Review on Testing Procedures and Quality Standards for Thermally Driven Chillers

Task Report 5.3.3

AIT

Ivan Malenković

With contributions from:

Annett Kühn, TU Berlin

Marcello Aprile, Politecnico di Milano

Matthias Schicktanz, Fraunhofer ISE

Kyle Glusenkamp, University of Meryland

Version: 2.1

Date: 15/05/2012

Final Document

Contact Info

Address: Giefinggasse 2
1210 Vienna, Austria
Tel.: +43 50 550 6350
Fax: +43 50 550 6679
Email: ivan.malenkovic@ait.ac.at

Quality Assurance in solar thermal heating and cooling technology – keeping track with recent and upcoming developments

Table of contents

1 Introduction

The market for solar cooling systems has experienced a substantial growth over the past few years. Additionally, a shift from demonstration projects towards fully commercial installations can be observed. Accordingly, a number of new products, both thermally driven chillers (TDHP[1]) and packaged systems, have recently reached the market.

However, there are currently almost no quality assurance tools available to support further market growth. Testing standards for chillers, standardised system testing procedure or quality labels etc. are missing.

Within the QAiST project, possibilities and requirements for durability and performance testing of solar cooling systems have been examined. In this context, a review of relevant testing and performance evaluation standards for thermally driven chillers, as the core component of a solar cooling system, was carried out.

The review covered three types of available national and international standards:

- Standards for testing and rating of thermally driven chillers;
- Standards for performance evaluation of chillers and systems;
- Quality labelling schemes.

The standards can be further divided into three groups regarding the system boundary they apply to, Figure 1.

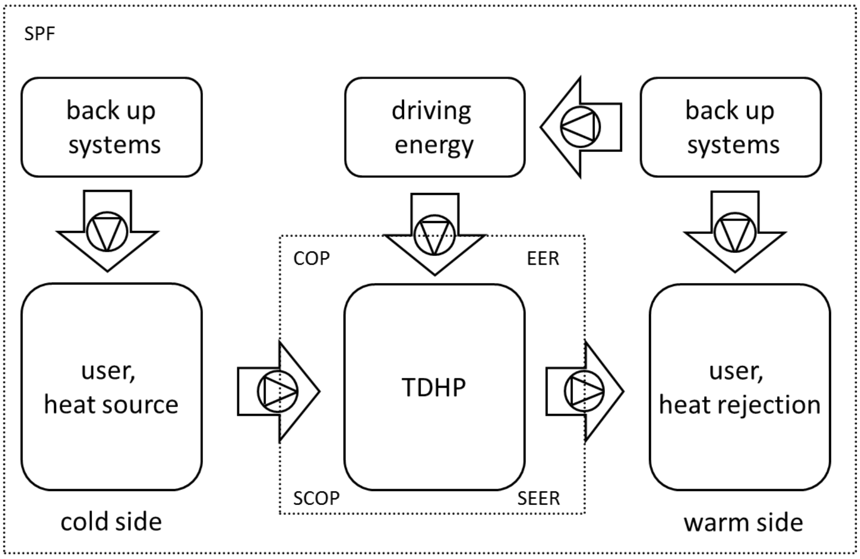

Figure 1: System boundaries of a TDHP system

[1] TDHP – Thermally Driven Heat Pump. There are no principal technical differences between a heat pump and a chiller – heat pump is predominantly used for heating applications and chiller for cooling applications.

The system boundary denominated with COP, EER, SCOP and SEER takes into account only the net useful energy output and energy consumption of the heat pump (or chiller) unit, in some cases including the proportionate energy consumption of the secondary heat transfer media circuits (driving energy, heat source and heat sink) to overcome the internal pressure drops (energy input correction).

The system boundary SPF includes all components of the energy supplying system and accounts for the overall energy consumption, including internal system losses. However, no standards for testing or performance evaluation of overall TDHP systems for cooling applications were found.

The following normative documents were collected and reviewed:

- EN 12309-2 [1]
- DIN 33830-4 [2]
- JIS B 8622 [3]
- ANSI/AHRI 560 [4]
- ANSI/ASHRAE 182 [5]
- VDI 4650-2 [6]
- EN 15316-4-2 [7]
- RAL-UZ 118 [8]

A classification of the documents regarding their scope is given in Table 1.

Table 1: Reviewed documents for TDHP units and systems

		System boundary		
		Chiller only	Chiller with energy input correction	Energy system
Scope of the document	Chiller testing and rating	DIN 33830-4 JIS B 8622 ANSI/AHRI 560	EN 12309-2:2000 ANSI/ASHRAE 182	
	Performance evaluation of chillers and systems		prEN 12309-2:2012 VDI 4650-2	EN 15316-4-2
	Quality labeling schemes	RAL-ZU 118		

2 EN 12309-2: Gas-fired absorption and adsorption air-conditioning and/or heat pump appliances with a net heat input not exceeding 70 kW – Part 2: Rational use of energy

The standard was prepared by the Technical Committee CEN/TC 299 "Gas-fired sorption appliances and domestic gas fired washing and drying appliances". The current version is EN 12309-2:2000. However, it is planned to revise the standard within the WG2 of the Committee, the work started at the beginning of 2011. The formal vote for the revised document is expected to start in mid 2012. The revised standard will include part load performance measurement and auxiliary electricity consumption. Further, a calculation method for Seasonal Primary Energy Ratio (SPER) is being developed, based on the temperature bin method and full and part load measurements.

The current version defines test methods and conditions for the determination of the gas utilization efficiency (GUE) of gas driven sorption (adsorption or absorption) air conditioning and/or heat pump appliances with a net heat input lower than 70 kW.

Both cooling mode (i.e. chiller or air-conditioner) and heating mode (i.e. heat pump) denominations are foreseen in the standard. Denominations in cooling mode include: air/water and water/water (water chiller), air/brine and water/brine (brine chiller), air/air and water/air (air conditioner), where the first term represents the heat sink medium and the second term the heat source medium. Denominations in heating mode include: air/water, water/water, brine/water, air/air, water/air, brine/air, where the first term represents the heat source medium and the second term the heat sink medium (in simple words, the second term is the medium providing the useful effect in both cooling and heating mode).

The GUE in cooling (heating) mode is defined as the cooling (heating) capacity to the gas input ratio:

$$GUE_c = Q_c / Q_T \qquad \text{eq. 1}$$

$$GUE_h = Q_h / Q_T \qquad \text{eq. 2}$$

Gas input (Q_T) is measured in kW according the following formula:

$$Q_T = 0.278 \cdot Vc \cdot H_{i(T)} \qquad \text{eq. 3}$$

where:

V_c is the volumetric flow rate of the test gas, dry, at 15°C and 1 atm, in m^3/h;

$H_{i(T)}$ is the net calorific value of the dry test gas at 15°C and 1 atm, in MJ/m^3.

Cooling and heating capacities are measured according to the type of heat transfer medium (liquid or air).

The full capacity GUE at steady state is the only performance figure defined throughout this standard. Therefore, auxiliary electricity consumption is not considered, nor the degradation effect due to part load operation (cycling effect) can be measured.

In cooling mode, test conditions are defined for the primary function (i.e. cooling). Heating at the condenser / absorber can be declared as a secondary function and the corresponding GUE shall be measured according to the conditions specified by the manufacturer. Heat recovery is an exception and specific conditions are defined in the standard.

Similarly, in heating mode, test conditions are defined for the primary function (heating). Cooling at the evaporator can be declared as a secondary function and the corresponding GUE shall be measured according to the conditions specified by the manufacturer.

Measurements shall respect the following maximum uncertainties:

- Water or brine temperature 0,3 K
- Water or brine temperature difference 0,1 K
- Air dry bulb temperature 0,2 K
- Air wet bulb temperature 0,2 K
- Flow rate (volume) 5 %
- Static pressure difference 5 Pa (<100 Pa), 5 % (>100 Pa)

According to the type of appliance, the following main test conditions are defined:

a) Water and brine chillers

Test conditions are denominated according to the appliance denomination. The first term is the heat sink medium inlet temperature and the second term is the heat source medium outlet temperature.

Water cooled water chiller:	W30/W7		
Water cooled brine chiller:	W30/B-7		
Air cooled water chiller:	A35/W7	A27/W7	A47/W7
Air cooled brine chiller:	A35/B-7	A27/B-7	A47/B-7

In water cooled chillers, the outlet temperature of the heat sink medium (water) is set 5°C higher (as a minimum) than the inlet.

The inlet temperature of the heat source medium (water or brine) is 5°C higher than the outlet.

Cooling capacity is measured at steady state conditions for at least 30 minutes at sampling intervals not higher than 2 minutes. Its expression, in kW, is as follows:

$$Q_c = V_m \cdot \rho \cdot c_p \cdot \Delta T \qquad \text{eq. 4}$$

where:

V_m is the volumetric flow rate of the heat source medium, in m^3/s;

ρ is the density of the heat source medium in kg/m^3;

c_p is the specific heat of the heat source medium, in kJ/kg K;

ΔT is the temperature difference of the heat source medium between inlet and outlet, in K.

Besides measurement uncertainties, steady state operation and matching of test conditions shall be guaranteed. The following deviations of arithmetic mean values and individual sampled values with respect to set values are admissible during the steady state measurement period:

Admissible deviations for arithmetic mean values

- liquid inlet temperature 0,2 K
- liquid outlet temperature 0,3 K
- liquid volumetric flow rate 2 %
- air dry bulb temperature 0,5 K

Admissible deviations for individual sampled values

- liquid inlet temperature 0,5 K
- liquid outlet temperature 0,6 K
- liquid volumetric flow rate 5 %
- air dry bulb temperature 1 K
- air static pressure difference 1 0 %

b) <u>Air conditioners</u>

Test conditions are denominated according to the appliance denomination. The first term is the heat sink medium inlet temperature and the second term is the heat source medium inlet temperature. When the medium is air, dry and wet bulb (in round brackets) temperatures are indicated.

Water cooled air conditioner: W30/A27(19), W15/A27(19), W45/A27(19)
Air cooled air conditioner: A35(24)/A27(19), A27(19)/A21(15),
A46(24)/A29(19)

Cooling capacity is measured in a calorimeter or though the enthalpy method as defined in ISO 5151:1994 [9].

Steady state operation and matching of test conditions shall be guaranteed. The following deviations of arithmetic mean values and individual sampled values with respect to set values are admissible during the steady state measurement period:

Admissible deviations for arithmetic mean values

- liquid inlet temperature 0,2 K
- liquid outlet temperature 0,3 K
- liquid volumetric flow rate 2 %
- air dry/wet bulb temperature 0,3 K
- air volumetric flow rate 5 %

Admissible deviations for individual sampled values

- liquid inlet temperature 0,5 K
- liquid outlet temperature 0,6 K
- liquid volumetric flow rate 5%
- air dry/wet bulb temperature 1 K
- air static pressure difference 10 %
- air volumetric flow rate 10 %

c) Heat pumps (with defrosting)

Water heaters

Test conditions are denominated according to the appliance denomination. The first term is the heat source medium inlet temperature and the second term is the heat sink medium outlet temperature. When the medium is air, dry and wet bulb (in round brackets) temperatures are indicated.

Air/water:	A7(6) /W50, A2(1.5)/W35, A15(12)/W50, A-7(-8)/W50
Water/water:	W10/W50, W10/W35, W15/W50
Brine/water:	B0/W50, B0/W35, B-5/W50

Heating capacity is measured at steady state for at least 30 minutes at sampling intervals not higher than 2 minutes. Its expression, in kW, is as follows:

$$Q_h = V_m \cdot \rho \cdot c_p \cdot \Delta T \qquad \text{eq. 5}$$

where:

V_m is the volumetric flow rate of the heat sink medium, in m^3/s;

ρ is the density of the heat sink medium in kg/m^3;

c_p is the specific heat of the heat sink medium, in kJ/kg K;

ΔT is the temperature difference of the heat sink medium between outlet and inlet, in K.

Air heaters

Test conditions are denominated according to the appliance denomination. The first term is the heat source medium inlet temperature and the second term is the heat sink medium inlet temperature. When the medium is air, dry and wet bulb (in round brackets) temperatures are indicated.

Air/air:	A7(6)/A20(12), A2(1.5)/ A20(12), A-7(-8)/ A20(12)
Water/air:	W10/A20(12), W15/A20(12)
Brine/air:	B0/A20(12), B-5/ A20(12)

Cooling capacity is measured in a calorimeter or though the enthalpy method as defined in ISO 5151:1994.

For all appliances in heating mode

Steady state operation and matching of test conditions shall be guaranteed. The following deviations of arithmetic mean values and individual sampled values with respect to set values are admissible during the steady state measurement period:

Admissible deviations for arithmetic mean values

- liquid inlet temperature	0,2 K
- liquid outlet temperature	0,3 K
- liquid volumetric flow rate	2 %
- air dry/wet bulb temperature	0,3 K
- air volumetric flow rate	5 %

Admissible deviations for individual sampled values

- liquid inlet temperature	0,5 K
- liquid outlet temperature	0,6 K
- liquid volumetric flow rate	5 %
- air dry/wet bulb temperature	1 K
- air static pressure difference	10 %
- air volumetric flow rate	10 %

Specific provisions are defined for measurements during defrosting. Inlet temperatures shall be constant during the heating period, whereas deviations are admissible during defrosting (± 5 K in the first 3 min from the beginning of defrosting, ± 2 K in the following 3 min and 1 K for the remaining defrosting period). Variations of outlet temperatures are allowed. The measurement period shall include an integral number of defrosting / heating cycles, shall last more than 2 h and less than 24 h.

3 DIN 33830-4: Heat pumps; absorption heat pump units; performance and operational tests

DIN 33830-4 is a German standard published in June 1988. It describes test conditions and scope of testing of performance and operational tests of absorption heat pump units for heating. The standard is applicable for water, ground or air source units; on the heat sink side, both water and air can be the heat transfer medium.

Both for the useful heat (indoor heat exchanger) and for the heat source (external heat exchanger), only one temperatures level is fixed - the outlet temperature from the unit (heating supply temperature for hydronic systems) or the inlet to the unit (air systems) and the inlet temperature to the unit (heat pump supply temperature), respectively. The mass flow rates are to be provided by the manufacturer.

The unit is to be tested under different ambient conditions according to the intended place of installation (indoor, outdoor) and according to the type of test (performance test, upper and lower limits of operation, defrost mode etc.). For the operation limit tests, the unit has to be tested under both 90% and 110% of the nominal voltage.

The temperature levels of the rating conditions are given in Table 2.

Table 2: Performance rating conditions

<table>
<tr><th rowspan="2">Heat source</th><th rowspan="2">System type</th><th>Heat source</th><th colspan="2">Heat sink</th></tr>
<tr><th>inlet temperature</th><th>water based - outlet temperature</th><th>air based - inlet temperature</th></tr>
<tr><td rowspan="2">Water</td><td rowspan="2"></td><td rowspan="2">10</td><td>35</td><td>20</td></tr>
<tr><td>X</td><td>Y</td></tr>
<tr><td rowspan="2">Brine</td><td rowspan="2"></td><td rowspan="2">0</td><td>35</td><td>20</td></tr>
<tr><td>X</td><td>Y</td></tr>
<tr><td rowspan="7">Air</td><td rowspan="2">no defrost</td><td rowspan="2">7</td><td>35</td><td>20</td></tr>
<tr><td>X</td><td>Y</td></tr>
<tr><td rowspan="2">automatic defrost</td><td>7</td><td rowspan="2">35</td><td rowspan="2">20</td></tr>
<tr><td>2</td></tr>
<tr><td rowspan="3">optional additional conditions, specified by the manufacturer</td><td>2</td><td>X</td><td>Y</td></tr>
<tr><td rowspan="2">P</td><td>35</td><td>20</td></tr>
<tr><td>X</td><td>Y</td></tr>
<tr><td colspan="3"></td><td colspan="2">X: defined by manufacturer, ≥ 45°C
Y: defined by manufacturer, ≥ 25°C
P: defined by manufacturer, ≤ 0°C</td></tr>
</table>

Additional operating conditions are provided for the limits of operation tests.

Besides performance and limits of operation, two additional tests should be carried out: water condensation test and automatic defrost tests for air units.

4 JIS B 8622:2009: Absorption refrigerating machines

The Japanese Industrial Standard JIS B 8622: 2009 applies for absorption refrigerating machines, absorption water chilling and water heating packages and absorption heat pumps with refrigerating capacities of more than 25 kW using water/LiBr as working pair.

Different classifications are specified:

1. Classification by application:
   - exclusive supply of chilled water
   - both supply of chilled and hot water (switching to chilled water or hot water)
   - simultaneous supply of chilled water and hot water
   - exclusive supply of hot water (by heat pump cycle)

2. Classification by refrigerating cycle (single/double effect type or a combination of both)

3. Classification by heating source, this standard covers:
   - City gas
   - Liquefied petroleum gas
   - Oil
   - Steam
     - Single effect type pressure 147 kPa, 127°C (saturation)
     - Double effect type pressure 785 kPa, 175°C (saturation)
   - Hot water
   - Exhaust gas

4. Classification by installation site (indoor/outdoor type, cooling tower incorporated type)

The standard rating conditions are given in Table 3. It is stated, however, that the values given in the table are applicable to steam absorption refrigeration machines and direct fired absorption water chilling and water heating packages. It is unclear under which are the standard rating conditions for other equipment types. The scale coefficient is the thermal resistance produced by scale in the water in heat exchanger tubes of chilled/cooling/hot water.

The test conditions for the heat source should be according to the specifications (or rated values) with tolerances shown in Table 4.

Table 3: Standard rating conditions in JIS B 8622

Item	Section			
	Use side		Heat dissipation side	
	Chilled (heat) water		Cooling water	
	Entering temperature	Leaving temperature	Entering temperature	Leaving temperature
Refrigerating capacity	(12°C)	7°C	32°C	(37.5°C)
Heating capacity	-	55°C	-	-
Flow rate	Fixed (Rated value)	-	Fixed (Rated value)	Fixed (Rated value)
Scale coefficient	0.086 m²K/kW	-	0.086 m²K/kW	0.086 m²K/kW
NOTE: The numerical values in parentheses in table are values for informative references.				

For different types of temperature and flow meters accuracy requirements are given. The accuracy of the temperature sensors in the chilled, hot and cooling water circuit for example shall be in the range of ±0.1°C and that of the flow meters in the range of ±2%.

The measurements should start after reaching the stationary state. This is described to be the state where the measurement values are stable within the tolerance of variation defined in Table 4.

Table 4: Test conditions in JIS B 8622

Measured quantity	**Permissible tolerance during the test**
Chilled water Leaving temperature Flow rate	 ± 0.5 K ± 5 % of the rated value
Cooling water Entering temperature Flow rate	 ± 0.5 K ± 5 % of the rated value
Heating water (in heat pump mode) Leaving temperature Flow rate	 ± 1 K ± 5 % of the rated value
Hot water (driving) Entering temperature -single effect -double effect Flow rate	 ± 1 K ± 2 K ± 5 % of the rated value
Steam (driving) Inlet pressure -single effect -double effect	 ± 20 kPa of the rated value ± 20 kPa of the rated value

The performance of the unit includes:

- Rating condition
- Refrigerating and/or heating capacity
- Heat consumption of the heating source
- Coefficient of performance
- Pressure loss for the chilled, cooling or hot water
- Body airtightness, withstanding pressure of the water side and withstanding pressure of the heating source side
- Insulation resistance
- Withstanding voltage
- Power consumption
- Performance of burning facility
- Safety devices (body, electricity-related, burning facility, safety devices for incidental facilities, e.g. hot water pump, leak detector, ventilation fan)

Beside these tests, methods for the evaluation of the part load characteristic and noise are given.

The coefficient of performance is defined as “a value obtained by dividing refrigerating capacity or heating capacity by the sum of heat consumption of heating sources and power consumption”. The heating or cooling capacity, as well as the heat discharge capacity, is calculated from the respective temperature and mass or volume flow measurements on the water side. In case that the heat insulation has not been applied, a diminishing factor (1-L) is used, where L indicates the body heat loss rate, as described in Annex C of the standard. Regarding the power consumption, there are no specifications related to the corrections due to pressure losses etc. as in EN 14511 [10], for example. No specification is provided about the exact system boundary for the power consumption measurement.

The coefficient of performance (COP) is calculated as:

$$COP = \frac{Q_{h,c}}{Q_i + A} \qquad \text{eq. 6}$$

where:

$P_{h,c}$ are the heating or the cooling capacity, in kW;

Q_i is the heat consumption of heating sources, in kW;

A is the electric power consumption, in kW;

A normative Annex describes also test methods for refrigerating and heating capacities under the part load condition, which is described to be “the condition under which the refrigerating machine is operated below the rated cooling capacity or the rated heating capacity”.

To adjust the machine’s output to the part load condition, four different control strategies are described:

1. Proportional control – the energy output follows exactly the load over the entire load range;
2. Proportional control plus on-off control – up to a certain load the machine operates in on-off regime. For the rest of the capacity range the machine operates with proportional control;
3. Phase control – up to a certain load the machine operates in on-off regime, where the on phase corresponds to a certain energy output below the rated capacity – low energy output. From that capacity up to the rated capacity, the machine's output switches between the low energy and the rated energy output;
4. On-off control – the machine switches between the rated and zero capacity to adapt to the part load condition.

The measurement procedures for each of the defined control strategies are described. In the case of continuous operation, the measuring method is the same as for the rating test. For the on-off operation, the measurement is performed under periodically fluctuating condition showing approximately the same pattern for each cycle. The number of cycles within the measurement period must be more than one and the measurement period must be more than 30 minutes.

The test conditions are similar to those for the rated capacity tests, with the following modifications or additions:

- The entering temperature for the cooling water shall be 32°C for the rated capacity and 27°C for the zero capacity. The values for any intermediate capacity should be obtained by interpolation;
- The fluctuating allowances regarding the average values of the chilled and hot water leaving and cooling water entering temperatures for the on-off operation is in the range of 1°C for chilled water and -1°C for hot and cooling water.

5 ANSI/AHRI 560: Standard for Absorption Water Chilling and Water Heating Packages

This standard applies to water/LiBr water chilling machines. It includes indirectly-fired single effect chillers (both steam- and hot water-fired), indirectly-fired double effect chillers (both steam- and hot water-fired), and directly-fired double effect chiller/heaters. It does not apply to machines that are air-cooled, exhaust gas-fired, or used only for heating.

The test procedure provides a definition with tolerances for steady state operation. Once the machine is in steady state, three sets of data are taken at a minimum of 5 minute intervals. The data taken is enough to establish the cooling produced, the driving energy provided to the machine, and in addition, an energy balance to verify the accuracy of measurements.

There are three sets of conditions for which data is to be taken: (1) full load "standard rating conditions," (2) full load "application rating conditions" and (3) part load conditions. The standard conditions are precisely defined, while the application conditions allow the manufacturer to choose from within a range of values for temperatures and flow rates.

The standard conditions are:

- 29.4°C cooling water entering temperature to the absorber/condenser
    - 0.065 L/s per kW of capacity for single effect
    - 0.072 L/s per kW of capacity for double effect
- 6.7°C chilled water leaving temperature from the evaporator
    - 0.042 L/s per kW
- Driving heat source is to be provided at the temperature and flow rate specified by the manufacturer

Application conditions can be chosen from within these ranges:

- Leaving chilled water: 4.4 to 8.9°C
- Entering absorber/condenser water: 26.7 to 32.2°C
- Flow rate of absorber/condenser water: 0.05 to 0.11 L/s per kW
- Flow rate of evaporator chilled water: 0.03 to 0.05 L/s per kW
- Flow rate of heating water for double effect machines follows manufacturer's setting
- Inlet steam pressure for single effect: 0 to 103 kPa gauge
- Inlet steam pressure for double effect: 0 to 861 kPa gauge
- Entering hot water to generator: 82 to 204°C

Part load is to be evaluated at 100 %, 75 %, 50 %, and 25 % of the full load capacity. The results can be represented in any one or more of the following three ways:

- At standard rating conditions, a weighted average (representing typical building loads) is calculated from the four part load fractions to obtain the integrated part load value (IPLV)
- At application rating conditions, the same weighted average can be calculated to obtain the non-standard part load value (NPLV).
- Separate part load data points can be reported, in which case they must be sufficient for calculating the IPLV or NPLV

In the event that a unit cannot operate down to 25 % part load, a cyclic degradation factor is applied to represent the part loads below the limit of the machine.

For the NPLV, the operating conditions can be chosen by the manufacturer, except that the entering cooling water temperature must be reduced, proportional to the part load factor, from the manufacturer-selected temperature at 100 % down to 21.1°C at 50 % load, and then fixed at 21.1°C from 50 % to 0 % load.

For the IPLV, operating conditions are the same as the standard conditions, with one change. The absorber/condenser entering water temperature must be 29.4°C at 100 %, 25.3°C at 75 %, and 21.1°C at 50 % and 25 %.

6 ANSI/ASHRAE 182-2008: Method of Testing Absorption Water-Chilling and Water-Heating Packages

This standard prescribes a method of testing absorption water-chilling and water-heating packages to verify capacity and thermal energy input requirements at a specific set of operating conditions. This standard applies to absorption packages used to chill and/or heat water and testing that will occur where proper instrumentation and load stability can be provided. This standard is not intended for testing typical field installations. The ANSI/ASHRAE 182 standard is a method of test (MOT) standard meant to be used in conjunction with a rating procedure such as ARI 560.

The standard applies only to water-cooled units. It applies to chillers using water/LiBr, ammonia/water, and other working fluids, both single- and double-effect. The chiller can be direct-fired by natural gas, LP gas, oil, or other fuel; or it can be indirectly fired by steam, hot water, a hot gas stream, or other hot heat -transfer fluids. It covers three modes of operation: cooling-only, heating-only, and combined cooling and heating.

Test data is to be taken at steady state conditions. Tolerances are defined for establishing steady state. Once steady state is established, three sets of data are recorded at a minimum of 5-minute intervals, and within a maximum 45 minute period.

For each data collection instance, the following data are recorded:

- Temperatures:
    - Chilled-water inlet
    - Chilled-water outlet
    - Cooling-water inlet
    - Cooling-water outlet
    - Water entering heating circuit (for units equipped with heating capabilities)
    - Water leaving heating circuit (for units equipped with heating capabilities)
- Pressures:
    - Evaporator water pressure drop
    - Absorber/condenser water pressure drop
    - Steam pressure
- Electrical power into unit
- Water flow rates:
    - Chilled water
    - Cooling-water
    - Hot water (for units with heating capabilities)

In addition, the driving heat into the machine is to be measured. The measurement method corresponds to the type of heat used (steam, hot liquid, direct fired, or exhaust gas).

- Steam consumption
- Fuel consumption
- Enthalpy change of exhaust gas through appliance

The temperatures, flow rates, and performance calculations are specified in ARI 560.

7 VDI 4650-2: Simplified method for the calculation of the annual coefficient of performance and the annual utilisation ratio of sorption heat pumps - Gas heat pumps for space heating and domestic hot water

The scope of VDI 4650-2 is to define a method to estimate seasonal performance figures of a gas fired thermally driven heat pump based on measurements under part load laboratory conditions. Current version of the guideline was published in November 2010. It is defined for monovalent[2] gas fired sorption heat pumps up to a heating power of 70 kW. As ambient heat sources ground water, boreholes, air and solar radiation gained by a solar collector are considered. The heat is used for domestic hot water preparation and space heating.

Basically, two seasonal performance figures are defined. The annual use efficiency η_N is defined as the produced heat per consumed fuel. The "Jahresheizzahl" – annual heating figure ζ, however, is defined as the amount of produced heat per amount of consumed fuel and electricity. Fuel and electricity are weighted equally, thus they are added without correction.

More precisely, the guideline defines a calculation procedure for several performance factors and use efficiencies:

- annual use efficiency for space heating with/without solar assistance
- annual use efficiency for domestic hot water with/without solar assistance
- annual performance factor for space heating with/without solar assistance
- annual performance factor for domestic hot water with/without solar assistance
- total annual use efficiency
- total annual performance factor

The calculation of the seasonal use efficiency and the annual heating figure is based on the temperature bin method. This means that the use efficiencies and heating figures are calculated form the measured performance in laboratory for several part load conditions. The average of these values is taken as a seasonal value. Based on DIN 4702-8 [11], the part loads are 13 %, 30 %, 39 %, 48 % and 63 % of full load heating power.

The assumption is that in part loads the volume flows are kept constant, thus part load is defined as a reduction of the heating loop inlet and outlet

[2] Monovalent – being the sole system for covering the heat demand of the user; no additional or back-up systems

temperature. A table is given within the document which defines the inlet and outlet temperatures for each part load condition, Table 5.

Table 5: Operation conditions for testing

Relative capacity	Heating temperature 35/28		Heating temperature 355/45		Heating temperature 70/55	
	T_{supply} [°C]	T_{return} [°C]	T_{supply} [°C]	T_{return} [°C]	T_{supply} [°C]	T_{return} [°C]
0,13	22,2	21,3	26,0	24,8	29,7	27,8
0,30	24,9	22,8	32,6	29,6	39,2	34,7
0,39	26,2	23,5	35,6	31,7	43,4	37,6
0,48	27,5	24,2	38,5	33,8	47,6	40,4
0,63	29,7	25,3	43,4	37,2	54,3	44,9

Both gas and electricity consumption should be measured during the tests. The liquid pump for the heating distribution system is considered proportional to the pressure loss through the heat pump unit.

The annual heating figure is calculated according to equations 7 and 8:

$$\varsigma_h = \frac{5}{\sum_{i=1}^{5} \frac{1}{\varsigma_{h,i}}} \qquad \text{eq. 7}$$

$$\varsigma_{h,i} = \frac{P_{i,th}}{Q_i + P_{i,el}} \qquad \text{eq. 8}$$

where

$\zeta_{h,i}$ is the heating figure;

$P_{i,th}$ is the heating capacity;

Q_i is the fuel consumption per time;

$P_{i,el}$ is the electricity consumption of the heat pump unit per time.

The annual use efficiency is calculated analogously, the partial use efficiencies $\eta_{h,i,}$ however, do not contain electricity consumption.

The heat source temperatures are provided for different heat source types, Table 6. The guideline also assumes that the temperature of the ambient source is reduced with increasing heating power. Therefore, the guideline also defines standard temperatures for the temperatures within this loop. This is true for bore holes, ground water, air and solar collectors. For solar collectors, an increase in source temperature is assumed due to the solar radiation on the collector. A temperature increase as a function of the aperture area is given (2,1 to 5,6°C) and should be added to the temperatures of the respective primary source.

Table 6: Heat source temperatures and correction factors for different heat sources

Relative capacity	Ground	Water*		Ambient air			
		7°C	10°C	-10°C	-12°C	-14°C	-16°C
0,13	9	0,98	1,01	16,2	15,9	15,6	15,4
0,30	8	0,99	1,02	10,9	10,3	9,7	9,1
0,39	7	1	1,03	8,4	7,6	6,8	6,0
0,48	6	1,03	1,05	5,7	4,8	3,8	2,9
0,63	5	1,05	1,07	1,2	0,0	-1,3	-2,5

* correction factors to be used in connection with the test results for ground-source heat pumps

For systems with direct solar heating or DHW support, a calculation method for both performance figures is provided. It takes into account the solar fraction (provided by the planer) and the additional electricity consumption for the heat transfer fluid.

The overall performance figures are calculated analogously to VDI 4650-1 [12].

8 EN 15316-4-2: Heating systems in buildings – Method for calculation of system energy requirements and system efficiencies – Part 4.2: Space heating generations systems, heat pump systems

The standard was elaborated by the CEN/TC 228 „Heating systems in buildings“. The current version was published in June 2008.

The scope of the standard covers both heating and DHW heat pumps, in alternate or simultaneous operation. The heat pumps can be driven electrically, with a combustion engine or thermally (absorption only). An overview of the considered heat sources and heat distribution systems is given in Table 7.

Table 7: Heat sources and heat sinks covered in EN 15316-4-2

Heat source	Heat distribution
air (outdoor and exhaust)	air
ground coupled (direct and indirect)	water
water (surface and ground)	direct condensation

The output data of the described calculations are:

- Driving energy of the system;
- Total thermal losses of the system;
- Total recoverable thermal losses of the system;
- Total auxiliary energy consumption.

EN 15316-4-2 describes two different methods for the calculation of the SPF, which differ regarding the needed input data, the considered operating conditions and the calculation periods:

- Simplified method based on the system typology, which delivers the SPF for the heating season. The input parameters are taken from the tables and do not take into consideration the specific configuration of the system. To use this method, a national annex is needed.
- Calculation based on the temperature bin method, which is explained in the standard itself or e.g. in [13]

The standard gives only the calculation methods, in most cases it does not prescribe which input data to use; in some cases, however, recommendations are provided.

The calculation of the SPF with the temperature bin method is performed following the defined ten steps:

1. Determination of energy requirement of every single bin;
2. Correction of steady state heating capacity / COP for bin source and sink temperature operating conditions;
3. Correction of COP for part load operation, if required;
4. Calculation of generation subsystem thermal losses;
5. Determination of back-up energy requirements of the single bins;
6. Calculation of the running time of the heat pump in different operation modes;
7. Calculation of auxiliary energy input;
8. Calculation of generation subsystem thermal loss recoverable for space heating;
9. Calculation of the total driving energy input to cover the requirements;
10. Summary of resulting and optional output values.

The cumulative heating degree hours should be given in a national annex or available from national standards.

The heating energy demand of the heating distribution system should be calculated according to EN 15316-2-3 [14]. The energy demand for each bin is calculated using a weighting factor calculation based on the heating degree hours for every bin. The domestic hot water demand is also calculated using weighting factors, similar to the heating energy demand.

The heating capacity and the COP <u>for the nominal capacity</u> should be determined according to a European standard. If possible, all relevant operation conditions should be considered or at least the operation conditions given in the standard. If the mass flows on the heat source or heat sink side differ from the design operating conditions, a correction by interpolation or extrapolation is possible.

Also, in order to cover the whole range of heat source and heat sink temperatures, the COP values should be interpolated or extrapolated from the measured values. If the COP for only one operating condition is available, a correction for both heat source and heat sink based on the constant exergetic efficiency can be performed and is described in an informative Annex.

Regarding the heat source, the following temperatures are to be used:

- For air-source heat pumps, the outside air temperature of the bin is to be used;
- For an exhaust air heat pump without heat recovery, the indoor temperature is the source temperature. If a heat recovery is included, combined test results for the heat pump and for the heat recovery unit can be used. Alternatively, an evaluation of the supply temperature according to the temperature variation coefficient of the heat recovery, e.g. according to EN 308 [15];
- For ground coupled or water heat pumps, values from national annexes or standards should be used. If none available, an example is given in an informative annex.

For the DHW, results from the measurements according to EN 255-3 [16] are to be used. Because of oscillating source temperatures, a correction has to be performed on the bases of constant exergy efficiency, same as for the heating operation mode. If no data from the tests are available, an average DHW charge temperature can be calculated.

Finally, the overall COP is interpolated from the test data for the heating and DHW operation mods.

For engine driven heat pumps and absorption heat pumps no reference to applicable test methods is given. It is however stated, that the same corrections regarding operating conditions apply. Examples for input data from measurement for heating are given in the informative annexes.

Regarding part load operation, the standard states, that the losses due to the on-off operation are negligible. They are not considered in the calculation, except if considered in the tests which yielded the input data. For the off mode, only the auxiliary energy consumption is regarded. If part load data are available from other standards, e.g. EN 14825 [17], the COP for each operating condition (every bin) should be interpolated and a load factor is to be calculated.

For DHW operation, the start-up losses are already considered in the EN 255-3. For engine driven and absorption heat pumps, the start-up losses have to be considered in the test standards.

Total thermal losses include the losses within the energy generation subsystem, thermal losses from all storages within the system as well as losses in the primary circulation pumps. These losses are accounted for both for the operation and the stand-by times. Some of the losses are recoverable, such as the losses to the heated ambient or the thermal losses of auxiliary components to heat transfer media. These recoverable losses are calculated and added to the energy output of the overall system.

If no storage is integrated in the heat pump (electrically driven) casing, the generator heat losses for the heating operation are not considered if no national standards are available. For engine driven heat pumps, the thermal losses of the engine have to be calculated, but no specific method is given – only references to other standards and possible calculation methods.

If an internal or an external storage is part of the system, the losses to the ambient have to be calculated for every temperature bin. The stand-by heat losses are either given from the storage tests or standard values from an informative Annex are used. The mean storage temperature is obtained from the system control settings. If the temperature in the storage varies according to the heating load, the mean temperature is calculated. For the DHW storage, the same method is applied, only different temperatures according to the regulations have to be taken into account.

For the thermal losses of the primary circulation piping EN 15316-2-3 and EN 15316-3-3 [18] are to be used.

In polyvalent systems, the back-up heating is considered for two reasons:

- If temperatures in the distribution system are needed which are higher than the temperature operation limit of the heat pump;
- The heat pump was not dimensioned to cover the full heating and/or DHW load. In this case two calculation methods are described.

The simplified method is based on the evaluation of the cumulative temperature frequency and the bivalent or low temperature shut-off point. Energy fractions for the heat pump and for the back-up system are obtained. The input data for the calculation are the bivalent or the shut-off point and the operation mode – alternative, parallel or semi-parallel. In all cases, the fraction of the energy delivered by the back-up unit is calculated from the ratio of the area under the cumulative temperature frequency curve representing the energy which is not delivered by the heat pump to the total heating energy needs.

The detailed calculation is based on the evaluation of the running time for 1 K bins. The detailed calculation takes also into account also the specific controller settings.

The operation time of the heat pump per bin is calculated from the produced heating energy and the respective heat pump capacity for the operating condition within a single bin.

While the estimation of the running time is quite straight forward in cases where the heat pump produces heating energy and DHW in clearly separated operation cycles, it can be quite difficult to differentiate between these two running times for the simultaneous operation mode, in which both are produced at the same time. The maximum running time in the simultaneous mode can be calculated from the minimum running time needed in both modes. This time can be corrected for different controller settings. The respective energies produced in this operation mode are calculated. From an energy balance, the fractions of the heating and DHW energies can be calculated. Finally, from these energies, the respective running time can be estimated.

For the calculation of the auxiliary energy consumption, the energy consumption of all system components should be considered. Energy already included in the testing standards has to be taken into consideration.

The energy input to the heat pump is calculated as the sum of the energy inputs for every bin, derived from the delivered heat and the heat pump efficiency under the bin operating conditions. Similar calculation is performed for the energy input to the back-up unit.

Finally, two seasonal performance factors (SPF) can be calculated:

- SPF of the generation subsystem during operation, including the heat pump itself and the back-up heater
- SPF of the overall system, including all auxiliary energy consumptions (e.g. for the heat source system and for stand-by operation)

Comprehensive information on various calculation procedures, as well as default values for different parameters used for the calculations is provided in the Annexes. In most cases, the information is available also for thermally driven heat pumps.

9 RAL-UZ 118: Energy-Efficient Heat Pumps using Absorption and Adsorption Technology or operating by use of Combustion Engine-Driven Compressors

RAL-UZ 118 is issued by RAL, the German Institute for Quality Assurance and Certification, governs the labelling of the environmental certificate “Der Blaue Engel” for gas driven heat pumps. RAL-UZ 118 is a collection of minimum standards a gas driven heat pump has to fulfil to gain the labelling. Current version is from March 2008.

It is valid for absorption type and adsorption type thermally gas fired heat pumps as well as for combustion engine driven compressors. The maximum heating power should not surpass 70 kW at a heating temperature of 40°C.

The minimum requirements for the “Der Blaue Engel” label are:

- The security standards are CE-conform;
- The refrigerant has a global warming potential (GWP) not higher than 15;
- The emission nitrogen oxids (NO_x) and carbon monoxide (CO) do not exceed a certain value. For gas fired heat pumps these values are CO < 50 mg/kWh and NO_x < 60 mg/kWh according to RAL-UZ 61, RAL-UZ 108 and RAL-UZ 109. For gas driven combustion engines and other devices these values are higher. For other fuels the emissivity should be NO_x < 250 mg/kWh and CO < 300mg/kWh according to 1. BImSchV [19];
- The use efficiency is at least 120 % for the temperatures 40/30°C according to DIN 4702-8;
- Electricity consumption is less than 30 $W_{el}/kW_{heat.}$

The measurements require modulation according to DIN 4702-2 [20] and DIN 4702-8.

DIN 4702-8 Central heating boiler; Determination of the standard efficiency and the standard emissivity

Scope of this standard is to define a norm use efficiency and a norm emissivity. It is valid for central heating boilers according to DIN 4702-1, DIN 4702-3 [21] and DIN 4702-6 [22]. Current version was issued in March 1990.

The norm use efficiency is defined as the amount of heat produced for heating or domestic hot water preparation per amount of energy consumed. The emissivity is defined as the mass of emissions per energy consumed. The consumed energy refers to the lower heating value, not the upper heating value.

Two different measurement concepts are applied for heating and domestic hot water preparation. The calculation of the norm use efficiency and the emissivity for heating is based on the method of bins. This means that the use efficiencies and emissivity factors are measured at laboratory conditions for several part loads. The average of the values at 13 %, 30 %, 39 %, 48 % and 63 % of full load heating power is taken as norm value.

The calculation of the norm use efficiency and the emissivity for domestic hot water preparation requires a measurement that exceeds 24 hours. Within this time a certain water consumption profile has to be used defined in the norm. At given times along a day a specific amount of water has to be taken with a specific flow rate. From this, the norm use efficiency and the norm emissivity is calculated.

The norm also provides a combined figure by mixing the case of heating and domestic hot water preparation. In the combined figure it is assumed that the domestic hot water consumption is constant during the year whereas heating is required for 265 days per year and not required for 100 days per year.

10 Assessment of the standards regarding solar cooling application

The reviewed documents can be divided into three groups, according to Table 1. The shortcomings of every group of normative documents are assessed.

Methods for testing of thermally driven heat pumps

- In some documents, the testing methods apply nominally to both absorption and adsorption machines, e.g. EN 12309-2. However, as pointed out in [23], a clear definition of test conditions and procedures for discontinuous processes is not provided.
- All European documents are related only to direct fired machines, only EN 12309-2 covers cooling applications.
- There are no methods for dynamic testing of thermally driven chillers
- There is no unified approach regarding the definition of the performance figure. In some cases the electricity consumption includes the proportional consumption of peripheral devices (pumps, ventilators), in some not.
- The COP (or the EER) is partly calculated as the ratio of the delivered useful energy to thermal energy consumption only and partly as delivered useful energy to a sum of the consumed thermal and electrical energies.
- European testing procedures do not provide any accurate information on testing under part load conditions.
- There is no reference to fluctuating temperatures of the driving energy, as it is often the case in solar cooling systems.
- Standard operating conditions provided within the documents do not fully cover the solar cooling applications. The chilled water temperatures are quite low and correspond to distribution systems with e.g. fan-coil; cooled ceilings are not considered. Generally, there is only one defined temperature level for the condenser/absorber circuit (except in EN 12309-2).
- No measurements of energy consumption during stand-by are prescribed.
- There are almost no durability-related tests included in the unit inspection.

Methods for seasonal performance calculation

- Calculation methods only for heating and DHW are available;
- No specific needs regarding performance figures for thermally driven technologies are considered (e.g. thermal and electrical SPF);

Requirements for quality labels

- Only one quality assurance certification scheme for TDHPs was found in Europe, the German “Der Blaue Engel” for gas driven heat pumps in heating mode. No other technologies or applications are covered.
- Both minimum thermal efficiency and maximum electricity consumption per kW capacity are required, but only for steady state operation.
- The rating of the heat pump should be carried out according to a gas boiler testing procedure.
- There are no reliability or durability requirements within the certification scheme.

11 Conclusion

Although some basic principles regarding testing and calculation methods, as well as operation conditions and a number of other requirements for testing and rating of thermally driven heat pumps can be applied also for TDHP in solar cooling applications, a number of features is missing and will have to be added to the existing documents or developed.

In the course of the survey, no standardised methods for solar cooling system testing and performance evaluation were found. This will also have to be addressed in the future, since a correct system design is crucial for an efficient operation. Also, it can represent the basis of a quality certification scheme, which is also missing at the moment.

Table 8: Comparison of standards for thermally driven heat pumps and chillers

		EN 12309-2: 2000		DIN 33830-4	VDI 4650-2	JIS B 8622	ANSI/AHRI 560	ANSI/ASHRAE 182
Application		heating and/or cooling		heating	heating and DHW	heating and cooling	indirect fired cooling direct fired cooling / heating	heating only, cooling only and combined heating and cooling
Technology		absorption and adsorption		absorption only	absortption and adsorption	absorption, water/LiBr	absorption, water/LiBr, indirect fired single and double effect direct fired double effect	absorption, single and double effect
Energy sources/sinks		sources: water, ground, air sinks: water, air		sources: water, ground, air sinks: water, air	sources: groundwater, water, air, solar energy sinks: water	sources: water sinks: water	sources: water sinks: water	sources: water sinks: water
Capacity		up to 70 kW		no limitation	up to 70 kW	more than 25 kW	no limitation	no limitation
Driving energy		direct fired, gas		direct fired, gas	direct fired, gas	direct fired: gas, oil indirect fired: water, steam exhaust gas	direct fired: gas, oil indirect fired: hot water, steam	direct fired: gas, oil, other indirect fired: hot water, steam, other
Auxiliary consumption		no		no	yes, through internal pressure losses	no specifications, pressure loss for chilled, cooling or hot water measured	no	no
Temperature levels	**driving energy / desorber**	-		-	-	according to manufacturer's specifications	hot water, inlet: 82 to 204°C	-
Temperature levels	**energy source / evaporator**	heating, inlet: air -7, 7, 15, 20 °C water 10, 15, 20°C brine -5, 0°C	cooling in/out: air 21, 27, 29 °C water 12/7°C brine 0/-5°C	water, inlet: 10°C brine, inlet: 0°C air, inlet: 2 and 7°C	water, in/out: 10/7°C brine, inlet: 5-9°C air, inlet: -2,5 - 20°C solar: +2,1 - 5,6 K to T_{air}	cooling: inlet 7°C	cooling: outlet 4,4 to 8,9°C	-
Temperature levels	**energy sink / absorber, condenser**	heating, outlet: air 20°C water 35, 50°C	cooling inlet: air 27, 35, 46 °C water 15, 30, 45°C	water, outlet: 35°C air, inlet: 20°C	three temperatures given: 35/28, 55/45 and 70/55. Temperature glide for part load conditions	cooling: inlet 32°C heating: outlet 55°C values apply only for direct and steam fired units	cooling, inlet: 26,7 zo 32,2°C	-
Test conditions		full load, steady-state		full load, steady-state	steady state, full and part load	full and part load, steady state and quasy-transient (e.g. on-off operation for part load)	full and part load load, steady state	steady state
Durability issues		some durability related topics as part of operational and safety requirements in Part 1 of the standard: servicing, weather resistance, limits of operation etc.		tests regarding limits of operation	-	-	fouling factor taken into account	-

References

[1] EN12309-2:2000 Gas-fired absorption and adsorption air-conditioning and/or heat pump appliances with a net heat input not exceeding 70 kW – Part 2: Rational use of energy, CEN, Brussels, 2000.

[2] DIN 33830-4:1988 Wärmepumpen; Anschlußfertige Heiz-Absorptionswärmepumpen; Leistungs- und Funktionsprüfung, DIN, Berlin, 1988

[3] JIS B 8622:2009 Absorption refrigerating machines. JSA, Tokyo, 2011

[4] ANSI/ARI 560: Standard for Absorption Water Chilling and Water Heating Packages. AHRI, Arlington, 2000

[5] ANSI/ASHRAE 182-2008: Method of Testing Absorption Water-Chilling and Water-Heating Packages. ANSI, New York, 2008

[6] VDI 4650-2: Simplified method for the calculation of the annual coefficient of performance and the annual utilisation ratio of sorption heat pumps - Gas heat pumps for space heating and domestic hot water. VDI, Düsseldorf, 2010

[7] EN15316-4-2:2008 Heating systems in buildings – Method for calculation of system energy requirements and system efficiencies – Part 4-2: Space heating generation systems, heat pump systems, CEN, Brussels, 2008

[8] RAL-UZ 118 Energiesparende Wärmepumpen nach dem Absorptionsprinzip, dem Adsorptionsprinzip oder mit verbrennungsmotorisch angetriebenen Verdichtern. RAL Deutsches Institut für Gütesicherung und Kennzeichnung e.v., Sankt Augustin, 2008

[9] ISO 5151:1994 Non-ducted air conditioners and heat pumps -- Testing and rating for performance. International Organization for Standardisation, 1994

[10] EN 14511:2011 Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling, CEN, Brussels, 2011

[11] DIN 4702-8 Ermittlung des Norm-Nutzungsgrades und des Norm-Emissionsfaktors. Deutsches Institut für Normung e.V., Berlin, 1990

[12] VDI 4650-1 Calculation of heat pumps - Simplified method for the calculation of the seasonal performance factor of heat pumps - Electric heat pumps for space heating and domestic hot water. VDI, Düsseldorf, 2003

[13] Wemhöner, C., Afjei, T., 2003, Seasonal performance calculation for residential heat pumps with combined space heating and hot water production (FHBB method), Swiss Fed-eral Office of Energy, Bern

[14] CEN, 2007, EN 15316-2-3: 2007 Heating systems in buildings. Method for calculation of system energy requirements and system efficiencies. Heat generation systems, thermal solar systems. CEN, Brussels

[15] EN 308:1997 Heat exchangers. Test procedures for establishing the performance of air to air and flue gases heat recovery devices. CEN, Brussels, 1997

[16] EN 255-3:1997 Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors. Heating mode. Testing and requirements for marking for sanitary hot water units. CEN, Brussels, 1997

[17] EN 14825:2011 Air conditioners, liquid chilling packages and heatpumps, with electrically driven compressors, for space heating and cooling – Testing and rating at part load conditions and calculation of seasonal performance, CEN, Brussels, 2011

[18] CEN, 2007, EN 15316-3-3:2007 Heating systems in buildings. Method for calculation of system energy requirements and system efficiencies. Domestic hot water systems, generation. CEN, Brussels

[19] Erste Verordnung zur Durchführung des Bundes-Immisionssutzgesetzes. Bundesgesetzblatt Jahrgang 2010, Teil I Nr 4 vom 1. Februar 2010

[20] DIN 4702-2 Central heating boilers; test code. Deutsches Institut für Normung e.V., Berlin, 1990

[21] DIN 4702-3 Central heating boilers; special gas boilers with atmospheric burners. Deutsches Institut für Normung e.V., Berlin, 1990

[22] DIN 4702-6 Central heating boilers; condensing boilers for gaseous fuels. Deutsches Institut für Normung e.V., Berlin, 1990

[23] Melograno, P. N., Fedrizzi, R., Sparber, W., Franchini, G, 2010, Test Procedures for Sorption Chillers Based on the Working Mode, EuroSun 2010, Proc. of the 2nd Int. Conference on Solar Heating, Cooling and Buildings, Graz