IEA-SHC TASK 43: SOLAR RATING AND CERTIFICATION PROCEDURES

Subtask A: Roadmap of Collector Testing and Certification Issues

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TABLE OF CONTENTS

1 INTRODUCTION

1.1 Sector description

The testing and characterization of solar thermal collectors and components have been investigated from the inception of the IEA Solar Heating & Cooling Programme[1]. Performance test procedures and characterization equations were originally developed for typical solar collector types under well-defined standard test conditions. In addition, short-term tests were developed to predict the long-term durability of standard collectors and systems. Presently, national and international testing laboratories in many IEA participant countries use these test procedures and characterization equations in order to determine a solar thermal product's performance and compliance with required safety and reliability standards. Based on the test certificates issued by accepted test laboratories the products are certified by certification bodies. In order to assess and compare solar thermal products, appropriate procedures are required. These procedures should account for aspects like thermal performance, safety and durability issues.

However, new and advanced solar thermal collectors are continually being introduced to the marketplace and are being submitted to national certification bodies. The existing testing and characterization procedures do not always accommodate these new products or allow them to be evaluated in a reasonable and consistent manner. This has caused the manufacturers of some of these advanced products to believe that they are being unfairly barred from participating in certain markets and their related incentive programs.

1.2 Goals

The objective of subtask A is to examine existing testing and certification procedures for low-temperature evacuated tube and flat-plate collectors, air heating collectors, medium- to high-temperature concentrating collectors, to identify weaknesses, inconsistencies in application, and significant gaps.

The objective of subtask A roadmap is the preparation of a reference document to be used as a guide which describes the existing collector testing procedures, how tests and standards are applied and how they relate to certification, identifying gaps, inconsistencies and weaknesses along with approaches to addressing problems. Develop recommendations for improving the system for emerging technologies where standards and testing procedures are still under development.

1.3 Document structure

Chapter 1 is an introduction to the sector and a description of the goals for the Task 43 Subtask A: Collectors and its roadmap. Chapter 2 gives an overview of the solar thermal market. Chapter 3 summarizes the current solar rating and certification standards. Chapter 4 introduces the need of common testing parameter definitions for fair energy comparisons between collector technologies.

[1] IEA-SHC Task 03, "Performance Testing of Solar Collectors," 1977-1987

Chapter 5 presents the low-to-medium temperature collector testing procedures for flat plate, evacuated tube and polymeric material collectors. Chapter 6 presents the air heating collector testing procedures. Chapter 7 presents the concentrator collector testing procedures, considering also durability issues. Chapter 8 presents the PV/T collector testing procedures and chapter 9 presents the solar fluid testing procedures.

The same information structure has been used from chapter 5 to chapter 9 and for each collector technology, starting with an evaluation of the current standards and certification procedures in order to identify their gaps and open issues. New testing approaches, which solve the previously detected gaps have been gathered to be used as a ground for the Task 43 subtask A research actions. Chapter 10 shows a collector testing standards comparison table.

2 SOLAR THERMAL MARKET OVERVIEW

The solar thermal collector capacity in operation worldwide equalled 172.4 GW_{th} corresponding to 246.2 million square meters at the end of the year 2009[2]. Of this, 151.5 GW_{th} were accounted for flat-plate and evacuated tube collectors and 25.1 GW_{th} for unglazed plastic collectors. Air collector capacity was installed to an extent of 1.2 GW_{th}.

The vast majority of glazed and unglazed water and air collectors in operation are installed in China (101.5 GW_{th}), Europe (32.5 GW_{th}), and the United States and Canada (15.0 GW_{th}), which together account for 86.4% of total installed. The remaining installed capacity is shared between Australia and New Zealand (5.2 GW_{th}), Central and South America (4.7 GW_{th}), the Asian countries of India, South Korea, Taiwan and Thailand (4.6 GW_{th}), Japan (4.3 GW_{th}), the Middle East represented by Israel and Jordan (3.5 GW_{th}) and some African countries (1.1 GW_{th}), namely Namibia, South Africa, Tunisia and Zimbabwe

The main markets for flat-plate and evacuated tube collectors worldwide are in China and Europe as well as in Australia and New Zealand. The average annual growth rate between 1999 and 2007 was 23.6% in China, 20% in Europe, 26% in Canada and the USA and 16% in Australia and New Zealand. Although the installed capacity of flat-plate and evacuated tube collectors in the USA is very low compared to other countries, especially with regard to the large population in the USA, the market for new installed glazed collectors has been significantly growing in recent years.

In the year 2009 a capacity of 36.5 GW_{th} corresponding to 52.1 million square meters of solar collectors were newly installed worldwide. This means an increase in collector installations of 25.3% compared to the year 2008. The main driver for the market growth in 2009 was China whereas in key European markets as well as in the United States and other important economic regions, such as in Japan, the solar thermal sector suffered from the economic downturn, resulting in stagnating or decreasing local markets.

[2] IEA-SHC Solar Heat Worldwide 2011. Markets and contribution to the Energy Supply 2009

Between 2004 and 2009 the annually installed glazed water collector area worldwide almost tripled. The worldwide average annual growth rate between 2000 and 2009 was 20.8%.

The worldwide market of unglazed collectors for swimming pool heating recorded an increase between 1999 and 2002 and a slight decrease in 2003. After a slight increase from 2004 to 2006, the installed capacity rate declined again in 2007. The number of newly installed systems decreased significantly by 7.7% compared to 2008, accounting for 1.5 GW_{th} or 2.2 million of square meters in 2009, whereas there was an increase of 13.9% in the period 2007-2008.

Figure 1 shows the installed capacity of water solar thermal collectors of the ten leading countries.

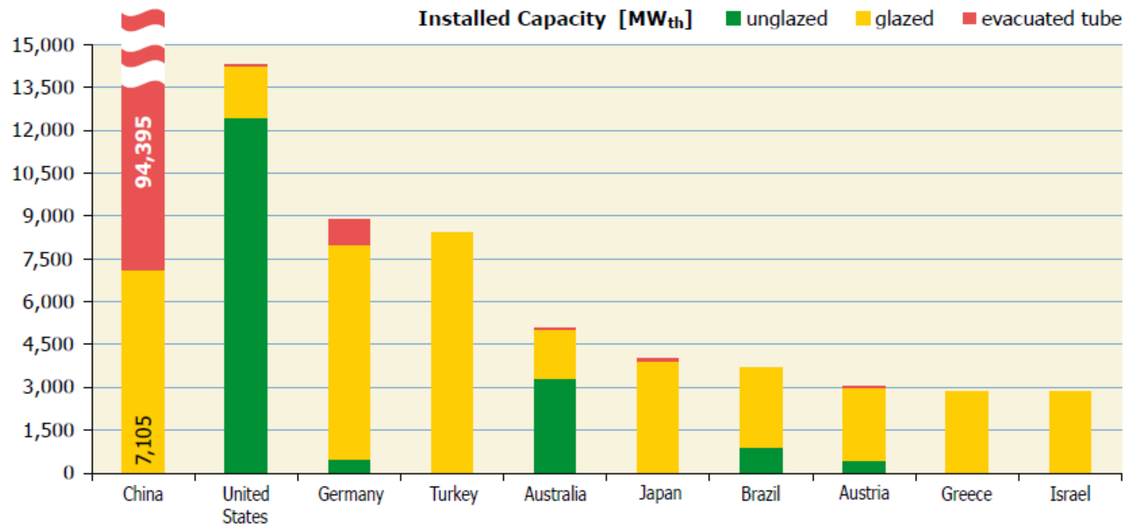

Figure 1. Water collector total capacity in operation of the ten leading countries at the end of 2009[2]

It should be mentioned that there is a growing unglazed solar air heating market in Canada and the USA. These un-glazed air collectors are used for commercial and industrial building ventilation, air heating and agricultural applications.

The final use of solar thermal energy varies depending on the region considered, seeFigure 2, but its widespread use is almost focused on low temperature applications like swimming pools, domestic hot water preparation and space heating in the residential sector.

Europe having a wider range of applications is an exception to that, where around 10% are medium temperature solar thermal applications. The total EU-25 industrial heat demand represents an untapped potential estimated in 100 GW_{th}[3] where almost 60% are low (<80ºC) and medium (<250ºC) temperature applications which can be easily covered by solar thermal collectors already in the market and also through new medium temperature collector developments[4].

[3] IEA-SHC Task 33 and SolarPACES Task IV: Solar Heat for Industrial Processes - Potential for Solar Heat in Industrial Processes.

[4] IEA-SHC Task 33 and SolarPACES Task IV: Solar Heat for Industrial Processes – Medium Temperature Collectors. State of the art within task 33. Subtask C.

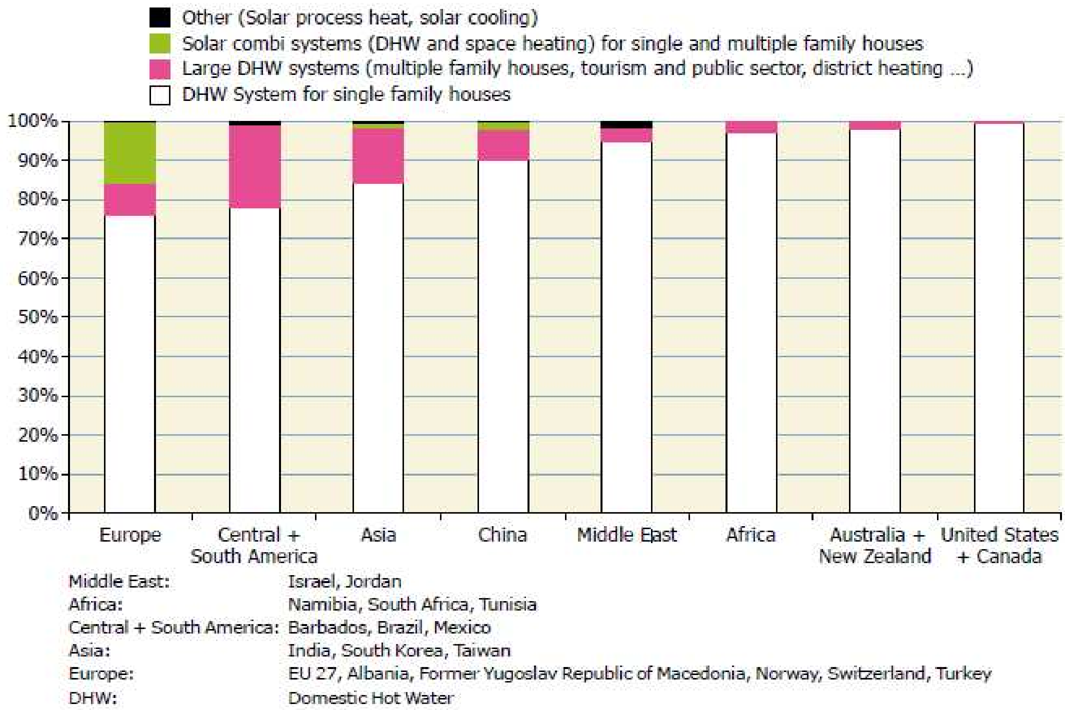

Figure 2. Solar thermal energy applications distributed by region, area installed in 2009[5]

Under the IEA-SHC Task 33, several new development activities[6] for medium temperature process heat collectors have been carried out. To give a short overview on these developments, three categories are introduced:

- Vacuum tube collectors and improved flat-plate collectors: double-glazed flat plate collectors with AR glazing and hermetically sealed collectors with inert gas fillings, or a combination of both. These collectors are installed in a fixed orientation; no sun-tracking system. Full utilisation of the global solar radiation.
- Stationary (i.e. non-tracking) low-concentration collectors: stationary CPC type collectors. The concentration factor is low (approx. 1.5 to 2) in order to avoid sun-tracking. The acceptance angle of the concentrating reflectors reduces the utilisation of the solar radiation.
- Concentrating tracking collectors: parabolic trough, Fresnel collectors or Fixed Mirror Solar Collectors (FMSC) with small aperture widths. Only the direct solar radiation is used.

The current PV/T market is very small, but nevertheless, PV/T has good advantages concerning integration in buildings and the potential of significant market expansion in the near future. There is a potential market expansion[7], considering that the EU targets for 2020 are set at 100 million m^2

[5] IEA-SHC Solar Heat Worldwide 2011. Markets and contribution to the Energy Supply 2009.

[6] Booklet at http://www.iea-shc.org/publications/downloads/task33-Process_Heat_Collectors.pdf Subtask C SHC-IEA-Task 33.

[7] PVT Roadmap: A European guide for the development and market introduction of PV-Thermal technology. EU-supported Coordination Action PV-Catapult.

for solar thermal (corresponding to 70 GW_p thermal) and 3 GW_p for PV, this potential market is mainly found in the residential sector, but also can include municipalities, energy companies, sport facilities and hotels.

3 SOLAR RATING AND CERTIFICATION STANDARDS

Testing the thermal performance and quality of solar collectors has a relatively long history. The present European test standards were developed on the basis of ISO and ASHRAE standards that originate before 1990.

Most well-known test methods, such as ISO9806-1 and EN12975-2, are under steady-state conditions to test the collector thermal performance. These steady-state test methods require strict stable testing conditions. The concentrating collectors are mentioned at the ASHRAE 93-77, ISO9806-1 and EN12975-2 standards. See the comparison table for the existing standards at chapter 10.

3.1 International Standard ISO 9806

The IS0 9806 standard consists of the following parts, under the general title test methods for solar collectors:

- Part 1: Thermal performance of glazed liquid heating collectors including pressure drop
- Part 2: Qualification test procedures
- Part 3: Thermal performance of unglazed liquid heating collectors (sensible heat transfer only) including pressure drop

The IS0 9806 Part 1 provides test methods and calculation procedures for determining the steady-state and quasi-steady-state thermal performance of solar collectors. It contains methods for conducting tests outdoors under natural solar irradiance and for conducting tests indoors under simulated solar irradiance. It is not applicable to tracking concentrating collectors, only gives some information in the annex for special biaxial incident angle modifiers of parabolic-trough concentrating collectors.

The testing conditions for the thermal performance are:

- Collector inlet temperature variation less than ± 0.1K during the specified time before and during each test
- Minimum difference temperature of 1.5K
- Ambient temperature t_a must vary less than ± 1.0 K
- G> 800 $W.m^{-2}$ and ΔG no more than 3%
- G measured with an incidence angle less than 30º
- Flow rate variation less than 1%
- Wind speed between 2 and 4 m/s
- 4 equally spaced values of inlet fluid temperature

- The spectrum-weighted value of the transmittance-absorptance product at normal incidence must not differ more than 3% from the value of the transmittance-absorptance product calculated using the standard spectrum.

The ISO 9806 Part 2 is dedicated to the durability tests and applies to all types of solar collectors, including integral collector storage systems but excluding tracking concentrating collectors. It describes the following testing procedures:

- Internal pressure tests for absorbers
- High-temperature resistance test
- Exposure test
- External thermal shock test
- Internal thermal shock test for liquid-heating collectors
- Rain penetration test
- Freezing test
- Impact resistance test (optional)
- Final inspection

The ISO 9806 Part 3 establishes methods for determining the thermal performance of unglazed liquid heating solar collectors. It contains methods for performing outdoor tests under natural solar radiation and simulated wind and for performing indoor tests under simulated solar radiation and wind. It is not applicable to those collectors in which a thermal storage unit is an integral part of the collector and those collectors in which the heat transfer fluid can change phase, nor is it applicable to collectors affected by condensation of water vapour from the ambient air.

3.2 European Standard UNE-EN 12975-2

The most commonly used methodology is the steady state according to EN 12975-2 is applicable to glazed, unglazed and evacuated tube collectors. It allows two different test methods to determine the thermal performance: the steady-state (SS) and the quasi-dynamic (QD).

The steady-state method according to part 6.1 of this standard is applicable only to no-tracking collectors. This standard is not applicable to those collectors in which a thermal storage unit is an integral part of the collector and also is not applicable for qualification tests to tracking concentrating collectors, only the thermal performance test as given in clause 6.3 (quasi-dynamic testing) is applicable to most concentrating collector designs, from stationary non-imaging concentrators as CPCs to high concentrating tracking designs.

The collector is tested over its operating temperature range in order to determine its efficiency characteristic. Data points are obtained for at least four water inlet temperatures evenly spaced over the collector operating temperature range. Especially, one inlet temperature shall be selected in such a way that the average temperature in the collector lies within the range of ambient temperature ± 3 K, in order to obtain an accurate determination of the optical efficiency: η_0. At least four independent data points shall be obtained for each inlet temperature for outdoor test and 2 data points for indoor test.

The following testing conditions must be considered for both testing methods:

- Minimum temperature difference of 1K
- Ambient temperature t_a must vary less than ± 1.0 K (indoor) or ± 1.5 K (outdoor)
- Flow rate variation less than 1%
- 4 equally spaced values of inlet fluid temperature
- For the steady-state test method:
  - Collector inlet temperature variation less than ± 0.1ºC during specified period
  - Data points variation ΔG no more than 50 $W.m^{-2}$
  - G> 700 $W.m^{-2}$
  - G_d/G < 30%
  - G measured with an incidence angle less than 20º or for an angle which doesn't change the incidence angle modifier more than 2%
- For the quasi-dynamic test method:
  - Collector inlet temperature variation less than ± 1ºC during the specified period
  - Incidence angle from 20º (or for an angle which doesn't change incidence angle modifier more than 2%) to 60º.
- The efficiency curve model is defined for the steady-state method as:

$$\frac{Q}{A} = F'(\tau\alpha)_{en} G_b - c_1(t_m - t_a) - c_2(t_m - t_a)^2$$

And for the quasi-dynamic state method as:

$$\frac{Q}{A} = F'(\tau\alpha)_{en} K_{\theta_b}(\theta) G_b + F'(\tau\alpha)_{en} K_{\theta_d} G_d - c_1(t_m - t_a) - c_2(t_m - t_a)^2$$
$$- c_3 u(t_m - t_a) - c_4(E_L - \sigma T_a^4) - c_5 \, {dT_m}/{dt} - c_6 u G$$

The long-wave irradiance dependence of the collector is modeled in a similar way as described in the ISO 9806-3, for unglazed collectors testing, but here it is treated as a heat loss term. The coefficients in the previous equation are explained below:

c_1 heat loss coefficient at (t_m-t_a)= 0 is modelled as $F'U_0$ [W/(m^2 K)]
c_2 temperature dependence of the heat losses, equal to $F'U_1$ [W/(m^2 K^2)]
c_3 wind speed dependence of the heat losses, equal to $F'U_u$ [J/(m^3 K)]
c_4 long-wave irradiance dependence of the heat losses, equal to F'_e [–]
c_5 effective thermal capacitance, equal to $(mC)_e$ [J/(m^2 K)]
c_6 wind dependence of the zero loss efficiency, a collector constant [s/m]
$K_{\theta d}$ incidence angle modifier (IAM) for diffuse radiation, a collector constant [–]
$K_{\theta b}(\theta)$ incidence angle modifier (IAM) for direct (beam) radiation [–]

For the steady-state test method when using a solar simulator and when testing collectors containing spectrally selective absorbers or covers, it is mandatory to check the effect of the difference in spectrum on the effective transmittance-absorptance product ($\tau\alpha$) for the collector.

This effect should be correct if the difference between the product $(\tau\alpha)_e$ under the simulator and under the solar radiation spectrum (with an optical air mass AM1.5) differs by more than ± 1%.

The range for calculating this product is detailed (the measurement of the solar simulator spectral qualities shall be performed on the collector plane over the wavelength range between 0.3 μm and 3μm and shall be determined with bandwidths of 0.1 μm or smaller. But it is not described how to measure the optical properties. An outdoor check of the optical efficiency η_0 could be enough to control this effect.

According to this standard, the incidence angle modifier can be measured in steady state conditions with an incidence angle θ ± 2.5º. The definition of the incidence angle modifier is in this case:

$$K(\theta) = \frac{\eta(\theta)}{\eta(0^\circ)}$$

The measurement is usually done at an angle θ = 50 ±2.5º. For conventional flat plate collectors, this angle will be sufficient. For some collectors with unusual optical performance characteristics, or if it is required for a simulation software, angles of 20°, 40°, 60° and others have to be determined too.

It can also be performed by the quasi-dynamic test method obtaining the parameter b_0 assuming the following equation for the incidence angle modifier, mainly for the flate-plate collector, as described in e.g. ASHRAE 93-77.

$$K_{\theta b}(\theta) = 1 - b_0\left[\left(\frac{1}{\cos\theta}\right) - 1\right]$$

For the asymmetrical collectors there is no equation but it is required to measure at different incidence angles (at least 20º, 40º, 60º). For evacuated tubes o CPC collectors the incidence angle modifier is measured on the longitudinal and transversal planes separately and assuming that: $K_\theta(\theta) = K_{\theta L} \cdot K_{\theta T}$ and using the following correlation: $\tan^2(\theta) = \tan^2(\theta_L) + \tan^2(\theta_T)$.

The standard includes the following durability test procedures:

- Internal pressure
- High-temperature resistance
- Exposure
- External thermal
- Internal thermal
- Rain penetration
- Freeze resistance
- Internal pressure (retest)
- Mechanical load
- Impact resistance
- Final inspection

3.3 American Standard ASHRAE 93

This standard is for a steady state performance test and defines the following testing conditions for thermal performance:

- Ambient temperature (t_a) less than 30ºC
- G> 790 W.m^{-2} and G_d no more than 20%
- The efficiency formula is defined as:

$$\eta_g = \frac{\int_{T_1}^{T_2} \dot{m} c_p (t_{f,e} - t_{f,i}) dT}{A_g \int_{T_1}^{T_2} G\, dT}$$

This standard gives a procedure for determining the collector incident angle modifier for non-concentrating, stationary concentrating and for single-axis tracking collectors. It gives the following formula for the collector incident angle modifier:

$$K_\theta = \frac{\eta_g}{\left(A_a / A_g\right) F_R (\tau\alpha)_{e,n}}$$ for non-concentrating collectors

and:

$$K_\theta = \frac{\eta_g}{\left(A_a / A_g\right) F_R [(\tau\alpha)_e \rho\gamma]_n}$$ for concentrating collectors

For a collector with isotropic behaviour: $K_\theta = 1 - b_0 \left[\left(\frac{1}{\cos\theta} \right) - 1 \right]$

3.4 American Standard ASTM E 905-87

The American standard ASTM E 905 – 87 (Standard Test Method for Determining Thermal Performance of Tracking Concentrating Solar Collectors) covers the determination of thermal performance of tracking concentrating solar collectors that heat fluids for use in thermal systems. It is applicable to collectors with a geometric concentration ratio of seven or greater but not applicable to fixed mirror-tracking receiver collectors or to central receivers, or to phase-change collectors.

This test method determines the thermal performance of tracking concentrating solar collectors that heat fluids for use in thermal systems for outdoor testing only, under clear sky and quasi-steady state conditions.

The testing conditions for the thermal performance are:

- Collector inlet temperature variation less than ± 0.2ºC or ± 1.0% of the value of Δt_a whichever is larger, during the specified time before and during each test

- Collector difference temperature variation less than ± 0.4ºC or ±4.0% of the value of Δt_a whichever is larger, during the specified time before and during each test
- Before and during ΔG and ΔG_b no more than 4%
- Ambient temperature (t_a) must vary less than ± 2.0ºC
- Mean G_b> 630 W/m^2 and min G y min G_b>200 W/m^2
- G_b measured with an angular field of view between 5º and 6º.
- 4 equally spaced values of inlet fluid temperature

The net rate of energy gain is defined as: $\dot{Q} = \dot{m} c_f \Delta T$ and the efficiency formula as $R(\theta) = \frac{\dot{Q}}{E_{s,D} A_a}$, but no model is provided for the efficiency curve.

This standard also provides the test methods for determining the time response and the incident angle modifier. According to this standard the incidence angle modifier is expressed as:

$$K(\theta_{\parallel}) = \frac{R(\theta_{\parallel})}{R(\theta_{\parallel} = 0^{\circ})}$$

This equation is similar to other standards. The testing procedure requires measuring it with an angle accuracy of ± 2.5º. There are two different testing procedures (one for 2 axis tracking and the other for 1 axis tracking from θ=0º to θ for which efficiency is one-half).

Determination of the angle range (aperture angle range) for which R>0.98.

3.5 Global standards harmonization

The path to a common international standard for solar thermal collectors started when the CEN TC312 WG1 started revising the EN 12975 standard due to the approval of the QAIST[8] project, founded by the European Union within the IEE program in June 2009. At the same time the IEA-SHC Task 43 started its activities in order to disseminate and built consensus around the EN 12975 revision activities on a global level, also due to the ISO TC180 lack of activity during past years concerning the ISO 9806 revision. In October 2009 the ISO TC180 decided to closely follow the EN12975 revision process for a future ISO 9806 revision.

In April 2011, the CEN TC312 WG1 submitted to CEN a draft proposal for the EN 12975 revision and in August 2011 an ISO TC180 ballot resolved that the ISO 9806 standard will be based on the EN 12975 standard. The CEN TC312 WG1 decided to postpone the public enquiry of the EN 12975 revision in order to catch up with the ISO 9806 revision process. In September 2011, it was decided that the EN ISO 9806 will be developed under the Vienna Agreement with CEN lead establishing joint working groups from CEN TC312 and ISO TC180 to develop a common international standard for solar thermal collectors. It was also agreed to create a multi-part standard on collector components and materials, also under Vienna Agreement with some parts lead by CEN and others by ISO:

- ISO lead – Part 1: Evacuated tube durability and performance
- ISO lead – Part 2: Heat pipes for evacuated tubes - Durability and performance
- CEN lead – Part 3: Absorber surface durability and other parts to be considered like glazing and insulation materials

The date of availability for the new EN ISO 9806 standard will be around June 2013. This international standard will pave the way towards a global certification scheme for solar thermal collectors.

4 PARAMETER DEFINITIONS

New parameter definitions covering the type of collectors considered within the subtask A have been commonly agreed and developed within the IEA-SHC Task 43, the CEN TC312 WG1, the solar thermal electric plants subcommittee from AENOR (Spain) and revised by Jean-Marc Suter former convenor of the ISO TC180 WG1. The definitions should be general enough to cover the different collector technologies allowing a fair comparison of their thermal performance test results. Most of the definitions are dealing with concentrating collector terms are mainly applicable to line-focus collectors due to the difficulty of having broad definitions which also cover central receiver systems (out of the scope of testing standards).

[8] QAIST: Quality Assurance in solar thermal heating and cooling technology. http://www.qaist.org

The main criterion used for the definition proposals was to maintain the ISO 9488 definitions as far as possible and new terms not present in the ISO 9488 are taken mainly from existing standards or technical papers:

- Standards:
  - EN ISO 9488:1999 Solar Energy Vocabulary
  - ISO 9806-1:1994 and ISO 9806-2:1994
  - ASHRAE 93-2003
  - CAN-CSA-F378-87(R2004)-Collectors-2412326
  - ASTM E905 - 87 (2007)
  - SRCC OG 600
- Technical papers:
  - Lüpfert, Paper_Standards_Oxaca-draft227
  - Biggs,1979 / Duffie,1980 / Falcone and Kistler,1986 / Montes-Pita,2008
  - Stine,2001 / Forristal,2003 / SAM,2009
  - Eickhoff,2002 / Fisher,2004 / Perers,1997

A new set of definitions has already been included in the EN 12975 revision and this set will be also included in the next ISO 9488 Solar Energy vocabulary. The terms included in this set are the following ones:

Acceptance angle, Cleanliness factor, Collector optical axis, Collector rotation axis or tracking axis, Collector useful power, Combined assembly, Concentrator, Concentrator axis, Cosine loss, End effects, Fail-safe, Incident angle modifier, Intercept factor, Longitudinal angle of incidence, Longitudinal plane, Maximum operating temperature, Minimum acceptance angle, Module, Nominal collector power, Near-normal incidence, Non concentrating collector, No-Flow condition, Outgassing, Optical efficiency or zero loss efficiency, Passive, Peak efficiency, Peak optical efficiency, Peak power, Quasi-dynamic test, Rated Performance, Receiver aperture, Receiver efficiency, Reconcentrator, Reflector or Reflective Surface, Rim angle, Shadowing, Site assembled collector, Specular reflectance, Spillage, Sunshape, Thermal performance, Tracking angle, Transversal angle of incidence, Transversal plane, Trigger or safety activation temperature.

5 LOW-TO-MEDIUM TEMPERATURE COLLECTOR TEST PROCEDURES

It has been already mentioned that there are different test methods for solar thermal collector characterization and certification. The main ones are the American standard ASHRAE 93-77, the international standard ISO 9806-1 and the European standard EN12975-2. Those procedures test the reliability and the efficiency of solar thermal collectors. The thermal performance characterization test methods for solar collectors are different mainly in the duration time of the testing period, the testing conditions, and the mean temperature of the working fluid.

5.1 Flat plate collectors

Flat-plate solar collectors absorb solar radiation and transfer the energy to a working fluid, without concentrating the incident radiation before the absorption, hence using both the direct and diffuse solar radiation.

The main components are the transmission cover, the absorber plate with high absorptance and low emitance layer and the casing with insulation behind the absorber plate. The transparent cover is used to reduce convection losses from the absorber plate through the restraint of the stagnant air layer between the absorber plate and the glass. It also reduces radiation losses from the collector as the glass is transparent to the short wave radiation received by the sun but it is nearly opaque to long-wave thermal radiation emitted by the absorber plate.

A flat-plate collector has a large heat absorbing area, however it has the highest heat loss of all collector types; that is why it is usually limited to low temperature applications, usually less than 80ºC. This collector does not require sun-tracking and it is fixed on a structure with an optimum tilt angle (which is approximately the location latitude) and oriented directly facing the equator.

5.1.1 Current standards and certification procedures

The main applicable standards are: ISO 9806-1, EN 12975 and ASHRAE 93 which have been already described in chapter 3.

5.1.2 Gaps and open questions

The exposure test according to the European standard has been under a lot of debate, mainly due to its inability to maintain uniform test conditions all over Europe. The exposure tests over 30 days according to the European standard EN-12975-2 are still in question.

The rain penetration test according to the European Standard has 3 different criteria to define if a collector passes or fails this test (by weighing the collector, by means of humidity measurement or by means of estimating the condensation level). Those 3 different criterions do not guaranty uniform testing conditions all over Europe labs.

Existing test procedures for performance testing of collectors - for certain types of collectors - do not give correct performance characterisation with "non-typical" flow rates.

5.1.3 Testing approaches

CEN/TC312

The French laboratory CSTB for example recommend for this accelerated ageing test to extend the exposure period from 6 to 12 months, but this proposal has the disadvantage to be highly time consuming. Another solution is the adaption of the Australian Standard AS/NZS 2535.1 which describes a short period improved exposure test.

Most participants in the EU NEGST project have the opinion that one year is a too long testing period and recommend to further investigate the possibilities for using a test procedure similar to the Australian short term procedure. According to the last resolution 6/2007, taken by CEN/TC

312, on 2007-10-15 & 16, Nicosia / Cyprus, the performance of flat plate collectors at non typical flow rates should be also studied.

5.2 Evacuated tube collectors

Evacuated tube collectors (ETC) consist of an absorbing surface mounted in a vacuum glass tube to eliminate convection heat loss. This collector is composed of an array of glass evacuated tubes using water as working fluid.

Types of evacuated tube collectors:

- Single glass tubes
- Double glass tubes
- ETC with direct connection
- ETC with heat pipe connection

Table 1. Specific features relevant to all types of ETCs[9]

Specific feature	Implication on testing or system design
The comparatively low heat losses resulting in high stagnation- and maximum operation temperatures	• Difficult to determine efficiency at high temperatures with good accuracy • Difficult to determine unambiguous stagnation temperature • Special attention required in system design in order to avoid thermal stress on the heat transfer fluid
The non planar shape of the collector surface, either it is fitted with a reflector or not	• Difficult to determine proper loads for mechanical load tests • Bi- or multi axial incidence angle modifiers need to be determined in performance testing
The frequent use of (external) reflector mirrors	• Highly exposed component having a high influence on the performance but not being assessed in present test standards • Difficult to assess the long term effects on the collector output
The fragile structure of the vacuum tubes	• Impact resistance testing required in some regions
The fact that the performance is heavily dependent on the quality (level, durability) of the vacuum	• Difficult to determine vacuum loss in connection to quality tests • Difficult to assess the long term durability of the vacuum

5.2.1 Current standards and certification procedures

There is no specific test standard for ETC, the testing methodologies used for ETC are standards which were first written with the flate-plate solar collectors in mind. In most of standards, it is not considered the geometric and thermal specific behaviour of these collectors.

The main difference between ETC and flate-plate collector in the European standard EN 12975-2 involves the incidence angle modifier measurement.

9 Recommendations on testing evacuated tube collectors (ETCs). EU NEGST WP4 document D2.1.b at http://www.swt-technologie.de/html/publicdeliverables3.html

Evacuated FPC and ETC for water heating applications at temperatures under 100ºC can be tested under the ISO 9806-1. But in order to test their efficiency at low radiation levels, the test procedures for ETC are performed with quasi-dynamic methods.

5.2.2 Gaps and open questions

There are still gaps in the definitions and specifications of the ETC. As well as lacks in the thermal performance model, the capacitance determination, the mechanical load, the impact resistance, the freeze testing of heat pipes and the durability of the glass to metal seal.

The slope of the efficiency curve for an evacuated collector is low resulting from the elimination of convective heat losses. The efficiency model is not accurate, for example, for double-glass evacuated tube collectors and the measurement of the absorber temperature is difficult to perform in practice.

The evaluation of thermal capacitance is not really accurate. With the calculation method, according to chapter 6.1.6.2, it is underestimated and with the quasi-dynamic test it is overestimated.

The mechanical load test is not performed for evacuated tubes without reflectors by most of European laboratories, although it is advisable for snowy regions to realize the positive load test. For example, it can be used some wood pellets to simulate snow behaviour (see NEGST Project).

The impact resistance test is also not well-defined for tube with ice ball or steel balls.

Finally the problems related with vacuum losses are not tested at all under the available standards. This should be an important quality parameter to control.

5.2.3 Testing approaches[10]

- Study possible new models for efficiency curve.
- Define the incidence angle and location impact for hail ball impact tests.
- Define a test method to control vacuum losses
- Thermal capacitance modelling of ETCs has been reviewed in the Eurosol project and will be taken into consideration in the revision of EN 12975.
- For IAM test, there are some difficulties for heat-pipes (In most tests methods it is difficult to obtain 50º longitudinal angle: In simulator because it needs a really good collimation; in sun-tracker because of the changing tilt; In equator-facing test bench because of minimum tilt)

5.3 Polymeric material collectors

Conventional solar collector systems are based on materials (e.g. copper) with limited availability. The material supplies will not be large enough to cover up for the expected growth in solar thermal

[10] NEGST WP4 document D2.1.b at http://www.swt-technologie.de/html/publicdeliverables3.html

installations. These issues demand the introduction of new materials, of which polymers seem to have a strong preference in all respects. Polymers reveal a large cost reduction potential due to mass production, reduction in weight, freedom in structural and functional design and the potential to lead to a breakthrough for solar thermal energy production.

Polymeric collectors had a market share of 17% of the worldwide solar heating capacity in operation in 2007[11], which are almost exclusively unglazed absorbers for swimming pool heating. The USA represents the largest market for polymeric pool absorbers with a power production of 25.1 GWth in operation at the end of 2007. Pool absorbers are applicable in the low temperature range. In order to meet the requirements from the market for heating applications in the medium and high temperature range, the introduction of new polymeric materials and technology is essential. New materials can only be applied if the service-life is comparable to those in conventional products.

Unglazed absorbers in polymeric materials for (outdoor) swimming pool heating have been successfully in the market for more than 20 years. But there are a few commercial glazed collectors with polymeric absorbers. These are mostly designed for low-pressure systems, which are open vented and have pure water without antifreeze additives as heat carrier. Depending on the application polymeric absorbers have different design criteria to the solar collector system than conventional, metal-based absorbers; some designs have a built-in overheat/freezing protection mechanisms for the solar collectors, e.g. drain-back technology, ventilation or other designs to avoid thermal stagnation or freezing of the heat carrier in the solar loop.

The application of polymeric materials opens for new production techniques, allows new types of shapes and e.g. smart snap-designs. Many examples exists where polymeric collectors due to shape, design or simply due to the material have an added value due to its building integration, replacing conventional materials and producing thermal energy.

The applications of polymeric materials as collector components include:

- Unglazed absorbers, with high market penetrations as pool absorbers of rigid, extruded sheets of polypropylene (PP) with intrinsic channels, or with pipe structure are plain polyethylene (PE) pipes, etc.
- Glazing, which has to sustain the temperature gradient between the collector inside and the ambient temperature, solar irradiation, load of weather impacts due to wind, snow, hail and rain. Comprehensive work on the durability of polymeric glazing has been performed, in Subtask C of IEA-SHC Task 39, UV-resistant, thermotropic and anti-soiling coatings for polymeric surfaces are studied.
- Glazed absorbers, for example, a thermosiphon collector with blow-moulded absorber of PE, a flat-plate collectors with 10 mm PC twin-wall sheets as collector cover or modular

[11] IEA-SHC Solar Heat Worldwide. Market and contribution to the Energy Supply 2007

systems of polymeric or hybrid-polymeric collectors, which are available in various lengths and designed for replacing conventional roof- or facade covers.

- Integrated storage collector (ICS), for example, ICS with polypropylene casing and transparent insulation of cellulose triacetate, a moulded storage container in polyethylene, glazing in polycarbonate and heat exchanger in copper or a cylindrical tank under a transparent dome of PMMA with an inner, upper shell of PC and an outer, rear shell of HD-PE.
- Collector frame, low weight and easy installation are some of the major advantages of polymeric materials for collector frame and casings.

5.3.1 Current standards and certification procedures

ISO 9806 and ASHRAE 93 standards can be used, but their tests methods are not suitable for solar water heaters with an integrated storage system.

The standard EN 12975 can also be used but is of limited scope for polymeric innovations and is not suitable for solar water heaters with an integrated storage system. Five possible limitations of EN 12975 regarding polymer innovations follow. (1) In the performance test, the quadratic performance equation fails to represent thermal step change panels using thermochromics or thermostatic air vents. In the durability test, the limitations are: (2) description of polymers as organic, thus excluding silicone rubber which is inorganic; (3) use of absolute instead of functional pass-fail criteria, overlooking the flexibility of polymers; (4) incorrect test assumption that the peak pressures in water filled freeze tolerant collectors coincide with high temperature stagnation, when instead peak pressures may occur under freezing conditions; (5) the exposure test requires dry panels to stagnate for 30 days, but some polymer panels are continually pumped at high temperatures (and they dump heat to prevent boiling at low light levels).

5.3.2 Gaps and open questions

Thermal stagnation and risk for overheating is generally aimed to be avoided in any collector systems if these have metal-based or polymeric collectors. The intention with a built-in overheating mechanism for polymeric collectors is to be able to use low-cost commodity plastics in glazed collectors. Here are listed several overheating control strategies:

- Natural or forced ventilation of the collector between absorber/glazing or absorber/thermal insulation can be used for the overheat protection of polymeric collectors.
- Functional materials / thermotropic coatings switch from transparent to opaque at a critical temperature for the absorber material Tc. The coating can be applied on the glazing and reduces the transmittance or on the absorber and reduce the absorptance for temperatures above Tc.
- Another principle for the overheat protection is the change of refraction index of the collector glazing by a simple mechanism that reduces the solar radiation transmittance

To justify the high investments for a solar thermal system, generally a long lifetime in the range of more than 20 years has to be ensured. However, up to now most producers of polymeric glazing materials do not present reliable data on the ageing performance of their products over such a long time period.

5.3.3 Testing approaches

The weathering[12] properties of PMMA were in the range of glasses or even slightly better. Contrarily, material degradation was observed for PC, PET, PVC and UP. Soiling was strongly dependent on the exposure site and the glazing material. At the sub-urban site of Rapperswil (CH) a significant loss in solar transmittance in the range of 3-15% was measured. For the investigated fluoropolymers surprisingly high losses in transmittance (ETFE) or tendency for soil accumulation (FEP, PVF) was observed.

EU NEGST project recommends considering as a basis for potential future standardisation work the Swedish SP-method[13] focused to plastic- and rubber components in solar collectors. It focuses primarily on absorbers, reflectors, cover glazing and frames. The method can however with certain adjustments be applied to other polymeric material components, such as pipe systems and sealings. The purpose of the method is to ensure a 15-year lifetime of the components by lifetime analysis of included materials regarding mechanical characteristics, absorption and transmittance. The method is also intended to, in combination with other requirements, be used as a basis for P-marking of solar collectors.

5.4 Actions

As already explained in the chapter 3.5 the new EN ISO standard for collector testing has been lead and supported by the EU project QAiST[14]. This project has contributed to the new EN ISO standard with the following working topics:

- Extension of the standard scope to cover also medium temperature collectors (tracking/concentrating collectors) by setting up new definitions, clarifying the performance test conditions (based on the quasi-dynamic test method) and including durability and reliability tests procedures
- Clarification and strengthening of durability and reliability requirements of the following test methods:
    - Exposure test: which has been reorganised in order to be more flexible and allowing to perform part of the test indoors to reduce the testing time
    - Rain penetration test: the methodologies have been reduced to two accepted methods only. First is applying the weighing procedure as it was already defined in

[12] F. Ruesch, S. Brunold, Ageing Performance of Collector Glazing Materials – Results from 20 Years of Outdoor Weathering. 338 - Eurosun 2008 Proceedings.

[13] Polymeric materials in solar collectors - Test methods and technical requirements", Department of Chemistry and Materials Technology Borås 2004, Leo Spilg

[14] QAIST: Quality Assurance in solar thermal heating and cooling technology. http://www.qaist.org

the EN 12975. Second is to do the rain penetration test at the end of the test run and apply a final inspection subsequently. A more accurate procedure for the spraying (nozzles, positions, etc) has been defined.

- Mechanical load test: the test procedure is still under development, but a first clarification of the load level applied has been developed and it has been harmonised according to the IEC 61215 standard
- Impact resistance test: It has been defined as mandatory, and allows both testing methods (steel and ice ball) even if they are not directly comparable. The ice ball method has been also harmonised according to the IEC 61215 standard
- Freezing resistance test: no big change to the testing procedure but it has been demonstrated that it is highly recommended to perform this test to heat-pipe collectors
- Internal pressure test
- Final inspection: definition and clarification of the test criteria

- Harmonized collector energy output calculations
- Extension of the scope of the standard to cover air heating collectors
- Harmonized CE marking, fire safety and weather tightness

ISO TC 180 has recently started a new work item for a multi-part standard on collector components and materials:

- Part 1: Evacuated tube durability and performance
- Part 2: Heat pipes for evacuated tubes - Durability and performance
- Part 3: Absorber surface durability based on the draft from IEA-SHC Task X.

For further information on this topic, see the IEA-SHC Task 43 White Paper on Low-to-Medium Temperature Collectors.

6 AIR HEATING COLLECTOR TEST PROCEDURES

6.1 Introduction

Solar air systems are a promising technology in the active use of solar energy for heating but they have not yet entered the market with significant rates. As main barrier for a wide dissemination of solar air systems appears the lack of information and confidence on how these systems will perform. Testing of the respective components is therefore essential. Such tests should be reproducible and acknowledged, but up to now no common international standard exists for solar air collectors.

Air collector testing measurements of air-temperatures and air mass flows requires much higher effort for obtaining satisfactory accuracies. Moreover, leakage, the air flow pattern inside the collector and the much lower heat transfer from the absorber to the heat transfer medium are further complex affects. The assembling of the air system components, the way how the components are connected, how the system is operated are all very decisive factors for the efficiency of the whole air system.

6.2 Current standards and certification procedures

Some standardised testing procedure exists so far:

- The Italian Standard UNI 8937
- The US-American Standard ASHRAE 93-2003
- The Canadian Standard CSA F378.2: air heating solar collectors, released in September 2011

The UNI 8937 only gives an idea of how air collectors tests can be carried out, but does not detail the specific problems of solar air systems.

The ASHRAE 93-2003 is already a usable standard but since it describes procedures for testing of both liquid and air collectors it does take into account all possible variations of solar air collectors and leaves some uncertainties.

An outdoor transient test method has been included in the British Standard DD77[15].

Starting a standardisation process for testing solar air collectors was already discussed in the Technical Committee 180 of the International Standardisation Organisation (ISO), but no further steps were taken.

The recently published CSA F378.2 standard applies to solar collectors that use air as a heat transfer medium including the following collector types:

- glazed closed-loop recirculated air heating solar collectors
- unglazed closed-loop recirculated air heating solar collectors
- glazed open-loop ambient air heating solar collectors
- unglazed open-loop ambient air heating solar collectors

6.3 Gaps and open questions

The EU NEGST draft-standard does not include:

- Procedures for unglazed solar thermal systems, and regarding air collectors with polymeric materials
- Stagnation temperature
- Time constant
- Pressure drop
- Incidence angle modifier (IAM)

Required new testing procedures

Internal pressure tests for collectors:

- How relevant are pressure tests for air collectors?.

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[15] T.Oreszczyn, B.W.Jones, A transient test method applied to air heating collectors. Solar Energy Vol. 38," No. 6, pp. 425-430, 1987.

- Is it possible to reach relevant over pressure under real conditions?
- Internal pressure test may be dropped for open absorbers (i.e. transpired air collectors)

Fluid inlet temperature:

- Air collectors in combination with heat pumps can have an inlet temperature range starting at -20°C.
- How relevant are these testing conditions for air collectors?
- Is it applicable to chill down the testing environment to -20°C?

Wind dependency

For collector testing, it is essential to find out the wind dependency of a collector. Some collectors, especially uncovered, but also collectors with the air flow directly under the cover are strongly dependant on the wind speed. Recommendations for the wind simulation in the test bench can be found in the existing standard for testing water collectors.

Further research, on the impacts of the surrounding air speed, is needed for redefining the surrounding air speed requirement of the current draft or even defines new test procedures to determine the wind dependency in order to have a standard covering the needs of all stakeholders.

6.4 Testing approaches

6.4.1 IEA Task 14: Advanced active solar systems

The Air Systems Working Group of the IEA SHC Task 14 Advanced Active Solar Systems concentrated their study and improvement of a type of air-heating collector called the unglazed perforated-absorber collector, this type of collector was developed and initially used for preheating ventilation air in large industrial buildings. The air to be heated is drawn from outdoors through the distributed small holes of the absorber plate and it is mixed with some indoor air in order to maintain a set delivery temperature and then is distributed to the building interior.

6.4.2 IEA Task 19: Solar air systems

Within the IEA-SHC Task 19 "Solar Air Systems" more than twenty experts from nine countries, worked together investigating on series produced solar air collectors, done by Arsenal Research in 1999 (Fechner 1999). Seven long time proven products as well as prototypes from seven different countries, mainly from Europe but also from Canada and Australia have been tested. The main topics of development, investigation and research during this project have been:

- Development of a steady state testing procedure for solar air collectors, suited for all types
- Discussion on physically correct and proper efficiency presentations
- Development of different performance descriptions adequate for all common operation modes
- A comparison of available series-produced products
- Investigation of the technical behaviour of different types of air collectors
- Recommendations for an optimised utilisation of solar air collectors

- Recommendations for improvements of tested products
- Adaptation of the existing solar-laboratory-facilities for testing solar air collectors

6.4.3 NEGST draft-standard[16]

Within the EU project NEGST, a draft-standard for testing solar air collectors based on existing standards has been developed. This draft provides test methods and calculation procedures for determining the steady-state thermal performance of glazed air heating solar collectors.

It specifies test methods for determining the ability of a solar air collector to resist the influence of degrading agents. It defines procedures for testing collectors under well-defined and repeatable conditions and contains methods for conducting tests outdoors under natural solar irradiance and natural and simulated wind and also for conducting tests indoors under simulated solar radiation and wind.

6.5 Actions

The lack of an air collector testing standard has caused problems among manufacturers competing with slightly different solar air heating technologies to prove the quality of their products in order to have access to different solar thermal national subsidy programs. To remedy this situation, and to create a uniform system of test standards, a draft extension to the EN 12975 standard to cover solar air heating collectors was developed within the CEN/TC 312 WG1 by Fraunhofer ISE and proposed to the standardization committees at the end of 2010. The text is based on the ANSI ASHRAE 93 standard, but it was further developed. Since the beginning of 2011, the draft is in the comment phase and expected to be finally approved as part of the new EN 12975 standard in autumn 2012.

In a lot of aspects, solar air heating collectors can be tested in the same way as water heating collectors. The rainwater penetration, exposure, high-temperature resistance, external thermal shock, mechanical load and stagnation temperature tests as well as the final inspection can be applied in the same way as for water heating collectors.

However, some durability and reliability tests have to be modified for solar air heating collectors. The thermal performance test, the determination of the IAM (Incident Angle Modifier) and collector capacity, the internal thermal shock test and the internal pressure test must be adapted.

The pressure drop test is optional for water heating collectors, but it should be mandatory for air heating collectors. Unlike water heating collectors an air heating collector is usually not fully air tight. Therefore the classical tightness test is not appropriate. Since the leakage rate has a strong influence on the collector performance, it must be taken into account in the performance evaluation and thus has to be measured. In addition, the determination of the maximum start temperature is mandatory for solar air heating collectors, but not considered relevant for water heating collectors.

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[16] NEGST WP4 document D2.1 at http://www.swt-technologie.de/html/publicdeliverables3.html

In parallel to the European activities, the CSA F378.2 standard for solar air heating collectors was developed and published in Canada in 2011 for the comment phase. It is also based mainly on the ANSI ASHRAE 93 standard, but with several functional test details added, similar to the EN 12975 new draft. A summary of the tests covered by the three standards is given in Table 2.

The CSA F378.2 standard supports the convergence of the "American" and "European" method and is intended to come into force by mid-2011.

Table 2. Standards and tests for solar air heating collectors

	pr EN 12975-1: 2011	ANSI ASHRAE 93, 2003	CSA F 378.2, 2011	CEN-ISO 2012
Thermal Performance				
1) Thermal Efficiency	✓	✓	✓	✓
2) Incident Angle Modifier	✓	✓	✓	✓
3) Collector Capacity	✓	✗	✗	✓
4) Collector Time Constant	✓	✓	✓	✓
Durability and Reliability Tests				
1) Internal Pressure	✓	✗	✓	✓
2) High-Temperature Resistance	✓	✗	✓	✓
3) Exposure	✓	✗	✓	✓
4) External Thermal Shock	✓	✗	✓	✓
5) Internal Thermal Shock	✓	✗	✗	✓
6) Rain Penetration	✓	✗	✗	✓
7) Mechanical Load	✓	✗	✓	✓
8) Stagnation Temperature	✓	✗	✗	✓
9) Maximum Start Temperature	✓	✗	✗	✓
10) Leakage Test	✓	✓	✓	✓
11) Pressure Drop	✓	✓	✓	✓
12) Final Inspection	✓	✓	✓	✓

The extension for air heating collector draft of EN 12975 is limited to covered collectors, since the test methods for non-covered air heating collectors is not fully developed yet. However, Fraunhofer ISE is working on a subsequent draft extension, which shall be presented to the standardization committees by mid 2012. A summary of the solar collector types covered by the different standards is given in Table 3.

Table 3. Solar collector types, which are covered by the different standards

		pr EN 12975-1: 2011	ANSI ASHRAE 93, 2003	CSA F 378.1,2, 2011	CEN ISO in 2012
Water Collectors					
	Covered	✓	✓	✓	✓
	Uncoverd	✓	✗	✓	✓
Solar Air Heaters Open Loop					
	Covered	✓	✓	✓	✓
	Uncoverd	✗*	✗	✓	✓
Solar Air Heaters Closed Loop					
	Covered	✓	✓	✓	✓
	Uncoverd	✗*	✗	✓	✓

In Table 2 and Table 3, the CEN-ISO 2012 standard is also mentioned as a goal for a worldwide, unified solar air heating standard. Some important steps to achieve this goal have already been described. The setting of a joint working group of ISO and CEN under the Vienna agreement was done in September 2011. A unified CEN-ISO standard for solar air heating collectors is ready to be published for comments and could even be approved by the end of 2012 or the beginning of 2013.

For further information on this topic, see the IEA-SHC Task 43 White Paper on Air Heating Collectors.

7 CONCENTRATING COLLECTOR TEST PROCEDURES

There are basically two types of concentrating solar thermal collectors: stationary (like CPC) and sun-tracking. A sun-tracking concentrating solar collector usually has reflecting or refracting surfaces to focus the sun beam radiation into a smaller receiving area, thereby increasing the radiation flux. The main testing procedures in standards are usually developed for non-concentrating and stationary collectors.

7.1 Current standards and certification procedures

7.1.1 Collector performance test methods

American Standard ASHRAE 93

This standard considers the concentrator in the definitions and the incidence modifier angle test. It describes the different incident modifier angle behaviour for particular collectors, in part 8.2.3.1 "Collectors requiring more than one Incident angle modifier" and Annex G. It gives an efficiency model especially for concentrating collector which considers the fraction of specularly reflected radiation from the reflector and the reflectance of a reflecting surface.

$$\eta_g = (A_a/A_g)F_R[(\tau\alpha)_e\rho\gamma - (A_r/A_g)U_L(t_{f,i} - t_a/G_{bp}]$$
$$= \dot{m}c_p(t_{f,e} - t_{f,i})/A_g G_{bp} \;.$$

International Standard ISO 9806-1

This standard is clearly not applicable to tracking concentrating, only gives some information in the annex for special biaxial incident angle modifiers of parabolic-trough collectors.

American Standard ASTM E 905 – 87

The standard ASTM E 905 – 87 (Standard Test Method for Determining Thermal Performance of Tracking Concentrating Solar Collectors) covers the determination of thermal performance of tracking concentrating solar collectors that heat fluids for use in thermal systems. It is applicable to collectors with a geometric concentration ratio of seven or greater but not applicable to fixed mirror-tracking receiver collectors or to central receivers, or to phase-change collectors.

This test method determines the thermal performance of tracking concentrating solar collectors that heat fluids for use in thermal systems for outdoor testing only, under clear sky and quasi-steady state conditions.

European Standard UNE-EN 12975-2

This standard is not generally applicable to tracking concentrating collectors, only the thermal performance test as given in clause 6.3 (quasi dynamic testing) is applicable to most concentrating collector designs, from stationary non-imaging concentrators as CPCs to high concentrating tracking designs.

Part of the solar radiation measurement has to be adjusted in case of a tracking collector, and a pyrheliometer must be used to measure beam radiation.

For solar collector with sun-tracking for high concentration, the value K_d could be neglected if during the t-value identification at the first regression it is found not significant (t-value<2). So for high concentration $K_{\theta d}=0$ and $K_{\theta b}=1$.

$$\frac{Q}{A} = F'(\tau\alpha)_{en} G_b - c_1(t_m - t_a) - c_2(t_m - t_a)^2 - c_3 u(t_m - t_a) - c_4(E_L - \sigma T_a^{\ 4}) - c_5 \, {dT_m}/{dt} - c_6 uG$$

Moreover, the value c_3, c_4 and c_6 could be set to 0 if its t-value identification are found not significant too, and reducing the model.

$$\frac{Q}{A} = F'(\tau\alpha)_{en} G_b - c_1(t_m - t_a) - c_2(t_m - t_a)^2 - c_5 \, {dT_m}/{dt}$$

The steady-state test method (in clause 6.1) is generally not applicable for concentrating collectors.

7.1.2 Collector durability test methods

International Standard ISO

As it is said in the standard ISO 9806-1, it applies to all types of solar collectors, including integral collector storage systems with the exception of tracking concentrating collectors. In general none of the tests is applicable to a concentrating collector.

European Standard

The standard EN 12975-2 describes both the thermal efficiency tests and the durability tests for solar collectors. This standard applies to non concentrating collectors, the durability tests are not applicable to concentrator collectors with the exception of the thermal performance test.

Other durability standards,

That can be adapted for component durability issues:

- The standard EN 61701 applicable to photovoltaic (PV) modules specifies the module ageing test in a saline environment created from a dissolution in which the concentration of 5% of Chloride Sodium with an ambient temperature of 35ºC, performed during 96 hours.
- The standard for salt spray tests ISO 9227 (Corrosion tests in artificial atmospheres).

International Standard IEC

The degradation factors from environmental stresses in service conditions need to be evaluated and measured to predict the component expected service life from the results of accelerating ageing tests.

The general standard IEC 60721[17] can be used as a starting point, this standard contains recommendations for classifying stress severity for various climatic, mechanical, chemical, biological and electrical environments.

Although some standards are applicable to photovoltaic (PV) modules, they could be also used for solar thermal collectors. The standard IEC 61215 is applicable to photovoltaic (PV) modules.

Table 4. IEC 61215 tests and testing conditions

Test	Testing conditions
UV degradation test	5 kWh/m^2 between 280 nm and 320 nm 15 kWh/m^2 between 280 nm and 385 nm
Thermal cycles test	200 cycles from -40 to 85 º C
Humid heat test	1000 hours 85ºC, 85% HR
Hail impact test	Ice ball impact, 25 mm diameter and 23.0 m/s speed

The international standard IEC 62108 specifies the minimum requirements for the design qualification and type approval of concentrator photovoltaic (CPV) modules and assemblies suitable for long-term operation in general open-air climates as defined in IEC 60721-2-1. Those durability tests are similar to the standard IEC 61215 specific to photovoltaic modules.

Table 5. IEC 62108 tests and testing conditions

Tests	Testing conditions
Visual inspection (part 10.1)	Visual inspection No major visual defects
Electrical performance (part 10.2)	Outdoor, clear sky conditions DNI > 700 W/m^2, wind speed < 6 m/s.
Thermal cycling test (part 10.6)	T_C from −40 °C to T_{max}. 500 cycles if T_{max} = 110 °C, 1 000 cycles if T_{max} = 85 °C, 2 000 cycles if T_{max} = 65 °C,
Damp-heat test (part 10.7)	1 000 h at 85 °C and 85 % RH Or 2 000 h at 65 °C and 85 % RH
Humidity freeze test (part 10.8)	T_{max} and 85 % RH for 20 h followed by 4 h cool down to −40 °C; 20 cycles if T_{max} is 85 °C; 40 cycles if T_{max} is 65 °C.
Hail impact test (part 10.9)	At least 10 shots of 25.4 mm diameter ice ball at 22.4 m/s on areas where an impact by hailstone falling from 45° around the vertical line is possible.
Water spray test (part 10.10)	1 h water spray on each of four orientations.
Mechanical load test (part 10.13)	2 400 Pa on front and back, 1 h each, total of 3 cycles
UV conditioning test (part 10.15)	Expose to UV accumulation of 50 kWh/m^2. (This test could be combined with the outdoor exposure test of 10.16)

[17] IEC 60721, Classification of Environmental Conditions, International Electrotechnical Commission, P.O. Box 131, CH - 1211 Geneva 20, Switzerland.

Outdoor exposure test (part 10.16)	Expose to DNI accumulation of 1 000 kWh/m2 when DNI > 600 W/m^2.

Australian Standard

The Standard AS/NZS 2714:2002 is applicable to solar collector and heat pump water heaters, the section 4 gives general requirements for the collectors and the section 6 explain testing procedures. The most relevant part for solar collectors is:

Table 6. AS/NZS 2714 standard tests

Tests	**Clause**
Pressure test	Clause 6.2.3
Stagnation test for collector	Clause 4.5
Structural strength of collector	Clause 4.11
Protection against ingress of water (container and collector)	Clause 3.7 and 4.7
Hail resistance	Clause 4.6
Protection against freezing	Clause 4.10

7.1.3 Component durability test methods

Reflector test methods

There is no specific standard for the concentrator reflector of solar thermal collectors.

Mirror reflectance measurement

The Standard ISO 9050 (Glass in building — Determination of light transmittance, solar direct transmittance, total solar energy transmittance, ultraviolet transmittance and related glazing factors) gives details on the reflectance measurement that could be performed on reflector even if the scope is for glasses. The reflectance is measured between 300 nm to 2500 nm for quasi-parallel almost normal radiation incidence. For the measurements, the incidence angle on the sample shall be less than 10º from the normal to the surface, and the acceptance angle shall be less than 5º. The accuracy in reflectance measurement should be about ± 0,01.

The Standard ASTM E 424 – 71 test methods cover the measurement of solar energy transmittance and reflectance of materials in sheet form. The solar reflectance measurements ρ can be performed, according to this standard, using a spectroradiometer (method A) or a pyranometer (method B). With the method A, the reflectance is measured between 350 nm to 2500 nm. The solar reflectance is then calculated with normalized weighted ordinates energy intervals of twenty selected ordinates wavelength, as follows:

$$\rho = \sum_{\lambda=350\,nm}^{\lambda=2500\,nm} \rho(\lambda)E(\lambda)$$

The Standard ISO 9845-1 (Reference solar spectral irradiance at the ground at different receiving conditions) gives the spectral distribution of direct normal (with a 5,8º field-of-view angle) and hemispherical (on an equator-facing, 37º tilted plane with an albedo of 0,2) solar irradiance for air mass 1,5.

The Standard ASTM G173 – 03 gives tables for reference solar spectral irradiances: direct normal and hemispherical incident on a sun-facing plane tilted to 37° from the horizontal, in the wavelength range 280 to 4000 nm. The data are related to the absolute air mass of 1,5 and the direct irradiance contains a circumsolar component for a field of view of 5,8° centred on the sun.

In all those Standards the procedure to calculate the solar reflectance is given based on the spectral reflectance measurements and weighted with solar energy, summarized as follows:

$$\rho(SW,\theta,\varphi)=\frac{\int_{\lambda_1}^{\lambda_1}\rho(\lambda,\theta,\varphi)E_\lambda(\lambda)\partial\lambda}{\int_{\lambda_1}^{\lambda_1}E_\lambda(\lambda)\partial\lambda}$$

Where:

- $\rho(SW, \theta, \varphi)$: solar weighted reflectance
- $\rho(\lambda, \theta, \varphi)$: sample specular reflectance at a wavelength λ, with an incidence angle θ and an acceptance angle φ.
- $E_\lambda(\lambda)$: solar radiation spectral distribution at a wavelength λ
- λ_1 : wavelength range lower limit
- λ_2 : wavelength range upper limit

For hemispherical reflectance measurement the acceptance angle φ is 2π as all the reflected light is measured.

For concentrated solar power (CSP) applications it is more convenient to integrate the specular spectral reflectance curve over the direct normal solar spectral irradiances and for low temperature solar collector applications to integrate the hemispherical spectral reflectance curve over the global solar spectral irradiances.

The optical measurement is not specified in most of those Standards. However the SolarPACES report "Measurement of solar weighted reflectance of mirror materials for concentrating solar power technology with commercially available instrument" (Version 1.1 May 2011) makes a summary of the different techniques and commercial instruments used for mirror in CSP applications.

The main instrument to measure spectral reflectance is the spectrophotometer. This instrument is a photometer (a device for measuring light intensity) that can measure intensity as a function of the light source wavelength. Spectrophotometers are commonly used for measurements of transmittance, absorptance and reflectance of solutions and opaque materials making them effective for wide areas of application. To select the specific wavelength a monochromatic is used. The hemispherical reflectance is measured using an integrating sphere to detect all the diffuse light reflected by the sample. The diffuse light can be cut with a light-trap in the integrated sphere. As a results the spectral specular reflectance

$$\rho_s(\lambda)=\rho_h(\lambda)-\rho_d(\lambda)$$

The specular reflectance can also be measured directly without an integrating sphere But the accessories for the measurement of specular reflectance has a specific acceptance angle φ that should be well-defined. Generally, the acceptance angle is too large in CSP applications and so the information is lost but for low-temperature application it is enough.

Reflectometers are measurement devices that measure the intensity of the light source after reflection on a sample without spectral wavelength selection. Reflectometers that are equipped with integrating spheres may be suitable for hemispherical reflectance measurements if their sphere is large enough. The solar-weighted reflectance value achieved with a reflectometer utilizing only one or a few discrete wavelength bands as a light source is always an approximation with lower accuracy than the one which can be obtained with a spectrophotometer. Their capabilities are not suitable for evaluating the specular reflectance of solar mirror materials. It is important for CSP applications that the reflectometer measures the radiometric radiance of reflection.

Reflector accelerated ageing tests

Based on the IEA (International Energy Agency) Task 27: Solar Building Facade Components: Final Report-Subtask B-Part2, IEA Solar Heating and Cooling Programme (2007), the accelerated ageing tests have been summarized in Table 7.

Table 7. Screening testing for solar reflectors[18]

Degradation mechanism	Critical periods of high environmental stress	Suitable accelerated test methods and range of degradation factors
Degradation of the protective layer	At high cumulative dose of solar irradiation, photooxidation, hydrolysis, acid rain	Weatherometer tests: ISO 4892 Plastics - Methods of exposure to laboratory light sources (UV, temperature and RH) Condensation test + irradiation SPART 14 - acid rain modification of SAE J1960, which is a weatherometer test ASTM G155-00ae1 Standard practice for operating xenon arc light apparatus for exposure of non-metallic materials
Corrosion of the reflecting layer	Under humidity conditions involving reflector water condensation	Salt spraying and hostile gases-SP method 2499 A, also corresponding to ISO/CD 21207 method A
Surface abrasion	Wind, hail, cleaning	ASTM D4060-01 Standard Test Method for abrasion resistance of organic coatings by the taber abraser ISO 11998:1992 Paints and varnishes - determination of wetscrub resistance and cleanability of coatings
Surface soiling	Moisture, dust, dirt	ASTM D3274-95 Standard Test Method for evaluating degree of surface disfigurement of Paint Films by microbial (fungal or algal) growth or soil and dirt accumulation
Degradation of the substrate	Moisture, pollutants, acid rain, hail	Hail: ASTM E822-92(1996) Standard practice for determining resistance of Solar Collector covers to hail by impact with propelled ice balls ASTM E1038-98 Standard Test Method for determining resistance of Photovoltaic Modules to hail by impact with propelled ice balls
Loss of adhesion of protective coating	Moisture, pollutants, acid rain, hail, icing, UV, Thermal expansion	Hail: ASTM E822-92(1996) Standard practice for determining resistance of Solar Collector covers to hail by impact with propelled ice balls ASTM E1038-98 Standard Test Method for determining resistance of Photovoltaic Modules to hail by impact with propelled ice balls EN 12975-2 cap 5.10 Impact resistance test Icing: Build up of ice layers MIL-STD 810 E, Method 521 Icing /Freezing rain ISO 2653, ice formation, Test C Frost appearance IEC 60068-2-39,Z/AMD, combined sequential cold, low air pressure and damp heat test Thermal expansion: IEC 60068-2-14, Test N, Change of Temperature

[18] Task 27: Solar Building Facade Components: Final Report-Subtask B-Part2, International Energy Agency Solar Heating and Cooling Programme (2007).

		MIL-STD 810 E, Method 503.3, Temperature shock: ISO 10545 - Part 9 Ceramic tiles determination of resistance to thermal shock

Receiver test methods

There are no specific standards for the receiver (Heat Collecting Element) performance and durability tests.

Thermal characterization

The existing thermal characterization tests have different approaches and levels of testing complexity to obtain the thermal losses curve of a parabolic trough receiver. From the thermal losses test the receiver emitance can be obtained. According to the type of test bench used the thermal characterization methods can be:

- Outdoor test benches: Test benches using thermal oil loops for the performance test of a whole parabolic trough solar collector assembly (SCA) [19] like the LS3-HTF loop from PSA or a parabolic trough collector module mounted in a rotating test bench platform (with azimuth tracking) [20]. In both previous test benches the mass flow and the temperature difference between input and output are measured with the collector module oriented to the sky but in the shadow in order to determine the receiver thermal losses at a certain operating temperature.
- Indoor test benches which reproduce the receiver tube operating conditions in a controlled environment like a laboratory. The receiver operating temperatures are obtained by means of electrical heating sets which radiate the metallic absorber tube of the receiver. When temperature stationary conditions at a certain temperature are reached the electrical power supplied to the heating sets is equivalent to the receiver thermal losses at that temperature. Reproducing the test at different operating temperatures allows to obtain the characteristic receiver thermal losses curve and the thermal emitance for a temperature range from 100ºC to 500ºC. This testing procedure was developed by NREL[21] and adopted by other R&D test centers and receiver manufacturers, some of them already take part in the only intercomparison test performed up to now[22].

[19] [19] V.E. Dudley, G.J.Kolb, M.Sloan, D.Kearney. "Test Results SEGS LS-2 Solar Collector". SAND94-1884, Sandia National Laboratories, December 1994

[20] P.Heller, M. Meyer-Grünefeld, M. Ebert, N.Janotte, B.Nouri, K.Pottler,C.Prahl, W.Reinalter, E.Zarza. "KONTAS – A Rotary Test Bench for Standardized Qualification of Parabolic Trough Components". SolarPACES 2011 - International Symposium on Concentrating Solar Power and Chemical Energy Systems. Granada

[21] F.Burkholder, C.Kutscher. "Heat Loss Testing of Schott's 2008 PTR70 Parabolic Trough Receiver". Technical Report NREL/TP-550-45633, May 2009

[22] S.Dreyer, P.Eichel, T.Gnaedig, Z.Hacker, S.Janker, T.Kuckelkorn, K.Simly, J.Pernpeintner, E.Luepfert. "Heat loss measurements on parabolic trough receivers". SolarPACES 2010 - 16th International Symposium on Concentrating Solar Power and Chemical Energy Systems. Perpignan, France

A part from the previous tests there several technical reports about the failures during operation of CSP plants and tests which complement the thermal loss curve like the vacuum level analysis or the use of different gases to reduce the receiver thermal losses[23].

Optical characterization

The existing optical characterization test methods for tubular receivers can be group in two categories: the destructive method and the non destructive method.

The destructive characterization method and the measurement equipments are based in the standard ASTM E424-71 and uses samples to measure the optical properties. Among the measurement devices the following ones can be highlighted:

- UV-VIS-NIR reflectance measurement equipment, able to measure at variable angle according to the ASTM standard.
- Far IR Fourier Transform measurement equipment with accessories to measure reflectance / emitance.

The highest disadvantage from the destructive method is that is conceived for measuring flat samples and it's difficult to adapt to tubular samples because the integration sphere ports are not well suited for that.

The non destructive characterization method allows to measure the optical properties without destroying the receiver sample, it is performed to the whole receiver tube. There are several methods[24] [25] to measure the optical properties of the receiver tube or the solar transmittance (τ_s) and solar absortance (α_s) or the optical efficiency[26] (**$\tau\alpha$** product).

7.2 Gaps and open questions

The parameter definitions of current standards should be extended to include new concentrating developments and emerging concepts.

The current standards are mainly focused on different testing methodologies for determining the concentrator collector thermal performance, using outdoor steady state or quasi-dynamic methods, see previous chapter 7.1.

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[23] G.Gong, X.Huang, J.Wang, M.Hao. "An optimized model and test of the China's first high temperature parabolic trough solar receiver". Solar Energy- August 2010. Elsevier Ltd

[24] E.Mateu, M.Sanchez, D.Perez, A.Garcia de Jalón, S.Forcada, I.Salinas, C.Heras. "Optical characterization test bench for parabolic trough receivers". SolarPACES 2011 - 17th International Symposium on Concentrating Solar Power and Chemical Energy Systems. Granada

[25] J.Pernpeintner, N.Lichtenthäler, B.Schiricke, E.Luepfert, T.Litzke, W.Minich. "Test benches for the measurement of the optical efficiency of parabolic trough receivers using natural sunlight and solar simulator light". SolarPACES 2010 - 16th International Symposium on Concentrating Solar Power and Chemical Energy Systems. Perpignan, France

[26] C.Kutscher, F.Burkholder, J.Netter. "Measuring the optical performance of evacuated receivers via an outdoor thermal transient test". SolarPACES 2011 - 17th International Symposium on Concentrating Solar Power and Chemical Energy Systems. Granada

Less developed are the durability or qualification tests methods for concentrator collectors. The lack of a specific standard, leads to a wide range of durability tests possibilities causing the following problems:

- Need to review a wide range of durability test standards from other technology fields to perform tailor made durability tests which are adapted from several "selected" standards.
- Difficulties to compare durability test results from different manufacturers or testing laboratories, because they are based on different standards or testing conditions.
- No common definition for accelerated test exposure conditions that can differ a lot from service life conditions. Microclimate characterization and degradation factors also need to be assessed.
- Validation of predicted service life through outdoor exposure tests or data from their components or materials service life, where reliable test results are obtained, in most cases, after a new material is commercially launched.

7.3 Testing approaches

7.3.1 Concentrating Solar Power (CSP) test methods

<u>Receiver performance tests</u>

Outdoor – Thermal Loop Tests:

- Use measurement of flow and temperature difference to calculate energy gained or lost.
- Sandia Rotating Platform: AZTRAK test bench for a single collector element, Plataforma Solar de Almería: EuroTrough Collector, and SEGS Collector Test Loops.
- Rapid field observations:
  - IR receiver temperature measurements[27]
  - Loss of vacuum or hydrogen detection
  - Optical quality assessment with different techniques[28] (Photogrammetry, Distant Observer, Lasertracking, etc)
  - New methods have to be developed or investigated

Indoor – DLR, Schott, NREL, CENER and others:

- Electrical resistance heating of HCE[29]
  - Heat receiver to steady state temperature
  - At steady state power consumption is equal to thermal losses
- Non destructive optical receiver characterisation: solar spectral glass transmittance (τ) and absortance (α)

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[27] M. Pfänder, E. Lüpfert, P. Pistor, Infrared temperature measurements on solar trough absorber tubes. Solar Energy 81 (2007) 629–635.

[28] T.J. Wendelin, Optical Characterization of Concentrating Solar Power Technologies at NREL.

[29] F. Burkholder and C. Kutscher, Heat-Loss Testing of Solel's UVAC3 Parabolic Trough Receiver. Technical Report NREL/TP-550-42394 January 2008.

- Receiver temperature measurements/estimation by infrared camera
- Receiver non invasive measurement of gases

Optical characterisation, mirror alignment and mounting quality tests

Some of the different optical tools that have been already mentioned in the receiver performance tests are needed to improve initial designs, provide quality control during manufacture/assembly and maintain performance during operation. The collector optical quality and durability is also related with the structural collector behaviour, especially in CSP but also in other type of collectors.

Reflectivity and accelerated ageing tests

Solar reflector materials are based on several constructions like metalized thick and thin glass mirrors, front surface aluminized reflectors, silvered polymers, and multilayer dielectric designs. The most broadly used solar reflectors are thick glass mirrors that are produced by applying a silver reflection layer on a metal substrate (copper) on an upper glass layer (>1mm thick) using wet chemistry processes, and a backside paint layer to extend mirror service life protecting it from abrasion and corrosion. A widespread application of concentrated solar thermal power technologies depends largely on developing a durable low-cost reflector, new candidate solar reflectors based on polymeric materials or light weight constructions have been developed to reduce weight, increasing design and manufacture flexibility but maintaining the high corrosion resistance and excellent durability of the thick mirror glass reflectors.

A broad experience leaded by NREL has been gathered in accelerated indoor and outdoor exposure tests[30] for candidate solar reflectors with different reflector constructions[31]. It is very important to check the concordance between the accelerated ageing tests results with the real service conditions outdoor measurements.

7.3.2 SRCC standard 600

The 600 draft standard document is being elaborated by the SRCC Subcommittee on Concentrating Collectors.

7.4 Actions

7.4.1 New EN ISO collector standard

The EN 12975-2:2011 revision includes as an informative annex the reliability testing of concentrating and/or tracking collectors. The advances of the EN 12975 revision will be also

[30] T.Fend *, B. Hoffschmidt, G.Jorgensenb, H. Küster, D. Krüger , R. Pitz-Paal , P. Rietbrock , K.J. Riffelmann Comparative assessment of solar concentrator materials, Solar Energy 74 (2003) 149–155.

[31] C.E. Kennedy, K. Terwilliger, Optical Durability of Candidate Solar Reflectors, Journal of Solar Engineering (2005) Transactions of the ASME Vol. 127 262-269.

adopted in the present ISO 9806 revision process. These advances are described in the following paragraphs.

General requirements

- Concentrating collectors shall demonstrate suitable performance and ability to protect themselves from common failures in standard operation during their lifetime.
- The collector shall be assembled according to manufacturer's specifications. If the collector has active mechanisms those mechanisms shall be operational during testing and shall be supplied by manufacturer. Concentrating collector designs which include a factory sealed container charged with a fluid used in the collection of heat shall be tested without the removal of this element.
- The protection systems can be active or passive. The manufacturer shall define the equipment protection features and if the equipment require an external energy supply to operate or not.
- The collector can present a combination of active and passive controls, so the test sequence shall be selected to verify suitable operation of controls during normal operating conditions.

Reliability tests

Exposure test

The test shall be performed according to the procedure described in the corresponding section of the EN 12975-2:2011 (almost like the EN 12975-2:2006 procedure), but taking into account the following indications:

- Concentrating collectors shall be tested in outdoor exposure conditions, and all their components and subsystems shall be validated to be functional during the exposure period. If the collector includes active systems they shall be active and operational during the exposure test.
- Collectors shall be mounted outdoors but shall not be filled with heat transfer fluid, unless controls are used to manage both a no-flow and high temperature conditions according to the manufacturer's instructions. In that case, collectors shall be filled with the heat transfer fluid and such controls shall be verified.
- Collector designs which include a factory sealed container charged with a fluid used in the collection of heat shall be tested without heat transfer fluid flowing through them unless controls are used for over temperature protection.
- At least once a week, collectors shall be subjected to visual inspection and any change in the physical appearance shall be registered and reported with the test results.

Active and passive control test

The manufacturer must identify all active and passive protection controls which are present in the collector. The manufacturer shall submit their control set points and parameters in order to verify their suitable operation during normal working conditions.

A test cycle during the exposure period will be established for testing the active and/or passive controls which are necessary to keep the collector in working conditions. Their operation shall be validated to be functional, in such a way that any failure can be detected. The test cycle shall include as events, the loss of electrical supply and the blockage of tracking mechanism (if present). The verified control functions shall be described and reported with the test results.

High temperature resistance test

The test shall be performed according to the procedure described in the corresponding section of the EN 12975-2:2011 (almost like the EN 12975-2:2006 procedure), but taking into account the following indications:

- High temperature resistance test shall be carried out during the exposure test.
- If controls are present to manage both a no-flow and high temperature condition, the collector must be filled with heat transfer fluid and it should not be able to reach stagnation conditions. Such controls shall be validated to be functional and the collector shall reach the maximum operating temperature defined by the manufacturer.
- The verified control functions shall be described and reported with the test results.

Internal thermal shock test

The test shall be performed according to the procedure described in the corresponding section of the EN 12975-2:2011 (almost like the EN 12975-2:2006 procedure), but taking into account the following indications:

- It is not applicable to those parts of the collector which are factory sealed.
- It is not applicable to those collectors in which heat transfer fluid is continuously flowing for protection purposes. In that case control(s) used to manage a no-flow condition shall be validated to be functional in such a way that any failure can be detected.
- The verified control functions shall be described and reported with the test results.

Mechanical load test

The test shall be performed according to the procedure described in the corresponding section of the EN 12975-2:2011 (almost like the EN 12975-2:2006 procedure), but taking into account the following indications:

- As concentrating collectors have different geometries, specific and suitable procedures must be designed to test resistance against mechanical load. The procedure carried out shall be clearly described with the test results.
- When according to the manufacturer’s instructions, controls are present to protect the collectors against wind or snow load, the control functions shall be validated to be

functional, if it is possible, and they shall demonstrate resistance to failures associated with collector normal operation.

- The verified control functions shall be described and reported with the test results.

The following tests will be performed as described in the corresponding chapters of the EN12975-2:2011 standard (almost identical test procedures like the EN12975-2:2006 for non concentrating collectors: flat plate or evacuated tube):

- Internal pressure test for absorbers
- Rain penetration test
- External thermal shock test
- Impact resistance test
- Final inspection and test report

7.4.2 CSP standardization activities

At the beginning of 2010 the Spanish Association for Standardization and Certification (AENOR) created a new subcomittee inside the electricity production technical committee (AEN/CTN206) to deal with standardization activities related with solar thermal electric plants. This subcommittee is comprised of R&D Centres of excellence in renewable energy and Spanish industrial partners. The aim of this subcommittee[32] is to create a series of Spanish Standards (UNE) that will define procedures to qualify components (receiver tubes, sun tracking systems, reflectors, etc.), subsystems (solar field, thermal storage system and power block) and complete CSP plants. Within this subcommittee, three different working groups (WG) have been created concerned with different aspects of the CSP plant: the first working group deals with standardization aspects related to the solar field and the CSP plant as a whole; the second working group develops standardization procedures related to the solar field components; and the third working group is focused on the standardization of thermal storage systems for CSP applications.

Due to the lack of standardization in this field, the Spanish Committee launched a proposal to the International Electrotechnical Commission (IEC) for the establishment of a new IEC Technical Committee. The request was accepted –twenty countries voted in favour, and nine of them communicated their interest to participate actively in the work. So the IEC SMB (Standardization Management Board) approved the creation of the IEC TC 117 Solar Thermal Electric Plants, allocating the secretariat to the Spanish National Committee. The first meeting will be held in March 2012, after this kick-off meeting and once the program of work is agreed, the Spanish CSP projects will be considered at an international level.

[32] M.Sanchez et al. "Overview of activities related to the development of Spanish standards for concentrating solar thermal power plants.17th Symposium on Concentrating Solar Power and Chemical Energy Systems - SolarPACES 2011, Granada,Spain.

In the near future it is expected a close collaboration between the recently created IEC/TC117 and the ISO/TC180 related with the concentrating/tracking collectors and their components.

For further information on this topic, see the IEA-SHC Task 43 White Paper on Concentrating Collectors.

8 PV/T COLLECTOR TEST PROCEDURES

PV/T is a solar energy device using PV as a thermal absorber. By using the heat generated in the PV, a PV/T device generates not only electrical, but also thermal energy. PV/T devices can be very different in design, ranging from PV/T domestic hot water systems to ventilated PV facades and actively cooled PV concentrators.

8.1 Current standards and certification procedures

One of the main bottlenecks for PV/T is the lack of certification, and standardization. It is important that the reliability and life time of PV/T laminates is thoroughly assessed, which requires further research and dedicated test procedures.

Performance certification is defined for either solar thermal systems (EN 12975 or ISO 9806) or for PV Power systems (IEC 61215 and IEC 62108 Concentrator photovoltaic (CPV) modules and assemblies – Design qualification and type approval), but currently not for combined systems.

8.2 Gaps and open questions

Indoor test facilities[33]

- Sun simulator performance: Solar spectrum, irradiance, beam homogeneity, spectral distribution, wind and sky/ambient temperatures.

Performance tests

- The electrical performance affects the thermal performance. Therefore, it should be clear whether the characterisation of a PV/T module should be with or without production of electricity. There is a need to define and include in the EN 12975-2 a procedure for operating the PV option in a standardised way.
- A PV/T collector is more sensitive to spectral variations than a normal collector, resulting in problems with indoor measurements.
- Stagnation temperatures and active over heating protection.

Reliability

- In glazed PV/T collectors, the PV may be subject to substantially higher temperatures than are prescribed for thermal cycling in the PV standard IEC 61215.
- Due to the metal rear, short circuiting needs more attention.

[33] Indoor Test Facility PVT-Panels. A Feasibility Study, June 2002 ECN.

- It should become clear whether the PV tests can be carried out on laminate level, or should be carried out on PV/T module level

8.3 Testing approaches

Recently, as a part of the EU PV-Catapult[34], a performance test has been drafted[35] for flat-plate PV/T liquid modules with crystalline silicon cells. In addition, a discussion paper has been written on reliability issues for these modules.

Also in the Subtask C: Product and System Development, Tests and Evaluation from IEA-SHC Task 35 PV/Thermal Solar Systems, the aims were to develop, test and evaluate PV/Thermal solar system components and concepts from the experience of products already on the market. The most important activity was to suggest and evaluate a standard method for performance testing of PV/T collectors, for this reason several market available collectors had been tested. A certification process for PV/T systems was also discussed.

Last Solar Keymark Network meeting has taken the following decision concerning Solar Keymark Certification of PV/T collectors: Solar Keymark Certification of PV/T collectors as a solar thermal product is possible provided the measurements of the thermal performance are performed with and without electricity production. For the electrical load applied for the electricity production a MPP tracker shall be used.

8.4 Actions

No actions will be taken within the IEA-SHC Task 43 about this topic.

9 SOLAR FLUID TEST PROCEDURES

In regions where weather conditions can cause ambient temperatures below zero, solar thermal collectors are usually filled with an antifreeze fluid to prevent the bursting of pipes.

A number of standardized and non standardized test methods are available to determine corrosion of metals in contact with fluids used in solar applications. The maximum lost of metal mass for different metals is not given by the standards but proposed publications conclude that heat-transfer fluids for solar applications proved excellent corrosion protection. But corrosion is usually not a problem in solar applications as long as the installation is well designed, with an appropriate and in good condition solar fluid.

Manufacturers usually give upper temperature limits for the solar application fluids of 120-175ºC, which are under the stagnation temperatures of modern flat plate collectors and much lower if evacuated tube collectors are considered.

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[34] PVT Roadmap: A European guide for the development and market introduction of PV-Thermal technology. EU-supported Coordination Action PV-Catapult. For more information, see www.pvtforum.org.

[35] EU PV-Catapult deliverable D8-6: PVT performance measurement guidelines.

During stagnation conditions and unfavourable emptying behaviour of collector fields, solar fluids based on glycol mixtures deteriorate with time, leading to two different problems: metal corrosion and plugging of pipes, filters and pumps due to the degradation products of the solar fluid. For this reason it is very important to test not only the fresh solar fluid, but also the lifetime solar fluids in a given application. The influencing parameters for a given application are: the number and total time of collector stagnations, pressure of the collector field, type of collector emptying behaviour, presence of metals, presence of oxygen, etc. Due to this reason is necessary to check periodically the condition of the solar fluid, and replace it if necessary.

9.1 Current standards and certification procedures

Several standardized corrosion test methods for metals in contact with antifreeze have been developed by the American Society for Testing and Materials (ASTM). All the testing methods have in common that they are only focused on the corrosion on metals or other materials and not on the antifreeze properties change over its service lifetime. The most relevant standards for solar fluids are mention below.

9.1.1 ASTM D1384

It is a standard corrosion testing method for engine coolants in glassware, and it was not developed for solar applications, but it is the standardized corrosion test that solar antifreeze manufacturers refer in their product declarations. In this method metal samples are immersed in aerated antifreeze solutions for 336 hours at a constant temperature of 71ºC or 88ºC, and after the test the metal loss due to corrosion is measured. This test is not giving much information about the antifreeze properties for solar applications because the test temperature is too low compared with the ones encountered under the solar system operating conditions.

9.1.2 ASTM E72

This test is a laboratory screening of metallic containment materials for use with liquids in solar heating and cooling systems, and it has been developed for the prediction of performance of metals in combination with a specific solar fluid under solar application service conditions. This test covers six testing procedures focused on detecting the changes in the nature of the fluid that might significantly alter its corrosivity, but the lifetime of the antifreeze fluid is not considered. All the test of this standard recommends a minimum testing time of 30 days because of the time dependence of corrosion factors. The tests measure the metal loss due to corrosion.

9.1.3 ASTM E745

This test is a standard practice for simulated service testing for corrosion of metallic containment materials for use with heat-transfer fluids in solar heating and cooling systems, and its purpose like the other standards is to determine the performance of the metallic containment material instead of the antifreeze fluid deterioration. It describes three practices for testing where a minimum testing time of 6 months because of the time dependence of corrosion factors. The final evaluation is similar to the previous ASTM standards.

9.2 Gaps and open questions

No standard test method has been found for solar fluid deterioration and lifetime under specific conditions. Several non standardized investigation methods were developed by different authors. The temperature limits and lifetime estimation of solar fluids are poorly documented and also their compatibility with plastic materials clearly lack in standardized methods, so further work is needed to create a standard test method.

Also the solar fluid toxicity level should be considered due to the different country or region legislations.

9.3 Testing approaches

Within the EU NEGST project CEN/TC312 has been recommended to consider initiating standardisation on "solar fluids". A very solid basis for such work is presented in the four resource documents from M.Haller, P.Vogelsanger, SPF, 2005[36]:

- Report on corrosion and lifetime tests for solar fluids
- Report on properties and standard tests of solar fluids
- Recommendations for the elaboration of missing testing procedures for solar fluids
- Recommendations for the use of standards for solar fluid parameters

9.4 Actions

No actions will be taken within the IEA-SHC Task 43 about this topic.

10 COLLECTOR TEST STANDARDS COMPARISON TABLE

Test	Standard	Test procedure
High temperature resistance	EN 12975	Collector A minimum 1 h with G > 1000 W/m² and ambient temperature 20 – 40 °C, wind < 1 m/s
	ISO 9806-1	
	ISO 9806-2	Collector A minimum 1 h with G: A) 950 - 1049 ; B) 1050 - 1200 ; C) > 1200 (W/m²) and ambient temperature: A) 25 - 29,9 ; B) 30 - 40 ; C) > 40 °C, wind < 1 m/s
	Standard 100-8	
	CAN/CSA-F378-87	Collector A minimum 1,5 h with G (I) = 950 + 5*(30-T_{amb}) W/m², wind < 5 m/s
	ANSI/ASHRAE standard 93	
	AS/NZS 2735.1	Collector A according to ISO 9806-2
	AS/NZS 2712	Collector A performance according to AS/NZS2535.1 G_{mean} = 1050 W/m² with max 20 W/m² deviation at 6 points T_{amb} > 30 °C (Level 1) / >38 °C (Level 2), 12 h irradiation on / 12 h irradiation off for 10 days
Exposure	EN 12975	Collector A according to ISO 9806-2 Class A

[36] NEGST WP4 documents D2.7 a, b, c and d at http://www.swt-technologie.de/html/publicdeliverables3.html

Test	Standard	Test procedure
		30 days with G > 14 MJ/m² 30 h with G >850 W/m² and T_{amb} >10°C
	ISO 9806-1	
	ISO 9806-2	Collector A, B, C 30 days with G: A) 14 ; B) 18 ; C) 20 MJ/m² 30 h with G: A) 850 ; B) 950 ; C) 1050 W/m² and T_{amb} >A) 10 ; B) 15 ; C) 20 °C
	Standard 100-8	Collector A 30 days with G > 17 MJ/m²
	CAN/CSA-F378-87	Collector A, first the collector will be filled according to Ba / Bb / Bc drain and close. Exposition phase started after closing of pipes 30 days with G > 17 MJ/m²
	ANSI/ASHRAE standard 93	
	AS/NZS 2735.1	Collector A according to ISO 9806-2
	AS/NZS 2712	
External thermal shock	EN 12975	Collector A 2 times according to ISO 9806-2 Class A minimum 1 h with G (W/m²) and T_{amb} (°C) as in 30 h exposure
	ISO 9806-1	
	ISO 9806-2	Collector A 2 times minimum 1 h with G (W/m²) and tamb (°C) as in 30 h exposure
	Standard 100-8	Collector A 3 times according to ISO 9806-2 Class B minimum 1 h with G >950 W/m² and T_{amb} > 15°C
	CAN/CSA-F378-87	
	ANSI/ASHRAE standard 93	
	AS/NZS 2735.1	Collector A according to ISO 9806-2
	AS/NZS 2712	
Internal thermal shock	EN 12975	Collector A 2 times according to ISO 9806-2 Class A minimum 1 h with G (W/m²) and T_{amb} (°C) as in 30 h exposure
	ISO 9806-1	
	ISO 9806-2	Collector A 2 times minimum 1 h with G (W/m²) and T_{amb} (°C) as in 30 h exposure
	Standard 100-8	Collector A 1 time according to ISO 9806-2 Class B minimum 1 h with G >950 W/m² and T_{amb} >15 °C
	CAN/CSA-F378-87	Collector A 1 time minimum 1 h with G >900 W/m²
	ANSI/ASHRAE standard 93	
	AS/NZS 2735.1	Collector A according to ISO 9806-2
	AS/NZS 2712	
Rain penetration	EN 12975	Collector A, Test duration 4 h
	ISO 9806-1	
	ISO 9806-2	Collector A, Test duration 4 h
	Standard 100-8	
	CAN/CSA-F378-87	Collector A, Test duration 30 min.
	ANSI/ASHRAE standard 93	
	AS/NZS 2735.1	Collector A according to ISO 9806-2
	AS/NZS 2712	Collector A 10 min. rain penetration, 4 h drying with shaded aperture
Impact resistance	EN 12975	Collector A according to ISO 9806-2 or with 7.5 g ice ball 10 times with 23 m/s ± 5%
	ISO 9806-1	
	ISO 9806-2	Collector A or B max. 5 cm from the edge max. 10 cm from the corner. Steel ball 150 gram +/- 10 g each 10 times at 0,4 / 0,6 / 0,8 / 1,0 / 1,2 / 1,4 / 1,6 / 1,8 / 2,0 meter in height
	Standard 100-8	Collector A according to ISO 9806-2 for none tempered glass
	CAN/CSA-F378-87	
	ANSI/ASHRAE standard 93	
	AS/NZS 2735.1	Collector A according to ISO 9806-2
	AS/NZS 2712	Collector A - no glass pieces > 50 mm with ice ball according to EN 12975 with steel ball 63 gram at 2.9 m height, 3 different positions, 150 mm from corner or edge
Mechanical	EN 12975	Collector A minimum + 1000 Pa, minimum - 1000 Pa
	ISO 9806-1	

Test	Standard	Test procedure
Load	ISO 9806-2	
	Standard 100-8	
	CAN/CSA-F378-87	Collector A + 1500 Pa, - 2000 Pa
	ANSI/ASHRAE standard 93	
	AS/NZS 2735.1	
	AS/NZS 2712	Collector A positive and negative load
Final Inspection	EN 12975	Collector A
	ISO 9806-1	
	ISO 9806-2	Collector A, B, C
	Standard 100-8	Collector A
	CAN/CSA-F378-87	Collector A
	ANSI/ASHRAE standard 93	
	AS/NZS 2735.1	Collector A
	AS/NZS 2712	
Thermal performance	EN 12975	Collector B, pre-conditioning 5h with G > 700 W/m², diffuse fraction < 30 %. Steady State or Quasi-Dynamic Testing.
	ISO 9806-1	Collector A, tilt-angle latitude ± 5° but not less than 30°, diffuse fraction < 20 %. Collector area: 0,1 % accuracy, minimum global irradiation G >800 W/m². Wind speed 2 - 4 m/s. Volume flow 0.02 kg/(s*m²), max. drift +/- 10 %, deviation mass flow ± 1%, Deviation Irradiation ± 50 W/m². Deviation T_{amb} ± 1 K, deviation inlet temperature ± 0,1 K. T_{out}-T_{in} >1.5 K, T_m-T_{amb} at η_0 ± 3K. Conditioning phase minimum 15 min and measurement phase minimum 15 min.
	ISO 9806-2	Collector A according to ISO 9806-1
	Standard 100-8	Collector A, 5 minutes measurement points / 0,07 g/(s*m²) according to ISO 9806-1
	CAN/CSA-F378-87	Collector A according to ANSI/ASHRAE
	ANSI/ASHRAE standard 93	Minimum global irradiation G >790 W/m², deviation irradiation ± 32 W/m², diffuse fraction < 20 %. Max. T_{amb} 30 °C. Wind speed 2.2 - 4.5 m/s, volume flow 0,02 g/(s*m²). Deviation inlet temperature ± 2% or 1°C Deviation mass flow ± 2% or 0,000315 l/s. Deviation T_{amb} ± 1,5 K. Conditioning phase 2*times constant or minimum 10 minutes. Measurement phase minimum 0,5*times constant or minimum 5 minutes.
	AS/NZS 2735.1	Collector A, tilt-angle latitude ± 5° but not less than 30°, diffuse fraction < 20 %. Collector area: 0,1 % accuracy, minimum global irradiation G >800 W/m². Wind speed 2 - 4 m/s. Volume flow 0,02 kg/(s*m²), max. drift +/- 10 %, deviation mass flow ± 1%, Deviation Irradiation ± 50 W/m². Deviation T_{amb} ± 1 K, deviation inlet temperature ± 0,1 K. T_{out}-T_{in} >1.5 K, T_m-T_{amb} at η_0 ± 3K. Conditioning phase minimum 15 min and measurement phase minimum 15 min.
	AS/NZS 2712	