of a much wider strategy by EU policy makers to adopt internally consistent efficiency metrics for HVAC products that cover heating and cooling and are powered by any fuel source. This results in use of a metric expressed as a percentage (that is usually higher than 100%) called seasonal primary energy ratio or SPER. Conversion of SPER to SEER is possible, but varies slightly by chiller type (but SEER is not comparable with IPLV).
- The EU market is dominated by small to medium capacity air-cooled chillers used mostly only during high outdoor temperatures; the US has far more large water-cooled centrifugal chillers that are used all year round.

- The EU approach is generally technology-neutral and does not set requirements separately by compressor technology, whereas the US, China and others do so for water-cooled chillers.
- Differences in the typical design basis of HVAC systems, with the EU having heated or cooled water distributed throughout the building and the US using mainly ducted air. This also led to the EU market being dominated by reversible heat pump chillers that provide heating and cooling. (In turn, this contributed to the fundamental policy differences noted above).

The **technical reasons** for the differences in the EU approach are several and result in the following gross differences in efficiency rating:

- EU methods are designed to assess the chiller in isolation and include adjustment factors for the energy consumed by fans and pumps that does not specifically contribute to the cooling function (e.g. that which moves air or water through the wider HVAC system); whereas the US approach does not make such adjustments as the requirements are part of building regulations that take account of the wider HVAC system in other ways. This results in differences ranging between 3% and 30% depending upon the unit type and configuration.
- The rating points for seasonal part load assessments are adjusted to climatic conditions in EU, US (and Japan), which causes differences of between 5% and 20% in measured efficiency.
- The EU methods allow account to be taken of low power operational modes and the effect of this is to reduce measured consumption by between 1% and 6% for typical chillers.
- Differences in the treatment of manufacturing and measurement tolerances give rise to differences of up to 2.5%.

These technical factors result in overall differences between IPLV and SEER ratings of between 16% and 38% for most chiller types but the differences are highly inconsistent and variable by chiller type. Therefore, IPLV and SEER cannot be directly compared in policy, market average or any other terms.

Differences in approach for process and other non-standard cooling

There are further differences in approach for chillers used in process cooling or non-standard comfort cooling, for which more time is spent at higher loading levels and in lower ambient temperatures: In the EU, a separate and quite different set of loading and rating points is specified under the metric called seasonal energy performance ratio (SEPR); but in the US (also Canada) such chillers are assessed using the same comfort cooling rating and loading points, however the MEPS are specified at different levels for COP and IPLV, called ‘Path A’ compliance (where the alternative ‘Path B’ is for standard comfort cooling).

Downsides of differences in approach to standards

The lack of coherence of seasonal metrics and standards between EU and the rest of the world means that:

- It is difficult for policy makers to set coherent standards;
- It is extremely hard to set an EU best chiller in the context of best performing chillers from the rest of the world, and to analyse the relative performance of markets;
- More efficient large water-cooled chillers are likely to be found in the USA; more efficient variable speed scroll units (small capacity) are likely to be found on the EU market (as a result of market demand as well as policies);
- There is a practical barrier to trade as exporters or importers must test and certify according to two, or potentially several, standards;
- Standards could end up more demanding in one economy compared to others as differences are not apparent, resulting in different costs to manufacturers of trading in each economy, further divergence and lost energy savings in those with lower standards;
- A barrier exists to setting ambitious, coherent and appropriate energy efficiency policies across all economies.

Making EU/US comparison possible through manufacturers' selection software

The International Organization for Standardisation (ISO) aborted an attempt to develop an international testing standard for chillers (ISO19298) after several years of effort, when it became apparent to participants that few economies would be likely to use it. (The emerging standard was collating a set of rating points, from which users would pick those most suitable to their climate - so results would still not be truly comparable).

There is good prospect, however, of ensuring much wider availability of performance data in standard formats and according to any necessary metrics as almost all manufacturers now provide chiller selection software for specifiers. Indeed, AHRI (Air-Conditioning, Heating and Refrigeration Institute) and other certification systems now focus on certifying the manufacturer's chiller selection software and not directly the performance of individual chillers. The software can provide seasonal metrics and in most cases can deliver a full performance map of the unit in a tabulated format. If manufacturers' software is set up to provide IPLV and SEER metrics in standard formats, then comparisons could be made of typical product performance against the regulatory requirements of the US, EU and other economies and relative stringency and market performance could be benchmarked.

Possible ways forward

Adapting selection software to deliver data in the different metrics and in standard formats appears to be the obvious and potentially least cost route to facilitate the comparison process.

In the medium term, there are options to include better approaches in mandatory information requirements, perhaps such that manufacturers in the EU and Japan publish data at standard IPLV rating points, as well as using SEER and IPLV at Japan's rating points (exporters would almost certainly be generating this data already). This would make possible the necessary policy and market analysis at suitable intervals. Also, steps to encourage greater cooperation between industry and technical standards groups in the US and EU would be useful (with AHRI and Eurovent and between ASHRAE and CEN/CENELEC), and between policy makers (perhaps via the US/EU cooperative agreement for policy makers on ecodesign).

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2 Introduction

This is a project report for the IEA 4E Mapping and Benchmarking initiative regarding packaged liquid chillers. Following initial research in 2014, it was agreed that conventional IEA 4E mapping and benchmarking analysis of COP and EER for chillers would be of little relevance to new policy and that the seasonal (part load) metrics IPLV (of the US) and SEER (of the EU) are not currently comparable.

This project aims to compare standards where possible but importantly to understand the status of, and barriers to, harmonisation. It also examines the motives and pathways to better comparability of market average performance and regulatory stringency between economies. The focus is on product policy standards, rather than building codes that generally deal with the wider HVAC system – even though some building codes also set standards for components (such as ASHRAE 90.1).

This report covers the mapping of policies and test methods; barriers to harmonisation; impacts, incentives and routes to closer harmonisation.

3 Scope of products included in analysis

The rationale for the scope of products included in this analysis is given in the document Product Definition for Packaged Liquid Chillers, V1.0, 9 January 2015. In summary, the definition is:

> *'A factory-built and prefabricated piece of refrigeration equipment that is primarily intended to cool down and maintain the temperature of a liquid by means of an electrically driven vapour compression cycle within a refrigeration process, including at least a compressor and an evaporator within a "package". The chiller may or may not integrate the condenser, the coolant circuit hardware and other ancillary equipment.'*

Intended applications:

- For comfort cooling in central air conditioning plant
- For commercial, industrial and process cooling applications on 'high temperature' applications

Included types:

- Includes chillers defined as 'high temperature'* (equivalent to temperatures used for comfort cooling)
- With both air-cooled and water-cooled condensers
- Reversible heat pumps are included within scope on equal terms, but only to assess their cooling performance.

Excluded types:

- low temperature, medium temperature and floor cooling applications*
- chillers exclusively using evaporative condensing
- bespoke chillers (i.e. those assembled on site or designed for a specific application)
- chillers using absorption or adsorption technology
- chillers using engines to run the compressor.

* Where temperature ranges are defined as:

- ‘Low temperature’ means that the process chiller is capable of delivering its rated cooling capacity at an indoor heat exchanger outlet temperature of -25°C at standard rating conditions (also called 'low brine') with leaving brine temperature between -8°C and -25°C
- ‘Medium temperature’ at -8°C, also called medium brine, with leaving brine temperature between + 3°C and - 12°C
- ‘High temperature’ at +7°C, also called air conditioning chillers, with leaving chilled water temperature between + 2°C and + 15°C.
- Floor cooling with a cooling temperature at the outlet of +18°C.

Notes:

1. High temperature industrial process chillers are very similar to air conditioning chillers in terms of temperature range and engineering principles. But because process chillers generally have much higher annual usage hours, many differ in specifics of control and efficiency features: industrial users often choose to invest more in efficiency and reliability due to much higher usage factor and consequences of failure.
2. High temperature process chillers account for about 20% of overall high temperature chiller unit sales in Europe, and because they are typically larger than comfort cooling chillers, process chillers account for around 35% of annual capacity sales.

4 Comparing test methodologies in use

4.1 Previous study comparing chiller standards

The CLASP study *Improving Global Comparability of Appliance Energy Efficiency Standards and Labels* (September 2014) did briefly review the situation regarding the comparability of chiller standards around the world, amongst 100 other products. That study noted that test procedures and metrics for chillers vary widely, performance also varies with climatic conditions and the study was unable to determine any adjustment factors to render test results even indicatively comparable.

4.2 List of test methodologies

Information available on the various test methods is summarised in Table 1, in terms of scope, compressor type and capacity limitation. Note that heat reclaim units are integrated both in the USA and in the EU while thermo-syphon (also known as ‘free cooling’) is excluded in both cases.

Standards for the EU and the USA are readily available for analysis; standards for the other countries have been evaluated through other published papers or summary translations, as the full national standards were not available to the authors.

The test methodologies identified below are in use. Note: *Annex 5. Further details of policies in each economy* is mainly focused on policies but also provides some further information about test methods:

Europe:

- EN 14511-2013 *Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling.* This is the basis for cooling and heating capacity and calculation of EER.
- Calculation of the European Seasonal Energy Efficiency Ratio (ESEER) for comfort cooling applications from the Eurovent-Certita certification company *Certification program for liquid chilling packages*[1]. The formula for calculating the ESEER has the same format as that for IPLV, but the factors used are different and it includes different climatic conditions in Europe compared with those typical in the US. Note that the ESEER values have been changed to adapt to the EN14511 standard conditions in 2012 (inclusion of corrections for pump and fan pressure losses compensation, c.f. section 4.3.1).
- Calculation of Seasonal Energy Efficiency Ratio (SEER) for comfort cooling applications from EN 14825-2013 *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*. This is also the accepted standard for draft chiller regulations[2] but it is not yet used by the industry (at least until the upcoming European regulation for chillers is published). Until then, and since 2004, the industry uses ESEER.
- Calculation of Seasonal Energy Performance Ratio (SEPR) for industrial process cooling applications from the document published by the Joint Industry Expert Group of the European Partnership for Energy and the Environment (EPEE) *Transitional method for determination of the SEPR (Seasonal Energy Performance Ratio) for chillers used for refrigeration and industrial applications*[3]. SEPR is calculated in an identical way to SEER, but with higher average loading over the year and assumes equal usage during the whole year, in all ambient temperatures.

USA:

- AHRI 550/590-2011 *Performance Rating of Water Chilling Packages Using the Vapor Compression Cycle* test method for electrically operated water chilling packages. This standard defines the calculation and test method for the COP full load and IPLV seasonal performance indicators.

Canada:

- CSA-C743-02 *Performance Standard for Rating Packaged Water Chillers*[4]. It is thought to be identical to the AHRI 550/590 standard, because the MEPS requirements are the same as in the ASHRAE 90.1 standard. But the standard is not available to the authors.

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[1] Available at http://www.eurovent-certification.com. Accessed January 31 2015.
[2] See Draft EU regulation COMMISSION WORKING DOCUMENT, implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for air heating products, cooling products and high temperature chillers, July 2013.
[3] Document prepared in support of the draft EU ecodesign regulation for chillers, version of 20 September 2013. Available from: http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/product-groups/freezing/chillers/index_en.htm
[4] Additional information available at http://www.csa-intl.org

Australia:

- AS/NZS 4776-2008 *Liquid-chilling packages using the vapour compression cycle*:
    - Calculation of the US AHRI[5] COP and IPLV seasonal performance indicator 4776.1.1 Part 1.1: *Method of rating and testing for performance—Rating*
    - Method for testing of the US AHRI COP and IPLV seasonal performance indicator 4776.1.2 Part 1.2: *Method of rating and testing for performance—Testing*
    - Australia authorizes manufacturers certified according to Eurovent or AHRI certification programs to use the declared performance values for COP and IPLV minimum performance standards. The MEPS values and compliance are explained in this substandard, part 4776.2 Part 2: *Minimum energy performance standard (MEPS) and compliance requirements*

Japan:

- Method of calculation of testing of the EER and IPLV (rating conditions of the US IPLV AHRI standard are adapted to Japan's climate conditions) are defined in JIS B 8621: 2011 (JRAIA/JSA) *Centrifugal water chillers* (which covers water-cooled centrifugal chillers with rating capacity above 350 kW) and JIS B8613: 1994 *Water Chilling Unit*. A Japanese standard that covers positive displacement chillers has not been identified.

China:

- Minimum allowable values of the energy efficiency and energy efficiency grades for water chillers GB 19577-2004 *Minimum allowable values of the energy efficiency and energy efficiency grades for water chillers*. This standard defines the COP and IPLV indices but the exact rating conditions used could not be verified. Minimum requirements are defined for COP only. However, the Chinese building codes, GB50189-2005 and 2014 (standard for commercial buildings in China (equivalent to US ASHRAE 90.1)) require both minimum COP and IPLV values. According to Feng et al 2014, COP and IPLV values are directly comparable to US AHRI 550/590:2011 COP and IPLV ones.

Chinese Taipei:

- Chinese national standards of Chinese Taipei[6] CNS 12575: 2004 *Water chilling unit* and CNS 12812: 2004 *Centrifugal water chiller*.

Republic of Korea:

- No specific chiller standard has been identified.

[5] AHRI: Association of Heating and Refrigeration Industries.
[6] Standards are published by Chinese national standard of Chinese Taipei.

Table 1. Comparison of characteristics of international chiller performance test standards.

		SCOPE			COMPRESSOR TYPE		CAPACITY LIMITS			ENERGY EFFICIENCY PARAMETERS				TOL.
Region / country	**Standard**	Air-cooled	Water-cooled	Evaporatively-cooled	Centrifugal	Positive displacement	For air-cooled	For water-cooled	For evaporatively-cooled	Full load ratings	Seasonal ratings	Correction for fans / pumps	Inclusion of low power modes in seasonal ratings	Inclusion of tolerances
EU	EN14511	x	x		x	x				x		x	x	
EU	EN14825	x	x		x	x					x	x	x	
EU	Eurovent	x	x		x	x					x	x		
EU	SEPR	x	x		x	x					x			
Australia / New Zealand	AS/NZS 4776	x	x		x	x	>350 kW	>350 kW		x	x			x
USA	AHRI 550/590 (2)	x	x	x (1)	x	x				x	x			x
Canada	CSA-C743-02	x	x	x	x	x				x	x			x
Japan	JIS B 8621		x		x			>300 kW		x	x	(un-clear)		x
Chinese Taipei	CNS 2575		x			x		x		x				
Chinese Taipei	CNS 2812		x		x			x		x				

(1) Evaporatively-cooled condensers are included in the standard but not in the certification program

(2) The standard does not specify capacity limits but the certification program does.

4.3 The differences between test methods

We focus here on air-cooled and water-cooled package chillers which are the most common products on the market. (Evaporatively-cooled chillers are not considered).

In overview, most countries investigated have adopted the US COP and/or IPLV performance indicators that are defined in ASHRAE 90.1 (Australia, New Zealand, Canada, Chinese Taipei), or plan to do so (in the case of China), although sometimes with adaptation of the rating conditions to suit local climate and/or usage (in the case of Japan). One remaining difference on full load metrics is that the USA and other economies based on the US standard do not include the corrections for fan and pump pressure losses that are included in the EU metric.

Australian and New Zealand regulations adopted USA full load COP and part load IPLV, but for chiller certification they recognise both the USA AHRI and EU Eurovent certification schemes for their regulatory registration database (E3, 2007). For certified chillers, manufacturers are exempted from presenting a test report. Declared values can be used to show compliance with MEPS requirements.

Regarding seasonal performance indicators, Europe is diverging from the widely adopted reference US IPLV, as Europe is progressively building its own set of standards for different products (first with air conditioners and air source heat pumps and more recently, chillers and water-based heat pumps).

The main differences between test methods and their impacts on measured efficiency are the following, in descending order of impact:

- Part load rating conditions: differences in overall IPLV and SEER vary across typical chillers by between 16% and 38%;
- Full load rating conditions: the net impact of differences in full load efficiency values has not been estimated in detail ; it is thought to be low (lower than measurement tolerances) except for fan and pump corrections for high efficiency water-cooled chillers where it may well reach 15 % (Rivière et al., 2012), see section 4.5.1.

Within those broad impacts, the following specific issues and impacts are identified:

- Fan and pump pressure losses corrections: likely impact ranging between 3% and 30% depending on the specific unit (up to 15 % at full load), this makes a large difference under part load conditions (see *Annex 4. EU fan and pump pressure losses corrections*);
- Seasonal performance calculation methods and weighting coefficients (for comfort cooling and for process or non-standard applications): likely impact ranging between 5% and 20% depending on the specific unit;

- Inclusion of low power modes in the EU: For the calculation of the EU SEER,[7] the annual electricity consumption includes the power consumption during active mode, thermostat-off mode, standby mode, off mode and that of the crankcase heater (see *Annex 2: Calculation of energy consumption in low power modes*). The US IPLV method does not take low power modes into account. Likely impact ranging between 1% and 6% depending on specific unit;
- Tolerances: likely impact ranging between 0 and 2.5% depending on the manufacturer policy (see *Annex 3. Estimation of the impact of tolerances on declared efficiency data*).

The approaches to full load and to part load efficiency rating, and to calculation of seasonal efficiencies are considered in the sections that follow.

4.3.1 Full load rating conditions

The standard rated Energy Efficiency Ratio (EER) used for energy efficiency comparison at full load has the same definition for all standards: EER is the ratio of the cooling capacity to the power input of the unit. In the USA and in Australia it is called coefficient of performance (COP). Both EER and COP are expressed in W/W (or Btu/hr/W in the USA, which is easily converted to W/W).

EER or COP correspond with the efficiency at the maximum cooling capacity that the unit can deliver at given source conditions. The standard rating conditions used vary slightly between the USA (ARI standard 550/590-2003) and in Europe, as shown in Table 2, and are close to ISO reference temperature points.[8]

However, in the latest version of the US ASHRAE 90.1 standard (2011), the standard rating conditions have been aligned[9] for air-cooled and water-cooled chillers; evaporator and condenser water flow rates have been adjusted to reach 5 K temperature difference across the heat exchangers and leaving temperature set points have been aligned to 7°C outlet at the evaporator and 30°C inlet at the condenser.

It still remains the case that Japan, and probably Middle-Eastern countries may use different standard full load rating conditions because of their specific climate and/or design habits.

[7] From EN 14825-2013 *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*.
[8] As defined in air conditioner and heat pump standards (ISO, 1998), (ISO, 2010), (ISO, 2011).
[9] It is likely that regional standards published before 2011 (probably AS/NZS 4776 and Taiwan) still use US standard rating conditions of before 2011.

Figure 1 and Figure 2 show how the COP of AHRI 550/590 is defined, as compared with the EER of EN 14511:2013. The basic definitions of 'Net refrigerating capacity' (box A) and 'Total cooling capacity' (box E) are very similar, but the differences lie in the adjustments to those basic capacities (boxes B, C and F). In addition, the electric power input of the chillers is defined from specific components under EN 14511 (box G) but is the total of all inputs under AHRI 550/590 (box D). The overall impact of these differences is an accumulation of the impact of the separate differences, which include rating conditions, fan/pump pressure corrections, calculation methods and tolerances.

Table 2. Standard rating conditions for EER or COP according to AHRI 550/590-2003, EN14511: 2013, JIS B 8621:2011. Also according to the draft ISO PWD 19298:2007 which was abandoned by ISO before completion.

	Condenser			Evaporator	
	Air-cooled	Water-cooled		Chilled water inlet temperature	Chilled water outlet temperature
	Air inlet temperature	Water inlet temperature	Water outlet temperature		
EN14511 (2013)	35°C	30°C	35°C	12°C	7°C
US : AHRI 550/590 (2003)	35°C	29.4°C	No specific temperature (but condenser flow rate 0.054 L/s per kW)	(Evaporator flow rate 0.043 L/s per kW)	6.7°C
JIS B 8621[10] (2011)	N/A	32°C	37°C	12°C	7°C
Draft ISO PWD 19298 (2007) (abandoned standard)	Low 27°C Med 35°C High 46°C	Low 28°C Med 30°C High 32°C	Low 33°C Med 35°C High 37°C	12°C	7°C

[10] Source : http://www.hitachi-ap.com/products/business/chiller_heater/centrifugal/higher_spec.html

Figure 1. Calculation of COP_R from AHRI 550/590-2003 (for the US and Canada plus many other economies).

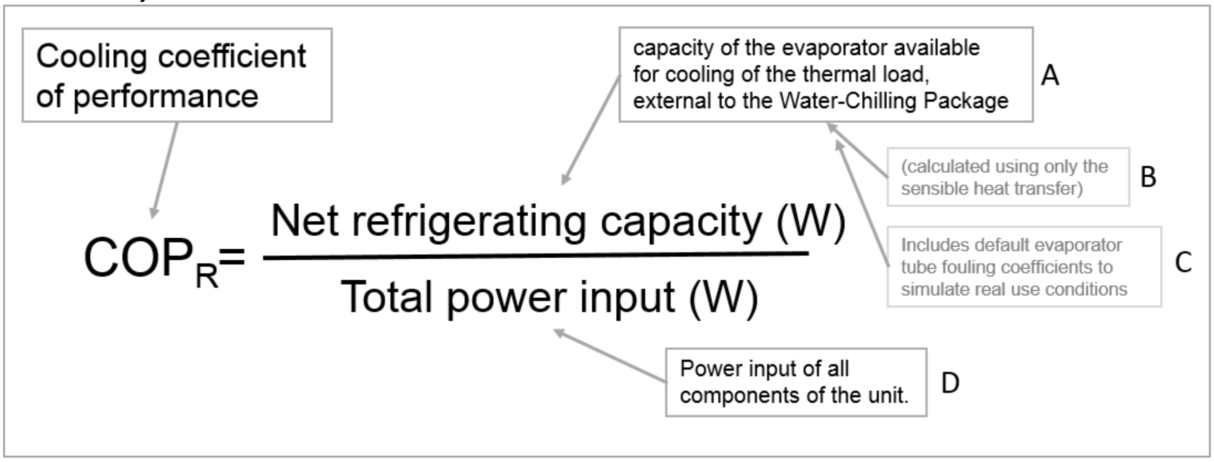
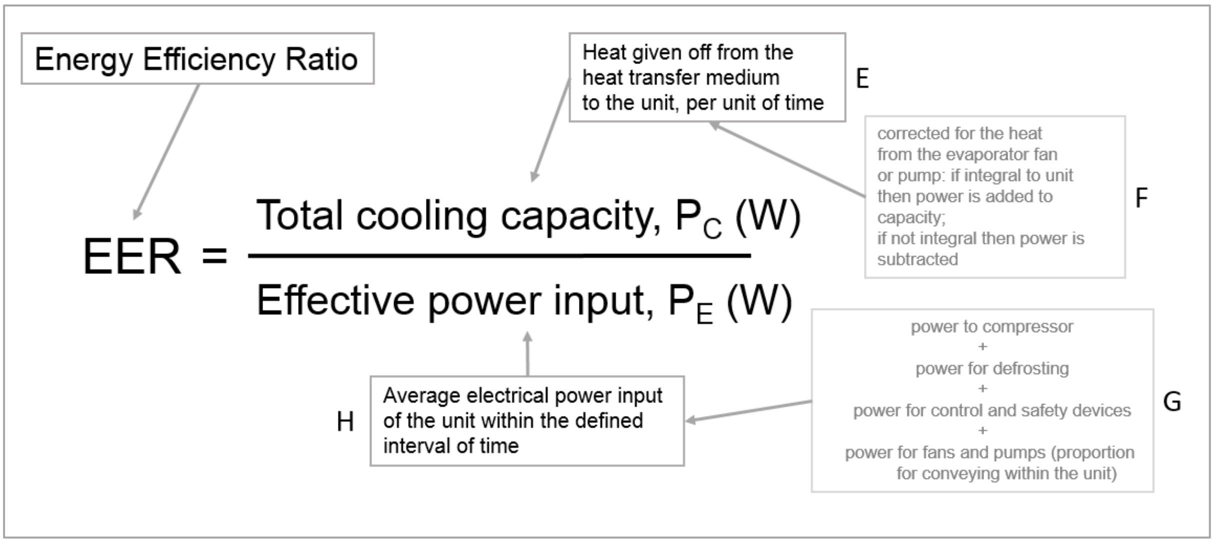


Figure 2. Calculation of EER from EN 14511:2013 (for the EU).



4.3.2 Part load rating conditions

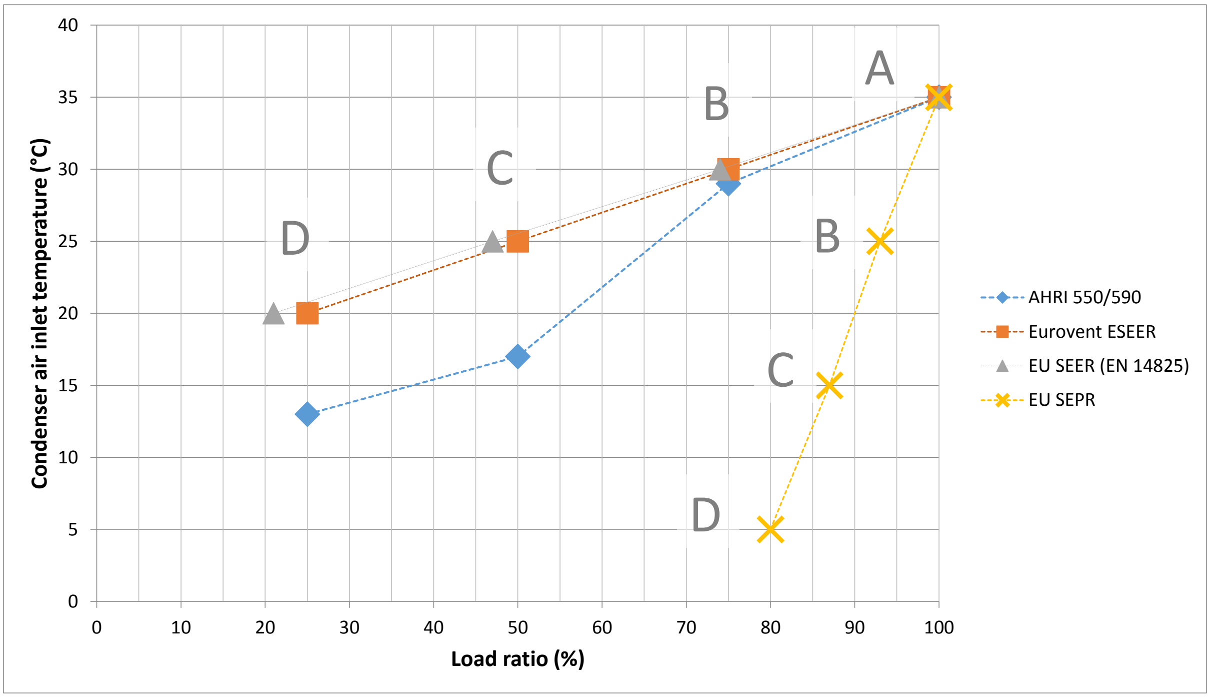
In all standards that cover seasonal performance, the standard seasonal rating is based on part load ratings at different cooling loads and outdoor temperatures (or of condensing water temperatures for water-cooled chillers). These different rating points are usually referred to as rating points A, B, C and D.

These load curves and part load rated conditions are shown in Table 3[11] and illustrated graphically in Figure 3 for the different seasonal performance standards AHRI 550/590 IPLV, Eurovent ESEER, CEN 14825 SEER and EU SEPR, both for air-cooled and water-cooled chillers. Table 3 also includes a description of the applications for which each set of rating points are appropriate.

It should be added that it is not only the part load rating conditions that will influence the seasonal performance ratings, but also the testing and interpolation methods used to measure/calculate the EER for each of the four rating points, which slightly differ in the different methods.

[11] JIS B 8621 seasonal performance calculation method and testing points could not yet be identified.

Figure 3. Visual representation of part load rating conditions (varying condenser inlet and load ratio) of air-cooled chillers (above) and water-cooled chillers (below) in international standards.



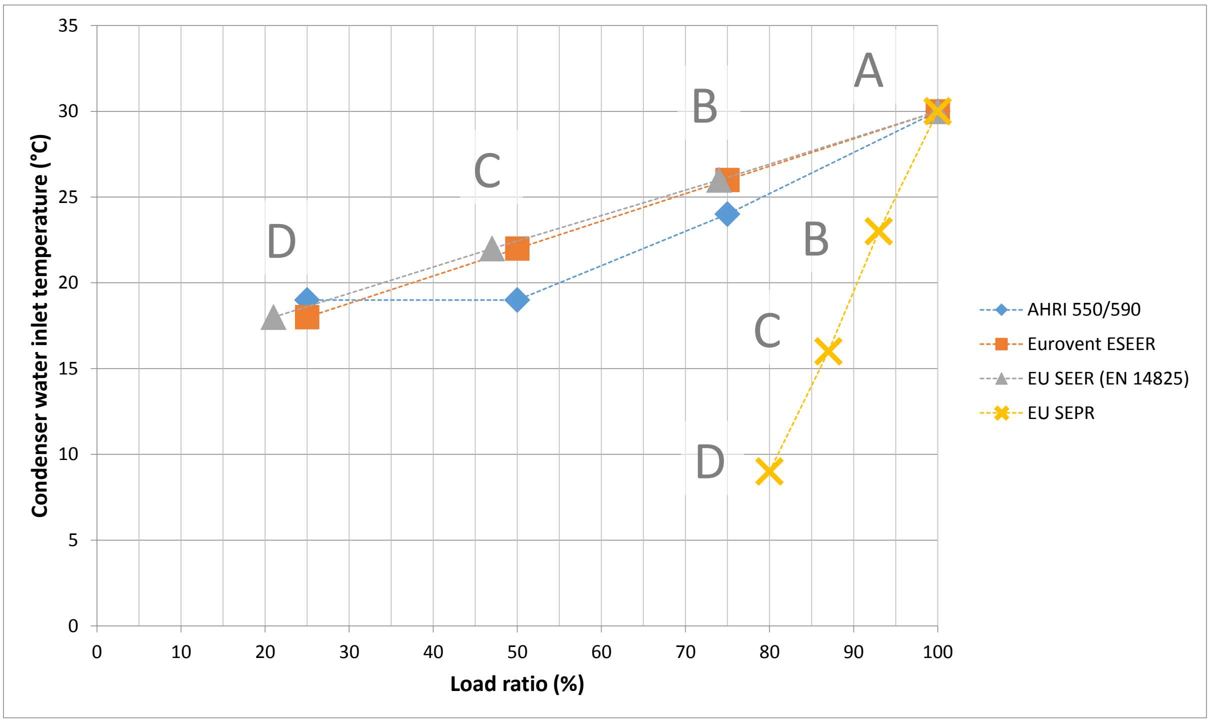


Table 3. Part load rating conditions (varying condenser inlet and load ratio) of air-cooled and water-cooled chillers in international standards - tabulated values. These are shown graphically in Figure 3.

	Rating point label	Load ratio in %	Inlet air temperature in °C	Inlet water temperature in °C	Load weighting (% of year assumed to be spent in each condition)	Indicative reason for the stated load and temperature profile
AHRI 550/590	D	25	13	19	12%	Used for comfort cooling applications so highly variable loading down to 25% - reflects variation in ambient temperatures during a typical year. Temperatures reflect typical US conditions.
	C	50	17	19	45%	
	B	75	29	24	42%	
	A	100	35	30	1%	
Eurovent ESEER	D	25	20	18	23%	Used for comfort cooling applications so highly variable loading down to 25% - reflects variation in ambient temperatures during a typical year. Temperatures reflect typical EU conditions.
	C	50	25	22	41%	
	B	75	30	26	33%	
	A	100	35	30	3%	
EU SEER (EN 14825)	D	21	20	18	N/A (calculated from bin data, i.e. temperature / hours profile	Used for comfort cooling applications so highly variable loading – profile reflects variation in ambient temperatures during a typical year. Temperatures reflect typical EU conditions.
	C	47	25	22		
	B	74	30	26		
	A	100	35	30		
EU SEPR[12]	D	80	5	9	N/A (calculated from bin data, i.e. temperature / hours profile)	Used for industrial and process applications so has high load ratios, reflecting the typical way in which process loads occur, also operation all year, including in winter.
	C	87	15	16		
	B	93	25	23		
	A	100	35	30		

4.3.3 Seasonal performance calculations for comfort cooling applications

Once chiller performance at the four rating points (A, B, C and D) is evaluated, these must be weighted to derive a single annual (or ‘seasonal’) performance indicator. There are two methods, both developed by the USA: IPLV method and simplified bin method.

The **IPLV method** appears simpler and requires only the weighting of four performance points according to pre-set hours per year spent at each point. (The four

[12] The SEPR profile may prove useful later on in this study and that is why it is reported here. However, there is no need to compare/harmonize this profile to the standard air conditioning SEER or ESEER profiles.

points were originally derived from a bin method analysis to derive typical load and hours per bin, but now the four points and weightings are simply used).

In the **simplified bin method**, it is necessary to model the performance between the four performance points for each temperature bin (an example temperature bin is shown in Table 4). The EU adopted this more complex method because the heating mode is also included in the EN14825 standard and the simplified bin method can accommodate the non-linearity in performance introduced by the backup resistance heater, for heat pumps in heating mode; this was impossible to do with the IPLV method.

Further details of these two methods are shown in *Annex 1. Further details of calculation method for IPLV and simplified bin method* The EU adopted the simplified bin method for both air conditioners and chillers.

Table 4. Example of temperature bin table. Bin number j, outdoor temperature Tj in ºC, number of hours per bin hj and part load ratio corresponding to the reference cooling season planned for chillers in Europe (EC, 2013a).

j #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Tj °C	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
hj h	205	227	225	225	216	215	218	197	178	158	137	109	88	63	39	31	24	17	13	9	4	3	1	0
Part load ratio	5%	11%	16%	21%	26%	32%	37%	42%	47%	53%	58%	63%	68%	74%	79%	84%	89%	95%	100%	105%	111%	116%	121%	126%

4.3.4 Seasonal performance calculations for process and non-standard cooling profiles

IPLV and the simplified bin method described above are suitable for comfort cooling chillers that are used predominantly during high ambient temperatures and with highly variable loading (i.e. with a standard air conditioning usage profile). This is in contrast with process cooling loads and other non-standard chillers that may be used all year long, and so also in low ambient temperatures, with a high load ratio for much of the year. The approaches of the US and the EU differ significantly for process applications:

- In Europe, the seasonal energy performance ratio (SEPR[13]) profile is used to rate the performance of process chillers that are used all year and at 80% loading and higher (see Figure 3, Table 3 and section 4.2).
- In the USA, the same metrics are used both for comfort cooling chillers and for process chillers and non-standard comfort cooling applications; both use standard rating full load COP and IPLV *at comfort cooling conditions*. However, to recognise the fact that different applications require chillers optimised in different ways, the US regulations offer two routes to qualify[14]:

[13] The name SEPR was selected only to make it distinct in name from SEER.
[14] ASHRAE 90.1-2010 – *Energy Standard for Buildings except Low-Rise Residential Buildings*, published by ASHRAE.

- ‘Path A’ requires a lower IPLV performance and higher COP (full load) performance. This is intended for process cooling and non-standard comfort cooling applications that spend more of their time close to full loading;
- ‘Path B’ requires higher IPLV (part load) performance and lower COP performance. ‘Path B’ is intended for standard comfort cooling applications that have highly variable loading.

The MEPS levels for Path A and Path B are shown in Table 12 on page 70. Canada is proposing to adopt MEPS with Path A and Path B but these were not in effect at March 2015.

4.4 Quantifying the impact of differences between standards

4.4.1 Description of the model used to quantify impacts

In order to attempt to quantify the impact of these differences, a model of chiller performance is useful that was developed under the ENTR Lot 6 preparatory study (Rivière & al., 2012). Typical products per chiller category were configured from options available in manufacturers’ catalogues in order to derive LCC analysis on the various options, whilst looking for cost-effective policy options to improve chiller energy efficiency. For these chillers, US and EU seasonal indices were calculated, as well as the impact of the pressure losses correction and of the low power modes. This provided an indicative analysis of the impact of some aspects: simplified performance curves were derived based on full load EU manufacturer data and ESEER figures; in some cases, IPLV values were also available. This enabled detailed performance models to be made for the base cases. As part of the Lot 6 study, improvement options were evaluated for impact on ESEER using the public database of ESEER values from Eurovent Certification and on more detailed analysis provided by some manufacturers. For each option, the performance curves of the base case were modified to reflect the performance increase and an IPLV could be computed. This model provides the comparative SEER, ESEER and IPLV data shown in the figures of this section.

4.4.2 Overall comparison of IPLV, SEER and ESEER metrics for the same chillers

In Table 5 and in Figure 4, the three different seasonal performance indices are compared for typical comfort cooling chillers and highest efficiency models. Values are only indicative of the absolute importance of the differences and of the variations across models. The relative sizes are shown as ratios to the SEER values in Figure 5.

The broad conclusions that can be drawn are that:

- Typical ratios of $ESEER_{gross}$ versus $SEER_{net}$: the difference encompasses pressure and fan corrections, an adapted seasonal performance calculation method and the low power modes; the differences vary widely across chiller type and efficiency from about 8% to 26% and may be larger in case of higher than median pressure losses at heat exchangers.

- Typical ratios of IPLV versus $SEER_{net}$: the main difference with the comparison above is the climate which gives more weight to lower condensing temperatures; this leads to ratios to $SEER_{net}$ values ranging from 16% to 38%.

The magnitude of the differences and the variability of those differences show that it is very difficult to compare or benchmark seasonal performance indices. Adjustment cannot be done using simple coefficients of conversion as even when broken down as in Table 2, the factors are not robust and the full product range is not sufficiently covered.

Table 5. Estimated impact of the differences in EU and US seasonal metrics for specific example configurations of chillers for comfort cooling, as illustrated in Figure 4, adapted from (Rivière & al., 2012).

		$ESEER_{gross}$		IPLV	
	$SEER_{net}$	Value	Ratio to $SEER_{net}$	Value	Ratio to $SEER_{net}$
Air-cooled 100 kW	3.4	3.7	110%	3.9	116%
Max efficiency air-cooled 100 kW	4.5	5.0	112%	5.5	123%
Air-cooled 400 kW	3.5	3.8	108%	4.1	118%
Max efficiency air-cooled 400 kW	5.3	5.8	109%	6.4	121%
Water-cooled 100 kW	4.3	5.2	121%	5.6	131%
Max efficiency water-cooled 100 kW	5.5	6.9	126%	7.4	135%
Water-cooled 1000 kW	5.1	5.7	113%	6.1	121%
Max efficiency water-cooled 1000 kW	8.0	9.6	120%	11.0	138%

Figure 4. Comparison of SEER, ESEER and IPLV calculated for standard types of chiller.

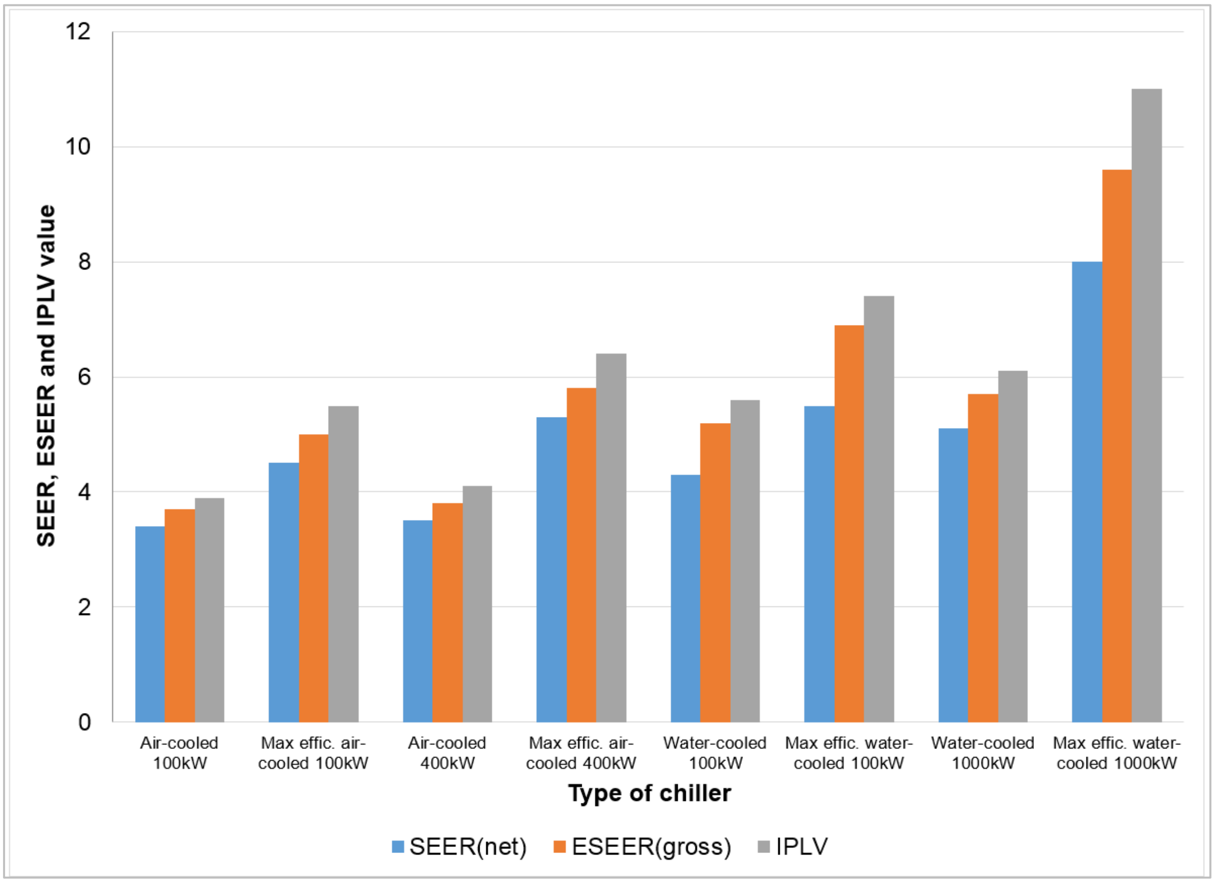
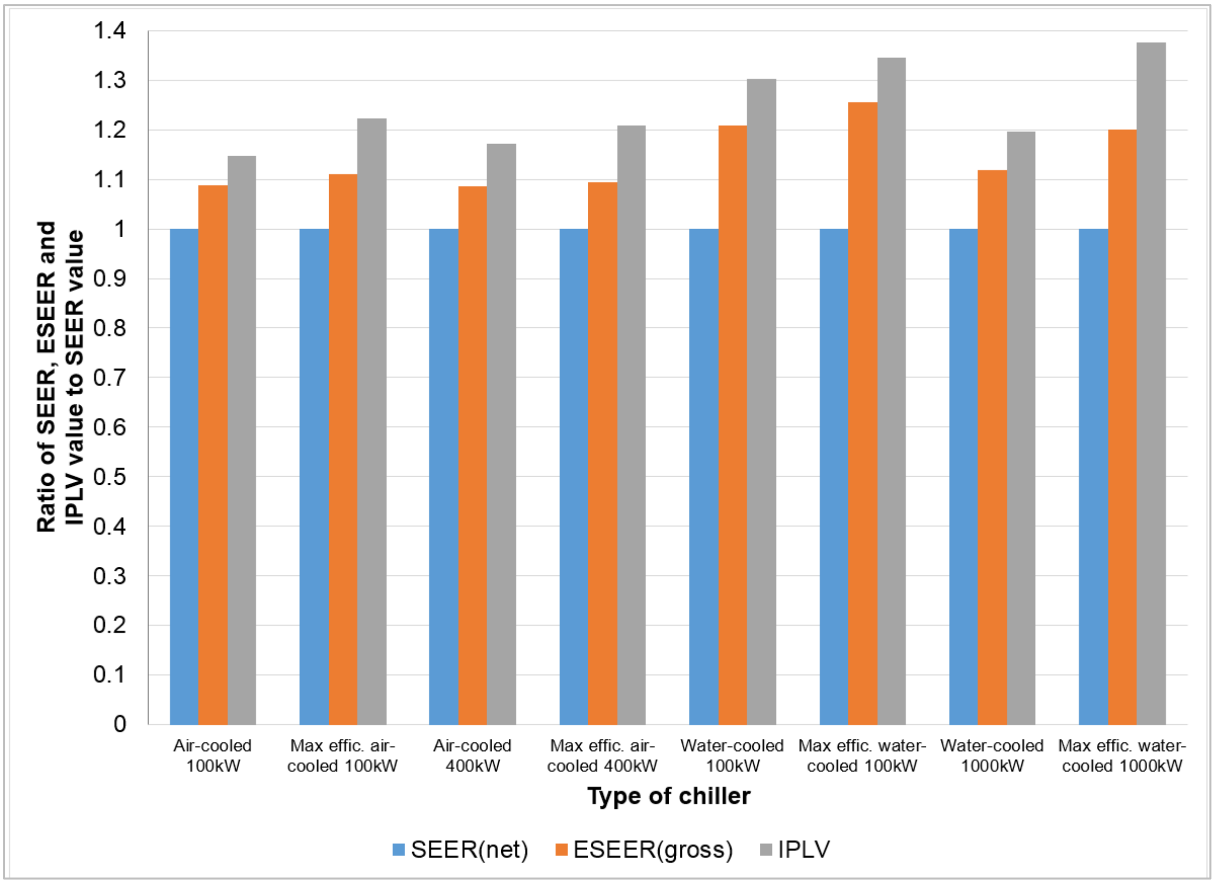


Figure 5. Ratio to compare SEER with ESEER and with IPLV, as calculated for standard types of chiller.



4.4.3 Quantification of impact of seasonal efficiency calculation methods, fan/pump pressure loss corrections and inclusion of low power modes

Table 6 and Figure 6 show results derived from the Lot 6 model to quantify the impacts of these issues on the measured efficiency.

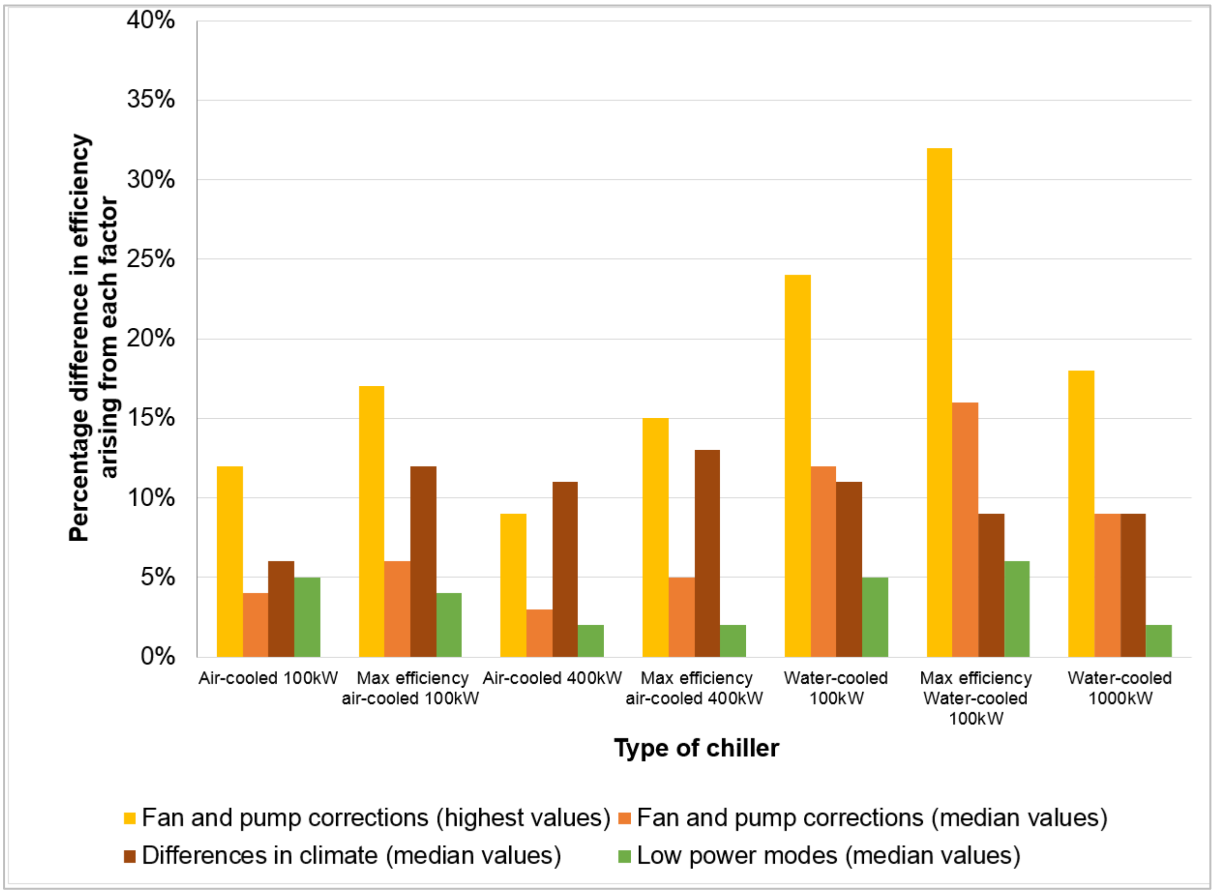
As with the overview in the preceding section, this analysis cannot account for variability across the whole product range and so must be seen as indicative only. However, it appears that the most significant factors to take into account are, first, the impact of fan and pump corrections and, second, the difference in climate/load curve conditions between Europe and the USA. Indicative values are given on the impact of low power modes in Table 6 below: their impact is considered low, but there is little other information available.

Table 6. Estimated increase in seasonal performance versus $SEER_{net}$ when not accounting for fan and pump and low power modes correction and when changing from EU to US seasonal performance metrics, adapted from (Rivière & al., 2012).

		Fan and pump corrections (*)		Low power modes	Differences in part load ratings and in seasonal metrics
	SEERnet	Median	High	Median	Median
Air-cooled 100 kW	3.4	4%	12%	5%	6%
Max efficiency air-cooled 100 kW	4.5	6%	17%	4%	12%
Air-cooled 400 kW	3.5	3%	9%	2%	11%
Max efficiency air-cooled 400 kW	5.3	5%	15%	2%	13%
Water-cooled 100 kW	4.3	12%	24%	5%	11%
Max efficiency water-cooled 100 kW	5.5	16%	32%	6%	9%
Water-cooled 1000 kW	5.1	9%	18%	2%	9%
Max efficiency water-cooled 1000 kW	8.0	14%	29%	1%	19%
Average value:		**8%**	**18%**	**4%**	**10%**

(*) Only for fan and pump correction is data available to compute both median and high impact of the differences in the metrics.

Figure 6. Results of modelling typical chiller performance to show the impact of various factors on performance, as compared with the conventional SEER value: increase in SEER when not accounting for fan and pump correction, low power modes, and when using more favourable US IPLV load curve conditions versus EU SEER conditions.



4.4.4 Quantifying the impact of tolerances

The draft EU regulation allows a tolerance of SEER of 8% and SEPR of 6% when verification tests are made by enforcement authorities, but this tolerance is specifically excluded from use by manufacturers when declaring efficiency figures: the manufacturer is not allowed to declare a value 'better' than that in the test report or that results from calculations/simulations. For the AHRI 550/590 standard, there is a tolerance equal to 10.5% on the IPLV value.

This can lead to different impacts depending on the manufacturer and on the verification policies used:

- In a perfect world, the differences in tolerances may well have no impact on the efficiency declaration of the manufacturers, i.e., 0% impact; this would for instance be the case if a batch of units was tested and the average of all testing was used to check compliance, and supposing that all testing laboratories for verification and from manufacturers were perfectly calibrated.
- In practice, a manufacturer may be able to make measurements more precisely than defined in the standard (internal measurements on the refrigerant fluid can lead to much more precise measurements). Where ambiguity exists under regulations, some manufacturers could decide to declare seasonal performance figures that exploit part or the totality of the tolerance allowance (up to 10.5% in the USA), although this is specifically prohibited under draft EU regulations. Reputable manufacturers would generally choose to under-rate their chillers, in order to avoid any failure in compliance checks.

The truth probably lies between these two bounds (0% and 10.5%) but can only be quantified by enforcement authorities or certification companies (AHRI and Eurovent Certification) by comparing compliance checking results and manufacturer declarations. Further details on tolerances are given in *Annex 3. Estimation of the impact of tolerances on declared efficiency data*.

4.5 Summary of comparability between standards

4.5.1 Comparability of full load ratings (COP, EER)

From analysis in section 4.3, differences on full load ratings are around 5% for both the USA and the EU ratings. Other differences in standards, variations in standard rating conditions and fouling (in the USA standard), are thought to have a lower than 5% impact. The deviation which can potentially be larger than 5% is the correction for fan and pump losses that has an average median value of 8% but is 32% in one selected case (see Table 6) – this factor is important when considering EER measured according to the EN14511 standard. Thus, it appears that EER or USA COP metrics for chillers can be compared directly between different regions with reasonable confidence. Only European EER values should be treated with more care since the EER value appears a few percent lower than EER or COP values in other standards, mainly due to the correction for pump consumption that is included. However, there may be important deviations for specific units, and impacts are higher for water-cooled chillers than for air-cooled chillers.

Nevertheless, these differences do not prevent policy makers making reasonably robust comparisons of full load COP and EER requirements between economies.

4.5.2 Comparability of part load ratings (IPLV, SEER)

Unlike with full load ratings, the differences in seasonal performance metric calculations are much more important and of the order of 16% to 38% so that for comfort cooling, SEER, ESEER and IPLV absolute values cannot be compared directly.

Similarly, SEPR values involve a very different assessment and weighting of usage compared with USA COP or IPLV values, so that it is also difficult to compare the relative ambition of these requirements.

This is why the second phase of this analysis was proposed: to model the performance of a representative set of typical chillers in order to generate both IPLV and SEER values for them and so enable a fair comparison of regulatory requirements and (possibly) market average efficiency.

5 Policies in force

5.1 Summary of policy situation

Minimum energy performance standards (MEPS) and energy label policies across the economies studied are summarized in Table 7 and Table 8 respectively.

For packaged chillers, most policies use MEPS, except China with its additional comparative label. Some of these requirements are linked to building codes (USA, France, and UK). In other countries, regulations apply to products themselves at the time of placing them on the national/regional market (rather than the building or system within which they are used).

The main difference is the metric used for MEPS requirements which can be based upon full load ratings performance (COP[15] or EER), or based upon a seasonal performance metric (mainly the US IPLV but also the EU SEER) as also shown in Table 7 and Table 8.

Australia, the USA, Canada and China have already adopted MEPS based on seasonal performance indices and Europe plans to do so. This is an important trend for energy efficiency as this enables comparison of product performance in a way that simulates performance in the field much better than with full load rating standards alone.

Europe first adopted the same approach as Japan (the Eurovent Certification ESEER: US IPLV methodology with different climate/use conditions) and now is planning to adopt a unique set of metrics across heating and cooling products based upon SEER (cooling mode) and SCOP (heating mode) (using a simplified bin method).[16]

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[15] In the US, COP can have units of Btu/hr/W, but this is easily converted to W/W.
[16] For more information on metrics, please refer to section 4.3.3.

The contrast in approach to cover chillers that are not designed for a comfort cooling load profile has already been noted in section 4.3.4 (the EU choosing SEPR; the US and others choosing ‘Path A’ and ‘Path B’ options).

MEPS are presented in the graphs for air-cooled chillers in section 5.2 and then for water-cooled chillers in section 5.3. MEPS for full load (EER or COP) are shown separately to MEPS for part load (IPLV or SEER). Standard rating EER figures are considered comparable; any differences due to testing standards are limited to a few percent of measured efficiency, which is discussed in more detail in section 4.3.1. Regarding part load figures, direct comparison between the USA IPLV and EU SEER or SEPR is not possible and thus IPLV and SEER values are also presented on separate graphs.

Table 7. Summary of mandatory MEPS policies in force in major economies.

Economy	Type of policy	Full load or part load MEPS	Date of introduction or review	Scope	Comments
USA	Mandatory MEPS included within ASHRAE standard 90.1	Full load COP and part load IPLV	1992 under EPAct; 2007, 2013	Air-cooled and water-cooled, all capacities.	MEPS implemented via building codes on installation.
Canada	Mandatory MEPS included within CSA-C743-02	Full load COP and part load IPLV	2004	Chillers for comfort cooling: air-cooled up to 700 kW and water-cooled up to 7000 kW; absorption chillers up to 5600 kW.	Testing equivalent to AHRI 550/590; aligned with ASHRAE standard 90.1 of 2004. Update being considered in 2015 to align with ASHRAE 90.1 2007.
Australia / New Zealand	Mandatory MEPS included in AS/NZS 4776, Parts 1.1 and 1.2	Full load COP and part load IPLV	2009	Air-cooled and water-cooled, all capacities.	Aligns with ASHRAE 90.1 2010.
EU[17]	Proposed MEPS (none in force at 2015)	Part load (SEER and SEPR)	(Expected 2017)	Comfort cooling chillers: air-cooled and water-cooled, all capacities. Process chillers: air-cooled and water-cooled, all capacities.	Initially adopted IPLV but with modified rating points (ESEER); now adopted SEER (and SCOP) which covers both cooling (and heating) products. Comfort cooling chillers (SEER) and process chillers (SEPR) regulated separately.

[17] Eurovent scheme details at http://www.eurovent-certification.com/en/Certification_Programmes/Programme_Descriptions.php?lg=en&rub=03&srub=01&select_prog=LCP-HP.

Economy	Type of policy	Full load or part load MEPS	Date of introduction or review	Scope	Comments
UK	Mandatory MEPS for installed chillers, under Building Regulations	Full load EER	Last update 2014	Air-cooled and water-cooled chillers, all capacities – for new chillers installed in new and existing buildings.	
France	Mandatory MEPS under building regs	Full load EER	2007	Air-cooled and water-cooled chillers, all capacities – for new chillers installed in new and existing buildings.	
China[18]	Mandatory MEPS	Full load COP and IPLV	Product policy 2004 Building regulation 2014	Air-cooled and water-cooled, all capacities.	
Chinese Taipei	Mandatory MEPS	Full load COP	2003; 2005	Air-cooled and water-cooled, all capacities.	Reference AHRI 550/590 and JIS standards.
Japan	No specific policy identified, but generally uses COP and IPLV with modified climate and testing conditions.				
Republic of Korea	No specific policy identified.				

[18] China labels summary at http://www.energylabel.gov.cn/en/EnergyEfficiencyStandards/FormulationandRevisionofStandards/detail/734.html. Additional information on the standard for commercial buildings in China (equivalent to the US ASHRAE 90.1) can be found in Feng & al, 2014.

Table 8. Summary of energy label policies in force in major economies.

Economy	Type of policy	Date of introduction or review	Scope	Nature of labels
China[19]	Mandatory labels	2004	Air-cooled and water-cooled, all capacities.	Grade 1 (best) to Grade 5 (poorest)
EU[20]	Voluntary labels (industry certification scheme)	c. 2005	Air-cooled to 600 kW; water-cooled to 1500 kW, plus medium and low temperature applications. For cooling and heating mode.	A (best) to G (poorest)

[19] China labels summary at http://www.energylabel.gov.cn/en/EnergyEfficiencyStandards/FormulationandRevisionofStandards/detail/734.html.
[20] Eurovent scheme details at http://www.eurovent-certification.com/en/Certification_Programmes/Programme_Descriptions.php?lg=en&rub=03&srub=01&select_prog=LCP-HP.

5.2 Air-cooled chiller policy stringencies compared

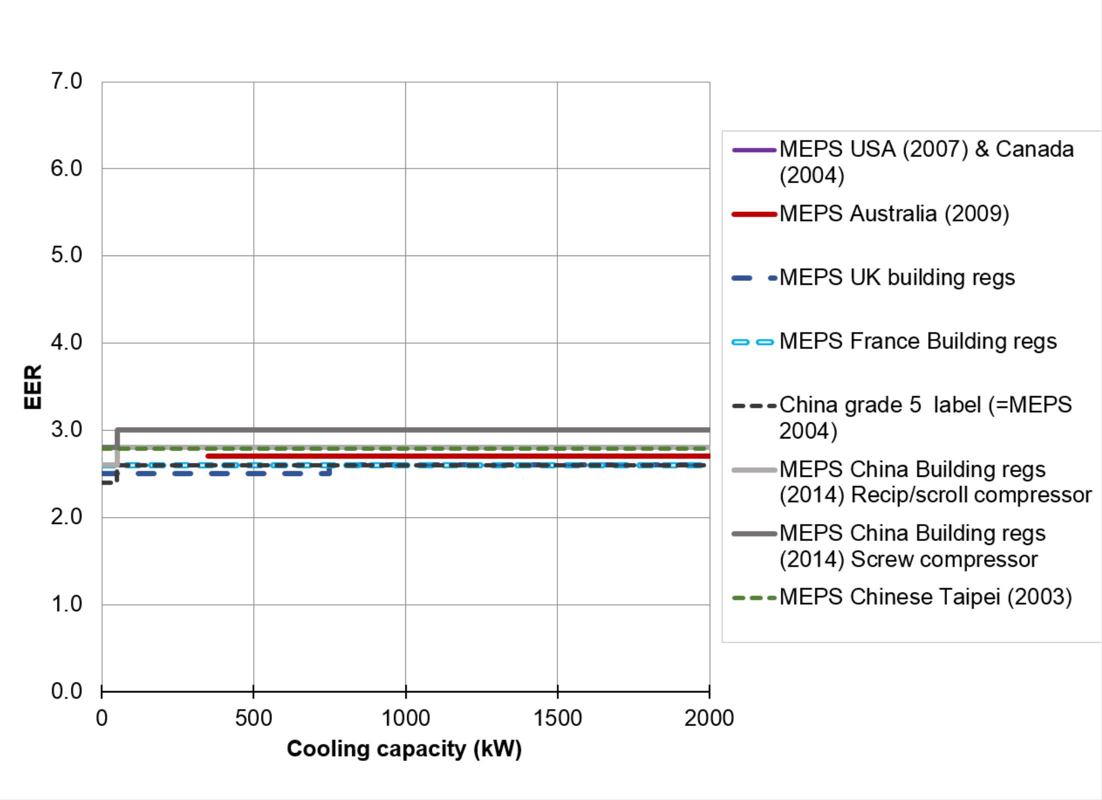
Air-cooled chillers EER or COP

Regarding air-cooled chillers, the most ambitious MEPS is 3.0 for screw chillers in China and then 2.8 EER for USA and Canada. The maximum differences between the stringency in different economies vary between 13% and 16%. MEPS requirements and other initiatives based on the full load ratings are shown in Figure 7 (both parts show the same set of data but zoomed in for clarity in the lower version).

The range of energy labels (best label class threshold to worst label threshold) is shown in Figure 8 – the mandatory label scale for China overlaps significantly in range with the voluntary label scale for the EU via the Eurovent Certification Company.

Note that there is an uncertainty of around 8% on comparability of the various full load MEPS levels, due to the differences in testing standards and tolerances (see section 4.5.1).

Figure 7. MEPS chillers, air-cooled, full load EER (kW/kW). Upper graph is set for direct comparison with Figure 11 and Figure 12; the same data appears in lower graph, but zoomed in for clarity.



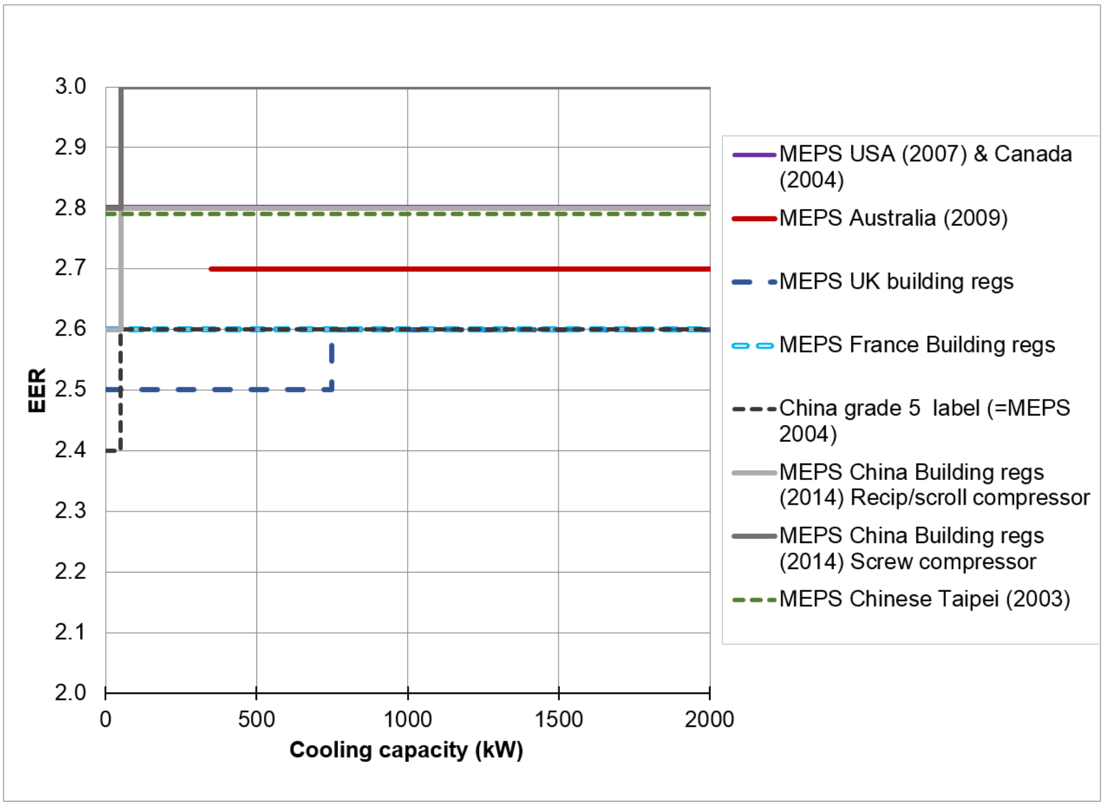
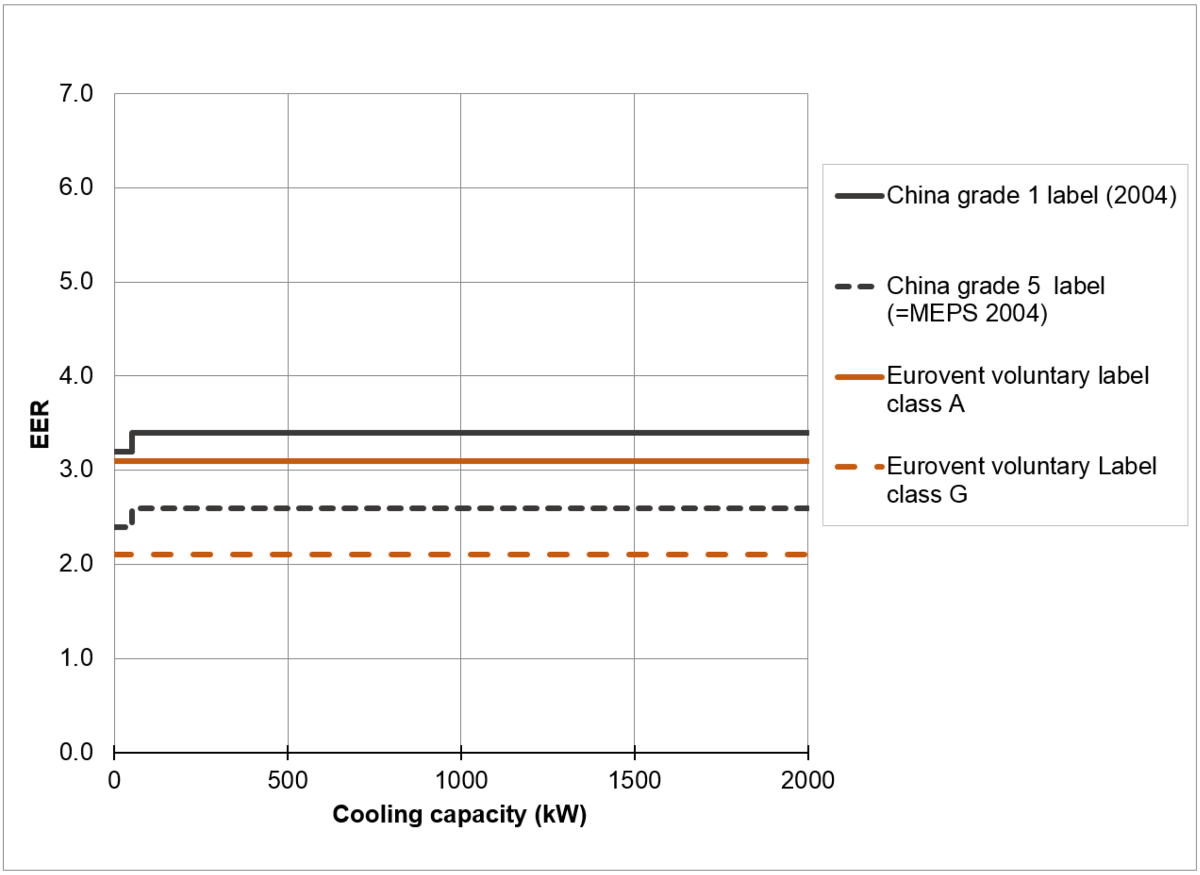


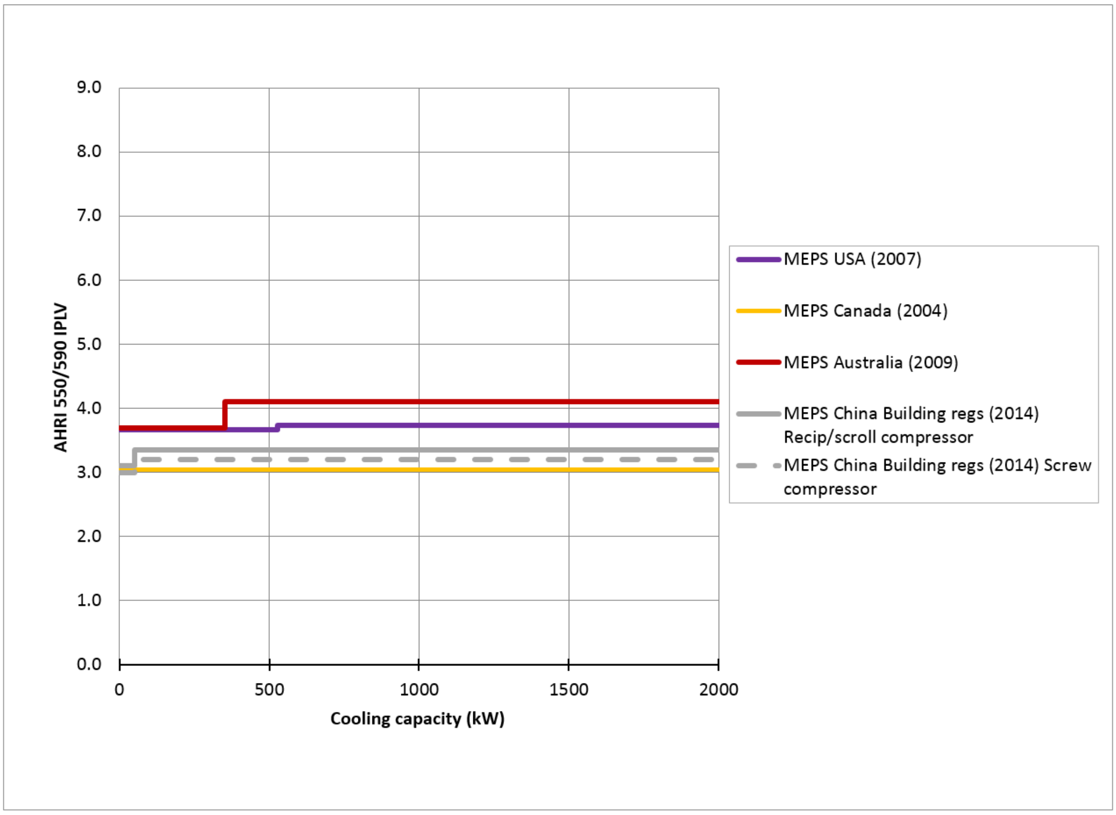
Figure 8. Range of energy labels for air-cooled chillers, full load EER or COP (kW/kW).



Air-cooled chillers IPLV

Regarding seasonal performance values, two countries have followed the USA ASHRAE 90.1 IPLV based MEPS: Canada, whose values are based on ASHRAE 90.1: 2004 and Australia. Australian MEPS of 2009 are 10% more ambitious than those of the USA from 2007, and 34% more demanding than those of Canada from 2004.

Figure 9. MEPS chillers, air-cooled, part load IPLV (kW/kW).

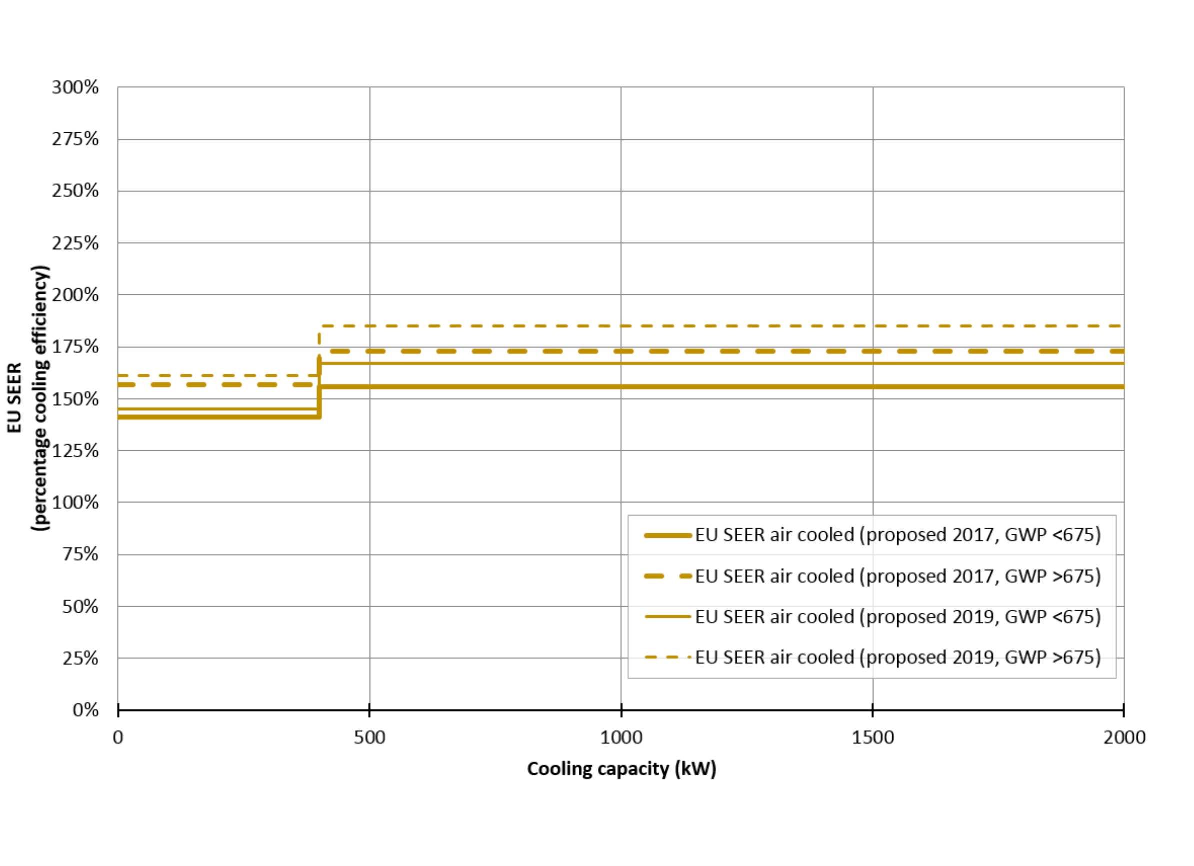


Air-cooled chillers SEER and SEPR

Europe plans to adopt requirements for air-cooled chillers in terms of SEER (as shown in Figure 10) and SEPR. SEER is expressed in the EU working document as 'percentage useful efficiency of cooling products' in primary energy terms, in order to express efficiency of cooling products in the same units whatever energy type these are driven by, electricity and gas or other means – the figures are shown in Table 20 and Table 21 on page 76. The SEER figures from which the percentage useful efficiency figures were derived are shown in Table 18 and Table 19, page 76[21]. It is apparent that absolute values of the requirements in 2019 are numerically higher than the most ambitious IPLV requirements, but values cannot be compared directly until the modelling proposed in Part B of this project is completed. Similarly, SEER and SEPR thresholds cannot be directly compared (even when SEER is converted to kW/kW) and so they cannot be shown together.

[21] To convert percentage useful cooling efficiency to an efficiency ratio SEER (kW/kW), it is necessary to multiply by 2.5, then add three percentage points to efficiency requirements (for a control factor); and then for water-cooled chillers only, add a further five percentage points to compensate for water pumping on the condenser side.

Figure 10. Proposed MEPS for EU chillers, air-cooled, seasonal efficiency SEER (expressed as percentage useful cooling efficiency). GWP is the global warming potential of the refrigerant used in the chiller.



5.3 Water-cooled chiller policy stringencies compared

Water-cooled chillers EER

There is generally an increase in the requirements with higher cooling capacity because of the change in technology employed for higher capacity units: larger centrifugal chillers have higher full load EER than positive displacement compressors; amongst the positive displacement compressors that predominate at lower capacities, screw compressors (used at the higher capacity end of this region) have better full load EER than scroll or reciprocating compressors (due to several factors, i.e. not limited to the compressor technology itself - these differences in technology are reflected in the setting of MEPS by technology in the US and Canada, as seen in Figure 11.

The MEPS values of the different policies that apply to air-cooled 'Path A' applications (see section 4.3.4) and those for general applications are shown in Figure 11. The variation in MEPS requirements at full load conditions is over 100%, with EER of 3 in France up to 6.1 in USA/Canada (for 1500 kW). The most stringent MEPS for water-cooled chillers are those of the USA and Canada.

MEPS values for chillers assessed according to Path B and according to general applications are shown in Figure 12; these show a similar range as for Path A, but with Canada and Australia setting the most stringent requirements.

Note that there is an uncertainty of around 8% on comparability of the various full load MEPS levels, due to the differences in testing standards and tolerances (see section 4.5.1).

Figure 11. MEPS for water-cooled chillers, full load EER, general and 'Path A' for process cooling and special conditions (kW/kW).

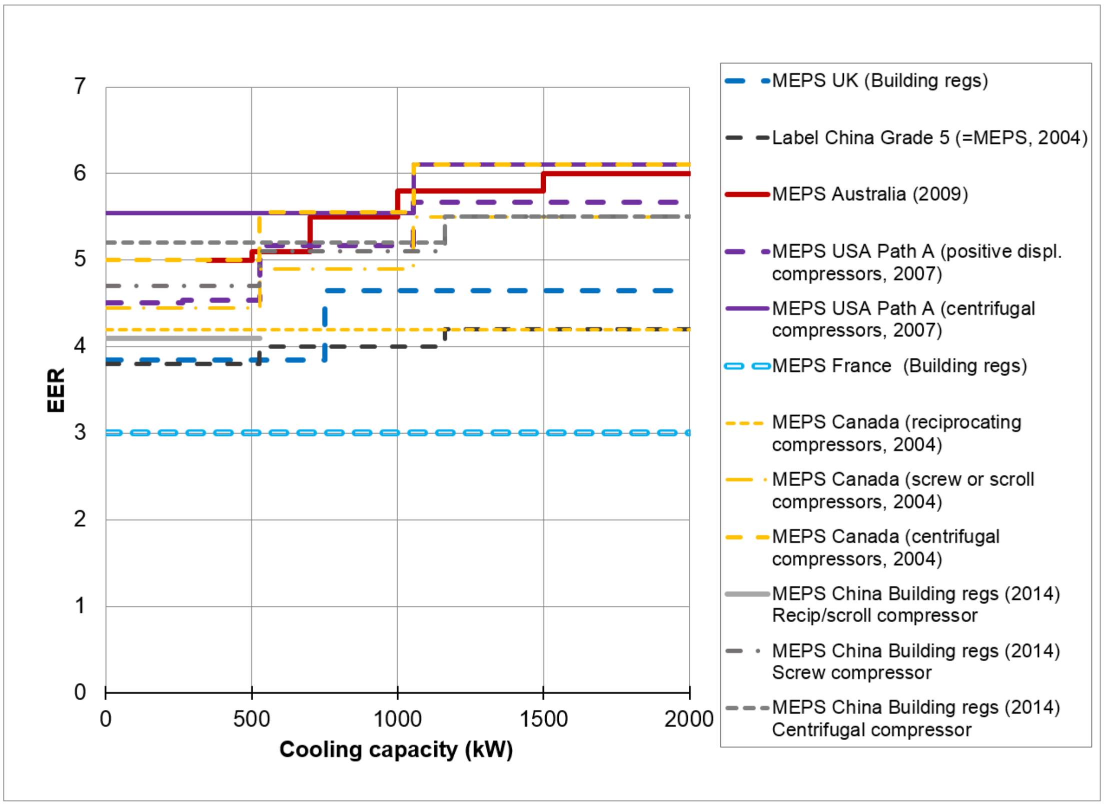
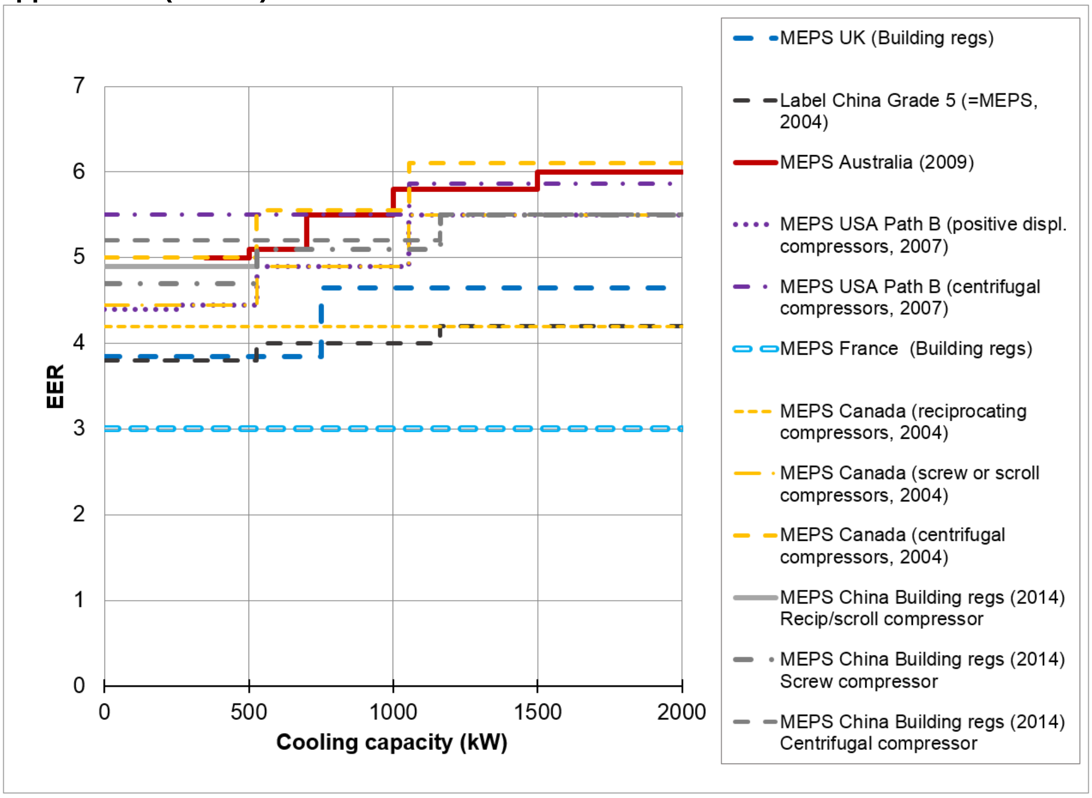


Figure 12. MEPS for water-cooled chillers, full load EER, general and 'Path B' for comfort cooling applications (kW/kW).



Water-cooled chillers IPLV

The MEPS values of the different policies that apply to water-cooled 'Path A' applications (US) and those for general applications (Australia, Canada) are shown in Figure 13. The range of MEPS values is very much narrower for the water-cooled seasonal efficiencies for Path A type applications, compared with full load efficiencies. But Figure 14 shows the very much more ambitious requirements according to Path B for the US since 2007.

Figure 13. MEPS for water-cooled chillers, part load IPLV, general and 'Path A' (kW/kW).

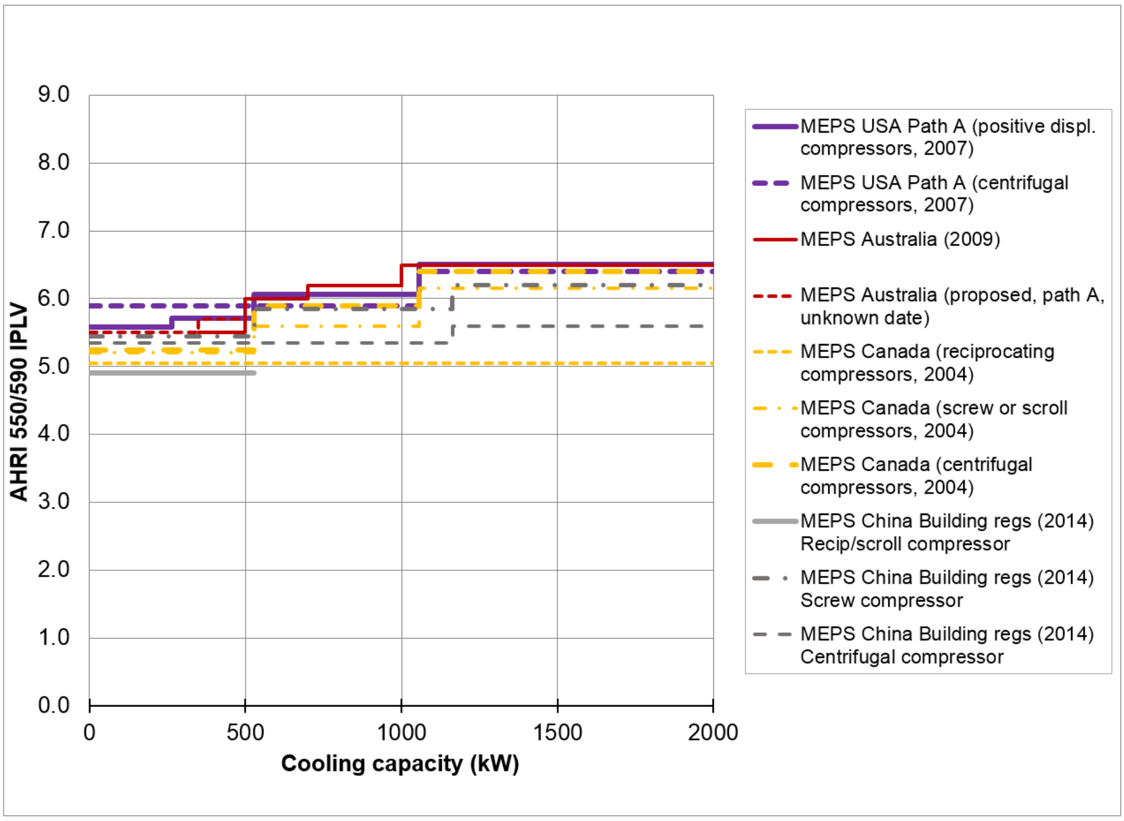
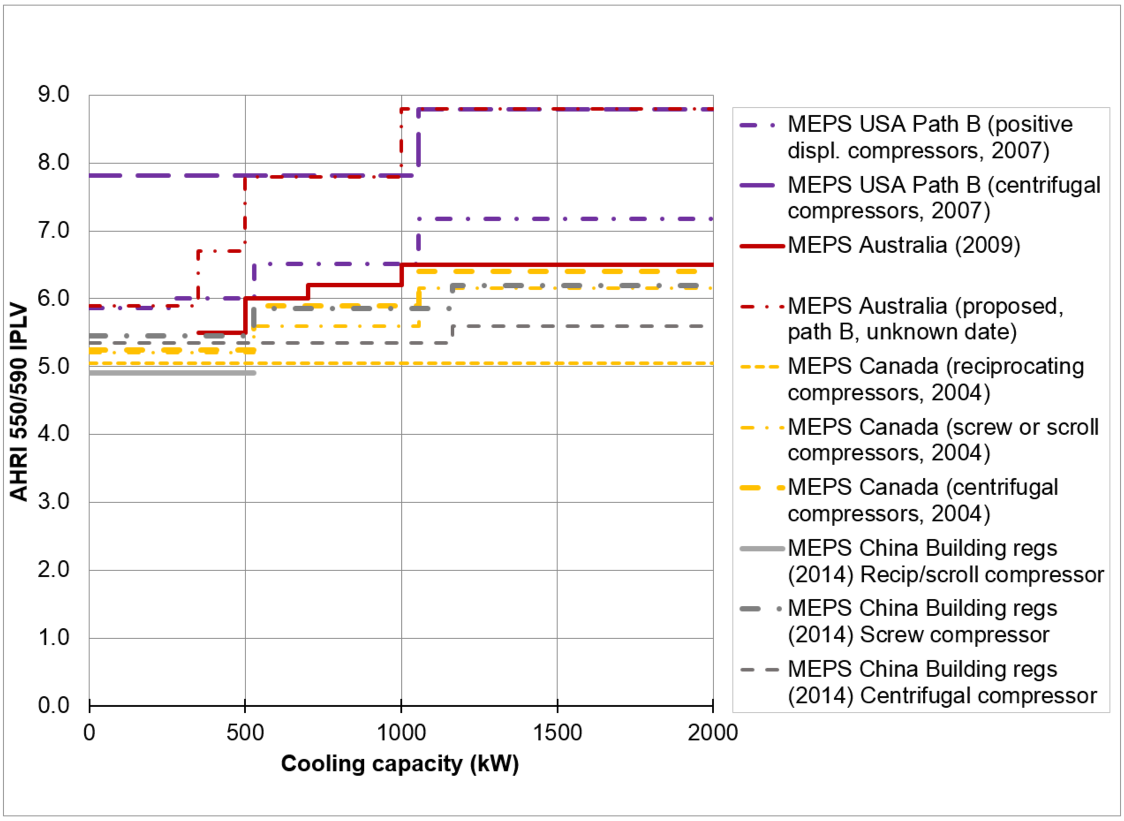


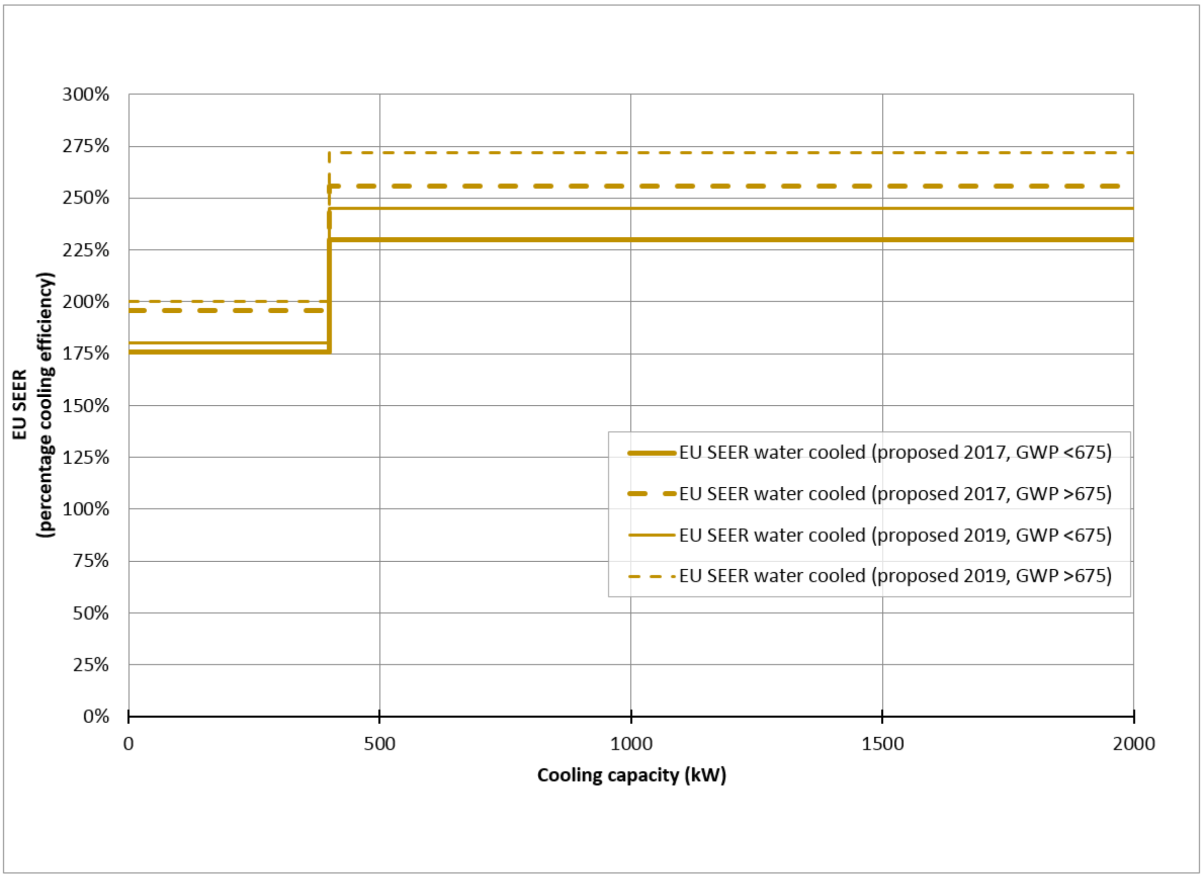
Figure 14. MEPS for water-cooled chillers, part load IPLV, general and 'Path B' (kW/kW).



Water-cooled chillers SEER and SEPR

As with air-cooled chillers, Europe plans to adopt requirements for water-cooled chillers in terms of SEER (see Figure 15) and SEPR. SEER is expressed in the EU working document as 'percentage useful efficiency of cooling products' in primary energy terms, in order to express efficiency of cooling products in the same units whether driven by electricity or by gas or other means – the figures are shown in Table 20 and Table 21 on page 76. The SEER figures from which the percentage useful efficiency figures were derived are shown in Table 18 and Table 19, page 76.[22] It is apparent that absolute values of the requirements in 2019 are numerically higher than the most ambitious IPLV requirements, but values cannot be compared directly until the modelling proposed in Part B of this project is completed. Similarly, SEER and SEPR thresholds cannot be directly compared (even when SEER is converted to kW/kW) and so they cannot be shown together.

Figure 15. Proposed MEPS for EU chillers, water-cooled, seasonal efficiency SEER (expressed as percentage useful cooling efficiency). GWP is the global warming potential of the refrigerant used in the chiller.



[22] To convert percentage useful cooling efficiency to an efficiency ratio SEER (kW/kW), it is necessary to multiply by 2.5, then add three percentage points to efficiency requirements (for a control factor); and then for water-cooled chillers only, add a further five percentage points to compensate for water pumping on the condenser side.

6 Summary of barriers to harmonisation

The main barriers identified in this case are summarised in Table 9 and graded for importance to slowing progress towards harmonisation as high, medium and low.

Table 9. Summary of barriers to harmonising test methods and standards. Right hand column is relative significance of the factor to slowing progress towards harmonisation, graded indicatively as high, medium and low.

Barrier	Description, and how the barrier affects progress	Potential solution(s)	Significance
People involved in making specific standards do not know how to go about aligning standards	Industry may not have the necessary oversight to align standards, in terms of knowledge of foreign markets or understanding of the challenges of comparing different metrics and policies.	Several non-governmental organisations and international bodies (CLASP, SEAD, ASEAN etc[23]) have an interest in better harmonisation and can provide specific expert help, if invited into the processes.	High
Lack of pressure or incentives from policy makers to better align	Industry may naturally not have significant incentive to align standards and it takes political will to make this happen.	Policy makers do have international mechanisms available to work on this in many product areas (SEAD, ASEAN etc).	High
Time pressure on committees means no time to consider alignment	Standards committees consist mostly of industry and independent experts giving time voluntarily and the teams are up against administrative and sometimes against regulatory time constraints. Processes of standard development appear externally to be very long, but committees will have a limited number of meetings at which all changes can be discussed and agreed.	Alignment with other economies may not be an immediate priority unless imposed and supported from outside the committee.	High
Risk that test method changes force changes to products and costs	New or adjusted test methods could require new or adjusted products; some may involve increases in cost of product and/or cost of testing. Such changes are often accompanied by correlated changes to regulations. This risk can prevent reaching consensus in standards working groups and so block change.	Period over which changes are mandated should take account of natural business investment cycles with minimum uncertainty, but without delays that could compromise the will and momentum for change.	High

[23] CLASP = Collaborative Labelling and Appliance Standards Program (http://clasp.ngo); SEAD = Super-efficient Equipment and Appliance Deployment initiative (http://www.superefficient.org); ASEAN = Association of South East Asian Nations (http://www.asean.org).

Barrier	Description, and how the barrier affects progress	Potential solution(s)	Significance
Revision of standards is not synchronised between regions, so changes cannot be discussed at crucial times	It would be a rare coincidence for two or more standards committees in different economies to be grappling with similar changes at the same time as there is no general international synchronisation of standards development by product area.	International umbrella organisations such as ISO or IEC are effective to ensure concerted efforts across economies.	Medium
Costs of re-testing and information updates if methods are changed	Manufacturers from economies that agree to change their methods will face costs of retesting and update of communications materials.	The reasons for change must be persuasive to overcome this.	Medium
Concerns that competition from outside the economy could increase if better aligned	Reducing barriers to trade through harmonised requirements does increase market access for competitors from abroad. Whilst often beneficial in the longer term, fears of this can prevent experts from manufacturers reaching consensus and so block change.	There is increasing evidence that competition can enhance performance of local business and markets, but the importance and interests of SMEs must be carefully taken into account as these are often the most vulnerable during major market change.	Medium
Lack of mechanisms and links for experts to discuss closer alignment between regions	Experts on a standards committee in one economy may not have personal links with experts on corresponding committees.	There are many international collaborative mechanisms that should support and encourage such links (IEA4E, SEAD, APEC-ESIS, ASEAN[24] etc). Such groups could be mobilised to assist but must be co-ordinated closely with the technical committees.	Medium

[24] IEA4E = IEA Energy Efficient End-use Equipment Implementing Agreement (http://www.iea-4e.org); APEC-ESIS = Asia-Pacific Economic Cooperation Energy Standards Information System (http://www.apec-esis.org).

Barrier	Description, and how the barrier affects progress	Potential solution(s)	Significance
Difficulty in agreeing a compromise on rating points between different climate zones	If harmonisation on universal conditions was to be reached, then the compromise could mean that test results are not representative of some or all economies.	A pragmatic route is simply to agree a common set of conditions from which the closest match is selected, to at least limit diversity. Not harmonisation, but at least limiting divergence.	Low
Uncertainty whilst new test methods, metrics or policy measures are developed	Whilst new standards are developed, often in tandem with new regulations, there will be some uncertainty and turmoil in the markets.	Industry experts are almost always engaged; processes are transparent to an extent and suitable advance warning is built into the processes.	Low
Risk of changing comparability of different cooling equipment within the same economy	Cooling equipment of many types includes similar technologies and it can be useful to retain comparability where they can be used to fulfil similar purposes (e.g., air conditioners of various types). If changes disrupt this comparability then there could be information gaps and some loss of transparency.	This is a complex area that is dependent upon local market and policy frameworks – no simple solution exists. (Note that the EU policy approach was driven by a desire to achieve much higher coherence of performance metrics across all HVAC plant).	Low
Discontinuity with historical data - so performance trends cannot easily be tracked	Mildly problematic for policy makers as longer term trends are harder to discern.	Results can usually be retrospectively adjusted if necessary to gain adequate insight. Improved outcomes will outweigh this problem.	Low

7 Overview of why we have a lack of harmonisation

As described in the previous sections, it is the EU that is now significantly out of line with the rest of the world in terms of chiller metrics and standards; and since it was the US that pioneered such standards and strongly influenced standards in most parts of the world, the story of lack of harmonisation is largely about those two economies – the EU and US:

To summarize, the main reasons for differences between the US and EU approaches are:

a) In the US, the chiller metrics are designed for integration with building regulations (via ASHRAE 90.1) and so wider HVAC system issues are accommodated differently to the EU ecodesign approach which examines the chiller in isolation.

b) National or regional differences in the markets for heating and cooling mean that the dominant types, capacities and technologies of chillers are different: the European market is dominated by small to medium capacity air-cooled chillers used mostly only during high outdoor temperatures; the US has far more large water-cooled centrifugal products that are used all year round.

c) Differences in the local ambient conditions and so the necessary rating points.

d) Differences in the typical basis of HVAC systems, with the EU having heated or cooled water distributed throughout the building and the US using mainly ducted air, led to the EU market being dominated by reversible heat pump chillers (providing heating and cooling).

e) Policy makers in the EU have taken an integrated approach to space conditioning policy, with the same type of metric now used for heating and cooling, regardless of fuel type: the seasonal primary efficiency ratio (SPER) which is expressed as a percentage.

Further details on these points are explained below.

The US was the first economy to regulate chillers when requirements were incorporated into the ASHRAE 90.1 standard in the late 1970s or early 1980s. The ARI 550/590 standard that included IPLV was published in 1984.

It is important to subsequent developments and lack of alignment that this US requirement arose via a building regulation, not from conventional ‘product policy’ such as ecodesign. Performance metrics within building regulations are structured to integrate with wider HVAC and building system efficiency and so test methods and performance data can have different scope of factors and be presented differently. One example is that in the US, fan and pump corrections are not included in the chiller metric but in the building calculation; whereas in the EU chillers are regulated in isolation of their building specific use. So for the EU, fan and pump corrections as well as low power mode operation are integral to the testing standard to avoid energy efficiency bias at the product level.

When the EU trade body Eurovent Certification decided to adopt a seasonal performance metric, the AHRI ‘IPLV’ standard had already been established. However, Eurovent reasoned that the markets in the US and in Europe are different: the US has chillers that are typically larger in size and used in large buildings that require cooling all year round, and the majority are of the centrifugal type and water-cooled. This contrasts with the EU since, even in the years 2000 to 2010, in Europe the market was (and remains) dominated by reciprocating, screw and scroll type compressors. EU applications are predominantly small to medium capacity air-cooled chillers and cooling demand is strongly related to outdoor ambient temperatures (cooling only required during warm seasons/days). These fundamental differences in dominant technology, capacity range and cooling demand are further contributory factors to the lack of alignment.

Japan adapted the IPLV test conditions and load curve to its own local climate, whilst keeping the basic methodology that is described in AHRI 550/590. The manufacturers in Europe also decided to adapt the rating points of the IPLV index to a more typical European level (the air inlet temperature, for example, as low as 12.8 °C at 25% load, was considered too low for the EU). Coefficients, testing conditions and a methodology were developed for the EU in the EECCAC project (Adnot, 2003)[25] and these were adopted in the form of the ESEER seasonal metric which has been used by Eurovent Certification since 2007. Climate-based differences in rating points thus form a third significant contributory factor.

The next step of the evolution is linked to another market difference between the US and Europe: US heating systems are mainly based on distribution of conditioned air (that is, cooled or heated and/or dehumidified); in Europe, heating is mainly based around wet systems (boiler + hot water circulated through pipework and radiators). This greatly encouraged the development of reversible chillers (i.e., heat pumps that deliver cooled or heated water that is circulated around the building). A significant proportion of chillers sold in Europe are now reversible, in contrast to the US, for which cooling-only chillers dominate.

Not only does this difference in technologies lead to differences in system performance, but it also led policy makers down a different path to classify and influence HVAC system efficiency: the EU developed a seasonal performance indicator for heating mode, as well as for cooling. The CEN TC 113 working group 7 had to develop a seasonal performance indicator for the heating mode applicable to both reversible air conditioners and reversible chillers. It also had to cover the backup electrical resistance heater and balance point in the calculation. As a result, a simplified bin method was adopted.[26] Recent policy developments in the EU have unified metrics to be comparable across all cooling and heating equipment and across the different fuels (air conditioners, chillers, boilers, thermal heat pumps, refrigeration equipment running on electricity, gas and other fuels). This cohesive policy approach led directly to the current primary energy based metric for chillers that is unique to

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[25] Energy Efficiency and Certification of Central Air Conditioners (EECCAC) FINAL REPORT - APRIL 2003, J Adnot, ARMINES et al, study for DG TREN.
[26] Faced with the same problem, the US took a similar decision for their air conditioners: the standard AHRI 210/240 uses the simplified bin method to rate the cooling and heating performances of air-to-air air conditioners and heat pumps.

the EU. Such integration would be less likely in the US where professional organizations such as ASHRAE and AHRI make standards and metrics that are approved by authorities on an equipment type basis.

8 The consequences of lack of alignment

The lack of harmonisation results in poor transparency between the performance of chillers in the US and the EU. This is a problem when policy makers want to set coherent standards and in particular it is extremely hard to identify the global best performing products and relative performance of markets. This, however, is a transient need of policy makers: cross-comparison is useful at time of policy-setting but this does not mean that immediately apparent transparency is essential, as long as some means to assess relative performance is found when needed.

The differences identified in section 7 mean that more efficient large water-cooled chillers are likely to be found in the USA, although confirmation is difficult as EU manufacturers do not declare their large chiller performances in the Eurovent Certita Certification database. It is therefore extremely difficult to assess the impact that technology transfer could have on maximum SEER values for example (there is currently little transatlantic trade in chillers, despite market dominance of a handful of global manufacturers). Conversely, variable speed scroll units are likely to develop more rapidly and to a higher efficiency on the EU market due to higher demand than in the US.

The differences also result in a practical barrier to trade as specifiers in one economy cannot compare with products available in the other market and manufacturers wanting to export must meet the costs of testing and certification according to two or several standards.

On a similar theme, this could also result in policy makers in one economy setting standards more demanding than those in other economies, resulting in different costs of trade, further divergence of markets and possibly poor standards in economies where the building sector is highly cost-driven.

Transparency on the relative efficiency of the same products on both markets would help to establish ambitious, coherent and appropriate energy efficiency policies in both economies. So the lack of coherence and transparency could result in lost energy savings and in higher user and manufacturer costs.

These downsides must be balanced against policy benefits for the EU from taking its own approach of having comparable metrics between different HVAC product types (heating and cooling and fuel types): fair assessment of products such as electric heat pumps versus gas boilers is necessary and useful for the EU market. The EU standards are also based on a functional approach – efficiency of the service delivered to the end user, rather than separated by product type and even in some cases by technology (centrifugal chiller standards different to those for reciprocating chillers, for example, in the US and Canada).

9 The benefits of closer alignment of standards and policies

The principal benefits of closer alignment arise through the improved transparency of standards and performance thresholds between economies. These can be summarised as:

a) Easier comparability of product performance between regions and so, amongst other benefits, it is easier to spot (and perhaps purchase) excellent products and technologies from those regions;

b) Fairer regulation for all manufacturers and an “even playing field” for trade between regions;

c) Transparency enables policy makers to understand stringency of standards elsewhere and so raise performance to a demanding but effective level;

d) Increased international competition that drives suppliers to better products;

e) Reduced barriers to trade (easier export/import), including reduced costs of testing through fewer tests per product;

f) Also, in common with many cooling technologies, policy makers and manufacturers are grappling with the phase-out of many types of refrigerant and the development of others. Transparency of performance could assist greatly in the understanding of how refrigerants emerging in different markets and different regions perform.

As noted above, these benefits must be weighed against any potential advantages of retaining independent policy paths that result in non-comparable efficiency levels and product performance data.

10 Previous attempts to achieve comparability

10.1 ISO 19298: a global chiller test method

There has been a previous attempt to develop an internationally agreed test method for chillers under ISO: The ISO/TC 86/SCG working group 9 prepared a draft ISO standard 19298 *Proposed Working Draft: Liquid-Chilling Packages Using The Vapour Compression Cycle* (ISO, 2006). This standard intended to identify a limited set of both rating and testing conditions from which could be selected those that were suitable to local conditions and applications. This project got to the stage of a working document internal to the working group during early 2006 and was curtailed at some point after that. The working document included amongst other issues:

- Full load rating conditions (harmonized at the evaporator side but with 3 choices at the condenser side to reflect different climates);
- Application conditions (full capacity rating conditions over the operating range of the units with varied source temperature and flow rates);

- Minimum part load ratings over the application conditions;
- Testing methods;
- Tolerances.

The document allowed some degrees of freedom for regions to adapt rating conditions as suited their own climate and several possible full capacity ratings were proposed. The harmonisation regarding seasonal performance metrics was low and only covered the basic method. The IPLV methodology (as used in the US and also in Europe at that time with the similar Eurovent ESEER coefficient) was only proposed as an informative annex, with supplementary coefficients proposed for other regions with different (and mainly hotter) climates.

Reasons why the project failed were sought from ISO participants, looking for insight into the challenges faced. The response was that chillers working group members decided that most regions around the world are developing and using their own standards in lieu of any global standard, to meet their regional energy efficiency (policy) requirements. Given that the ISO standard would require a lot of time to complete development and thereafter to maintain, this investment appeared unlikely to be worthwhile if few would choose to use it.

10.2 More comprehensive published performance information

It was proposed during the EU Lot 6 preparatory study (Rivière & al., 2012) to require that chiller manufacturers publish more information in the format of a 'performance map'. This was with the aim of helping specifiers and HVAC engineers to select the best products for a given project, building and climate. The recommendation was not included in subsequent drafts of the EU regulation, but is explained in some more detail here because it gives some insight into the complexities and challenges faced by manufacturers and by specifiers of these products.

Detailed technical performance information is often made available by manufacturers directly to customers to make energy calculations on a specific application. Once the cooling load is known, the performance of specific chillers should be evaluated for the expected load curve, outdoor conditions, air or water flow rates, combination of chiller units etc. (this would rarely coincide with the typical loading expressed in the 'standard' IPLV or SEER metric). But the lack of standardization of data formats and the fact it is not readily available publicly makes the comparison of several units from competing manufacturers almost impossible. The actual data could be readily available from chiller selection software which is now used by most manufacturers. If the output of the software was made available in standard formats, then comparison of seasonal performance metrics would no longer be a problem. The standardised formats could be used as a harmonised input data to national building regulations.

It was suggested in the Lot 6 report that chiller published ratings should include application ratings (at other than standard rating conditions) within the operating limits of the equipment for a variation of:

- Chilled water temperature (indoor side), in increments of 2°C or less;
- Condenser inlet temperature (whether air-cooled, water-cooled or evaporatively-cooled, in increments of 5°C or less;
- Part load information (where 100% load refers to the full rated capacity); for 'discrete step unloading' machines, it was suggested that part load rating data should be provided for each 'step' of the machine's capacity; for 'continuously variable unloading' machines part load data should be provided at least for 100%, 75%, 50%, and 25% or to the minimum load point.

It was suggested that the performance map information should include cooling capacity, power input and COP at each of those rating points. Note that the same information could be adapted also to other products such as absorption chillers, water-cooled air conditioners and gas engine air conditioners.

11 Pathways towards better comparability

11.1 Chiller selection software as an alternative to harmonisation

Harmonisation of the standards seems unlikely, given the reasons for difference explained in section 7, but is not the only way to achieve a level of comparability between standards. Under both the AHRI and the Eurovent chiller performance certification systems, it is not necessary to test all chillers at all rating points required to calculate the seasonal performance metrics. Instead, the certification systems now focus on certifying the manufacturer's chiller selection software. The software enables specifiers to make a product selection with a certain (limited) choice of design options[27] and calculates performance at the standard rating points and at any particular application rating points (different source temperatures/flows). The software can provide seasonal performance metrics and in most cases can deliver a full performance map of the unit in a tabulated format (i.e. with varying ambient temperature, water temperature and load conditions to make a yearly calculation with a building energy simulation tool).

Whilst software may have started with only the big multinational manufacturers, it is thought it is now used by the vast majority of manufacturers including SMEs, as it is so much more flexible and cost effective than large programmes of product testing, which is the alternative way to generate data.

Hence, for the purpose of comparing the ambition of different metrics, normalisation may not be required. If manufacturers' software could be set up to provide IPLV and SEER metrics in standard formats, then comparisons could be made of typical product performance against

[27] For example to specify Northern weather kit for air-cooled chillers; corrosion resistant treatment for marine environment; extra high efficiency option; low noise; variable speed pump and control included; larger heat exchangers.

regulatory requirements of US, EU and other economies. Through careful sampling of products, this would enable benchmarking of relative stringency and market performance.

11.2 Evaluating historical and software options

It is apparent from the analysis of section 7 that the EU and Japan have good reasons for pursuing their own metrics and harmonisation is highly unlikely. The option of restarting the ISO international test standard initiative appears pointless without determination from EU and Japanese policy makers to realign with IPLV and the US style approach.

Instantly transparent performance information may not therefore be feasible and so remaining options are to work on chiller performance information availability from manufacturers that would enable comparisons between economies to be made:

a) When specifying chillers for a given application and so ensuring that the best chillers can be identified from any market of choice;
b) When policy makers need to benchmark (proposed) regulations for stringency to ensure appropriate policy outcomes and a reasonably level playing field for competition;
c) When policy makers and any other market players wish to benchmark average performance of chillers in different economies.

Adapting selection software to deliver data in the different metrics and in standard formats appears to be the obvious and potentially least cost route to facilitate the comparison process. Some level of verification through product testing would of course be necessary, and this is already built into the AHRI, Eurovent and similar industry-led certification processes.

Most economies are aligned with the US IPLV system and policy makers in each of them will decide if local trade situations or other reasons would justify mandating (or encouraging) data availability in two (or more) metrics. The cost to manufacturers may be quite small for software changes, but total cost would depend also on the data verification and maintenance processes such as additional testing and regular cross-checks with product engineering over time. The case for mandating manufacturers in the EU and Japan to publish data at standard IPLV rating points is likely to be stronger, based on transparency for specifiers and end users and the desire of policy makers to ensure that their policies and markets are developing in line with economies in the rest of the world, despite operating under different metrics. Manufacturers in the EU and Japan that export will almost certainly be generating this data already – the information requirement would place minimal additional burden on them.

11.3 Steps to implement better information availability

The following steps are suggested for a way forwards for policy makers to ensure that appropriate information is made available in future:

1. **Detail the information and its presentational format(s)** that would be necessary to achieve the aims in order to have focused consultations with manufacturers (the data identified in section 10.2 provides a starting point).
2. **Verify with manufacturers and software providers that the proposed data can be made available through traditional software.** Also to estimate the scale of cost for software adaptation, additional product testing and any other burden that would be imposed along with any such information requirement. This should involve organisations that certify the software, such as AHRI and Eurovent.
3. **Investigate if any manufacturers could suffer a disproportionate burden** as a result, for example SMEs, or if any do not yet make use of such software.
4. **Detail and verify a methodology to enable policy makers to benchmark market average performance through harvesting this information.** This would involve designing a market sampling technique to analyse performance of selected typical products that could be aggregated up to be representative of the area of the market of interest. This could include deriving sales-weighted fleet averages for key product types. Careful consideration, and probably compromises, would be need to be made since chillers typical of one market would not necessarily be typical in another market: comparison could be made regarding like-for-like products or regarding most widely used chiller types; both results could be useful and/or interesting for different reasons.
5. **Detail and verify a methodology to enable policy makers to benchmark relative stringency of policies through harvesting this information.** This could involve finding a representative set of particular products across the range of capacities that just pass the requirements of one economy, and determining the performance of those same products according to the alternative metric. This could yield an approximate translation of the requirement into the alternative metric. Selection of the representative products would crucially take account of technology types, range of different manufacturers and different selection software, features and functionality of products common to both markets. In addition, differences in the scope of chiller types included under each policy could skew results. The process could be undertaken in both directions to cross-check for anomalies.
6. **Consider whether a programme of testing would be useful**, for a set of representative chillers according to both methodologies, to ensure that results are robust. Such a programme of US/EU testing is being considered for 2015/2016 under bilateral discussions between AHRI and Eurovent Certification.
7. **Encourage greater cooperation between industry and technical standards groups and between policy makers across economies**. For example AHRI/Eurovent and through the established US/EU cooperative agreement for policy makers on ecodesign.
8. **Implement the agreed information requirements through mandatory or voluntary means; review market and policy progress at suitable intervals using the methodologies.**

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Annex 1. Further details of calculation method for IPLV and simplified bin method

Method 1 - IPLV (and ESEER), as used for chillers in the US: the final seasonal performance coefficient is simply the weighted average of the efficiency of the rating points.

The IPLV is calculated as follows (AHRI, 2011):

$$IPLV = 0{,}01.\,\mathrm{EER}_A + 0{,}42.\,\mathrm{EER}_B + 0{,}45.\,\mathrm{EER}_C + 0{,}12.\,\mathrm{EER}_D \quad (1)$$

In SI units, IPLV and EER units are W/W.

Where A is the rating condition at 100% load and associated condensing source temperature condition T_A, B is the rating condition corresponding to 75% load, condensing source temperature condition $T_{B.}$

The ESEER is calculated as follows (ECC, 2015):

$$ESEER = 0{,}03.\,\mathrm{EER}_A + 0{,}33.\,\mathrm{EER}_B + 0{,}41.\,\mathrm{EER}_C + 0{,}23.\,\mathrm{EER}_D \quad (2)$$

Variation in the weighting coefficients translate the different building load curves, temperature frequency per outdoor temperature range and timetable of the building use.

Part load rating conditions are the same (25%, 50%, 75% and 100%) but for different source temperature conditions at the condenser (see Figure 3 and Table 3).

Method 2 - Simplified bin method, used for air conditioners in the US and for air conditioners and chillers in the EU - $SEER_{on}$[28], SEPR, from (CENb, 2013):

$$SEER_{on} = \frac{\sum_{j=1}^{n} hj \times Pc(Tj)}{\sum_{j=1}^{n} hj\left(\frac{Pc(Tj)}{EERbin(Tj)}\right)} \quad (3)$$

Where

- Tj is the bin temperature;
- j is the bin number;

[28] SEER is noted $SEER_{on}$ when the low power modes are not included but only the electricity consumption corresponding to the cooling energy delivered to the building.

- n is the amount of bins;
- Pc(Tj) is the cooling demand of the building for the corresponding temperature Tj;
- hj is the number of bin hours occurring at the corresponding temperature Tj;
- EERbin(Tj) is the EER value of the unit for the corresponding temperature Tj.

The values to be used for j, Tj and hj are supplied in the standards. The reference climate (load ratio and hours per bin) is given below in Table 10 for Europe (CEN, 2013b).

Table 10. Example of temperature bin table. Bin number j, outdoor temperature Tj in ºC, number of hours per bin hj and part load ratio corresponding to the reference cooling season planned for chillers in Europe (EC, 2013a).

j #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Tj °C	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
hj h	205	227	225	225	216	215	218	197	178	158	137	109	88	63	39	31	24	17	13	9	4	3	1	0
Part load ratio	5%	11%	16%	21%	26%	32%	37%	42%	47%	53%	58%	63%	68%	74%	79%	84%	89%	95%	100%	105%	111%	116%	121%	126%

The cooling demand Pc(Tj) can be determined by multiplying the full load value (Pdesignc) with the part load ratio for each corresponding bin.

This part load ratio % is calculated as follows:

$$\text{Part load ratio} = (Tj-16) / (35-16) \qquad (4)$$

The EER values at each bin are determined via interpolation of the EER values at part load conditions A, B, C and D.

For part load conditions above part load condition A, the same EER values as for condition A are used.

For part load conditions below part load condition D, the same EER values as for condition D are used.

Annex 2: Calculation of energy consumption in low power modes

For the calculation of low power mode under EU SEER[29], the year is divided into different modes of operation:

- Off mode (in winter time, the chiller is supposed to be non-operational),
- On mode:
  - Active mode hours
  - Thermostat off hours (chiller with cooling function on but there is no demand)
  - Standby (the building is not occupied)
  - When the chiller is on but there is no demand (Standby and Thermostat off hours), the crankcase heater is supposed to be on.

The split between hours is given in Table 5 for chillers.

Table 11. Yearly scenario of use for chillers in the average EU climate.

	Hours definition	Proposed normative values
A	Total hours per year	8760
B	Off mode (H_{OFF})	0 *cooling only and reversible products*
C	Hours for the reference cooling season, of which :	3673
D	- Thermostat off (H_{TO})	659
E	- Standby (H_{SB})	1377
F	Hours during which the building is occupied (C-E)	2296
G	Difference (C-D-E) = Active mode hours without setback correction	1637
H	**Equivalent active hours (H_{CE})**	**600**
I	Crankcase heater (H_{CK})	2036 *cooling only and reversible products*

Source: Rivière, P., et al., 2012, Report on Air conditioning systems, Lot 6 Ecodesign preparatory study: Air-conditioning and ventilation systems, Contract No. ENTR / 2009/035/ LOT6/ SI2.549494, July 2012.

The power consumption during active mode is derived from the calculation of $SEER_{on}$ (see 4.3.3).

The annual electricity consumption is determined as follows:

$$Q_{CE} = \frac{Q_C}{SEER_{on}} + H_{TO} * P_{TO} + H_{SB} * P_{SB} + H_{CK} * P_{CK} + H_{OFF} * P_{OFF} \qquad (5)$$

And

$$SEER = \frac{Q_C}{Q_{CE}} \qquad (6)$$

[29] From EN 14825-2013 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.

Where:

- Q_C = is the reference annual cooling demand, expressed in kWh;
- H_{TO}, H_{SB}, H_{CK}, H_{OFF} is the number of hours the unit is considered to work in, respectively, thermostat-off mode, standby mode, crankcase heater mode and off mode;
- P_{TO}, P_{SB}, P_{CK}, P_{OFF} is the electricity consumption during, respectively, thermostat-off mode, standby mode, crankcase heater mode and off mode, expressed in kW.

Annex 3. Estimation of the impact of tolerances on declared efficiency data

Tolerances are deviations to minimum performance requirements as published: as a hypothetical example, a manufacturer of a chiller with an IPLV value of 5 can, under regulations in some economies, state its value as 4.5 under a system that allows a tolerance of -10 % on the IPLV value. This would not be allowed, however, under recent clarifications for EU regulations.

Tolerances can account for different phenomena depending on product type:

1. Uncertainty of measurements during test (if the uncertainty of measurement is ±10% then an IPLV of 5 could be rated anywhere between 4.5 and 5.5[30] and still validate the declaration;
2. Uncertainty regarding the models used by the manufacturers to publish rated performances;
3. Uncertainty or variations in manufacturing processes;
4. Non reproducibility of test performances from one laboratory to another.[31]

When different regions apply different tolerance policies for the same range of products, this can lead to a deviation in the manufacturer declarations of performances and skew results when comparing performance and/or policy thresholds.

For chillers, points 1 and 2 above account for the majority of tolerance issues. Tolerances may be defined in the testing standard or in the legislation.

The impacts of differences are as follows:

a) Tolerances included in AHRI 550/950 (US) result in a tolerance of COP at full load of -5% and for IPLV of -10.5% (see below).
b) Tolerances defined for the ESEER by Eurovent (EU) are around -8% (Rivière & al., 2012) and -5% for full load ratings. Alternatively, the planned EU regulation encompasses tolerance requirements 'for market verification purposes' that are stated in the Annex to the draft regulations regarding Verification Procedures as:
   - -8% for the SEER requirements;
   - -6% for the SEPR requirements (average load ratio is higher and thus uncertainty is lower, which in turn enables tolerances for SEPR to be reduced as compared to SEER).

   The Annex to the EU regulation makes it clear that '*the verification tolerances defined in this Annex relate only to the verification of the measured parameters by Member State authorities and shall not be used by the supplier as an allowed tolerance to establish the values in the technical documentation*'. In the EU, the manufacturer is

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[30] Of course, if more than one test is allowed, it is possible to check statistically that the average is converging to the right value (but this requires a lot of tests).
[31] A recent example was the difficulty of comparing air conditioner performances in Europe and other parts of the world. It appeared the impact of altitude on the property of humid air and its consequences for performance had not been fully considered.

not allowed to declare a value ‘better’ than that in the test report or that results from calculations / simulations.

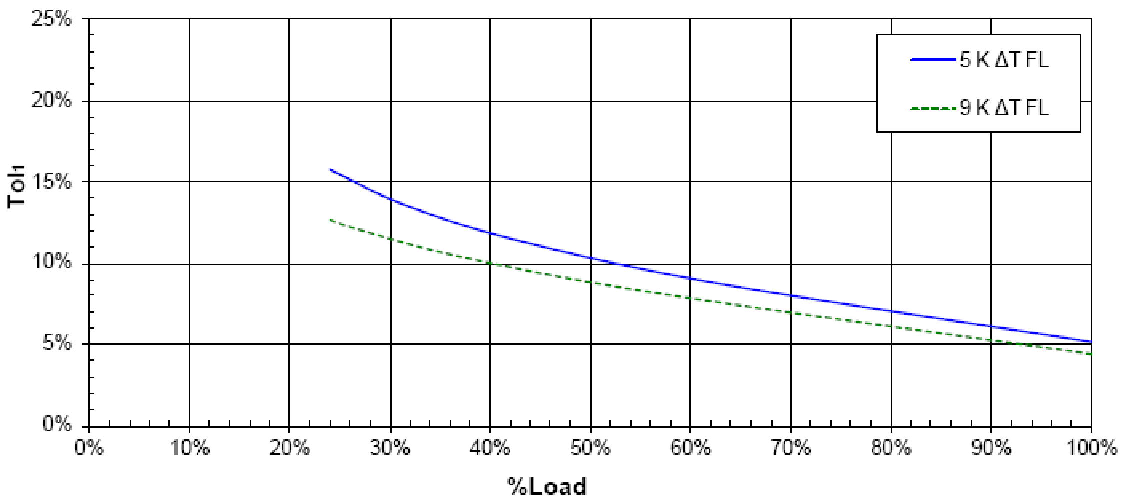
For Australia and Japan, tolerances are defined in the standards but these were not available for this research.

AHRI 550/590

The AHRI 550/590 standard defines the tolerance for the acceptance of a single test result. It is set proportional to the uncertainty of measurement. The uncertainty of measurement is a function of the part load ratio. The reason for this is that when the part load ratio is reduced, the temperature difference at the evaporator decreases and this leads to a larger uncertainty on the rated cooling capacity. Indeed, the temperature measurement uncertainty is constant whatever the load ratio. So when the temperature difference decreases, the relative magnitude of this uncertainty increases. For the same reason, the lower the temperature difference under standard full load rating conditions, the larger the uncertainty. This is illustrated in Figure 16 below.

On this graph, it also appears the tolerance at full load is 5%.

Figure 16. COP and capacity tolerance as a function of part load ratio and standard full load temperature difference at the evaporator (AHRI, 2011).



How does that combine for the IPLV metrics?

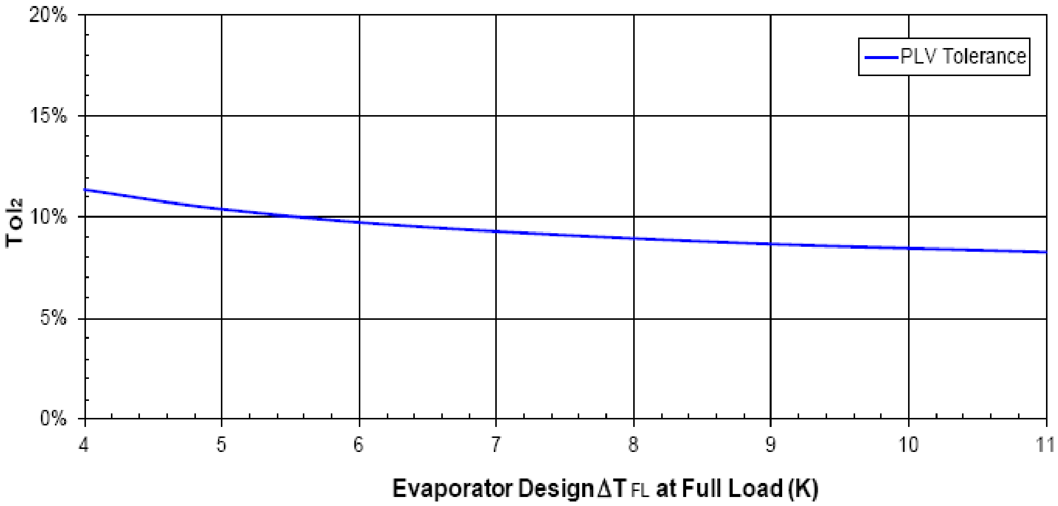
As shown in equation (1) above, the IPLV is the weighted average of four individual rating points with different load ratios, and then according to Figure 16, with different tolerance levels. Consequently, the IPLV metric tolerance can be defined as the weighted average tolerance as follows:

$$TOL_{IPLV} = \frac{\text{IPLV}-(0{,}01.\text{EER}_A.\text{TOL}_A+0{,}42.\text{EER}_B.\text{TOL}_B+0{,}45.\text{EER}_C.\text{TOL}_C+0{,}12.\text{EER}_D.\text{TOL}_D)}{IPLV} \quad (6)$$

Figure 17 below shows an illustration of the combined tolerance of the four IPLV testing points on the weighted average seasonal performance index.

The impact of the nominal water temperature difference inlet/outlet at the evaporator is shown. The lower the temperature difference, the higher the uncertainty on the IPLV value.

Figure 17. IPLV tolerance as a function of standard full load temperature difference at the evaporator (AHRI, 2011).



The water temperature difference across the evaporator is around 5K. This leads to a tolerance level close to 10.5%.

Annex 4. EU fan and pump pressure losses corrections

The reasons for the fan and pump correction used in EN 14511: 2013 are as follows:

- First, it enables fair comparison between standard air-cooled chillers and those which have an integral fan at the condenser. This recognises the function of the integral condenser fan to deliver static pressure to a duct network in addition to the pressure drop across the air heat exchanger which is required to ensure a correct air flow through the chiller heat exchanger. In the case of the AHRI method, ducted air-cooled chillers will be penalized for the consumption of any integral fan, whereas that supplementary power actually serves a purpose other than cooling.
- On the chilled water side of the unit, the correction serves the same purpose for chillers that include a pump. But even for chillers without an integral pump, this is a useful principle for design: it is possible to make chillers that are apparently very efficient, having a very large refrigerant/water heat exchanger but corresponding large pressure drop. In the field, this pressure drop results in large pumping energy consumption for the HVAC plant and so total system efficiency will not match that implied by the 'efficient' chiller.

The impact of this correction is generally low on full capacity standard efficiency rating for non-ducted air-cooled chillers and chillers not integrating the pump. But it may be important in other cases. In addition, it should be noted that it may have very large impacts for part load ratings even for standard chillers.

In addition, the AHRI 550/590 includes default fouling coefficients to correct available cooling capacity in order to simulate in-field results, whilst the EU does not include such factors. The impact of this correction is illustrated in the AHRI standard for one example (section C6.3.5). It leads to an equivalent 0.5 K penalization in water temperature level for a water/refrigerant condenser so to about 0.5 K for an air-cooled chiller. This leads to approximately 3% performance decrease for water-cooled chillers and 1.5% for air-cooled chillers.

Annex 5. Further details of policies in each economy

USA

> *'While the USA has equipment based MEPS for many products under the Energy Policy Act of 1992, the efficiency of air conditioning chillers is regulated as part of State building codes. The ASHRAE Standard 90.1 (Energy Standard for Buildings Except for Low Rise Residential Buildings) specifies the test standards and MEPS levels for chillers and this standard then forms the technical basis for the all-State building codes.'* (E3, 2007)

The objective of this standard is to provide 'Minimum Energy Performance Standards' (MEPS) and requirements for the 'energy efficiency design' of buildings other than low-rise residential buildings. ASHRAE Standard 90.1 was first issued in 1975, and has been revised several times since then (including revisions published in 1980, 1989, 1999, 2001, 2004, 2007, 2010 and most recently in 2013). The Energy Policy Act (EPAct) of 1992 made Standard 90.1-1989 'the law of the land'. Since then, the standard has been widely adopted across the United States and has also become a point of reference in building and energy codes around the world. Starting with the 2001 edition, the standard has been published every third year to coincide with the release of updated regulatory building codes (such as those published by the International Energy Conservation Code, IECC) (Rivière & al., 2012).

Minimum performance requirements are contained in the ASHRAE 90.1 standard and are mandatory minimum requirements (except for 'the simplified approach' which prescribes solutions which do not encompass chillers).

Minimum performance standards for chillers were published in the ASHRAE 90.1 2010 version which is now applied in most states in the USA. The 2013 version introduced a second tier of requirements which came into force in January 2015.

Table 12 provides the requirements for chillers in ASHRAE Standard 90.1-2013.

Table 12. ASHRAE 90.1:2013 – MEPS for Water chilling packages.

TABLE 6.8.1-3 Water-Chilling Packages—Efficiency Requirements[a,b,e]

Equipment Type	Size Category	Units	Effective 1/1/2010 Path A	Effective 1/1/2010 Path B	Effective 1/1/2015 Path A	Effective 1/1/2015 Path B	Test Procedure[c]
Air-cooled chillers	<528 kW	COP (W/W)	≥2.826 FL	NA[d]	≥2.985FL	≥2.866 FL	
			≥3.694 IPLV		≥4.048 IPLV	≥4.669 IPLV	
	≥528 kW		≥2.826 FL	NA[d]	≥2.985 FL	≥2.866 FL	
			≥3.768 IPLV		≥4.137 IPLV	≥4.758 IPLV	
Air cooled without condenser, electrically operated	All capacities	COP (W/W)	Air-cooled chillers without condenser must be rated with matching condensers and comply with air-cooled chiller efficiency requirements				
Water cooled, electrically operated positive displacement	<264 kW	COP (W/W)	≥4.513 FL	≥4.400 FL	≥4.694 FL	≥4.513 FL	AHRI 551/591
			≥ 5.588 FL	≥5.867 IPLV	≥5.867 IPLV	≥7.041 IPLV	
	≥264 kW and <528 kW		≥4.542 FL	≥4.456 FL	≥4.889 FL	≥4.694 FL	
			≥ 5.724 IPLV	≥6.007 IPLV	≥6.286 IPLV	≥7.184 IPLV	
	≥528 kW and <1055 kW		≥5.177 FL	≥4.903 FL	≥5.334 FL	≥5.177 FL	
			≥6.070 IPLV	≥6.519 IPLV	≥6.519 IPLV	≥8.001 IPLV	
	≥1055kW and <2110 kW		≥5.678 FL	≥5.509 FL	≥5.771 FL	≥5.633 FL	
			≥6.519 IPLV	≥7.184 IPLV	≥6.770 IPLV	≥8.586IPLV	
	≥2100 kW		≥5.678 FL	≥ 5.509 FL	≥6.286 FL	≥6.018 FL	
			≥6.519 IPLV	≥7.184 IPLV	≥7.041 IPLV	≥9.264 IPLV	
Water cooled, electrically operated centrifugal	<528 kW	COP (W/W)	≥5.553 FL	≥5.509 FL	≥5.771 FL	≥5.065 FL	
			≥5.907 IPLV	≥7.823 IPLV	≥6.401 IPLV	≥8.001 IPLV	
	≥528 kW and <1055 kW		≥5.553 FL	≥5.509 FL	≥5.771 FL	≥5.544 FL	
			≥5.907 IPLV	≥7.823 IPLV	≥6.401 IPLV	≥8.801 IPLV	
	≥1055 kW and <1407kW		≥6.112 FL	≥5.867 FL	≥6.286 FL	≥5.917 FL	
			≥6.412 IPLV	≥8.801 IPLV	≥6.770 IPLV	≥9.027 IPLV	
	≥1407 kW and <2110 kW		≥6.112 FL	≥5.867 FL	≥6.286 FL	≥6.018 FL	
			≥6.412 IPLV	≥8.801 IPLV	≥7.041 IPLV	≥9.264 IPLV	
	≥2110 kW		≥6.176 FL	≥5.967 FL	≥6.286 FL	≥6.018 FL	
			≥6.531 IPLV	≥8.801 IPLV	≥7.041 IPLV	≥9.264 IPLV	
Air-cooled absorption, single effect	All capacities	COP (W/W)	≥0.600 FL	NA[d]	≥0.600 FL	NA[d]	AHRI 560
Water-cooled absorption, single effect	All capacities	COP (W/W)	≥0.700 FL	NA[d]	≥0.700 FL	NA[d]	
Absorption double effect, indirect fired	All capacities	COP (W/W)	≥1.000 FL	NA[d]	≥1.000 FL	NA[d]	
			≥1.050 IPLV		≥1.050 IPLV		
Absorption double effect, direct fired	All capacities	COP (W/W)	≥1.000 FL	NA[d]	≥1.000 FL	NA[d]	
			≥1.000 IPLV		≥1.000 IPLV		

a. The requirements for centrifugal chillers shall be adjusted for nonstandard rating conditions per Section 6.4.1.2.1 and are only applicable for the range of conditions listed there. The requirements for air-cooled, water-cooled positive displacement and absorption chillers are at standard rating conditions defined in the reference test procedure.
b. Both the full-load and IPLV requirements must be met or exceeded to comply with this standard. When there is a Path B, compliance can be with either Path A or Path B for any application.
c. Section 12 contains a complete specification of the referenced test procedure, including the referenced year version of the test procedure.
d. NA means the requirements are not applicable for Path B, and only Path A can be used for compliance.
e. FL is the full-load performance requirements, and IPLV is for the part-load performance requirements.

[Note] Ratings for Path A are intended for units operating most of the time at full load, whereas Path B values are for chiller applications expected to run mostly at part load (see also table footnote "*b*" in Table 12). The energy efficiency rating (EER) and integrated part load value (IPLV) are reported in SI units for this version of ASHRAE 90.1.

The ASHRAE requirements allow for two compliance paths (A and B) for all types of chillers except air-cooled chillers. Each path imposes efficiency standards for both full load (COP) and part load (IPLV). The two compliance paths differ in that Path A imposes more stringent full load efficiency requirements than Path B, while Path B imposes more stringent part load efficiency standards than Path A. The dual path approach offers the designer the option to prioritize full load efficiency or part load efficiency, depending on the situation.

The two paths option was introduced for the first time in the 2010 version of the ASHRAE 90.1 standard.

Canada

Canada based its MEPS programs for chillers on the ASHRAE 90.1 2004 standard.

In 2004, Canada introduced MEPS for chillers that are intended for application in the air conditioning of buildings. Products covered include vapor-compression chillers with a capacity less than 7,000 kW with water condenser or less than 700kW with air condenser and absorption chillers up to 5,600 kW. Energy efficiency was defined as COP and the Integrated Part Load Value (IPLV) for various size and technology combinations. The MEPS was implemented in October 2004 and operates under the standard CSA-C743-02. This testing standard is equivalent to the American standard of ARI 550/590. A key difference between the Canadian MEPS regulatory program and that of the USA is that the regulation is on the water chillers themselves, as opposed to the USA, where the Building Codes are used to regulate the chillers to be installed in new buildings (E3, 2007).

Packaged water chillers must meet the following requirements (NRCan, 2015):[32]

- minimum coefficient of performance (COP) and integrated part load value (IPLV) as specified in CSA-C743-02, Section 6, and listed in Table 9, as shown below in Table 13,
- or minimum adjusted COP and non-standard part load value (NPLV) for centrifugal equipment not designed to operate at standard rating conditions in Tables 10 to 15 of CSA-C743-02.

[32] http://www.nrcan.gc.ca/energy/regulations-codes-standards/products/6953. Accessed 01/28/2015.

Table 13. Canada MEPS for water chilling packages.

Type	Capacity Range,	Minimum	Minimum
October 28, 2004			
Vapour Compression			
Air-cooled with condenser	< 528 (150)	2.80	3.05
	≥528 (150)	2.80	3.05
Water-cooled, reciprocating	all	4.20	5.05
Water-cooled, rotary screw, scroll	< 528 (150)	4.45	5.20
	≥528 (150) and ≤1055 (300)	4.90	5.60
	> 1055 (300)	5.50	6.15
Water-cooled, centrifugal	< 528 (150)	5.00	5.25
	≥528 (150) and ≤1055 (300)	5.55	5.90
	> 1055 (300)	6.10	6.40

This regulation is in line with USA ASHRAE standard 90.1 2004. Canada is considering an amendment to its regulations to reference test method CSA C743-09, which would align with the ASHRAE 90.1-2007 MEPS requirements, thus adapting Path A and Path B requirements. This was supposed to occur on January 1, 2011, but the information on the NRCan Internet site still mentions the old regulation.

Australia / New-Zealand

Australia/New-Zealand have based their MEPS programs for chillers on the ASHRAE 90.1 standard. Responsibility for coverage of chillers is split between E3 for product standards (based on ASHRAE 90.1) for chillers over 350 kW and building codes for chillers less than 350 kW. New Zealand standards only cover chillers over 350 kW.

The objectives of the Australian MEPS Standard are to:

- Establish minimum energy performance standards for the full load and part load performance of liquid chilling packages using the vapour compression cycle.
- Define minimum documentation requirements for registration of liquid chilling packages that are not certified by either AHRI or Eurovent; note that for chillers certified under these certification programs, manufacturers do not have to supply a performance test for the chiller model.

When rated and testing in accordance with AS/NZS 4776, Parts 1.1 and 1.2, the efficiency levels shall be not lower than those defined in Table 14. This standard originally included future proposed efficiency levels, but these will not be pursued and revised standards are under review in 2015. Note these levels of requirements and structure, with path A and path B, are the ones of the ASHRAE 90.1 2010 standard.

Table 14. Present Australia/New-Zealand MEPS for water chilling packages.[33]

Capacity (kWR)	Minimum COP		Minimum IPLV	
	Air-cooled	Water-cooled	Air-cooled	Water-cooled
< 350	N/A	N/A	N/A	N/A
350 – 499	2.70	5.00	3.70	5.50
500 – 699	2.70	5.10	3.70	6.00
700 – 999	2.70	5.50	4.10	6.20
1000 – 1499	2.70	5.80	4.10	6.50
> 1500	2.70	6.00	4.10	6.50

Note: kWR = kilowatt refrigeration.

Chinese Taipei

Chinese Taipei introduced MEPS for water chillers in January 2003 with the second phase of the regulations being introduced in January 2005. The regulations cover water-cooled volumetric and centrifugal compressors, as well as air-cooled chillers (E3, 2007).

Test standards are established in CNS 12575 for volumetric-type compressors (screw, scroll, piston, etc.) and in CNS 12812 for centrifugal-type compressors. These standards reference other region test standards, ARI 550/590 and the Japanese Industrial Standard (JIS). The current MEPS levels are shown in Table 15.

Table 15. MEPS in Chinese Taipei, source (Yu & al., 2014).[34]

Water-cooled type, volumetric compressors	Minimum COP
Cooling capacity < 150 RT	4,45
Cooling capacity > 150 RT< 500 RT	4,9
Cooling capacity > 500 RT	5,5
Water-cooled type, centrifugal compressors	
Cooling capacity < 150 RT	5
Cooling capacity > 150 RT, < 300 RT	5,55
Cooling capacity > 300 RT	6,1
Air-cooled type, all	2,79

China

China adopted labelling requirements for numerous energy-using products. These requirements are defined for each product in the specific standard as shown in the table below. China presently uses both full load metrics (supposedly for similar test conditions as in international or USA standards) and part load metrics.

[33] http://www.energyrating.gov.au/products-themes/cooling/chillers/meps/. Accessed 28/1/2015.
[34] F.W. Yu, K.T. Chan, R.K.Y. Sit, J. Yang, Review of Standards for Energy Performance of Chiller Systems Serving Commercial Buildings, Energy Procedia, Volume 61, 2014, Pages 2778-2782, ISSN 1876-6102, http://dx.doi.org/10.1016/j.egypro.2014.12.308.

For chillers, according to Jianhong, 2009, a comparative label based on full load rating conditions is defined in the standard GB19577- 2004 - *The minimum allowable values of energy efficiency and energy efficiency grades for water chiller*. It is believed that China has been developing a seasonal performance indicator based upon the US IPLV for chillers since 2009; sources consulted (Yu & al., 2014 and CNIS, 2015) suggest that the Chinese product standard itself had not changed at time of writing.

Energy efficiency labels for chillers are also in GB19577- 2004 and are reproduced in Table 16. Grade 5 is in practice a minimum performance requirement.

Table 16. Energy grades (in terms of COP) for chillers in China.[35]

Type	Rated Cooling Capacity (CC)/kW	Energy Efficiency Grade (COP)/(W/W)				
		1	2	3	4	5
Air-cooled or evaporatively-cooled	CC≤50	3.20	3.00	2.80	2.60	2.40
	CC>50	3.40	3.20	3.00	2.80	2.60
Water-cooled	CC≤528	5.00	4.70	4.40	4.10	3.80
	528<CC≤1163	5.50	5.10	4.70	4.30	4.00
	CC>1163	6.10	5.60	5.10	4.60	4.20

Nevertheless, China introduced minimum performance requirements for chillers in 2005 and in 2014 in the building code GB 50189 for commercial buildings (Feng & al, 2014). Full load requirements in 2005 were the same as in the product standard GB19577- 2004. But already in 2005, IPLV minimum performance requirements were established. This building code was updated in 2014. Both minimum COP and IPLV requirements in this standard evolved from 2005 to 2014 as shown in Table 17 below.

[35] Source: http://www.energylabel.gov.cn/en/EnergyEfficiencyStandards/FormulationandRevisionofStandards/detail/734.html.

Table 17. COP and IPLV chiller MEPS in the Chinese standard for commercial buildings GB50189 (and comparison with US ASHRAE 90.1 values), source (Feng & al, 2014).

	ASHRAE90.1-2013			GB50189-2005				GB50189-2014		
		Path A								
	CC[6] (kW)	COP	IPLV	Type	CC (kW)	COP	IPLV	CC (kW)	COP	IPLV
Water cooled	＜264	4.69	5.87	Reciprocating /Scroll	<528	3.8	N/A	≤528	4.1	4.9
	264-528	4.89	6.29							
	528-1055	5.33	6.52		528-1055	4		N/A		
	1055-2110	5.77	6.77		1055-1163					
	1163-2110				>1163	4.2				
	＞2110	6.29	7.04							
	＜264	4.69	5.87	Screw	＜528	4.1	4.47	≤528	4.7	5.45
	264-528	4.89	6.29							
	528-1055	5.33	6.52		528-1055	4.3	4.81	528-1163	5.1	5.85
	1055-1163	5.77	6.77		1055-1163					
	1163-2110				＞1163	4.6	5.13	＞1163	5.5	6.2
	＞2110	6.29	7.04							
	＜528	5.77	6.4	Centrifugal	＜528	4.4	4.49	≤1163	5.2	5.35
	528-1055				528-1055	4.7	4.88	1163-2110	5.5	5.6
	1055-1163	6.29	6.77		1055-1163					
	1163-1407				＞1163	5.1	5.42	＞2110	5.8	6.1
	1407-2110		7.04							
	＞2110									
Air cooled	≤528	2.99	4.05	Reciprocating /Scroll	≤50	2.4	N/A	≤50	2.6	3.1
			4.14		＞50	2.6		＞50	2.8	3.35
	＞528		4.05	Screw	≤50			≤50		3
			4.14		＞50	2.8		＞50	3	3.2

Europe

EU legislation in preparation

Regarding chillers, in Europe, there is presently a draft regulation in preparation regrouping requirements for air conditioners and air-based heat pumps with heating capacities above 12 kW and chillers (EC, 2013a). The draft regulation has been discussed with the Ecodesign Consultation Forum following two studies on comfort cooling and process chillers: DG ENTR Lot 1 impact assessment study (Tait, 2012) and DG ENER Lot 6 (Rivière et al, 2012). The latter reports included the SEER and SEPR figures shown in Table 18 and Table 19. A working document for the EU regulation has been made available that includes the envisaged minimum seasonal space cooling efficiency requirement shown in Table 20 and Table 21, but no formal regulation had been proposed to the Regulatory Committee at June 2015. Values below are thus indicative.

Table 18. Comfort cooling chillers - envisaged minimum SEER requirements in Europe.

Comfort cooling chillers	Minimum SEER values			
Refrigerant fluid GWP	GWP > 675	GWP ≤ 675	GWP > 675	GWP ≤ 675
Categories	2017	2017	2019	2019
Air-to-water chiller with rated output < 400 kW	4,0	3,6	4,1	3,7
Air-to-water chiller with rated output. 400 kW	4,4	4,0	4,7	4,2
Water/brine-to-water chiller with rated output < 400 kW	5,1	4,6	5,2	4,7
Water/brine-to-water -cooled chiller with rated output. 400 kW	6,6	5,9	7,0	6,3

Table 19. Process chillers - envisaged minimum SEPR requirements in Europe.

Process chillers	Minimum SEPR values	
Categories	2017	2019
Air-cooled with rated output < 400 kW	4,5	5
Air-cooled with rated output >= 400 kW	5	5,5
Water-cooled with rated output < 400 kW	6,5	7
Water-cooled with rated output >= 400 kW and < 1000 kW	7,5	8
Water-cooled with rated output >= 1000 kW	8	8,5

Table 20. Comfort cooling chillers, first tier (2017) envisaged minimum seasonal space cooling efficiency requirements in Europe, expressed as a percentage (these are derived from the SEER figures in Table 18).

	GWP > 675	GWP ≤ 675
Air-to-water chiller with rated output < 400 kW, when driven by an electric motor	157	141
Air-to-water chiller with rated output ≥ 400 kW when driven by an electric motor	173	156
Water/brine to-water chiller with rated output < 400 kW when driven by an electric motor	196	176
Water/brine to-water -cooled chiller with rated output ≥ 400 kW when driven by an electric motor	256	230

Table 21. Comfort cooling chillers, second tier (2019) envisaged minimum seasonal space cooling efficiency requirements in Europe, expressed as a percentage (these are derived from the SEER figures in Table 18).

	GWP > 675	GWP < 675
Air-to-water chiller with rated output < 400 kW, when driven by an electric motor	161	145
Air-to-water chiller with rated output ≥ 400 kW when driven by an electric motor	185	167
Water/brine to-water chiller with rated output < 400 kW when driven by an electric motor	200	180
Water/brine to-water -cooled chiller with rated output ≥ 400 kW when driven by an electric motor	272	245

High temperature process chillers and comfort cooling chillers are planned to be regulated in the same European regulation; low and medium temperature process chillers are in a separate regulation. Distinction between comfort cooling and process chillers would be done on the basis of manufacturer declaration, with the possibility to propose dual use if the product can respect both sets of requirements.

UK building regulations

There are minimum performance requirements for new installations of chillers for comfort cooling in new and existing buildings. These are full load EER based upon the EN14511 standard. For comfort cooling systems in new and existing buildings, the full load Energy Efficiency Ratio (EER) of each cooling unit of the cooling plant should be no worse than in Table 22.

Table 22. Minimum Energy Efficiency Ratio (EER) for comfort cooling chillers in the UK.

Type	Minimum cooling plant full load EER
Vapour compression cycle chillers, water-cooled <750 KW	3.85
Vapour compression cycle chillers, water-cooled >750 kW	4.65
Vapour compression cycle chillers, air-cooled <750 kW	2.5
Vapour compression cycle chillers, air-cooled >750 kW	2.6

French building regulations

For existing buildings, minimum requirements exist for chillers based upon the EN14511 standard: EER > 2.6 for air-cooled chillers, EER > 3 for water-cooled chillers.

EU industry voluntary energy label scheme

ECC (Eurovent Certification Company) introduced a label for chillers about ten years ago; it is based on the gross EER. It is a comparative label with letters from A to G defined by main chiller type. In addition, the catalogue of certified products publishes the ESEER value.

The label is established in terms of EER with the temperature and flow conditions of the EN 14511:2008 standard. EER and capacity are in ‘gross’ values.

Table 23. Eurovent chiller energy efficiency classes, cooling mode.

EER Class	Air-cooled	Water-cooled
A	≥ 3.1	≥ 5.05
B	2.9 - 3.1	4.65 - 5.05
C	2.7 - 2.9	4.25 - 4.65
D	2.5 - 2.7	3.85 - 4.25
E	2.3 - 2.5	3.45 -- 3.85
F	2.1 - 2.3	3.05 - 3.45
G	< 2.1	< 3.05

Japan

No specific policy identified.

Korea

No specific policy identified.