Quality Assurance in solar thermal heating and cooling technology

Keeping track with recent and upcoming developments

Summary report
Impact resistance testing

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1. Introduction

Hail stone testing with real ice balls is a common procedure in testing outdoor exposed products which have a functional or safety relation to eventual cracking or breaking (e.g. PV modules are tested according IEC 61215 chapter 10.17).

There are two methods for impact resistance testing described in chapter 5.10 of EN 12975. One method is using a steel ball of 150g and dropping it on the collector surface to check the resistance. The second is using an ice ball of 25mm.

A future market for solar thermal products when they are used as façade integrated elements fulfilling not only one, but several purposes. The level of resistance towards hail is then one important characteristic.

Because of a tendency of an increasing number of increasingly severe hail events, insurance companies are interested in a clear statement on hail resistance of solar collectors based on third party tests.

2. Hail stone testing in the IEC Standard for PV modules (IEC 61215)

The method allows using one of the following ice ball sizes:

Table 1: Ice balls allowed to be used according to IEC 61215

Diameter	Mass	Test velocity	Diameter	Mass	Test velocity
mm	g	m/s	mm	g	m/s
12,5	0,94	16,0	45	43,9	30,7
15	1,63	17,8	55	80,2	33,9
25	7,53	23,0	65	132,0	36,7
35	20,7	27,2	75	203,0	39,5

Requirements for these ice balls are:

- No cracks visible to the unaided eye
- Diameter within +-5% of that required
- Mass within +-5% of the appropriate nominal value of table above

The test is mandatory.

3. Hail stone testing in the Swiss procedure

The Swiss procedure allows using one of the following ice ball sizes:

Table 2: Ice balls allowed to use according to the Swiss testing procedure

						Tolerance
diameter [mm]	25	30	35	40	45	± 5%
mass [g]	7.53	13.0	20.7	30.8	43.9	± 5%
velosity [m/s]	23.0	25.2	27.2	29.0	30.7	± 5%
kinetic energy [J]	2.0	4.1	7.7	13.0	20.7	

It also clusters the collectors in classes according to their shape and surface structure. Instructions for production and storing of the ice balls are identically with IEC 61215.

The test is mandatory.

4. Hail stone / Impact resistance testing in the EN 12975

Chapter 5.10 allows for two (both optional) methods of impact resistance test. One is using a steel ball another is using an ice ball.

The steel ball used is:

Table 3: Steel ball allowed to be used according to EN 12975

Diameter [mm]		tolerance
Mass [g]	150	+-10
Drop height [m]	0,4 up to 2,0 in steps of 0,2	

The ice ball used is:

Table 4: Ice ball allowed to be used according to EN 12975

		tolerance
Diameter [mm]	25	± 5%
Mass [g]	7,53	± 5%
Velocity [m/s]	23	± 5%

5. Proposal for hail stone testing for prEN ISO 9806

In prEN ISO 9806 a mandatory hail resistance test is proposed. The procedure for this test was developed and discussed within the QAiST project.

The discussion was constructive in the sense that despite the fact that there were quite different opinions within the QAiST group, a common proposal for revision of this test could eventually be included in the new standard draft. The proposal reflects on the one hand the interests of the industry to have a simple, cheap and repeatable method using the steel ball and on the other hand the test labs asking for a method closer to “real conditions” harmonized with the method used in PV module testing.

In the end there was a proposal prepared and handed over to the CEN TC 312 WG1 secretariat and so there is a changed revision available in the prEN ISO 9806.

The proposal is bringing together the definition on collector classes from the Swiss approach. It takes over partly the table of acceptable ice balls from the IEC 61215. It defines very detailed the point of impact where to shoot at and the number of shots. Particularly on this issue the draft will be commented, because of feed back from partners, telling that where to shoot is not clear. In a CEN TC 312 WG1 meeting in Stockholm, there was a longer discussion on the possible procedure. Most aspects of the consensus which was discussed there was implemented in the proposal (see also minutes of the TC meeting), some points were over looked without intention and have to be commented during inquiry phase still.

The ice balls proposed are:

Table 5: Ice balls allowed to be used according to prEN ISO 9806

Diameter [mm]	Mass [G]	Velocity m*s^{-1}]	kinetic energy [J]
25	7,53	23,0	2,0
35	20,7	27,2	8,0
45	43,9	30,7	20,7
55	80,2	33,9	46,1
65	132,0	36,7	88,9
75	203,0	39,5	158,4

The productions as well as other requirements on the ice balls are identical with the IEC 61215.

The steel ball method was not changed from EN 12975.

A new reporting was proposed to give more detailed and transparent information. To test a collector on the “pass” criteria of the hail resistance test the steel ball test is

accepted. As there is the assumption that the impact generated by a dropping steel ball is always harder to with stand than from a comparable ice ball which is deforming in the moment of impact.

In case a collector does fail the hail testing using the steel ball, one has to repeat the testing with the ice ball method to either back up or revise the fail/pass decision.

6. On-Going and future work

As there is consensus among the experts that the two methods are not directly comparable in their results, and as there is consensus that hail testing is a relevant test in most cases, future work is needed to find one common method to use.

The shooting areas will be more clearly defined, this is shown in the following two pictures, which will be parts of comments to the draft.

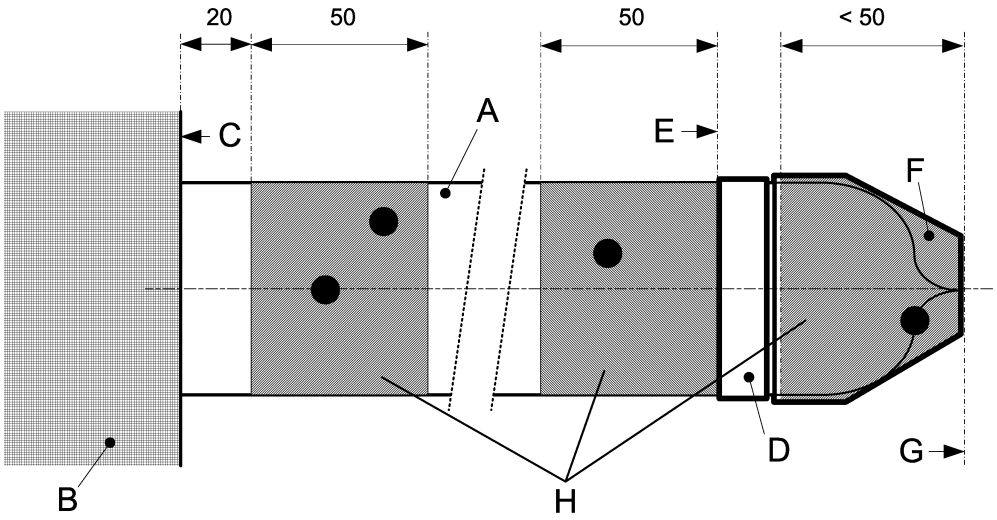

Figure 1: Sketch specifying the shooting areas for a typical ETC

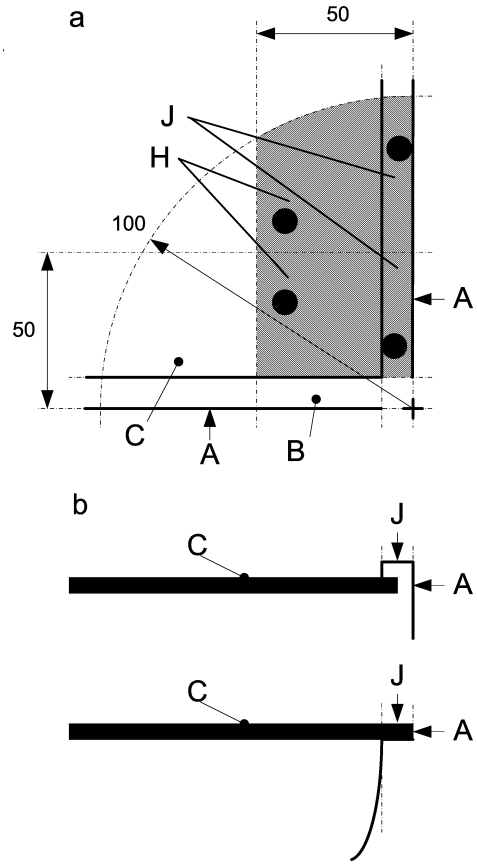

Figure 2: Sketch specifying the shooting areas for a typical FPC

A possible development of the testing procedure could also be, to substitute the ice balls by another material like clay or plastics. Empirical rows of shooting ice balls on glass probes (very standardized equipment from microscopy) at Fraunhofer ISE in 2010 showed that the impact impulse is very repeatable. Therefore the homogeneity of the projectile is an important factor of course. To produce ice balls in such a way that they are homogenous and fulfil the normative requirements on diameter tolerance and weight is not trivial. So to make the method cheaper a substitute at lower effort could be a solution.

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7. Annex A “Working paper of QAiST”

Working paper for methods of the hail stone resistance test

Introduction

The hail stone testing procedure of collectors by using ice balls is a reliable and repeatable method to test the impact resistance and therefore the durability of the modules against hailstones. For this reason it is demanded to change the optional hailstone test to a mandatory test method in the revision of the EN12975-1,2:2006. It is recommended to establish the second testing method (using ice balls) according to EN12975-1,2:2006.

In the following the testing requirements as they might most likely be established and required in Switzerland were taken into account. Please see references for more detail.

Discussion:

Is the objective of this test procedure the assessment of the extent to which a collector can withstand the effects of heavy impacts caused “only” by hailstones or an assessment of the ability of collector modules to withstand impacts in general (independent from the kind of impact).?

S.Mehnert: From my understanding the objective of this test procedure should firstly assess the effects of hail impacts against ice balls. A general assessment of the impact resistance against impacts caused by different materials is a too wide area. Than we have also to take into consideration the shape of the impact material and …

Methods

1 General

According to this testing procedure the hailstone resistance of solar thermal collectors is evaluated. Thermal collectors are classified in different hailstone classes depending on its hailstone resistance.

2 Area of application

The testing method contains all solar thermal collectors coming under the norm EN12975.

3 Test items

Group I: flat plate collectors with only one single cover **.**

Group II: Large scale collectors modularly constructed, having multiple identically covers. It is sufficient to test one representative single module with an accordant cover surface.

Group III: Vacuum tube collectors. An entire module (not a single tube) needs to be tested with the minimum of required tubes (see below).

4 Test setup

The test setup need to fulfil at least the standards according to EN12975-1,2:2006

4.1 Pre-storage of the sample

Generally no pre-storage of the sample is necessary. In the case of collectors including at least one material other than glass or metal at the relevant impact spot, the collector needs to be exposed outside for at least 15 days and gaining at least 250 MJ/m² irradiation. The irradiation may also be applied by a solar simulator according to EN12975-2:2006. A maximum of 14 MJ/m² and day needs to be observed and the collector needs to be exposed for at least 12 hours a day outside.

4.2 Ice balls

The ice balls are made of water and should be entirely free of air bubbles and must not have cracks that are visible to the unaided eye. The applied ball diameters are mentioned in table 1. In principle it is allowed to test with different diameters analogously. The testing procedure is being conducted with ice balls having a temperature of -4°C ± 2°C

						Tolerance
Diameter [mm]	25	30	35	40	45	± 5%
Weight [g]	7.53	13.0	20.7	30.8	43.9	± 5%
Impact velocity [m/s]	23.0	25.2	27.2	29.0	30.7	± 5%
kinetic energy [J]	2.0	4.1	7.7	13.0	20.7	

Table 1: Mass of the ice balls and testing velocities

Annotation: The velocities given in this table are equal to the velocities given within ISO IEC 61215:2005 for the ball diameters 25 mm, 35 mm and 45 mm. The other diameters are not given within this standard.

4.3 Testing instrument

The testing instrument needs to fulfil the requirements according to EN12975.

5 Shooting area and angle

The firing area and angle are adapted to different collector types:

a. **Glazed flat plate collectors**:

Collectors with a transparent cover: The impact point needs to be maximum distance of 5 cm from the edge and maximum distance of 10 cm from the corner of the collector cover.

For each diameter during the testing procedure a different corner needs to be chosen. The shooting angle is vertical to the collector surface. Each testing procedure with a certain diameter comprises 10 shots.

b. **Unglazed collectors**: The same definitions as for the glazed collectors are valid.

Furthermore it needs to be assured that also the tubes containing the fluid are hit. Other reasonable impact points need to be considered if it is not possible to hit the fluid containing tubes due to geometrical reasons.
Unglazed collectors need to be filled with water or with an adequate solar fluid. The collectors are tested under atmospheric pressure.

c. **Vacuum tube collectors**: For each diameter of ice ball four randomly chosen tubes of the collector are tested. The impact point needs to be in a distance less than 15 cm from the upper or lower end (visible aperture).
Two tubes of them are being shot at the upper end („up“). The other two tubes are shot at the lower end (“down”). The shooting angle is vertical onto the tube axis.

One cracking of one tube is permitted and needs to be compensated with an additional testing of two more tubes at the same position. Example: cracking of a lower tube end: two additional tubes need to be tested at the lower end.

d. Collectors that cannot be **classified clearly into the category a.) b.) or c.)** need to be tested at each ice ball diameter with 16 shots.
The impact points needs to be distributed evenly across the whole collector area. The coordinates of the impact points need to be defined before the testing, mentioned in the testing report and have to be documented with photos.

The following rule applies to all collector types: Are further obviously weak spots visible, having an influence of the functionality or safety of the collector (e.g. frame, mounting parts, exposed fluid containing parts, mirrors etc.) they need to be tested additionally. Each spot needs to be tested applying four shots at the chosen diameter.
These weak spots need to be mentioned and documented with photos in the testing report. It has to be documented if no further weak spots are identified.

5.1 Missing shots

Missing shots with velocities beyond the tolerance need to be mentioned in the protocol. Shots with too low speed are not valid and need to be repeated. Shots with too high speed are valid if no damage occurs.

5.2 Elements for facades

Collectors especially made for the use in facades may also be tested as elements for facades. The angle of the ice ball shooting impact needs to be lower than 45° and is not vertical to the collector surface. For vacuum tube collectors it needs to be

documented that the tubes are oriented vertically. The test angle is 45°. Tubes being installed horizontally cannot be considered as elements for facades.

6 Function of components
The thermal collector is proved of appearance and mechanical aspects.

6.1 Damage criteria

Appearance: Aesthetical defects (little dents) affecting negatively neither the function nor the power output of the collector, need to be documented in the testing report but are not a failing criterion. Dents with a depth > 3 mm and dents being readily identifiable in a distance of 5 m are a failing criterion.

Mechanical aspects: Breaking of the glass or other damage of the cover or other collector parts affecting negatively according to the test laboratory the durability (e.g. leakiness) or power output (due to dissolution of coating, scattering of cover) or influencing negatively the safety of the product are failing criterions.

6.2 Measuring method

Appearance: The appearance is tested under daylight or artificial light without dazzling effect and a distance of 5 m between the testing person and the object.

Mechanical aspects: The solar collector needs to be examined visually (distance testing person and sample object maximum 0.5 m)

7 Test report
The test report contains all the technical details relevant for a test report according to EN12975. Additionally details on the testing instruments and the testing procedure need to be mentioned. All impact points are documented (also the impact points resulting form shots out of the tolerance of speed) including the weight of the ice ball and the measured speed.

8. Text proposal for prEN ISO 9806

“Impact resistance test

Objective

This test is intended to assess the extent to which a collector can withstand the effects of heavy impacts caused by hailstones

The testing of the solar collector to determine its impact resistance can be done by one of two methods, i.e. by using ice balls or steel balls. As the steel ball does not lose any energy due to its deformation at the impact it is assumed that this method is the more severe if the two methods are carried out with balls giving the same kinetic

energy. Therefore method 2 (Steel ball) shall only be used for “pass” judgements. If method 2 results in a failure, this must be confirmed by a test according to method 1.

Method 1: Impact resistance test using ice balls

NOTE As test method 1 is closer to reality for hail resistance, this method is preferable.

Apparatus

a) Moulds of suitable material for casting spherical ice balls of the required diameter. The diameters are given in

Diameter [mm]	Mass [G]	Velocity $m*s^{-1}$]	kinetic energy [J]
25	7,53	23,0	2,0
35	20,7	27,2	8,0
45	43,9	30,7	20,7
55	80,2	33,9	46,1
65	132,0	36,7	88,9
75	203,0	39,5	158,4

b) Table 6.

c) A freezer, controlled at -10 °C ± 5 °C.

d) A storage container for storing the ice balls at a temperature of -4 °C ± 2 °C.

e) A launcher capable of propelling an ice ball at the velocity as specified by the manufacturer according to

Diameter [mm]	Mass [G]	Velocity $m*s^{-1}$]	kinetic energy [J]
25	7,53	23,0	2,0
35	20,7	27,2	8,0
45	43,9	30,7	20,7
55	80,2	33,9	46,1

65	132,0	36,7	88,9
75	203,0	39,5	158,4

f) Table 6 within ± 5 %, so as to hit the collector within the specified impact location.

g) A rigid frame for supporting the collector, with the impact surface perpendicular to the path of the projected ice ball; the support shall be stiff enough so that there is negligible distortion or deflection at the time of impact.

NOTE In some cases the impact resistance of others then the perpendicular angle might be of interest.

h) A balance for determining the mass of an ice ball to a standard uncertainty of ± 2 %.

i) An instrument for measuring the velocity of the ice ball to a standard uncertainty of ± 2 ms^{-1}. The velocity sensor shall be no more than 1 m from the surface of the collector.

As an example, **Error! Reference source not found.** shows in schematic form a suitable apparatus comprising a horizontal pneumatic launcher, a vertical collector support and a velocity meter which measures electronically the time it takes the ice ball to traverse the distance between two light beams. This is only an example as other types of apparatus including slingshots and spring driven testers have been successfully utilized.

Ice balls

The ice balls shall be made of water. They shall be entirely free of air bubbles and shall not have cracks that are visible to the unaided eye. The standard diameter shall be 25 mm but any of the diameters listed in
Table 6 may be specified for special environments. The testing procedure is being

Diameter [mm]	Mass [G]	Velocity $m*s^{-1}$]	kinetic energy [J]
25	7,53	23,0	2,0
35	20,7	27,2	8,0
45	43,9	30,7	20,7
55	80,2	33,9	46,1
65	132,0	36,7	88,9
75	203,0	39,5	158,4

conducted with ice balls having a temperature of -4°C ± 2°C

Diameter [mm]	Mass [G]	Velocity m*s^{-1}]	kinetic energy [J]
25	7,53	23,0	2,0
35	20,7	27,2	8,0
45	43,9	30,7	20,7
55	80,2	33,9	46,1
65	132,0	36,7	88,9
75	203,0	39,5	158,4

Table 6 - Ice ball masses and test velocities (according to IEC)

Procedure

a) Using the moulds and the freezer, make sufficient ice balls of the required size for the test, including some for the preliminary adjustment of the launcher.

b) Examine each one for cracks, size and mass. An acceptable ball shall meet the following criteria:

1) no cracks visible to the unaided eye;

2) diameter within ± 5 % of that required;

3) mass within ± 5 % of the appropriate nominal value given in

Diameter [mm]	Mass [G]	Velocity m*s^{-1}]	kinetic energy [J]
25	7,53	23,0	2,0
35	20,7	27,2	8,0
45	43,9	30,7	20,7
55	80,2	33,9	46,1
65	132,0	36,7	88,9

75	203,0	39,5	158,4

4) Table 6;

c) Place the balls in the storage container and leave them there for at least 1 h before use.

d) Ensure that all surfaces of the launcher likely to be in contact with the ice balls are near room temperature.

e) Fire a number of trial shots at a simulated target in accordance with step g) below and adjust the launcher until the velocity of the ice ball, as measured with the velocity sensor in the prescribed position, is within ± 5 % of the appropriate hailstone test velocity given in

Diameter [mm]	Mass [G]	Velocity $m*s^{-1}$]	kinetic energy [J]
25	7,53	23,0	2,0
35	20,7	27,2	8,0
45	43,9	30,7	20,7
55	80,2	33,9	46,1
65	132,0	36,7	88,9
75	203,0	39,5	158,4

f) Table 6.

g) Install the collector at room temperature in the prescribed mount, with the impact surface normal to the path of the ice ball.

h) Take an ice ball from the storage container and place it in the launcher. Take aim at the impact location and fire. The time between the removal of the ice ball from the container and impact on the collector shall not exceed 60 s.

Impact location and impact velocity

The impact locations are adapted to different collector types:

a) **Glazed flat plate collectors**:
The impact point needs to be maximum distance of 5 cm from the edge and maximum distance of 10 cm from the corner of the collector cover. Within this area the most critical point should be used. (Compare Figure 3) The test procedure shall be started with the smallest ice ball velocity or a velocity specified by the manufacturer. For each ice ball velocity during the testing procedure a different

corner needs to be chosen. Each test procedure with a certain velocity comprises 4 shots.

NOTE 1 The most critical points are often the edge of the glass.

NOTE 2 Large scale collectors modularly constructed, having multiple identically covers. It is sufficient to test one representative single module with an accordant cover surface.

b) **Unglazed collectors**:
The same definitions as for the glazed collectors are valid. Furthermore it needs to be assured that also the tubes containing the fluid are hit. Other reasonable impact points need to be considered if it is not possible to hit the fluid containing tubes due to geometrical reasons. Unglazed collectors need to be filled with water or with an adequate solar fluid. The collectors shall be tested under at least atmospheric pressure.

c) **Vacuum tube collectors**:
The impact point needs to be in a distance less than 10 cm from the upper or lower end (visible aperture). If the clamps between the inner and outer glass tubes are not covered also this area shall be used. Two tubes are being shot at the upper end („up“). Two tubes are shot at the lower end (“down”). The shooting angle is perpendicular to the tube axis. (Compare Figure 3) The test procedure shall be started with the smallest ice ball velocity according to Table 6 or a velocity specified by the manufacturer. For each ice ball velocity one

Diameter [mm]	Mass [G]	Velocity $m*s^{-1}$]	kinetic energy [J]
25	7,53	23,0	2,0
35	20,7	27,2	8,0
45	43,9	30,7	20,7
55	80,2	33,9	46,1
65	132,0	36,7	88,9
75	203,0	39,5	158,4

randomly chosen tube of the collector shall be tested. Each test procedure with a certain velocity comprises 4 shots per tube (2 at the upper and 2 at the lower end).

NOTE Vacuum tube collectors: An entire module (not a single tube) needs to be tested with the minimum of required tubes (see below)

d) Collectors that cannot be classified clearly into the category a.) b.) or c.)
The impact points need to be distributed evenly across the whole collector area. The coordinates of the impact points need to be defined before the testing, mentioned in the testing report and have to be documented with photos. Each test procedure with a certain velocity comprises 4 shots.

NOTE Are further obviously critical spots visible, having an influence on the functionality or safety of the collector (e.g. frame, mounting parts, exposed fluid containing parts, mirrors etc.) they need to be tested additionally. Each spot needs to be tested applying four shots at the chosen velocity. These critical spots need to be mentioned and documented in the testing report.

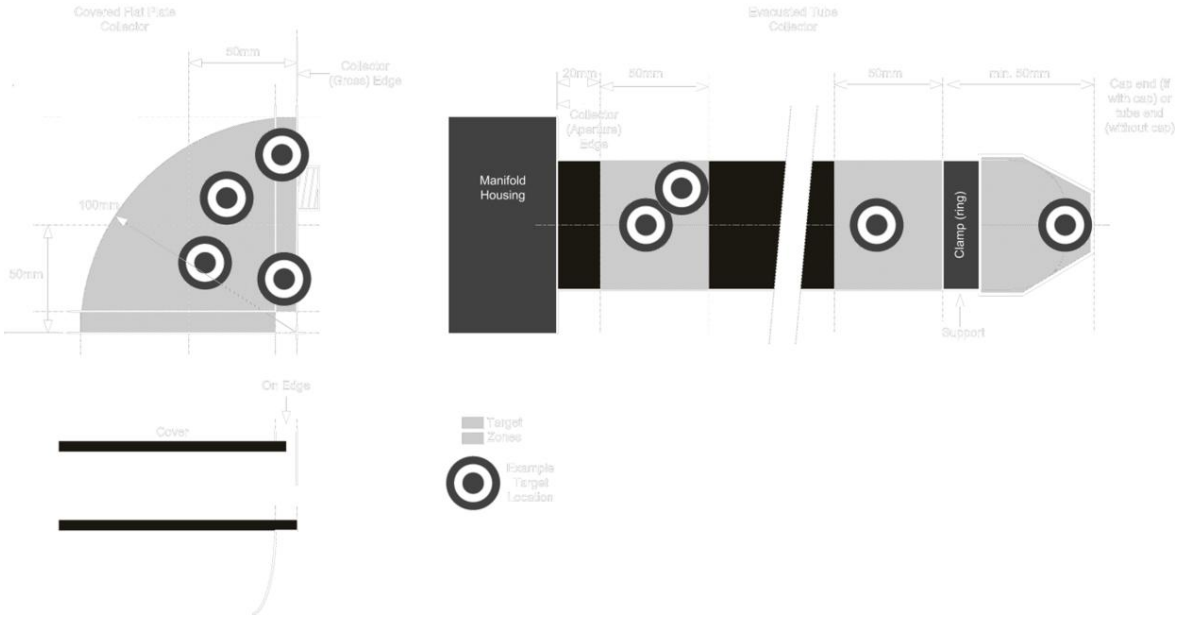

Figure 3 - Impact locations adapted to different collector types

Method 2: Impact resistance test using steel balls

The collector shall be mounted either vertically or horizontally on a support (see **Error! Reference source not found.**). The support may be stiff enough so that there is negligible distortion or deflection at the time of impact.

Steel balls shall be used to simulate a heavy impact. If the collector is mounted horizontally then the steel balls are dropped vertically, or if it is mounted vertically then the impacts are directed horizontally by means of a pendulum. In both cases, the height of the fall is the vertical distance between the point of release and the horizontal plane containing the point of impact.

The point of impact shall be no more than 5 cm from the edge of the collector cover, and no more than 10 cm from the corner of the collector cover, but it shall be moved by several millimetres each time the steel ball is dropped.

A steel ball shall be dropped onto the collector 4 times from the first test height, then 4 times from the second test height, etc. until the maximum test height is reached (as specified by the manufacturer). The test is to be stopped when the collector sustains some damage or when the collector has survived the impact of 4 steel balls at the maximum test height.

If the test is conducted according to method 2, the steel ball shall have a mass of 150 g ± 10 g and the following series of test heights shall be used: 0,4 m, 0,6 m, 0,8 m, 1,0 m, 1,2 m, 1,4 m, 1,6 m, 1,8 m and 2,0 m.

NOTE This method does not correspond to the physical effect of hailstones as the deformation energy absorbed by the ice particles is not being considered.

Results

Appearance: Aesthetical defects (little dents) affecting negatively neither the function nor the power output of the collector, are minor failures which shall be documented within the testing report.

Mechanical aspects: Breaking of the glass or other damage of the cover or other collector parts affecting negatively according to the test laboratory the durability (e.g. leakiness) or power output (due to dissolution of coating, scattering of cover) or influencing negatively the safety of the product are major failures which shall be documented within the testing report. The results of the inspection shall be reported, together with the number of impacts, the velocity and the ice ball diameter if method 1 is used and accordingly the height from which the steel ball was dropped and the number of impacts if method 2 is used.

Generally:

There is no consensus between the different test laboratories about the necessity to establish this test procedure as a mandatory test procedure within the upcoming standard until now. Perhaps we can use this working paper also to collect pros and cons related to this questions. (And please point out your name for further discussion)

Pros:

- basic information for insurance companies -> otherwise they will establish their own requirements/procedures (Mehnert)
- Anyway Switzerland will establish a hail test procedure. Thus this is our chance to take part in this issue.

9. List of related Literature

EN 12975-1:2006 - Thermal solar systems and components – Solar collectors; Part 1: General requirements

EN12975-2:2006 - Thermal solar systems and components – Solar collectors; Part 2: Test methods

ISO IEC 61215 2005
Bewertung der normativen Anforderungen der Prüfung auf Schlagfestigkeit thermischer Kollektoren durch simulierten Hagelschlag mit Eiskugeln; 19. Symposium Thermische Solarenergie, 06.05 – 08.05.2009 Bad Staffelstein; Stefan Mehnert

Quantification of the impact resistance of solar thermal collectors and photovoltaic-modules against severe hailstones; EUROSUN 2008, 7th – 10th October 2008, Lisbon, Portugal; Stefan Mehnert

Prüfbestimmungen zur Ermittlung des Hagelwiderstandes; SPF 2010