Product Definition for Packaged Liquid Chillers

9 January 2015

For further information refer to:  
http://mappingandbenchmarking.iea-4e.org/matrix
1. Summary Definition and Categorisation

Table 1: Summary of definition and segmentation for this analysis.

<table>
<thead>
<tr>
<th>Definition &amp; scope</th>
<th>Scope is limited to:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>“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 &quot;package&quot;. The chiller may or may not integrate the condenser, the coolant circuit hardware and other ancillary equipment.”</td>
</tr>
</tbody>
</table>

| 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 air conditioning*) |
|                | • 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                                                    |

| Other characteristics to be noted: | • Rated cooling capacity at full load and standard conditions |
|                                    | • Presence of free cooling capability to be noted, where fully integrated                            |
|                                    | • Refrigerant for which declared performance is rated                                                  |
|                                    | • Whether data is certified or as declared by the manufacturer.                                    |

* Where:

a) '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
b) ‘Medium temperature’ at -8°C, also called medium brine, with leaving brine temperature between +3°C and -12°C
c) ‘High temperature’ at +7°C, also called air conditioning chillers, with leaving chilled water temperature between +2°C and +15°C.
d) Floor cooling with a cooling temperature at the outlet of +18°C.
2. Product Sub-Category Rationalisation

This section explains the rationale behind the summary definition presented in Section 1, and how this was developed. Table 2 shows the first proposed way to break down the product category, and each aspect is discussed sections 2.1 to 2.2.

Table 2: Initial matrix definition of possible packaged liquid chillers sub-categorisation.

<table>
<thead>
<tr>
<th></th>
<th>Aspect</th>
<th>Possible Permutations</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Technology</td>
<td>Refrigeration cycle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vapour compression cycle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Absorption cycle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adsorption cycle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Engine chiller</td>
</tr>
<tr>
<td>B</td>
<td>Technology</td>
<td>Compressor type</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rotary vane</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reciprocating</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Screw</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scroll</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Centrifugal</td>
</tr>
<tr>
<td>C</td>
<td>Technology</td>
<td>Heat rejection medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Air cooled</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Water cooled</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evaporative cooling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ground heat sink</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other</td>
</tr>
<tr>
<td>D</td>
<td>Technology</td>
<td>Reversibility</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cooling only</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reverse cycle</td>
</tr>
<tr>
<td>E</td>
<td>Technology</td>
<td>Refrigerant</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R410A, R134a, R22, R407c etc.</td>
</tr>
<tr>
<td>F</td>
<td>Applications</td>
<td>End use</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Comfort cooling / space conditioning (central plant; high temperature plus floor cooling)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Industrial process cooling (Low, medium and high temperature)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Commercial cooling (Low, medium and high temperature plus floor cooling)</td>
</tr>
<tr>
<td>G</td>
<td>Functionality</td>
<td>Use of free cooling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chillers may or may not have functionality to provide cooling effect by thermo-syphon (or pump aided circulation), without operation of the compressor (this is a high efficiency mode in low ambient temperatures).</td>
</tr>
<tr>
<td>H</td>
<td>Functionality</td>
<td>Electrical supply</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Input voltage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frequency of supply (50Hz, 60Hz)</td>
</tr>
<tr>
<td>J</td>
<td>Functionality</td>
<td>Operating temperature range</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low temperature</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium temperature</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High temperature</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Floor cooling</td>
</tr>
</tbody>
</table>

1.1 Technology

Matrix Row A): refrigeration cycle

The vast majority of product performance data in public databases covers electrically driven vapour compression cycle chillers only; very little data is available on absorption cycle products. Similarly, there are few if any policies in place regarding efficiency of absorption cycle chillers.

- Proposal: To focus only on electrically driven vapour compression cycle chillers.

Matrix Row B): compressor type

Different compressor technologies (rotary vane, reciprocating, screw, scroll, centrifugal) will be used in chillers of different sizes and applications and different technologies have different efficiency characteristics. There are particular ranges and applications where certain technologies offer the best economic and efficiency advantage. Some manufacturers may specialise in certain technologies, but competitive forces will ensure that the most economic, and often efficient, solution predominates and there is no reason
to subdivide products in this analysis into separate categories by compressor type. 
Note: Policies in many regions set the most appropriate efficiency requirements for each of 
a set of capacity ranges (for example in the EU for chillers <400kW and >=400kW). The 
rationale to subdivide by capacity stems from the general differences in efficiency of the 
technology that dominates each capacity range. 
* Proposal: To ignore compressor technology.

**Matrix Row C): heat rejection medium**
Chillers can use any of several means to reject the heat at the condenser – to air, to water, 
to a heat sink in the ground, through evaporation of water and others. The performance of 
both air-cooled and water-cooled chillers is well covered in test methodologies and policies. 
The performance of chillers using evaporative cooling is complex and highly variable by 
application with a few policies and test methodologies including them. Similarly, 
performance of ground heat sinks is not well documented in public domain databases. 
Eurovent data implies that in the European market around 80% of comfort cooling sales 
are air cooled; 15% water cooled and 5% sold without condensers. Water cooled chillers 
account for just over 40% of sales of very large chillers (>1000kW), but less than 10% of 
small chillers (<100 kW).
* Proposal: To include only air cooled and water cooled chillers, with a likelihood that 
the majority of available data will be for air cooled chillers.

**Matrix Row D): reversibility**
Whilst the main focus of this analysis is chillers, many products are also able to reverse 
the refrigeration cycle direction to provide heat input to the heat transfer medium. This 
analysis has no interest in their heating effect, but the cooling performance of reversible 
products can also be included in the analysis. Such products will be noted as reversible in 
the analysis where possible. 
* Proposal: To include the cooling performance of reversible products.

**Matrix Row E): refrigerant**
Some data sources declare the refrigerant – this is useful to know as it does make a 
discernible difference to efficiency for the same technology and conditions. Note that in 
general technology is worked out to limit these differences so that it is difficult in practice to 
separate fluid and technology. 
* Proposal: To collect information on refrigerant when available, for possible analysis.

**1.2 Applications**

**Matrix Row F): end use**
There are technological and functional differences between the types of chiller used for 
comfort cooling applications versus the types of chiller used for industrial process cooling, 
even where the temperature of chilled water/brine being supplied may be the same (EU 
ecodesign policy, for example, has draft regulations separately for industrial process 
chillers and for air conditioning chillers). 
This distinction is largely down to the usage profile (proportion of full load), annual usage 
hours and impacts of product failure: 
* Industrial process chillers often run for over 7,000 hours per year (but typically 
4,380), and at 80% loading; consequences of failure can have severe and 
immediate impacts on processes and the business;
Most comfort cooling applications run for only 600 hours per year with highly variable loading\(^1\); impacts of failure are often not immediate and relate to inconvenience/discomfort rather than business critical.

Industrial process chillers are therefore typically much more expensive to run than air-conditioning chillers and require excellent reliability, which justifies higher investment in efficient technologies. Thus comparison of comfort cooling chillers with similarly sized industrial process chillers could give potentially misleading results (although the market reality is probably not so different for both categories if the temperature levels are similar). Comparison is, however, problematic as products may not be clearly distinguished in databases. Data on comfort cooling chillers is far more prevalent.

In terms of relative size of markets, comfort cooling accounts for around 80% of unit sales (almost all of which are ‘high temperature’ chillers); with industrial process chillers around 20%, of which around 80% of that 20% are ‘high temperature’ process chillers\(^2\). Thus high temperature chillers, for both comfort cooling and process applications, account for around 96% of chiller unit sales. The typical cooling capacity of process chillers is higher than that for comfort cooling chillers, such that process chillers account for around 35% of the annual cooling capacity of sales and are therefore more important to policy-makers than their simple unit sales (20% of the market) might imply. Performance data on industrial process chillers is significantly harder to obtain.

- Proposal: To not discriminate between end uses for chillers in data collection (collect all types), but to retain information on any end uses to bear in mind during the analysis. It is likely that comfort cooling chillers will account for the vast majority of available data and policies.

### 1.3 Functionality

**Matrix Row F): use of free cooling**

Some chillers are designed with the capability to provide cooling effect without running the compressor during periods of low ambient temperatures. This is called free-cooling or a thermo-syphon effect. In some cases, it can be assisted by a refrigerant pump. In both cases, energy consumption is lower than with a powered compressor, although fans and other system components still run and so savings are of the order of [30%]. However, the savings achieved by free cooling are not fully accounted for in test methods and depend upon the application. It is not therefore possible to take this into account into this analysis.

- Proposal: To ignore free cooling.

**Matrix Row G): electrical supply**

Input voltage and frequency of supply does affect the efficiency to a limited extent, but this is inherent in the national supply and is therefore not a factor that is compensated for in IEA 4E benchmarking.

- Proposal: To ignore this effect on the efficiency of chillers.

**Matrix Row J): operating temperature range**

The definitions of high, medium and low temperature operating range adopted for this analysis are:

---

\(^1\) Findings during research for the EU ecodesign regulations for industrial process chillers.

Product Definition: Packaged Liquid Chillers 9 January 2015

a) ‘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
b) ‘Medium temperature’ at -8°C, also called medium brine, with leaving brine temperature between + 3°C and - 12°C
c) ‘High temperature’ at +7°C, also called air conditioning chillers, with leaving chilled water temperature between + 2°C and + 15°C.
d) Floor cooling with a cooling temperature at the outlet of 18°C.

Comfort cooling chillers account for 80% of the market and almost all are of the ‘high temperature’ type; of the 20% of the market accounted for by industrial process chillers, around 16% are high temperature chillers, 2.2% medium and 1.8% low temperature (no data available on floor chiller sales at present). Since policies tend to focus on comfort cooling applications, analysis will focus only on high temperature chillers.

- Proposal: To focus on high temperature chillers.

2. Available data

The following datasets have been identified as publicly available and covering at least some of the scope described above. They are summarised in Table 3.

EU: Eurovent certification programme for liquid chilling packages and heat pumps (LCP-HP)

The programme covers standard chillers used for air conditioning and for refrigeration with any type of compressor (hermetic, semi-hermetic and open) and only electrically driven. Chillers may be air-cooled, liquid cooled or evaporative cooled. Reverse cycle chillers are certified in cooling and heating modes. The programme covers four temperature ranges:

- air conditioning, with leaving chilled water temperature between + 2°C and + 15°C
- medium brine, with leaving brine temperature between + 3°C and - 12°C
- low brine, with leaving brine temperature between - 8°C and - 25°C
- Floor cooling

The programme covers chillers under 35 different manufacturer brands and data is downloaded for each manufacturer separately or by chiller technical category (e.g. air cooled package, water cooled split).

Australia: E3 government registration database

The Australian government publishes a database of registered chillers. The downloadable data set of 678 products (at 2 January 2014) includes both COP and IPLV (US style seasonal efficiency data).

USA: AHRI certified products database

This certified products database does not include product performance information on the public website, but provides compressor type and designation and certifies the manufacturer’s software from which a technical specification can be derived.

---

UK: Energy Technology List\textsuperscript{6}
This scheme managed by the carbon trust provides independent endorsement of the best performing chillers on the UK market. Qualified products identified on the website but product conformance details are only accessible for each product individually. Data had not been obtained nor requested at August 2014, but this is likely to be largely a better performing sub-set of the Eurovent data set.

No data sources have yet been offered or identified for other countries and regions.

3. Comparison of policies
Policies for the countries/regions for which data is available will be compared in the analysis. In addition, even without product data, the following countries have policies that would be of interest to compare:

a) Japan US, Taiwan, China (which are moving faster than others).

b) Canada and France have policies regarding chillers that include MEPS

\textsuperscript{6} See https://etl.decc.gov.uk/etl/site/etl.html.
<table>
<thead>
<tr>
<th>Region</th>
<th>Data set source</th>
<th>Test method</th>
<th>Total number of chillers included</th>
<th>Metrics included</th>
<th>Other useful data included</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU</td>
<td>Eurovent certification</td>
<td>EN14511 (2011)</td>
<td>[well over 5,000, not downloaded all yet – need to assess how many are relevant] from 35 manufacturers</td>
<td>EER ESEER</td>
<td>Water pressure drop External static pressure at evaporator outlet</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>E3 government registration database</td>
<td>AS/NZS 4776.1.2</td>
<td>678</td>
<td>COP IPLV</td>
<td>Registration date</td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>AHRI</td>
<td>AHRI 550/590</td>
<td>250</td>
<td>[none in public data set]</td>
<td>Refrigerant Compressor type</td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td>Energy Technology List</td>
<td>EN 14511 (2011)</td>
<td>1305</td>
<td>[data set includes EER and capacity but only accessible product by product on public site]</td>
<td>Date added to list</td>
<td>Includes better performing chillers on UK market. Seeking full data set via DECC</td>
</tr>
</tbody>
</table>
3. Test methodologies

The available data, identified in Table 3, is derived using the test methodologies listed below. Section 4 describes the different performance metrics that are calculated, based on the measured energy results from these methods. The differences between the test methodologies and between metrics for which results and policies must be normalised before fair comparisons can be made are described in section 5.

1. EU: Cooling and heating capacity and calculation of EER based upon EN 14511-2011 *Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling*. Calculation of SEER from EN 14825 *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*

2. Australia: AS/NZS 4776.1.1 and AS/NZS 4776.1.2 [INSERT TITLE]

3. USA: AHRI 550/590 test method for electrically operated water chilling packages


The impact of differences between these test methods are considered further in section 5.

4. Metrics

The performance metrics used in the available data sets are:

Eurovent:

- **EER** - Energy Efficiency Ratio for Air Conditioning Applications. Ratio of the cooling capacity to the power input of the unit.
- **ESEER** - European Seasonal Energy Efficiency Ratio for Air Conditioning Applications (only for the cooling mode of air conditioning chillers). The ESEER is a weighed formula enabling to take into account the variation of EER with the load rate and the variation of air or water inlet condenser temperature.

Australia E3:

- **COP (kW/kW)** A ratio of the cooling capacity, in kW, to the total power input in kW (kW/kW), which represents the efficiency of the liquid-chilling package at specific rating conditions.
- **IPLV (kW/kW)** A single part-load efficiency figure for liquid-chilling packages calculated on the basis of weighted average operation at various partial load capacities and specific ambient conditions as described in the Standard.

AHRI:

- **SEER**

---

5. Normalisation

The main differences between test methodologies which give rise to differences in the measured energy consumption are, in approximate descending order of impact:

A. Ambient conditions for condenser (temperature)
B. Rating point conditions
C. How auxiliary power consumption is accounted for

The metrics of EER and COP for Europe, Australia and the USA are largely comparable once the performance figures are normalised due to these three test methodology differences.

However, the seasonal efficiency metrics ESEER and IPLV are based on different usage profiles and rating points and so cannot be directly compared. For example, the rating points and annual profile used to calculate ESEER for Eurovent rating is shown in Table 4. Because of these differences, these seasonal metrics cannot be directly compared.

The differences between them are complex and so any estimated adjustment factors would lead to significant uncertainties – indeed the EU ecodesign DG ENER Lot 6 preparatory study concluded that ‘direct comparison between the USA IPLV and ESEER for chillers is not possible’ (6 Task 1 report page 225). The available data sets do not provide the data necessary to calculate a comparable seasonal metric. This means that no normalisation is possible for the seasonal efficiency data without detailed insight into the performance parameters for each chiller, or by modelling the performance of chillers selected to be representative of each market and so extrapolating some generalised comparisons. Another alternative is that manufacturers could make available performance data for chillers in any suitable metric by use of their performance software.

Table 4. The rating points and annual profile used to calculate ESEER for Eurovent Certified data.
6. Data requirements

Necessary data fields for analysis of product performance would be:

‘rated cooling capacity’
Being the cooling capacity which the chiller is capable of delivering, when operating at full load. For the reference (EU) conditions, this is measured at standard rating conditions with the reference ambient temperature at 35°C for air-cooled chillers and 30°C water inlet temperature at the condenser for water-cooled chillers, expressed in kW ADD/EDIT AS REQUIRED.

‘rated energy efficiency ratio’
(EER, means the rated cooling capacity, expressed in kW, divided by the rated power input, expressed in kW, expressed at two decimal places)

Definition of the type of chiller for data segmentation.
In order to ensure that similar types of chiller being compared, it is necessary to know the following characteristics of each model:

- Whether chiller is rated low, medium or high temperature or floor chiller
- Whether air cooled or water cooled
- (Further aspects to be defined)