QUALIFICATION TESTING OF SOLAR COLLECTORS

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This report is part of the work within the IEA Solar Heating and Cooling Programme,
Task III : Performance Testing of Solar Collectors

Abstract

Within the participating countries of the IEA Solar Heating and Cooling Programme Task III on Performance Testing of Solar Collectors, much effort has been devoted to the development of qualification tests for the reliability and durability of solar collectors.

As part of their collaboration on collector durability and reliability, the Task participants agreed to review their qualification test methods and draw up a handbook of recommendations for procedures that includes a discussion of more innovative ideas that are under development.

The report on qualification testing of solar collectors gives an introduction to the area of qualification testing and an overview of the present state of qualification testing of solar collectors in 13 different countries as well as at the Joint Research Center in Ispra, Italy, and recommended procedures by International Organizations. This includes the ASTM Committee no. E-44 from USA, the International Standards Organization, ISO, the Collector and System Testing Group of the Commission of the European Communities, and the European Union of Agreement, UEATC. A short introduction to innovative solar collector qualification tests is also given.

INTRODUCTION TO THE INTERNATIONAL ENERGY AGENCY AND THE IEA SOLAR HEATING AND COOLING PROGRAMME

The International Energy Agency was formed in November 1974 to establish cooperation among a number of industrialized countries in the vital area of energy policy. It is an autonomous body within the framework of the Organization for Economic Cooperation and Development (OECD). Twenty-one countries are presently members, with the Commission of the European Communities also participating in the work of the IEA under a special arrangement.

One element of the IEA's programme involves cooperation in the research and development of alternative energy resources in order to reduce excessive dependence on oil. A number of new and improved energy technologies which have the potential of making significant contributions to global energy needs were identified for collaborative efforts. The IEA Committee on Energy Research and Development (CRD), supported by a small Secretariat staff, is the focus of IEA RD&D activities. Four Working Parties (in Conservation, Fossil Fuels, Renewable Energy, and Fusion) are charged with identifying new areas for cooperation and advising the CRD on policy matters in their respective technology areas.

Solar Heating and Cooling was one of the technologies selected for joint activities. During 1976-77, specific projects were identified in key areas of this field and a formal Implementing Agreement drawn up. The Agreement covers the obligations and rights of the Participants and outlines the scope of each project or "task" in annexes to the document. There are now eighteen signatories to the Agreement:

Australia	Italy
Austria	Japan
Belgium	Netherlands
Canada	New Zealand
Denmark	Norway
Commission of the European Communities	Spain
	Sweden
Finland	Switzerland
Federal Republic of Germany	United Kingdom
Greece (withdrew in 1986)	United States

The overall programme is managed by an Executive Committee, while the management of the individual tasks is the responsibility of the Operating Agents. The tasks of the IEA Solar Heating and Cooling Programme, their respective Operating Agents, and current status (ongoing or completed) are as follows:

Task I — Investigation of the Performance of Solar Heating and Cooling Systems - Technical University of Denmark (Completed).

Task II — Coordination of Research and Development on Solar Heating and Cooling - Solar Research Laboratory - GIRIN, Japan (Completed).

Task III — Performance Testing of Solar Collectors - University College, Cardiff, U.K. (Ongoing).

Task IV — Development of an Insolation Handbook and Instrument Package - U.S. Department of Energy (Completed).

Task V — Use of Existing Meteorological Information for Solar Energy Application - Swedish Meteorological and Hydrological Institute (Completed).

Task VI — Performance of Solar Heating, Cooling, and Hot Water Systems Using Evacuated Collectors - U.S. Department of Energy (Ongoing).

Task VII — Central Solar Heating Plants with Seasonal Storage - Swedish Council for Building Research (Ongoing).

Task VIII — Passive and Hybrid Solar Low Energy Buildings - U.S. Department of Energy (Ongoing).

Task IX — Solar Radiation and Pyranometry Studies - Deutscher Wetterdienst Meteorologisches Observatiurm, FRG (Ongoing).

Task X — Materials Research & Testing - Solar Research Laboratory, GIRIN, Japan (Ongoing).

Task XI — Passive Solar Commercial Buildings - Swiss Federal Office of Energy (Ongoing).

TASK III
PERFORMANCE TESTING OF SOLAR COLLECTORS

The overall goal of Task III is by international cooperation to develop and validate common test procedures for rating the performance of solar thermal collectors and solar domestic hot water heating systems.

Task III was initiated in 1977 with three subtasks:

Subtask A: Standard Test Procedures to Determine Thermal Performance

Subtask B: Development of Reliability and Durability Test Procedures

Subtask C: Investigation of the Potential of Solar Simulators

Upon the completion of these subtasks at the end of 1982, the Executive Committee approved an extension of the Task with the following three subtasks:

Subtask D: Characterization of the Thermal Performance of Solar Collectors

Subtask E: Development of a Capability to Evaluate Domestic Hot Water System Performance using Short-Term Test Methods

Subtask F: Development of a Basis for Identifying the Performance Requirements and for Predicting the Service Life of Solar Collector System Components

At the end of 1985 a further extension was approved, with a completion date at the end of 1987.

Participants in Task III (those marked * until the end of 1985 only) are: Australia*, Austria*, Belgium*, Canada, Denmark, F.R.Germany, Italy, Japan*, the Netherlands, Spain, Sweden, Switzerland, United Kingdom, United States and the Commission of the European Communities.

LIST OF CONTENT

SUMMARY

Within the participating countries of IEA Task III much effort has been devoted to the development of qualification tests for the reliability of solar collectors. The range of tests used in each country depends, of course, on the local climate conditions. The availability of the tests is also variable. In most countries national standards have now been drawn up, but many tests have also been developed by individual laboratories for their own use.

As part of their collaboration on collector durability and reliability, the Task participants have agreed to review their qualification test methods and to draw up a handbook of recommendations for procedures which are thought to contain the best features of those currently in use. In addition to well established qualification tests, the handbook should discuss some of the more innovative ideas currently under development.

An overview of the present state of qualification testing is given, with a presentation of operational experience with solar collectors together with the rest of the solar collector primary circuit, the different types of tests which are available and factors which might influence the choice and sequence of testing procedures. The qualification tests treated include tests for rain penetration, thermal shock, wind and snow pressure, hail impact, high temperature failure of covers and thermal insulation, and also ventilation of collectors.

The common report on qualification testing of solar collectors gives an overview of qualification test procedures used in 13 different countries as well as at the Joint Research Center in Ispra, Italy, and procedures recommended by ASTM, UEATC, ISO and the CEC Solar Collector and System Testing Group. A proposal for a minimum test procedure is also given.

The main focus of the report is on solar collector modules of what could be called normal size, typically 1 x 2 m. Solar

collectors of this size have been considered the most suitable for mass production and easy installation on to roofs. At the same time, they are quite easy to test, especially with indoor equipment. However, during the last few years, new solar collector designs of different types have been developed. Building integrated concepts are becoming more and more common, especially in connection with new-built housing. In Denmark and Sweden, high temperature Mega solar collector modules of 2 x 6 m for district heating systems with between 1000 and 5000 m^2 of solar collector area have been used in several demonstration projects. Naturally, there will be a need for useful test procedures, also for these new solar collector designs. The report includes a short discussion on qualification testing for these future-orientated components.

Peder Vejsig Pedersen

1. INTRODUCTION TO SOLAR COLLECTOR QUALIFICATION TESTING

1.1 Definitions of Reliability and of Qualification Testing

Solar collector reliability can be defined as the probability that unwanted incidents can be avoided during operation. Reliability characterizes the operation or the function of a solar collector while durability is a long-term characterization giving information about the ability of the solar collector to function and operate for an expected lifetime. This is illustrated in fig. 1.1.1. In [1] it is said that successful commercialization of solar energy systems requires that system goals are be established for costs, thermal performance and for "operational" reliability, maintainability and availability (RMA). Here is a detailed presentation of RMA techniques applied to solar heating and cooling systems (see fig. 1.1.2).

To ensure a satisfactory relation between investment and saving, a 20-year lifetime is generally considered acceptable for solar collectors. For less expensive solar collector constructions, like swimming pool panels, even a shorter life time can be accepted. With regard to building integrated solar collectors, it is desirable to find a product with a life time close to other building components, at least for part of the solar collector construction.

Building integrated solar collectors should have a built-in possibility for maintenance and repair, making it easy to change part of the construction, for example the absorber or the piping system, when necessary. Like many other building components, the cover system, the flashing and frame system and the insulation material and under-roof should last for more than 30 years.

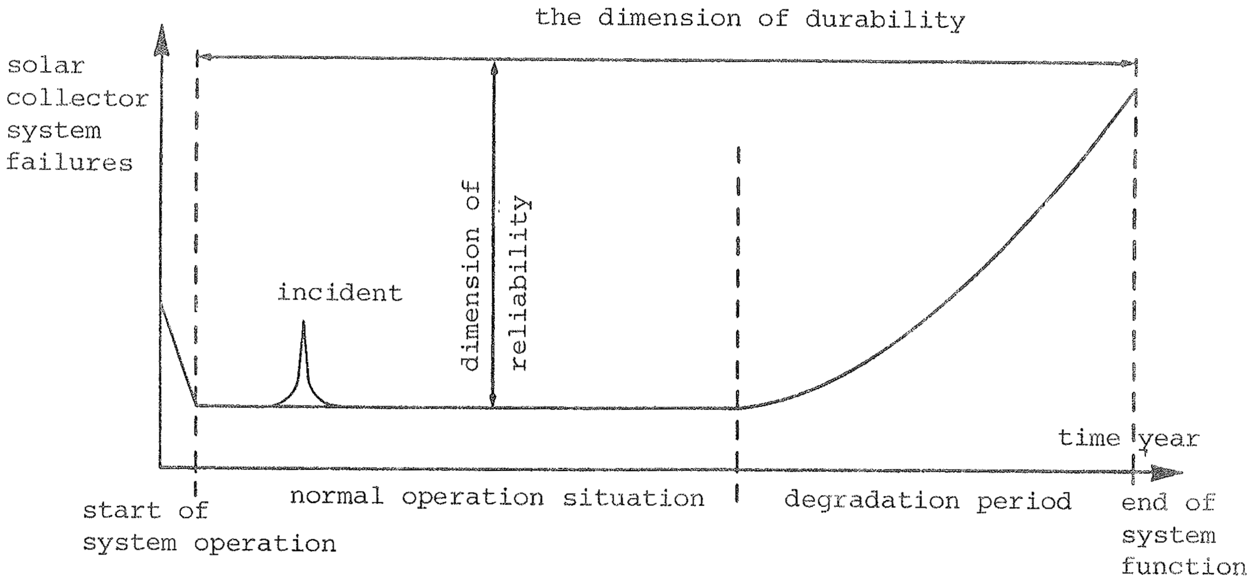
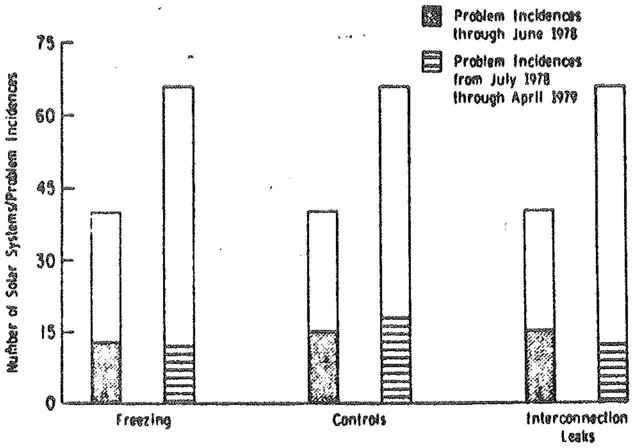
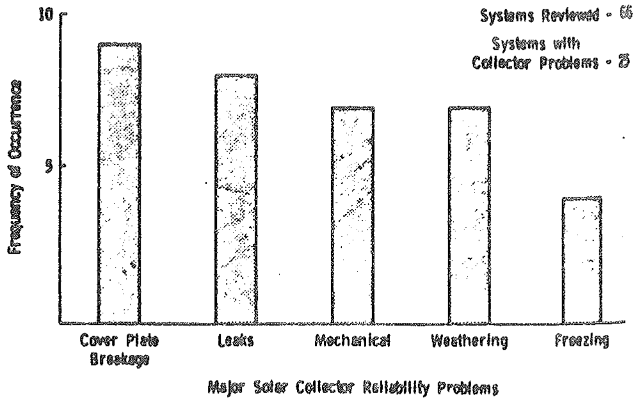


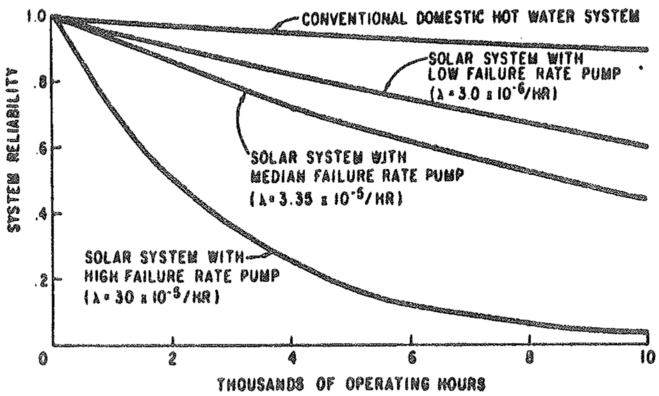
Fig. 1.1.1. The figure is an attempt to show how the function of a solar collector system can be characterized by the concepts of reliability and durability. The Durability is related to the expected period of satisfactory function. The Reliability is related to the probability of proper operation within the timescale of durability.



Recorded Problems at Solar-Energy Sites



Major Solar Collector Problems



Effects of Pump Failure Rate

Failure Rates of Components for DHW System Per 10^5 Hours

Component	Failure Rate
Collector	1.141
Collector Piping	1.058
Controller	1.40
Collector Pump	30.0 (high)
	3.349 (median)
	0.30 (low)
Piping System	0.30
Check Valve	0.301
Water Heater/Storage Tank	0.571

Fig. 1.1.2 Theory on how to handle reliability of solar collectors as presented in [1].

It is seen that solar DHW systems with a low pump failure rate are not as reliable as conventional DHW systems, at least when calculated in 1981.

In fig. 1.1.3 is given an example of calculated lifetime costs in Dcrs per kWh of produced solar energy as a function of lifetime, investment, production and operational costs. It is illustrated that if a certain increase of the lifetime can be reached, a rather large amount of money can be spent on maintenance and repair. 1 US $ = 7 Dcrs in 1989 [14].

If problems occur with regard to the quality or reliability of a solar collector, it can result in either some kind of catastrophic failure or an increased environmental stress being produced, for example in the case of rain penetration. In both cases the problem can affect the durability of the solar collector. While durability tests deal with estimation of lifetime of materials, reliability tests, which often also are called qualification tests, deal with the probability of failure.

A qualification test is by definition a short-term test and it is supposed to give information on the quality of a product, for example of a solar collector.

The development of qualification tests for solar collectors was initiated in the USA in 1978 by the ASTM Committee No. E-44 dealing with solar energy, [36, 45].

Since then work on qualification testing of solar collectors has been performed in most of the IEA participating countries. Furthermore, both individual countries and organizations, like The International Standards Organization, ISO, and The European Union of Agreement, UEATC, are developing standards for qualification testing of solar collectors, [48].

The Solar Collector and System Testing Group connected to the Commission of the European Communities, CEC, has been very active in developing recommendations for qualification testing during the last few years. This is reported in [2] and [3] and includes detailed information and results from

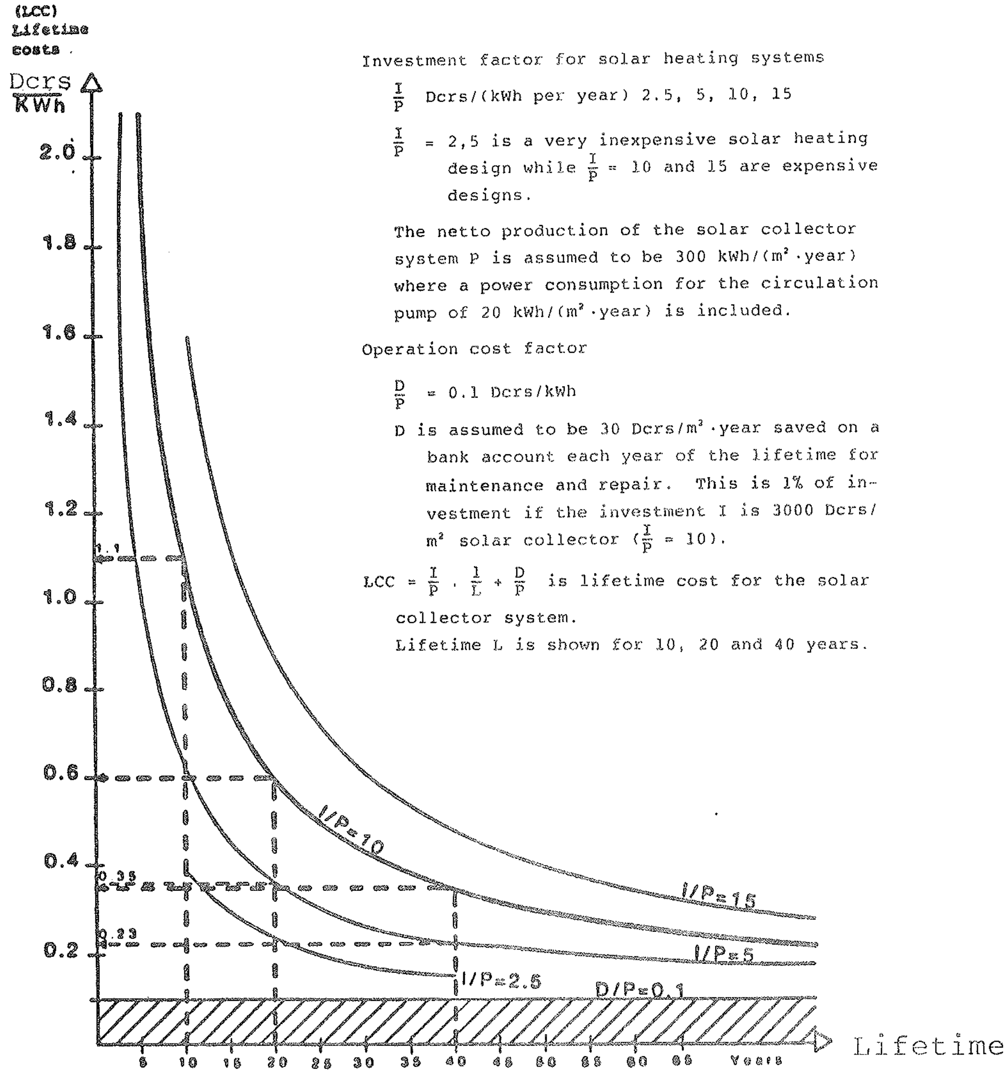


Fig. 1.1.3 Lifetime costs per produced kWh for 4 solar heating systems as a function of the lifetime (Denmark).

There is a considerable decrease of the lifetime costs when the lifetime is increased from 20 to 40 years.

Some of the savings could be used on maintenance and repair.

It was chosen to calculate lifetime costs of a solar heating system from the saving in kWh during the system lifetime instead of using Dcrs. This is due to the fact that the most important economic factor is the very uncertain fuel cost during the lifetime.

For I/P = 10, 16% of the lifetime cost is used on operation incl. maintenance and repair, when a lifetime of 20 years is considered. If this is increased to 40 years, the operation cost factor could be increased to include repair and changes of some components [4].

qualification testing of solar collector modules. It is not the aim for the IEA Task III to compete with this work and to be involved in a detailed validation of used procedures. It has been decided to use gained experience in another way and present an overview of existing qualification test procedures, including experience and examples of general interest, and also to present recommendations for outdoor exposure tests and innovative tests. A discussion on operational experience with solar heating systems will be used as a basis for the understanding of the necessary demands for solar collector qualification testing.

Qualification test procedures should always include a general investigation of <u>expected operation conditions</u> (environmental and system) in order to identify the solar collector quality and the ability to cope with normal operation conditions. In table 1.1 a list of aspects to be investigated in connection with the qualification tests performed in Denmark is shown as an illustration.

Table 1.1.1 Important aspects to be considered in connection with solar collector qualification tests (Denmark).

1. Thermal expansion of materials used
2. Thermal limits of materials used
3. Outgassing from solar collector construction materials
4. Absorber: Construction, materials, surface treatment
5. Operation pressure recommended
6. Ageing and corrosion aspects of materials used
7. Raintightness of construction, cover enclosure assembling, corners, connections
8. Absorber connections
9. Ventilation of collector box
10. Draining possibilities for collector box
11. Mounting and flashing system
12. Mechanical strength
13. Corrosion conditions of absorber and enclosure, galvanic corrosion
14. Possibilities for maintenance and repair
15. Recommendations for installation.

1.2 Operation Experience with Solar Heating Systems

Solar heating systems should be reliable for at least 15-20 years in order to make them economically attractive. The effort to reach more reliable solar heating systems has been concentrated mostly on solar collector modules as they represent a new technology and a major part of the total solar heating investment. At the same time, the solar collectors are the subsystem which is exposed to the most severe environmental influences of the whole solar heating system.

In the work done within the IEA Task III, we have not limited ourselves to looking at the solar collector alone, but have included connections, piping systems, controls, heat exchanger and storage tank. The reason for this is that evaluation of the primary circuit of solar heating systems is vital when reliability of solar collectors is considered. Most of the work on solar collector qualification tests in the IEA countries has, however, until now been concentrated on solar collector modules. Very often the qualification tests are carried out in connection with the normal thermal efficiency tests for solar collectors.

From experience gained within the last 6-7 years it has been made clear that it is not only the solar collector modules, but the complete solar collector primary circuit which very often causes problems with respect to reliability as well as durability. Especially, the development of more efficient collectors, first with selective surfaces and later with the use of convection suppression devices, makes it important to ensure a reliable function under all circumstances. It is very important to possess developed, self-functioning devices which will be secure against problems with airlocks, bad distribution and boiling. [6, 7, 8, 11, 24, 33].

An important activity within the IEA Task III work has been focussed on compilation and analysis of operational experiences with solar heating systems. This work was carried out for the complete solar heating system, including piping system, etc., and is reported in [4] and [5]

Several examples of failure modes of solar collectors reported by the participating IEA countries are given here. The examples include: covers breaking or collapsing at stagnation, insulation material which bulges, expands, turns brown or cracks at stagnation, collectors with a very high rate of air leakage, others which are not raintight. Also high temperatures lead to outgassing for nearly all collectors.

It has been experienced that solar collectors with ordinary black absorbers seldom reach more than 130°C in stagnation temperature, while solar collectors with a glass cover and selective absorber can reach stagnation temperatures of 180°C, and solar collectors with a teflon sheet as extra inner cover can reach 240°C.

In [4] is a presentation of results up to 1983 from 52 IEA inspections of solar heating systems in 11 different IEA countries, based on a reporting format developed in cooperation with the European Solar Collector and Systems Testing Group.

All together, 6975 m^2 of solar collectors were represented in this investigation. Participating countries were Sweden, United Kingdom, Denmark, Belgium, Austria, Australia, The Netherlands, Germany, Switzerland, USA and Japan.

Two of the installations were from Australia. Because of their age, 16 and 20 years, they were very interesting, as 20 years is considered to be the wanted and expected lifetime of a solar heating system. These two Australian solar heating systems were of a relatively good quality and had been operating without serious problems. There was still observed condensation in the collectors and a slight galvanic corrosion at the connections. It is obvious that it has especially been the outer parts, i.e. the enclosure, the attachment, the connections and the piping systems which have suffered from the 20 years of operation. These problems can to a large extent be referred to as quality problems in connection with mounting and installation (fig. 1.2.1).

The lifetime of the 52 inspected solar heating systems was estimated in the inspection reports. For most of the inspected systems a lifetime of 15-20 years was expected, and several examples of good design features were reported.

The installations which were between 2 and 5 years old had a lower expected lifetime. The reason could be a lower quality of the systems installed during the years 1975-1978, when the solar market expanded very quickly. It was also interesting to see that the installations which were less than two years old, seemed to be of a much better quality.

As part of the evaluation of problems and failures, the inspected solar heating systems were divided into three different groups. Group no. 3 was used for solar collectors which had serious failures or problems with reliability and durability, which could be referred to the construction or materials used and which would lead to an unacceptable low lifetime.

Group no. 2 was used for solar collectors with failures or problems which could easily be mended without completely changing the construction. And group no. 1 was used for solar collectors without failures or problems. 16 solar collectors were placed in group 1 with an expected lifetime of at least 20 years. 17 solar collectors were placed in group 2, and 12 solar collectors were placed in group 3. A few collectors were impossible to place in any of the groups.

System / Problem & failure number	AL 2 16 years old 1966	Comments	AL 3 20 years old 1962	Comments
Cover				
1.1 condensation	x	condensation common.	x	slight
1.3 dirt on cover			x	slight
1.5 breaking of cover			x	breakage of inner cover
1.7 cover missing			x	
Absorber				
2.1 dirt on absorber	x	on the upper half	x	absorber pale
2.2 corrosion on absorber	x	blue growth on lower header		
Assemply				
3.2 assembly leaking			x	water marks
3.3 degradation of sealant			x	sealant hard & brittle
3.4 steel screws corroded	x			
Insulation				
4.1 degradation of al-foil	x	galvanic corrosion near absorber plate		
Enclosure				
5.2 corrosion of enclosure	x	lower edges of casing rusting (some rusting through)	x	steel collector retainer clips rusting
Mounting				
6.3 failure of mounting	x	angle iron collectors rain - holes drilled		
Connecting & piping				
7.1 leaking piping	x	brazed joints leaks replaced with plast connections		one connection leaking
7.2 poor insulation	x	connections not insulated		
7.3 thermal expansion of pipes	x			

Fig. 1.2.1 Failures and problems reported for two old Australian solar systems.

In figs. 1.2.2 to 1.2.4 and in table 1.2.1 are shown some results from these investigations.

The work on operational experience with solar collector systems has also covered compilation of good design features of the systems. Figs. 1.2.5 and 1.2.6 show some main results concerning the condensation problem in solar collectors and the way in which to avoid them.

In USA interesting results on operational experience of solar heating systems in connection with the demonstration programme of 1st generation solar systems have been compiled in [6] from 1983. A special problem in connection with solar attic collector systems, for example roof integrated solar collector systems, was reported here. It was concluded that high temperatures could affect wood constructions in the roof. Strength and ignition temperatures could be reduced after a long exposure to high temperatures. It is recommended to keep temperatures in the attic below 70°C for strength reasons and below 100°C for fire hazard reasons.

The above investigation covered 1255 systems. 599 of the systems (48%) had one or more operational problems; 422 out of these had heat transfer fluid problems, 64% of them had serious problems regarding corrosions, and all open systems showed signs of corrosion. In closed systems it is considered important to check the glycols and pH values regularly. Especially after boiling, it is possible that a glycol acidic solution (low pH) is being developed, which might lead to heavy corrosion within a few months. This is reported in [7], [8] and [9].

EVALUATION OF SOLAR COLLECTOR INSPECTION REPORTS MADE WITH THE IEA-SOLAR COLLECTOR INSPECTION FORMAT AND ANALYZIED AS PART OF THE IEA-TASK III WORK. "FAILURE MODES AND GOOD DESIGN FEATURES OF SOLAR SYSTEMS IN OPERATION".

THE INVESTIGATION COVERED 52 DIFFERENT SOLAR COLLECTOR INSTALLATIONS IN 11 IEA-TASK III PARTICIPATING COUNTRIES.

- IN ALL 6975 M^2 SOLAR COLLECTORS ARE REPRESENTED IN THE ANALYSIS.
- 19 SOLAR COLLECTOR INSTALLATIONS HAD MORE THAN 50 M^2 COLLECTOR AREA. IN ALL 5930 M^2 SOLAR COLLECTOR AREA.
- 16 SOLAR COLLECTOR INSTALLATIONS HAD BETWEEN 10 AND 50 M^2 COLLECTOR AREA.
- 17 SOLAR COLLECTOR INSTALLATIONS HAD LESS THAN 10 M^2 COLLECTOR AREA.

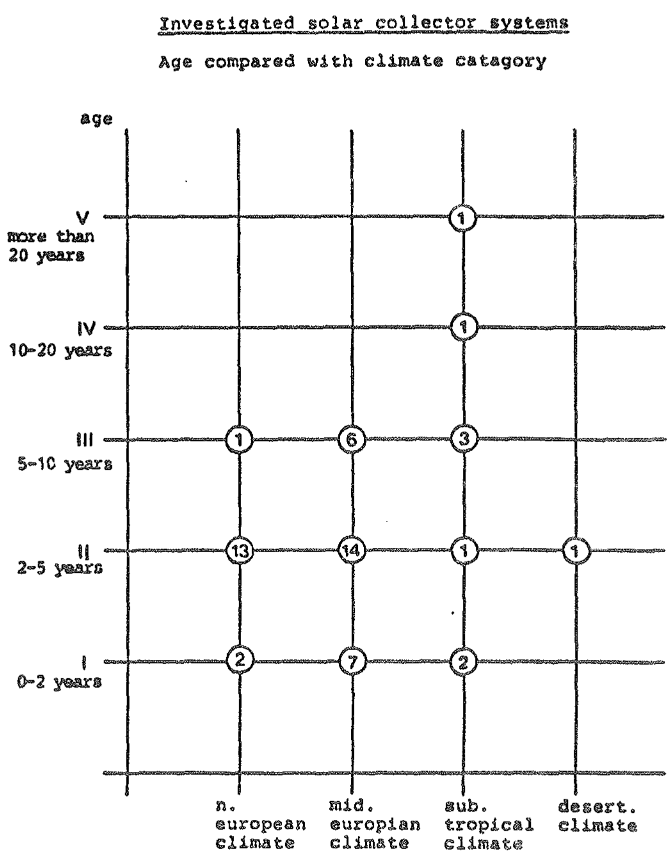


Fig. 1.2.2 IEA Task III investigation of 52 solar heating systems in 11 countries. Age is shown compared with climate.

SOLAR COLLECTOR TYPES	
SITE-BUILT ROOFINTEGRATED	4
ROOFINTEGRATED MODULES	13
MODULES ON ROOF	27
MODULES ON THE WALL	3
MODULES ON THE GROUND	2

INSULATION, THE BACK OF COLLECTOR	
MINERALWOOL	25
POLYURETHANE (PUR) FOAM	18
PUR FOAM + MINERALWOOL	3
PIR FOAM	1
AIR	1
CARDBOARD HONEYCOMB	1

PIPING SYSTEM MATERIALS	
COPPER	25
STEEL	11
STAINLESS STEEL	3
POLYETHYLENE PIPES	2
FLEXIBLE TUBES	4
POLYBUTYLENE	1

ABSORBER MATERIALS	
COPPER	17
STEEL	9
ALUMINUM AND COPPER	7
ALUMINUM	6
ALUMINUM AND STEEL	4
STAINLESS STEEL	3
ALUMINUM AND STAINLESS STEEL	2
POLYPROPYLENE	1
POLYSTYRENE	1

COVERS	
GLASS 3-6 MM	24
GLASS 2 LAYERS	8
GLASSFIBER REINFORCED POLYESTER	5
GLASS STRENGTHENED	4
ACRYLIC	2
ACRYLIC + FILM	2
TEDLAR COATED FILON	2
POLYCARBONATE, UV STABILIZED	1
PERSPEX	1

ABSORBER SURFACES	
SELECTIVE	32
BLACK	20

SOLAR SYSTEM TYPES	
DOMESTIC HOT WATER HEATING, (DHW)	36
DHW + SPACE HEATING (SH)	6
SWIMMINGPOOL HEATING	5
DHW + SH + COOLING (C)	2
SPACE HEATING ALONE	2
DHW + SWIMMINGPOOL	1

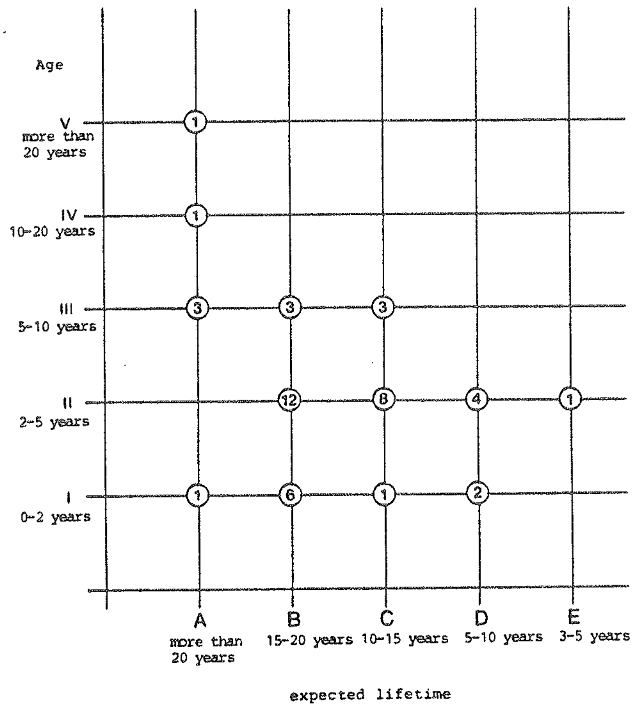
LIST OF
CONTRIBUTORS OF SOLAR COLLECTOR INSPECTION REPORTS:

SWEDEN	10
UNITED KINGDOM	7
DENMARK	6
BELGIUM	5
AUSTRIA	5
AUSTRALIA	5
NETHERLANDS	4
GERMANY	3
SWITZERLAND	3
USA	3
JAPAN	1
	52

Fig. 1.2.3 Data on participating countries, system types and utilized materials in IEA Task III investigation of 52 solar heating systems.

Investigated solar collector systems

Age compared with expected lifetime



Investigated solar collector systems

Durability catagory compared with expected lifetime.

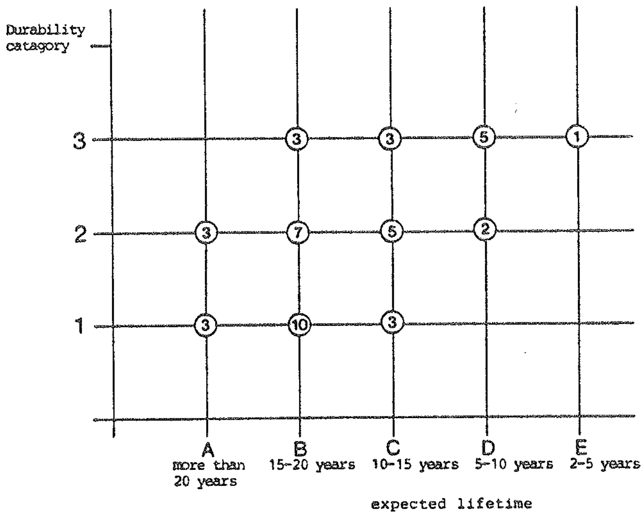


Fig. 1.2.4 IEA Task III investigation of 52 solar heating systems. Age and durability category (as defined in text) compared with expected lifetime. Number of systems in each combination is indicated inside the circles.

EXAMPLES OF REPORTED FAILURES

leakage of absorber
water leakage into collector
breakage of glass cover
airlocks, boiling, system problems
degradation of sealants
thin and bad pipe insulation
condensation in collector
dust/dirt in collector
degradation of piping system
corrosion in aluminum absorber
outgassing products on cover
control failures

EXAMPLES OF GOOD DESIGN FEATURES

aluminum foil over insulation
stagnation protection during installation
ventilation and drain holes with filter to avoid dirt
easy installation/good design
20 years lifetime reported
easy exchange of collector module
stainless steel or copper tubes in absorber
collector with plastic absorber designed for low stagnation temperature
easy exchange of cover
raintight design
plastic between aluminum and copper
airspace between polyurethane insulation and absorber
ventilation through back side of collector
ventilation holes at the top protected against rain

Table 1.2.1 Examples of reported failures and good design features in IEA Task III investigation of 52 solar heating systems in 11 countries.

Type 1 is the most common. Ventilation holes are only drilled into the bottom of the collector. Since there are no holes near the top, the chimney effect might press hot humid air out where it might condense again before leaving the collector.

Type 2 has the same ventilation holes as type 1, but ventilation holes are also placed near the top and should be protected against rain.

Type 3 has the ventilation holes placed through the backside of the collector, both at the top and the bottom. A solar collector with this type of ventilation had very seldom condensation, and the relative humidity was most of the time lower than that of the ambient.

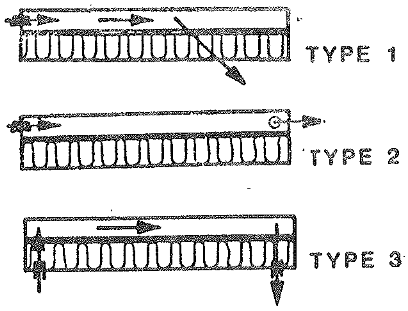


Fig. 1.

Three types of solar collector ventilation.

Fig. 1.2.5 Example of solar collector design evaluation with respect to ability to avoid condensation over along period. (Denmark). [4].

3 types of ventilations are shown.

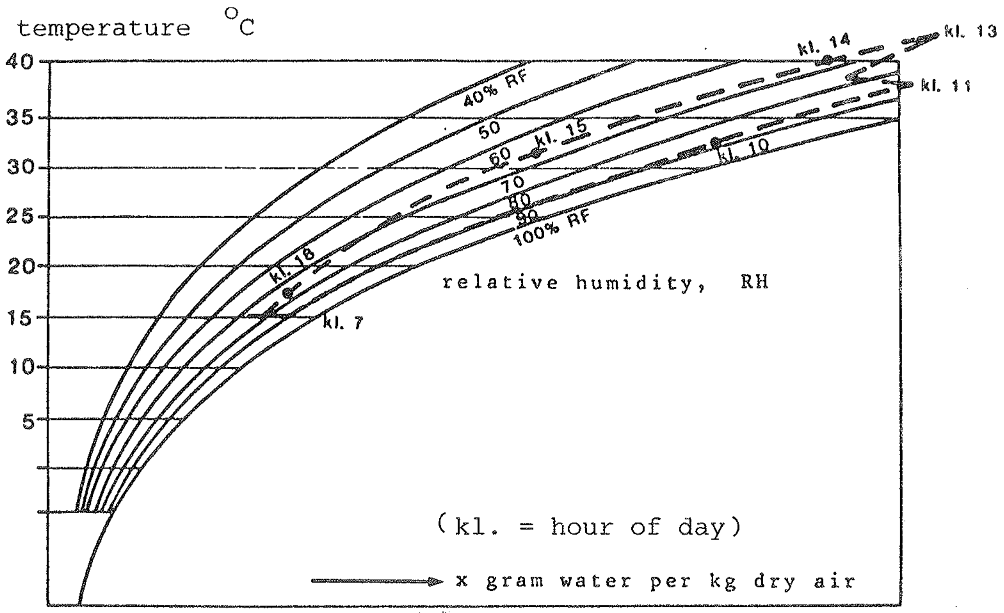


Fig. 1.2.6 The figure shows the changes of temperature and humidity in a solar collector during the day. The ventilation air in a solar collector can dissolve condensate on the inside of the glass cover when the absorber temperature rises because of increased solar insolation. This means strong requirements to the ventilation of the solar collector so hot humid air on its way out of the collector will not condense and leave water in the collector enclosure. Ventilation holes near the top of the collector protected against rain could be a means for this.

An investigation in Belgium regarding the reliability of solar heating systems, led to answers from 235 consumers, giving the following results:

- 55% had none or not important failures
- 24% reported condensation in the solar collector
- 19% had leaks from solar collector systems
- 18% reported air problems in the system
- 16% showed leaks in system parts in the house
- 11% reported failures of the cover
- 10% reported rain penetration.

Results from tests of 14 German solar heating systems performed in 1983 at the TÜV Institute in Munich are shown in table 1.2.2.

In table 1.2.3 you will find the results of the tests of another 18 solar heating systems for DHW, made in 1986. The quality of the best systems as well as on an average has been improved. [10].

In [11] inspection and evaluation of 100 solar systems of different types, installed 1976-1982 in Switzerland, are reported. The reliability of the solar systems increased significantly within this period (failure frequency reduced from 80% for the oldest systems to 20% for the newest). Defects in collector cover and control, leakage of collector loop, absorbers and connections and condensation were the most common failures. Only 15% of the systems were visited regularly for partial maintenance.

SYSTEM NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Price without installation DM	10900	10800	9500	10400	10300	9500	9200	6900	11300	8200	9900	10900	5200	9700
Solar collector area m^2	6.0	5.5	6.6	6.0	5.9	5.9	6.0	4.3	8.4	6.0	6.0	6.3	7.2	4.8
DHW-storage litre	300	400	517	300	380	300	360	300	500	400	350	350	350	300
Elec. heated part %	59	76	80	58	80	80	65	63	76	46	56	81	57	67
η_o of collector %	72	74	81	73	79	81	78	78	80	75	80	66	72	74
U_L of collector W/m^2 °C	3.0	3.4	4.1	3.4	5.3	4.8	3.8	4.5	3.5	3.8	5.4	5.0	5.1	3.4
Durability of collector	US	VG	US	S	G	S	S	G	S	S	S	G	VUS	S
Performance coefficient = Energy for DHW / Electric back-up energy — yearly	1.6	1.5	1.4	1.5	1.3	1.1	1.5	1.3	1.9	1.2	1.2	1.1	1.0	1.4
summer	2.7	2.4	2.3	2.2	1.9	1.5	2.6	1.7	5.3	1.6	1.8	1.4	1.3	2.0
winter	1.1	1.1	1.0	1.1	1.0	0.9	1.1	1.0	1.2	0.9	1.0	0.9	0.8	1.1
Solar production/yearly DHW use %	51	50	50	45	45	39	52	41	62	40	44	33	37	44
Efficiency of collector field yearly %	26	32	30	29	26	21	32	35	30	31	28	19	17	25
Solar collector evaluation	US	G	US	S	S	S	S	G	G	S	S	US	US	S
DHW-storage evaluation	G	US	G	G	US	VUS	US	S	S	S	S	S	US	US
Technical evaluation of system	S	S	S	S	US	US	US	S	S	S	S	US	US	US
Efficiency evaluation of system	S	S	S	S	US	US	S	US	G	US	US	VUS	VUS	S
Evaluation of safety	G	S	G	G	G	S	US	US	US	US	US	US	VUS	VUS
Evaluation of installation	S	G	S	S	G	G	G	G	S	G	S	G	G	VG
Total installation	S	S	S	S	US	US	US	US	US	US	US	VUS	VUS	VUS

Very good: VG, Good: G, Satisfactory: S, Unsatisfactory: US, Very unsatisfactory: VUS

Table 1.2.2 Main results from the test of 14 different German solar heating systems for domestic hot water performed in 1983. New results from 1986 are shown in table 1.2.3.

SYSTEM NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Cost without installation DM	6084	2964 1)	11183	9300	2)	9717	9533	8908	8900	9300	9063	11500	7250 6470 4)	9964	2045	2600	4500	3426 1)
Solar collector area m^2	8.2	1.96	4.8	6.6	6.0	7.5	9.0	6.0	5.5	7.3	7.0	9.2	6.6 4.9 4)	6.4	1.7	1.8	4.0	3.3
DHW-storage litre	400	240	300	500	400	500	525	360	300	400	400	1000	300	500	100	240	270	160
Electric heated part %	0.38	0.83	0.48	0.45	0.55	0.38	0.44	0.47	0.6 0.55 3)	0.33	0.54	0.51	0.53 0.60 4)	0.41	0.92	0.85	0.88	0.79
η_o % / U_L W/m^2 °C } of collector	0.82 3.2	0.63 1.9	0.64 2.3	0.78 4.6	0.76 3.4	0.71 3.8	0.67 4.2	0.72 3.4	0.77 5.5	0.77 3.8	0.78 5.9	0.68 5.2	0.76 3.4	0.83 3.7		0.80 4.0	0.78 4.7	
Solar production/yearly DHW use %	0.74	0.43	0.68	0.71	0.58	0.79	0.68	0.66	0.71 0.80 3)	0.77	0.67	0.65	0.60 0.51 4)	0.71	0.30	0.47	0.28	0.53
Efficiency of collector field/yearly %	0.24	0.49	0.37	0.28	0.30	0.24	0.22	0.32	0.2	0.29	0.23	0.19	0.28	0.30	0.27	0.32	0.26	0.28

1) without the DHW-storage, 2) in FRG not available, 3) with pump, 4) with 3 collectors

Table 1.2.3 Main results from tests of 18 different German solar heating systems for domestic hot water (1986). New and better systems compared to table 1.2.2. [10].

1.3 Additional Demands for Qualification Testing

In most cases the developed qualification tests have been linked only to solar collector modules of what could be called a normal size, typically 1x2 m. Solar collectors of this size have been considered the most suitable for mass production and easy installation on to roofs. At the same time, they are quite easy to test, especially with indoor equipment.

During the last few years new solar collector designs of different types have been developed. Building integrated concepts are becoming more and more common, especially in connection with new-built housing. An example is the site-built solar collector roof; a successful design of this is shown in fig. 1.3.1.

In Sweden, high temperature Mega solar collector modules of 2x6 m for district heating systems with between 1300 and 5000 m^2 of solar collector area have been used in several demonstration projects. In the future there will be a need for useful test procedures, also for these new solar collector designs, also shown in fig. 1.3.1.

Apart from the testing of solar collectors there is also a growing demand for qualification tests of solar collector system loops or primary circuits. When evaluating the reliability of complete solar heating systems, it is very important to consider problems with regard to temperature stability of utilized components, air locks, flow distribution, boiling and freezing.

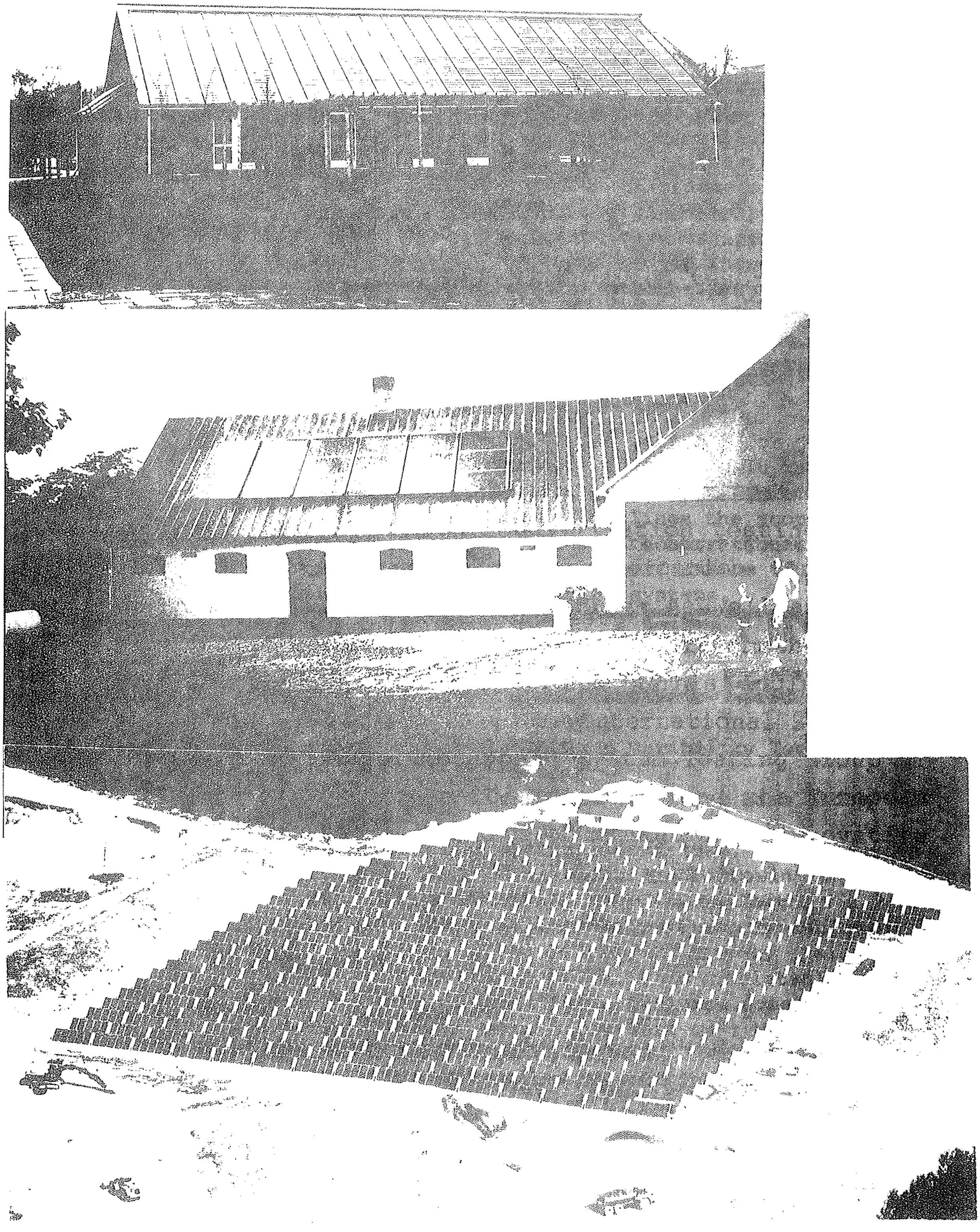


Fig. 1.3.1 Illustration of three different types of solar collectors: Roof integrated solar collector, small solar collector modules mounted and connected on to a roof construction and large MEGA solar collectors for district heating systems.

2. OVERVIEW OF QUALIFICATION TEST PROCEDURES USED FOR LIQUID SOLAR COLLECTORS

2.1 Qualification Testing Procedures used in various Countries

Table 2.1.1 shows an overview of qualification test procedures used in 13 countries and at the ISPRA Joint Research Center, and draft test procedures recommended by the CEC, European Solar Collector and System Testing Group, the UEATC and ISO. References in reference list: [2, 3, 9, 13, 14, 18, 19, 21, 26, 28, 30, 31, 36, 40, 41, 45, 48, 50, 56, 58, 61, 62, 63, 64, 65, 66, 67, 68].

TEST PROCEDURES USED	AUSTRALIA AS 2712-1984	AUSTRIA Önorm M7711-12	CANADA CSA, F378-M-1982	DENMARK	FRANCE NF 50-511	GERMANY DIN 4757 3-4	ITALY UNI-8796-1985	NETHERLANDS	SWEDEN SP-C12-302 A03 528/530/531	SWITZERLAND SN 165003/1	U.K. BS 5918:1983/84	U.S.A. NBSIR1305-A, ASTM E823-81	SPAIN INTA	ISPRA	CEC DRAFT SCSTG RECOMMENDATIONS	UEATC DIRECTIVE FOR THE AGREEMENT OF LIQUID CIRC. SOLAR COLLECTORS 1986	ISO TC 180 ISC 3
1 ABSORBER PRESSURE TEST			X	X	X	X	X	X	X		X	X	X	X	X	X	X
2 ABSORBER LEAK TEST											X				X		
3 HIGH TEMP. STAGNATION TEST	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
4 EXTERNAL THERMAL SHOCK TEST				X			X	X	X		X	X	X	X	X	X	
5 INTERNAL THERMAL SHOCK TEST			X	X	X		X	X	X	X	X	X	X	X	X		
6 RAIN PENETRATION TEST	X		X	X	X		X	X	X	X	X	X	X	X	X	X	X
7 COMBINED RAIN AND WIND LOAD TEST				X											X		
8 WATER RETENTION TEST	X										X				X		
9 AIR LEAKAGE TEST				X				X							X		
10 FROST TEST			X					X	X						X	X	
11 FREEZE PROTECTION TEST	X		X		X							X				X	
12 WIND/SNOW LOAD TEST	X			X	X				X			X	X	X	X	X	
13 HAIL TEST	X				X		X					X	X	X	X	X	
14 HEAT TRANSFER FLUID TEST/CORROSION										X							
15 RESISTANCE OF MOUNTING					X							X				X	
16 HYDRAULIC FITTING RESISTANCE					X												
17 MECHANICAL TEST OF COLLECTOR STRUCTURE AND SUPPORTING FRAME					X										X		
18 THERMAL CYCLING TEST				X				X									
19 UV RADIATION TEST														X			
20 SALT MIST EXPOSURE TEST							X										
21 OUTDOOR EXPOSURE TEST	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X
22 MATERIALS TEST	X			X	X							X					X

Table 2.1.1 Qualification test procedures used in 13 countries and at the Joint Reserach Center in Ispra, together with draft test procedures recommended by UEATC, ISO and the CEC Solar Collector and System Testing Group.

In table 2.1.2, 17 tests from table 2.1.1 are divided into destructive tests where a result can be some kind of a catastrophic failure, and qualitative tests where tests of a more environmental character are performed. In the latter case, catastrophic failures will not be identified, but the failures observed can lead to degradation over a longer period.

In table 2.1.2 is also presented the high temperature stagnation test together with the thermal efficiency test being the most common combination.

It is seen from table 2.1.1 that the most common test procedures are: The absorber pressure test, the high temperature stagnation test, the internal and external thermal shock tests, the rain penetration test and the outdoor exposure test. The experience and results from these tests are well documented.

1.	Efficiency test + high temperature stagnation test
2.	Qualification tests Destructive Tests: Absorber pressure test External thermal shock test Internal thermal shock test Frost test Freeze protection test Wind/snow load test Hail test Strength of mounting Hydraulic fitting resistance Mechanical test of collector structure and supporting frame Qualitative tests (environmental) Rain penetration test Combined rain and wind load test Water retention test Air leakage test Heat transfer fluid test (corrosion) Thermal cycling test Outdoor exposure test Material tests

Table 2.1.2 Classification of flat plate liquid solar collector tests.

2.2 Presentation and discussion of the most common and useful solar collector qualification tests

It has been discussed among the IEA Task III participants which of the solar collector qualification tests were the most commonly used and which sequence of tests to be recommended, based on the experience gained until now. The Solar Collector and System Testing Group of the CEC gives the following recommendations:

- High temperature tests and short term ageing should be near to the beginning of any sequence of tests.
- If an outdoor exposure test is made, external shock is included here, perhaps also internal shock.
- Freezing tests and mechanical tests are expensive; they should be placed at the end of a sequence.

The below mentioned tests and sequence of tests have been agreed upon as useful by the IEA Task III participants:

1. Absorber pressure test
2. Collector air leakage test
3. High temperture stagnation test
4. Internal thermal shock test of absorber followed by dry boiling and stagnation
5. External thermal shock test
6. Rain penetration test
8. Outdoor exposure test.

Each of the tests numbered 1 to 8 are presented in subsections 2.2.1 - 2.2.8 with a resumé of the normal procedures and a discussion on procedures, results and recommendations. More details can be found in references mentioned in the reference list.

2.2.1. ABSORBER PRESSURE TEST

normal procedure

The absorber of the solar collector is filled with water and connected to a safety valve, a pressure gauge and a valve. 1.5 times the maximum operation pressure allowed by the manufacturer is reached and the valve is closed. The safety valve is set to 1.3 times this pressure. After one hour changes in pressure are registered and possible swelling, distortion or rupture are identified by inspection. Accuracy is 5% for the pressure gauge.

In some cases, a leak test is performed with air under pressure of 0.5 bar in order to identify small leaks. The absorber pressure test is important, especially for plastic absorbers. A distinction should be made for collectors intended for open or closed systems.

results and recommendations

The absorber pressure test for fluid passageways normally specifies an excess pressure of 1.5 times the recommended maximum pressure. It is important to test plastic collectors at these pressures, and even metal absorbers can fail at the seams or buckle.

A distinction should be made between collectors intended for open or closed systems.

The pressure test is in the UK followed by an absorber air leakage test, because the leakage may be small. Following a pressure test with oil or water there is less danger of an explosion with pressurized air.

In Denmark, the transparent cover of the rain machine also functions as an extra safety when this test is performed.

2.2.2. COLLECTOR AIR LEAKAGE TEST

normal procedure

An air leakage test for the solar collector module can be performed by establishing various over-pressures and/or under-pressures in the collector module by use of a vacuum cleaner. The ventilation rate measured in m^3/h per 100 Pa pressure difference is identified to see if the ventilation rate is acceptable and thus avoid condensation problems which are common in wet and humid climates.

results and recommendations

In collector air-leakage tests a large over-pressure is applied to the collector and the volumetric flow rate of air is measured.

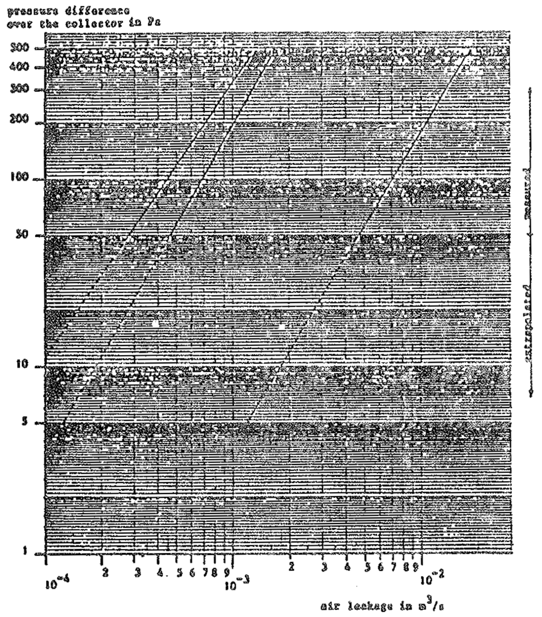
The leakage rate under over-pressure is not sufficient to characterize the leakage of the collector (and thus how susceptible it is to water vapour penetration) since other factors, such as the chimney effect, are important. In ref. [2] it is indicated that the combination of rain penetration and air leakage tests followed by observations of condensation provide the best measure for the tendency of a collector to cause moisture problems.

Experience with this test is mostly reported from Holland and Denmark. In fig. 2.2.1 is shown the test set-up at TNO in Holland, together with a diagram of reported results.

Air leakages between 1 m^3/h and 16 m^3/h at 50 Pa pressure difference are reported from Holland. These values are extrapolated to 5 Pa which is a more realistic pressure difference for solar collectors. In Denmark, the tested solar collectors are divided into five ventilation rate classes at 100 Pa:

Class 1	no ventilation		
Class 2	< 1	m^3/h	very low ventilation
Class 3	1-10	m^3/h	low ventilation
Class 4	10-20	m^3/h	normal ventilation
Class 5	> 20	m^3/h	high ventilation

Fig. 2.2.2 is an illustration of the Danish air leakage test procedure.



Air leakage of the collector as a function of the pressure difference over the collector.

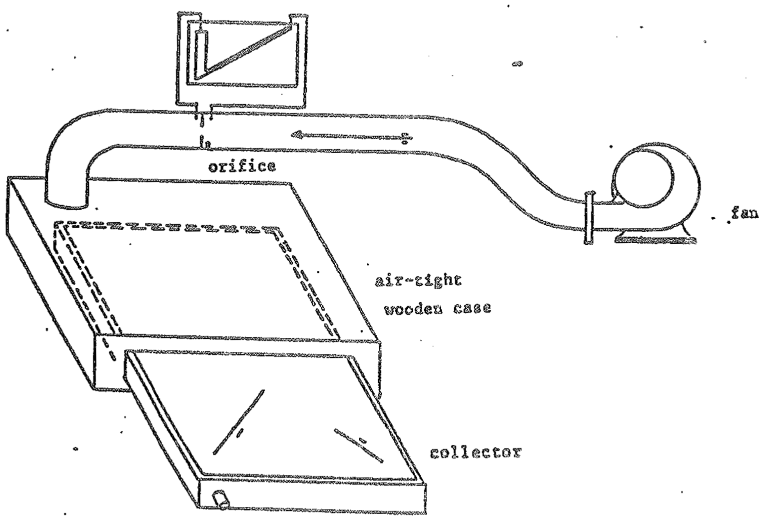
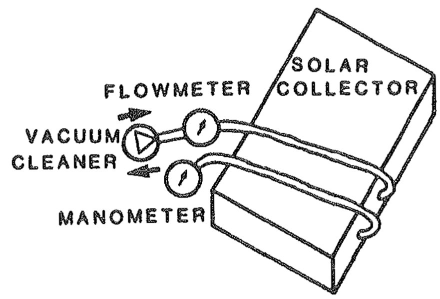


Fig. 2.2.1 Illustration of how a solar collector leakage test is performed in the Netherlands.



Equipment to establish ventilation rate in solar collectors. Two holes are drilled in the collector side between the absorber and the cover. One hole is connected to a vacuum cleaner used as a blower, and a flow meter. The second hole is connected to a precise manometer. Leakage rates in m^3/h are measured as a function of the pressure in Pa. The result is given in a diagram as shown above.

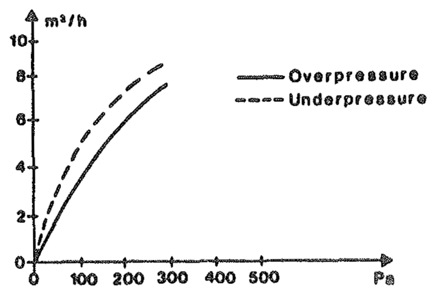


Fig. 2.2.2 Illustration of how a solar collector air leakage test is performed in Denmark.

Out of 22 tested solar collectors 11 were grouped as having a larger ventilation rate than 20 m^3/h at 100 Pa.
2 were grouped between 10-20 m^3/h
4 between 1-10 m^3/h and
8 were lower than 1 m^3/h.
1 collector was completely airtight.

2.2.3. HIGH TEMPERATURE STAGNATION TEST

normal procedure

It is normal to reach stagnation temperature at 850 W/m^2 for at least one hour as part of the normal thermal efficiency test for a solar collector. In some cases, the measured stagnation temperature at normal solar insolation is used to calculate the maximum stagnation temperature in order to identify problems with the materials used. As a qualification test, 6-8 hours of exposure is considered the least acceptable, for example to identify outgassing. The necessary irradiance level has been proposed between 850 and 1000 W/m^2, and the ambient temperature between 5°C and 30°C.

results and recommendations

The high-temperature stagnation test should last for at least 6-8 hours, during which time cracking of the glazing or outgassing from a breakdown of the gasket or sealant can be seen.

The stagnation test is considered to be a very important test by all the participants. Changes of the solar collector will be identified by inspection after the test.

The test could be combined with an irradiance cycling test, and should be followed by a rain-penetration test.

It is normal to specify the number of hours the collector should spend above a specified irradiance level (either indoors or outdoors). This level should be specified in relation to the ambient temperature gradients that stress the collector. (Generally, however, the glazing is sensitive to the ambient temperature, while the absorber is more influenced by the irradiance). This topic is discussed further in the new CSA standard from Canada.

There has been a lot of discussion within the CEC on which length of time was appropriate for stagnation tests, with 30 days often suggested. Also discussion on the stagnation temperature to be measured or not; and which reference conditions should be specified for indoor tests - 1000 W/m^2, with T_a at 30°C and air speed higher than 1 m/s, or 850 W/m^2 $T_a > 50°C$. The only agreement so far was that the stagnation test was one of the most important ones.

In Spain, experience has shown that a collector likely to fail in its first year would show this in a 30-day stagnation test. In Australia they use oil as heat transfer fluid, and simulate the expected maximum stagnation temperature, calculated as an extrapolated value at 1200 W/m^2 solar insolation.

Measurement of stagnation temperatures are often made with thermocouples placed on the back of the absorber plate. The thermocouples are protected with shrinking flex. The cover temperature at the middle of the cover and near the glass fillet, and the glass fillet temperature are also measured to identify risks of cover cracking.

2.2.4/5. THERMAL SHOCK TESTS AT STAGNATION

normal procedure

When the solar collector has been at stagnation for at least one hour with an irradiance of 850 W/m^2, cold water of less than 30°C is led through the absorber to perform an internal thermal shock test. After this a dry-boiling and a new stable stagnation will be performed for one hour. An external thermal shock will take place by spraying cold water on to the surface of the hot solar collector for 15 minutes. Because the cover of the collector gets cold, it is possible to identify rain leakage problems by a heavy condensation on the inside of the cover. Changes of the solar collector will be identified by an inspection after the test.

results and recommendations

The external thermal-shock test is also a rain-penetration test. Immediately after the collector has been sprayed with cold water, condensation appears on the glass, but this cannot be distinguished from water penetration at an earlier time.

Manufacturers claim that the immediate transition from stagnation to cold rain is very severe, and would not happen in practice. Moreover, failure is more likely due to a flaw in the particular piece of glass than a design failure. Nevertheless, the test is thought not to be very severe (and therefore not very revealing). Water at about 20°C in contact with glass at about 50°C does not normally cause problems.

The internal thermal-shock test can reveal buckling due to differential expansion.

2.2.6. RAIN PENETRATION TEST

normal procedure

The solar collector is mounted at an angle of 30° to horizontal. Water is sprayed on to the surface of the collector for one hour at least. This is with a total precipitation of 100 mm. Leaks can be identified by inspection or by weighing. If an underpressure of 100-500 Pa is introduced into the collector, it will be easier to identify leaks, but, of course, not at a realistic level.

results and recommendations

For the rain penetration test a 100 mm precipitation over a period of about an hour is appropriate. An overpressure or an underpressure of about 100 Pa can be applied to the collector interior - this can easily be done with a vacuum cleaner. Precipitation times between 1 and 4 hours are the most normal.

The rain penetration test is considered to be one of the most important qualification tests by all participants.

Within the CEC this is seen as the second most important qualification test. What is most significant is the amount of water retained by the collector rather than the amount that passes through.

All collectors (except those which are hermetically sealed) admit moisture. That is why drainage holes are recommended. The approach adopted in thermal performance testing in Canada is, therefore, to always test collectors when their inside is wet rather than when they are dry. Two tests would be too expensive. The test can be quantitative provided a mass difference of as little as 5-10 grams in 100 kg can be measured. Another approach is to measure how long it takes for condensation to form when the absorber is heated. The UEATC have 50 grams of water as a limit for water ingress after 4 hours of spraying.

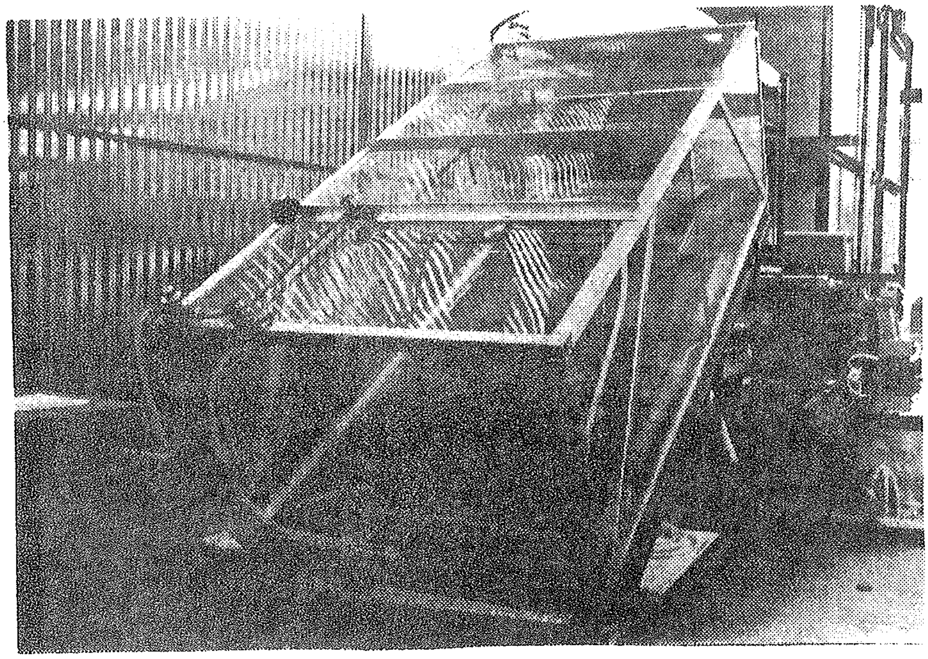
In Denmark, the result of only spraying water on to the collector is first investigated. Afterwards an underpressure is introduced between the cover and the absorber in order to make the test more severe. In collectors with only small leakages, which were difficult to identify during the first test, typically huge leakages are observed after the last mentioned test. Many leakages can be identified visually or by raising the collector after the test, to see if water runs out. In some cases, humidity measurement in the insulation material is useful. If necessary, the tested collector is finally disassembled in order to find the cause for a leakage. Figs. 2.2.3 and 2.2.4 illustrate the Danish rain test.

At the Thermal Insulation Laboratory in Denmark, an appreciable difference in rain penetration had been noted with underpressure than with overpressure, but this had not been observed at Ispra.

Rain testing of roof integrated solar collectors

At the Florida Solar Energy Center in USA, test recommendations for roof integrated solar collectors state that a sample collector, not smaller than 2 m^2 should be tested. The collector should be disassembled after the test. The Netherlands have a special test set-up for determination of raintightness of roof integrated solar collectors. This set-up is shown in fig. 2.2.5.

ISO also recommends a rain test on installed solar collectors followed by disassembling. This test ensures that the flashing system is also tested for rain penetration.



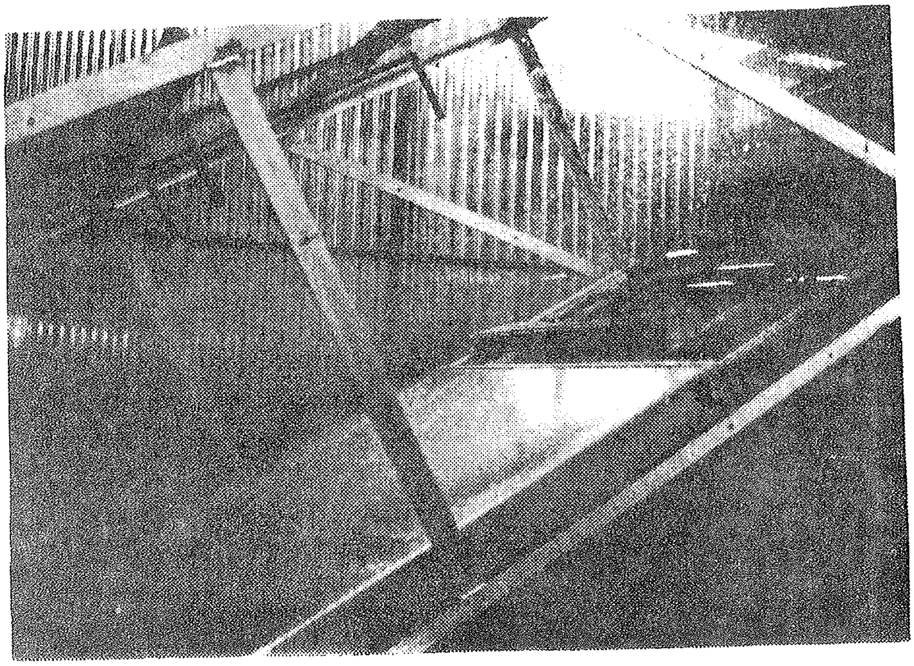
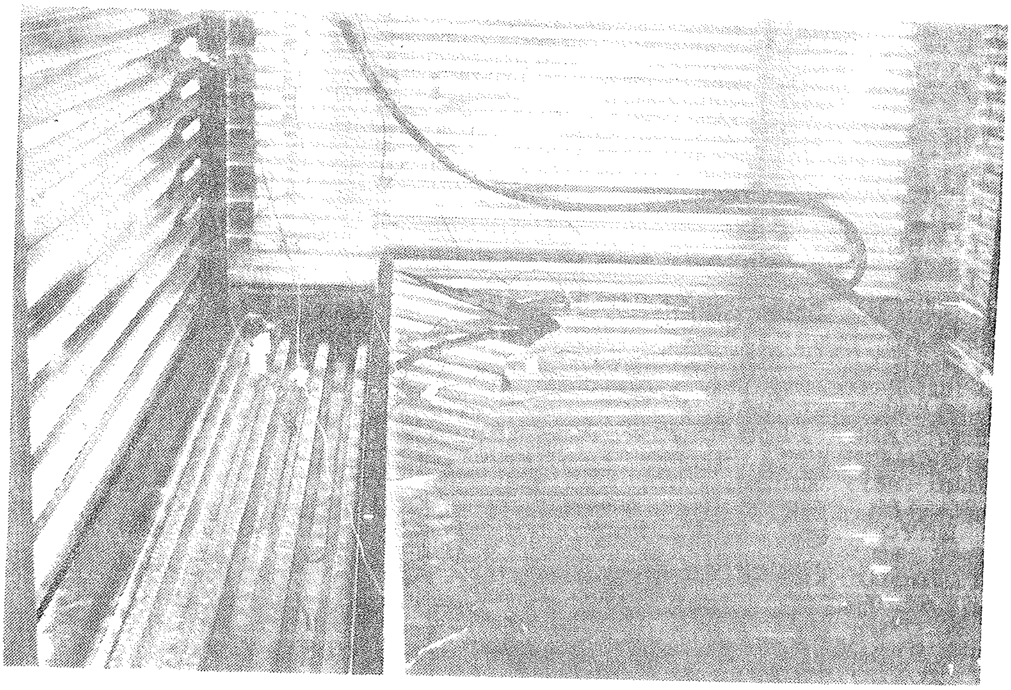


Fig. 2.2.3 Photo of rain test machine used at the Thermal Insulation Laboratory in Denmark.
Pressure test of absorber is also performed here.



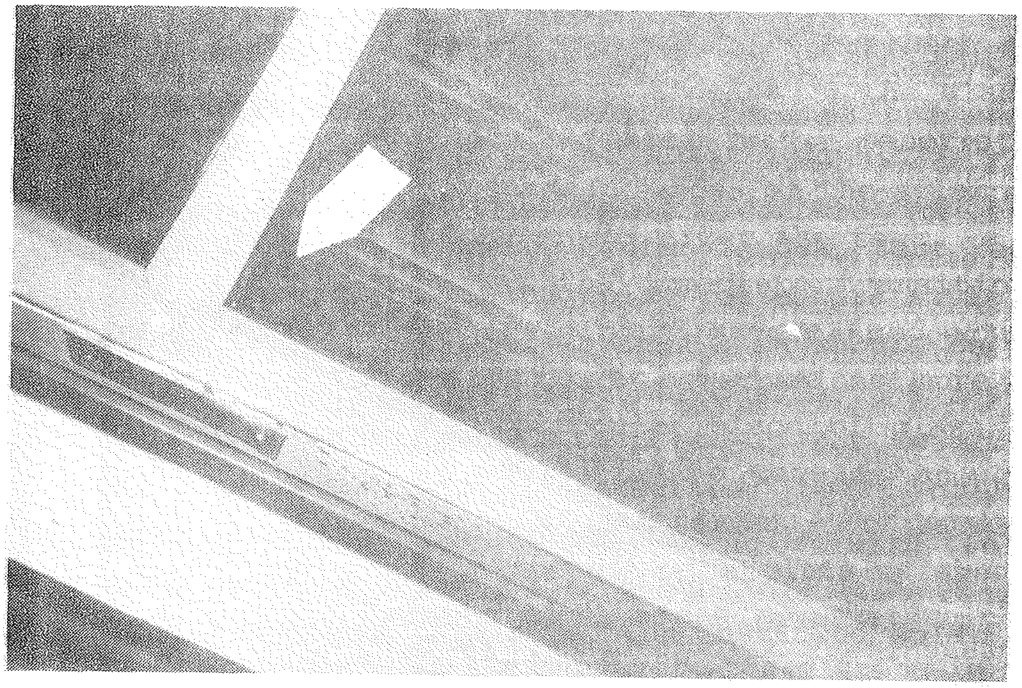
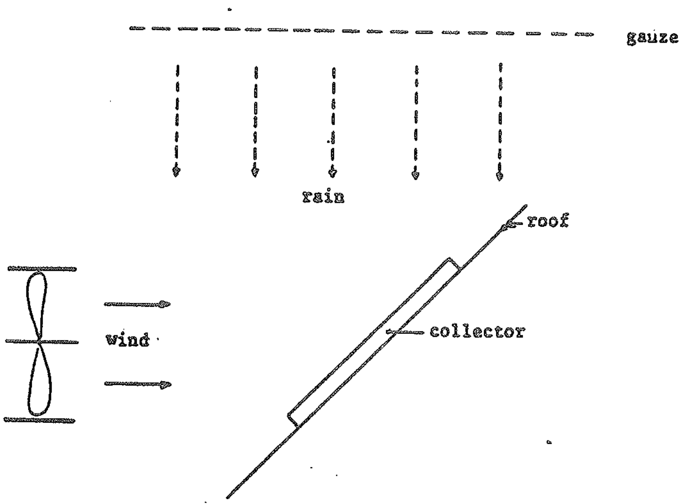


Fig. 2.2.4 Two examples of incidents seen in Danish qualification tests of solar collectors. Glass cover breakage and rain penetration.



Test set-up for the determination of the rain-tightness of a solar collector.

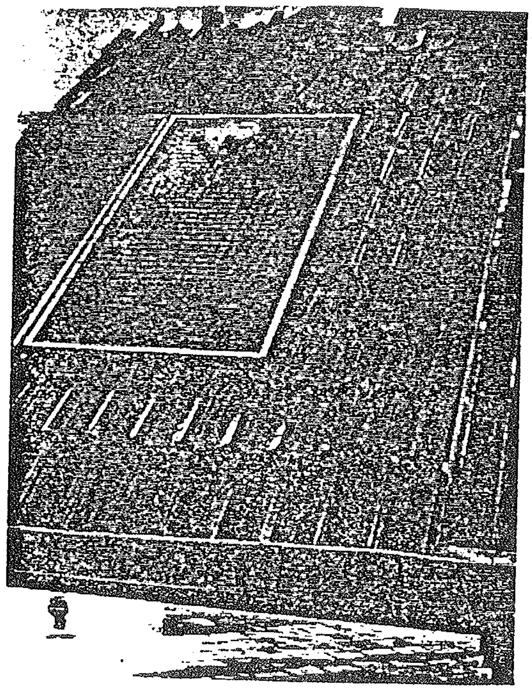


Fig. 2.2.5 In the Netherlands, the rain test is performed with the solar collector mounted in the roof as shown.

2.2.7. WIND AND SNOW LOAD TEST

normal procedure

Here different types of tests are being performed in various laboratories. In the US a load is applied to the cover. In Denmark, an under-pressure is applied to the collector interior. In France, suction pads are used to lift the collector by the glazing. In Sweden and at Ispra, a method developed for testing windows is employed. Some laboratories are testing until a failure occurs, others recommend applying a pressure difference of 2500 Pa and others again recommend less than this.

results and recommendations

Wind and snow load tests take different forms in different laboratories.

At Ispra, a double chamber with alternative positive and negative pressure is used - there must be holes in the collector. With pressures up to 2500 Pa, no problems have occurred, and the test is therefore not considered to be very revealing.

In France, it is believed that a problem could be caused by deformation of the frame rather than the glazing. In their approach, four 120 mm diameter suction pads are used to lift the whole collector by the glazing, and thus testing whether the cover is likely to separate from the frame.

In Sweden, a method developed for testing windows is used, and the effect of snow loading is also found.

The problem of wind (snow) loading is really a design problem, but now and then building authorities require proof of the strength of a collector module.

Some laboratories test to failure, but 2500 Pa is already a very high limit. The UEATC had set a value of 2400 Pa for plastics, and concluded that there was no real problem with glass.

2.2.8. OUTDOOR EXPOSURE TEST

normal procedure

This type of test has now and then been called "short term ageing test" or the "no flow 30 days test". Because of the limited time of exposure it is surely not an ageing test.

Solar collectors, in connection with a safety valve, are filled with water and installed outdoors. The stagnation temperatures and solar insolation will be registered normally. In USA and Canada, the solar exposure demands are four hours of more than 946 W/m^2, and 30 days with more than 4.7 kWh/m^2 per day.

results and recommendations

Since these exposure demands are difficult to reach, the UEATC and the Collector and Systems Testing Group (CSTG) of the EEC have reduced these demands. The CSTG recommends the following basic test conditions for the "short term ageing test", see also fig. 2.2.6.

The collector is exposed until at least 30 days with a minimum irradiation of 4 kWh/m^2, as recorded by the pyranometer, have passed. These days need not be consecutive. The collector must also be exposed for at least 30 hours to an irradiance greater than 850 W/m^2 when the surrounding air temperature is greater than 5°C. These hours must be made up of periods at least 30 minutes long. The first external thermal shock is caused during the first 10 of the 30 hours defined above, and the second during the last 10 of the 30 hours.

However, there has been some concern that this test procedure may not include long enough periods of time when the collector box is exposed to an atmosphere of high humidity. Because of this a test procedure for humid climates has been developed. Here the collector is sprayed with water (0.03-0.05 litre/sec · m^2) every night between sunset and sunrise to simulate a humid environment. For a period the collector might be screened from solar radiation during the day to maintain a high level of humidity in the daytime also.

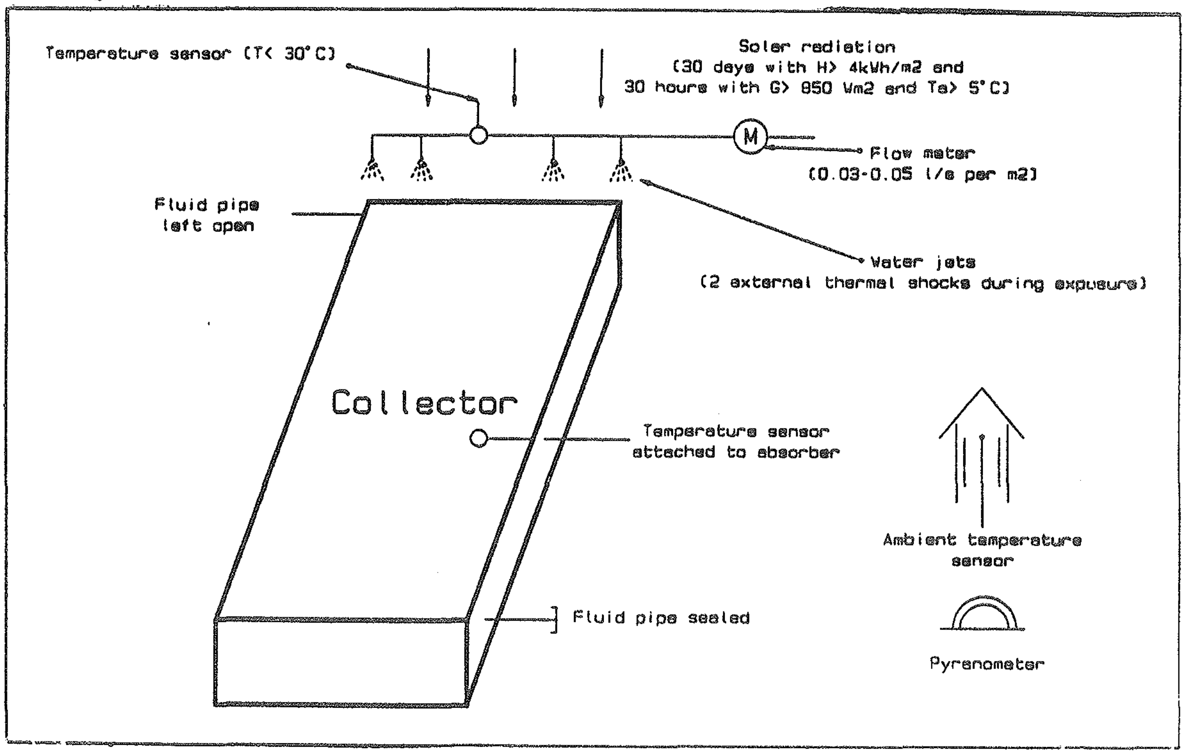


Fig. 2.2.6 Test procedure for the "short term ageing test" of the Collector and System Testing Group of the EEC.

2.3 Discussion on less used solar collector qualification test procedures

This section gives a short discussion on the test procedures which were not presented in chapter 2.2. Some of the results from these tests are also included in chapter 4 on innovative test procedures.

Combined rain and wind load test

In Denmark, the rain penetration test is followed by a more severe test with a combined rain and wind load. Here the wind load is simulated by establishing over- and under-pressure in the solar collector. The external thermal shock test, where water is sprayed on to a stagnated solar collector, can also be used to identify rain leakage problems. If water penetrates the collector, a heavy condensation will be formed on the inside of the cover when it is cooled.

Water retention test

In Australia and UK, the rain penetration test is followed by a water retention test in order to see if water, actually entering the solar collector, will drain out again.

Frost test

In some countries with a cold climate, namely Canada, the Netherlands and Sweden, a frost test is performed.

The frost test for tolerance to cold does not seem to be effective. In Canada, the test was performed with a slow temperature cycle and there was no effect. With a rapid cycle all collectors failed.

In Sweden, the test was performed when the interior of the absorber was wet, in order to observe the effect of repeated freezing and thawing. Water was also applied to the outside of the collector. A build-up of ice could damage the gaskets, but in fact this was a problem only where sealants are concerned; primarily it was a problem with regard to materials. In Sweden, the biggest effect of this test was observed in the pipe connection between two solar collectors. Two collectors were installed together and filled with heat transfer fluid and exposed to -20°C for 12 hours.

Freeze protection test

In Australia, Canada, France and USA, a separate freeze protection test is performed for solar collectors which are being used in drain down systems.

The freeze protection problem depends on the heat transfer fluid and on the collector slope.

Probably, the test should only be applied in cases where the manufacturer makes a specific claim for the freeze protection of the collector or for collector integrated storage types. The most relevant thing to test in this connection is the safety valve and control for drain down or drain back systems.

In Australia, an artificial sky temperature is used to test the freeze protection.

Heat transfer fluid test/corrosion test

In Switzerland, the qualification tests include a separate test of the heat transfer fluids, and corrosion aspects of these are identified. This is an outdoor test over a period of one to two years, in which two collectors are installed in a solar collector loop. Here, the qualification tests are performed in a combined way during a two-day period and repeated automatically for one year. (See also chapter 4.1).

Strength of mounting and hydraulic fitting resistance

In France, mechanical tests of strength of mounting and fittings are performed. The first test mentioned is also performed in USA.

Mechanical test of collector structure and supporting frame

In France, a mechanical test of the collector structure and supporting frame is also performed.

Thermal cycling test

In Denmark and the Netherlands, an indoor thermal cycling test has been performed as part of the indoor qualification test. This test is a supplement to the 30 days outdoor exposure test in climates with limited sunshine during the winter. This test is, however, rather expensive due to the fact that it needs a long time in the indoor solar simulator.

Hail test

There has been a lot of discussions on the importance of hail tests of solar collectors. Serious effects from hail storms have been reported, for example near the Research Center in Ispra and in Geneva. In Geneva a hail storm in August 1986 destroyed 70% of the glazing of a flat plate solar collector installation and evacuated tubular collectors were also destroyed. This hail storm is known to be the worst in this area for a hundred years. Hail resistance of solar collectors is believed to be a question of collector design and is most important in certain areas.

The UEATC recommended a steel ball dropping test. In the past, Ispra preferred the use of a hail gun (which fires specially made ice balls at the collector), but this was a complicated apparatus and required a complicated procedure. However, a comparison showed that a "severeness factor" of 6 related the breaking effect of steel balls and ice balls (a 15 J ice ball, for example, is equivalent to a 2.5 J steel ball), and the steel ball dropping test is now thought to be useful.

Phillips report that their evacuated tubular collector is resistant up to a steel ball impact speed of 7-10 m/s.

Other tests
In some countries, the qualification test is linked together with separate material tests in order to identify problems with the materials, especially in cases where new or new combinations of materials are used in the construction. These tests are not considered to be qualification tests, but durability tests performed to evaluate the possibility of a long service life of the solar collector. Other tests, like UV radiation tests and salt mist exposure tests, are also durability tests and will not be discussed further here.

2.4. Experience with a complete indoor qualification test programme in Denmark

In Denmark the work with development of qualification test procedures for solar collectors has been closely connected to the participation within IEA TAsk III, where Denmark has been in charge of the cooperative work within Subtasks C on reliability and durability, and F on service life testing of solar collectors. A detailed presentation of the equipment and procedures of the Danish test programme is given in [12], [13] and [14]. The main work on qualification testing in Denmark was made between 1980 and 1983 by a complete test of all 22 types of solar collectors sold in Denmark at that time.

It was concluded that especially solar collectors which are not raintight or which have problems with condensation over long periods cannot be expected to have a long lifetime.

For this reason it is an important requirement for the construction of solar collectors in the wet northern European climates that they are raintight and well ventilated with outside air.

Failures at the cover/enclosure assembly, the piping holes or at the corners are normally the reason for collector leaks.

Ventilation must be made in such a way that condensation in

the morning can be evaporated into the solar heated ventilation air inside the solar collector and can get out near the top without leaving condensed water in unwanted places.
Selective solar collectors which are common today can reach absorber temperatures of 180-200°C. This means that you must choose materials which do not deteriorate at high temperatures. Plastic foam insulation materials, for example, will suffer heavy degradation at temperatures exceeding 130°C. Outgassing from insulation and gaskets can reduce the transmission and can also have a corrosive effect. Plastic covers can collapse at stagnation because of a combination of a high stretching coefficient and a low heat transmittance. This can be prevented by a profilation of the cover.

Almost all of the 22 tested collectors had several good details and gave many examples of good use of materials.

On the other hand, many collectors had one or more failures in the construction and were not designed to meet all the demands a solar collector should be able to meet. Most of the collectors were first generation products whose development was not yet adapted for the experience from many years of practice.

The indoor tests were very useful because they can be performed in only three days in connection with the established solar simulator efficiency test. They can give the necessary indication of ability of collectors to withstand high temperatures, rain and wind loads.

A test journal is made for each of the tested solar collectors. This journal gives a detailed description of the solar collector, similar to the one in the IEA solar collector inspection format, but with more information (fig. 2.4.1). A pre-evaluation of the collector is made with respect to items mentioned in table 1.1.1 chapter 1.1.

DATASHEET ON SOLAR COLLECTOR RELIABILITY AND DURABILITY	Test no.:
Manufacturer: BATEC, LIDEMARKSVEJ 20, 4681 HERFØLGE	Type: BA22 SELECTIVE
Test Laboratory: THERMAL INSULATION LABORATORY, TECHNICAL UNIVERSITY OF DENMARK	Solar collector id-no.: 161

DESCRIPTION OF THE SOLAR COLLECTOR CONCERNING RELIABILITY AND DURABILITY*):

Collector construction: The collector consist of a frame of an extruded aluminiumprofile with a thickness of about 2 mm. The frame is assembled in the corners by screws. The glass lies on a flap of the frame and is fastened by a strips of aluminium along the two long sides and the upper side. In this way there are no troubles with rainwater and the strips. The absorber is fastened by the insulation and the four outsticking sockets. The insulation is fastened by the frame and the back plate which is made of a 0,7 mm aluminium plate. The back plate is fastened by rivets to the frame.

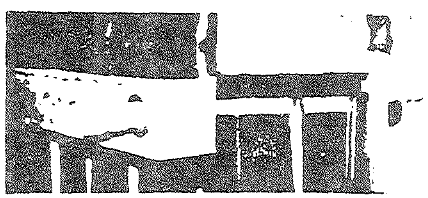
Collector tightening: Between the glass and the flap of the frame is a butylstrip. The joint between the glass and the frame is sealed with silicone jointing material. EPDM rubber nipples at the lead-ins.

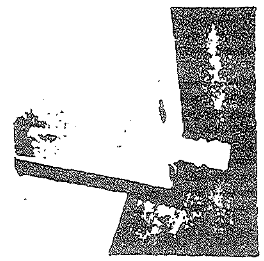
Ventilation: The collector is ventilated through the assembly between the back plate and the frame.

Draining: None.

Mounting: The collector can be mounted on the roof or be integrated in the roof. The underlying layer has to be waterproof to avoid problems with flashing if the collector is integrated in the roof. The fastening can be made with galvanized angle irons.

Details:





RESULTS FROM THE TESTS:

Pressure test of the absorber:
1,3 x max working pressure=325 kPa: No remarks

Ventilation test: The air change is greater than 100 m³/h by a high pressure of 500 Pa. The air change happens through the assembly between the frame and the back plate and at the assemblies between the lead-ins and the frame.

Temperature test:

Stagnation	: No remarks
Shockcooling of the absorber	: Some of the absorber fins buckled a little when the absorber was cooled
Dryboiling and stagnation	: No remarks
Shockcooling of the cover	: No remarks
Thermal cycle test	: No remarks

Water ingress test:
Waterprof without wind-pressure: No, the collector leaks between the frame and the back plate
Waterprof with wind-pressure: No, the collector leaks between the frame and the back plate

Simulation of wind load at the cover:
High pressure in the collector (750 Pa): No remarks
Low pressure in the collector (750 Pa) : No remarks

Comments to the test: Apart from the water ingress test there were no problems with the collector.

*) A further description of the collector is given on the datasheet on solar collector efficiency with the id-no. 161.

DATASHEET ON SOLAR COLLECTOR RELIABILITY AND DURABILITY	Date: 1984-03-07
Manufacturer: DANSK SOLVARME K/S, KABELVEJ 5, V. HASSING STRAND, 9310 VODSKOV	Type: KP V
Test Laboratory: THERMAL INSULATION LABORATORY, TECHNICAL UNIVERSITY OF DENMARK	Solar collector id-no.: 174

DESCRIPTION OF THE SOLAR COLLECTOR CONCERNING RELIABILITY AND DURABILITY*):

Collector construction: The collector consist of a frame of an aluminiumprofile. The frame is assembled in the corners by welding. The glass is fastened by the upper part of the aluminium frame. The glass is lying on a frame of wood in which both the absorber and the back plate are fastened too. The absorber have integrated headers at the top and at the bottom. The upper one has outsticking sockets and is closed at the midle so the fluid must run down in one side and up in the other side. On the front of the absorber is placed a selective adhesive tape. The back plate is a 1 mm aluminiumplate.

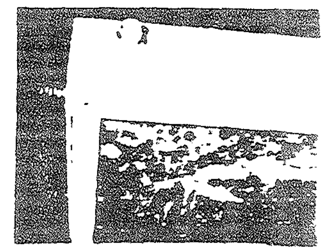
Collector tightening: The assembly between the glass and the frame is tightened with a sealing strip. Rubber nipples at the lead-ins.

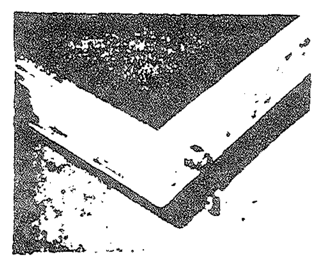
Ventilation: The space between the glass and the absorber is ventilated by two holes in the upper and two holes in the lower part of the wooden frame.

Draining: None.

Mounting: The solar collector can be mounted on the roof or be integrated in the roof as a flashing system can be delivered. The fastening can be made with fittings to the frame or by squareheaded screws from the back.

DETAILS:





RESULTS FROM THE TESTS:

Pressure test of the absorber:
1,3 x max working pressure=325 kPa: No remarks

Ventilation test: The air change is greater than 100 m³/h by a high pressure of 500 Pa. The air change happens through the ventilation holes, through the assembly between the alu-frame and the wooden frame and through the assembly between the back plate and the wooden frame.

Temperature test:

Stagnation	: No remarks
Shockcooling of the absorber	: No remarks
Dryboiling and stagnation	: No remarks
Shockcooling of the cover	: No remarks
Thermal cycle test	: No remarks

Water ingress test:

Waterproof without wind-pressure	: No remarks
Waterproof with wind-pressure	: No remarks

Simulation of wind load at the cover:
High pressure in the collector (750 Pa): No remarks
Low pressure in the collector (750 Pa) : No remarks

Comments to the test: None

*) A further description of the collector is given on the datasheet on solar collector efficiency with the id-no. 174.

Fig. 2.4.1 Example of reporting format for indoor solar collector reliability tests performed in Denmark.

3. FURTHER DISCUSSION ON OUTDOOR EXPOSURE TESTS

3.1 Proposal for a minimum Test Procedure

The qualification test procedures presented in chapter 2.2 are the most useful and in most cases also the most utilized tests. However, performance of qualification testing of solar collectors is not a regular practice in most countries, mainly due to the high costs of the tests. It was agreed between the IEA Task III participants that the cheapest and most practical qualification test procedure to be proposed as a minimum procedure would be an outdoor exposure test of solar collectors, performed before or after the thermal efficiency test.

As minimum test procedures the following could be proposed:

Absorber pressure test performed indoors or outdoors before the thermal efficiency test.

Outdoor exposure test with rain penetration and thermal shock tests on one of the first sunny days.

To identify the exposure level, measurements should be performed of $T_{absorber}$ and climate parameters, like $T_{ambient}$, irradiance, relative humidity of ambient and inside the solar collector, moisture on the inside of the cover near the bottom.

The test should be performed like the normal 30-days outdoor exposure test including the demands for temperature and insolation level. A demand for exposure level to relative humidity and rain during nighttime should be included.

To include testing of the mounting and piping installation and also perform a test under simulated operating conditions, the following is proposed:

Two solar collectors should be mounted into or on to a roof construction including the flashing system in case they are designed for roof integration. One of the solar collectors should be installed with a piping system as prescribed by the manufacturer, and it should be connected in a thermosyphon circuit to a non-insulated tank to simulate normal operation conditions. During the test period, tests should be performed with the collectors in operation and in stagnation as described above.

The actual tests used could be dependent on the climate for which the solar collectors are designed. There could, for example, be three different climate conditions, depending on the actual weather during the winter time:

a. Climate conditions with frost where it is wet and humid during the winter.

b. Climate with frost where it is sunny during the winter.

c. Sunny climates without frost during the winter.

Depending on the actual climate in which the solar collector is supposed to operate, different qualification tests could be used in order to ensure a good reliability in practice and a long lifetime of the solar collector system.

3.2 Identification of Short Term Degradation by Outdoor Exposure Tests

Several approaches have been made to identify solar collector degradation, for example observed in outdoor exposure tests, by use of measurements.

One method, reported by several institutes, is to perform a second thermal efficiency test after the outdoor exposure test in order to observe changes of the efficiency curve. This has been reported in [15] and [16]. The conclusion is that it is difficult to identify degradation using this method if the uncertainty of the monitoring methods is taken into account.

In [17] H. Birnbreier has a proposition for a simple method for measuring how the relationship between the absorber heat loss coefficient U_L and the effective transmittance - absorbtance product $(\tau\alpha)_e$ of a solar collector is changed at different irradiance values for example during one year. H. Birnbreier postulates that you can find the daily average $U_L/(\tau\alpha)_e$ value of a collector by measuring the stagnation temperature of the absorber T_s, the ambient temperature T_a and the irradiance I. You then have:

$$\frac{U_L}{(\tau\alpha)_e} = \frac{\int_0^{24h} I \, dt}{\int_0^{24h} (T_s - T_a) \, dt}$$

This is when you assume that the heat capacity of the collector is constant and the midnight absorber temperature is the same as it was 24 hours earlier.

Change of the average $\frac{U_L}{(\tau\alpha)_e}$ value as a function of $\int_0^{24h} I \, dt$ could be used as measure of quality changes of a collector over a period of, for example, one or two years.

In [18] G. Riesch proposes, instead of using 24 hours, to integrate over a few hours from one time when the absorber temperature is T1, over a period where it is climbing to T2 and at a later time again falling to T1. This is also the basis for the experiments used in the Swiss outdoor exposure test procedure (see chapter 4).

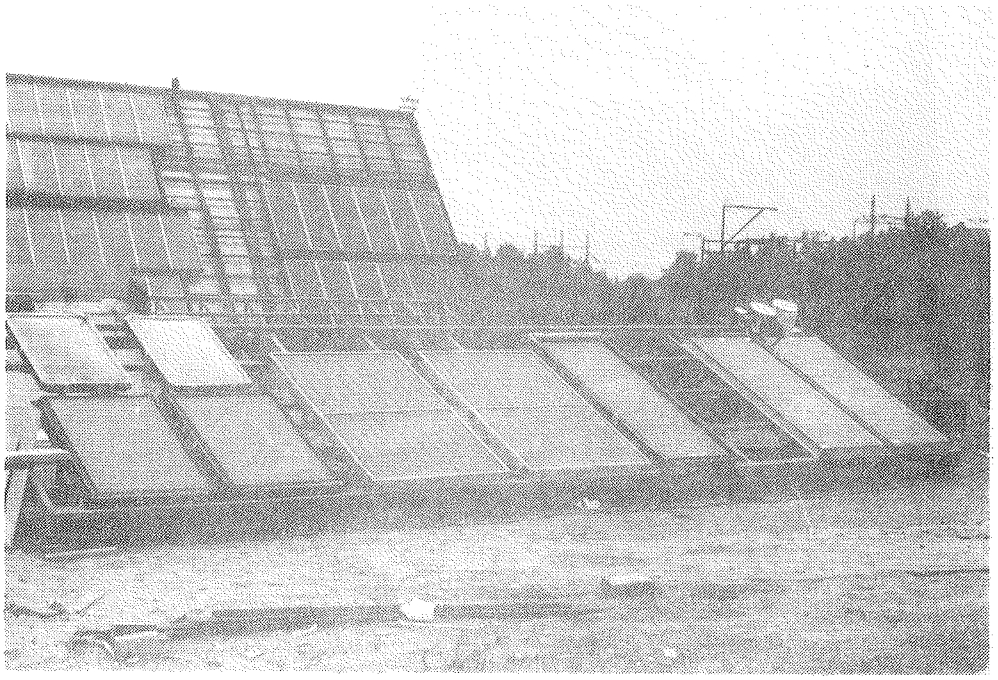
A third approach is to register the temperature difference $T_s - T_a$ and the irradiance I at noon on sunny days and use their ratio as an indicator of collector quality. This method has been recommended as being useful together with the previously mentioned method, [19] as a basis for identifying changes of the collector quality.

Dawson, Thomas and Wahlman [20] found that the mentioned methods require clear day conditions, and that the use of closely matching test conditions should make it possible to detect changes in the order of 0.1 in solar transmittance, absorptance or emittance.

In 1981, 20 solar collectors were placed in an outdoor stand at the Thermal Insulation Laboratory in Denmark. Continuous measurements of stagnation temperatures and climatic parameters were made for two years in order to identify humidity and condensation problems, and to investigate if changes of collector quality could be identified by using the previously mentioned methods.

Figs. 3.2.1 and 3.2.2 show examples of solar collectors tested in outdoor stagnation at the Thermal Insulation Laboratory, and the monitoring device with hourly recording of measured data.

In fig. 3.2.3 and example of analysis of stagnation temperatures is shown as a basis for evaluation of degradation. It was possible to identify changes for most of the solar collectors by using the Birnbreier method and by using the method where stagnation temperatures are measured around noon. But the changes were not very significant, and it was not possible to identify a clear correlation to degradation observed in practice by visual inspection of the solar collectors. For example, solar collectors with heavily degraded backside insulation or with moisture built up inside the collector.



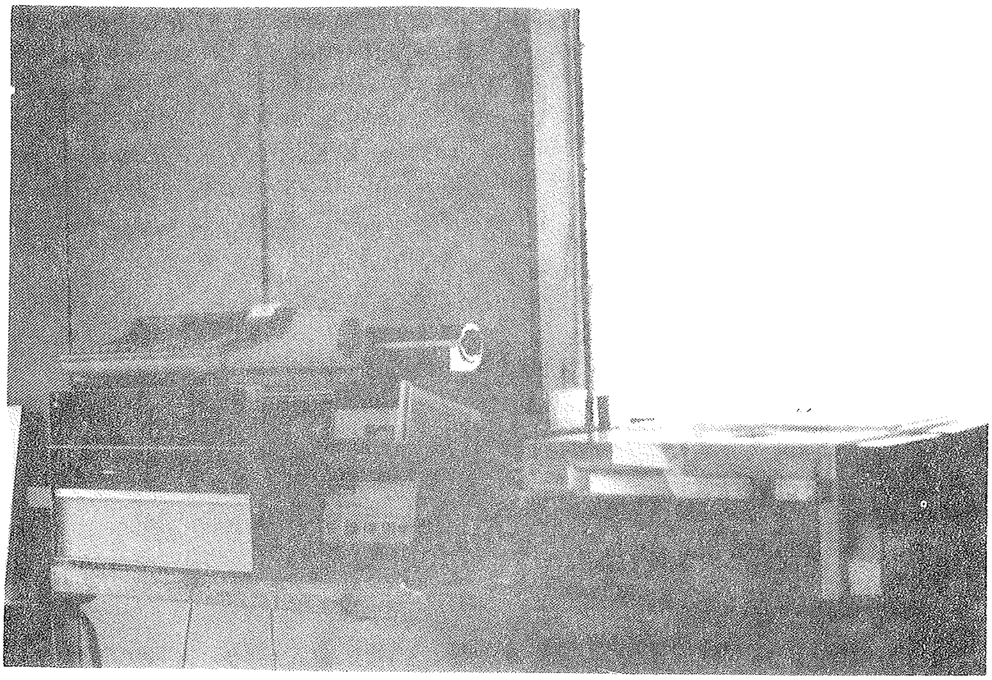
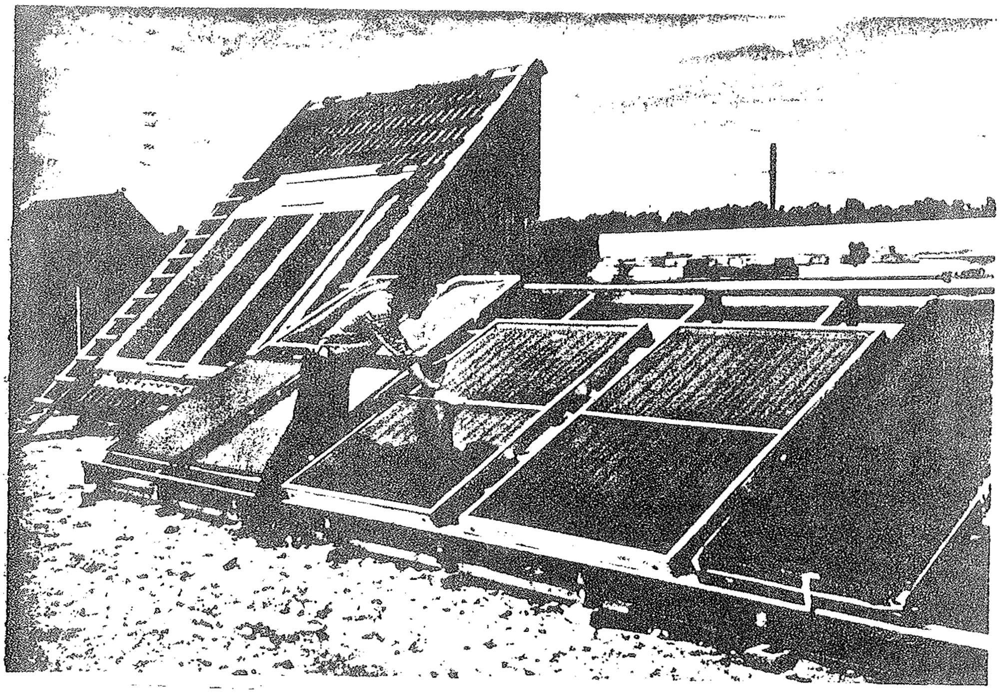


Fig. 3.2.1 20 solar collectors were tested in outdoor stagnation at the Thermal Insulation Laboratory from 1981 to 1983.
Solar insolation, ambient temperatures and stagnation temperatures were measured as hourly values.



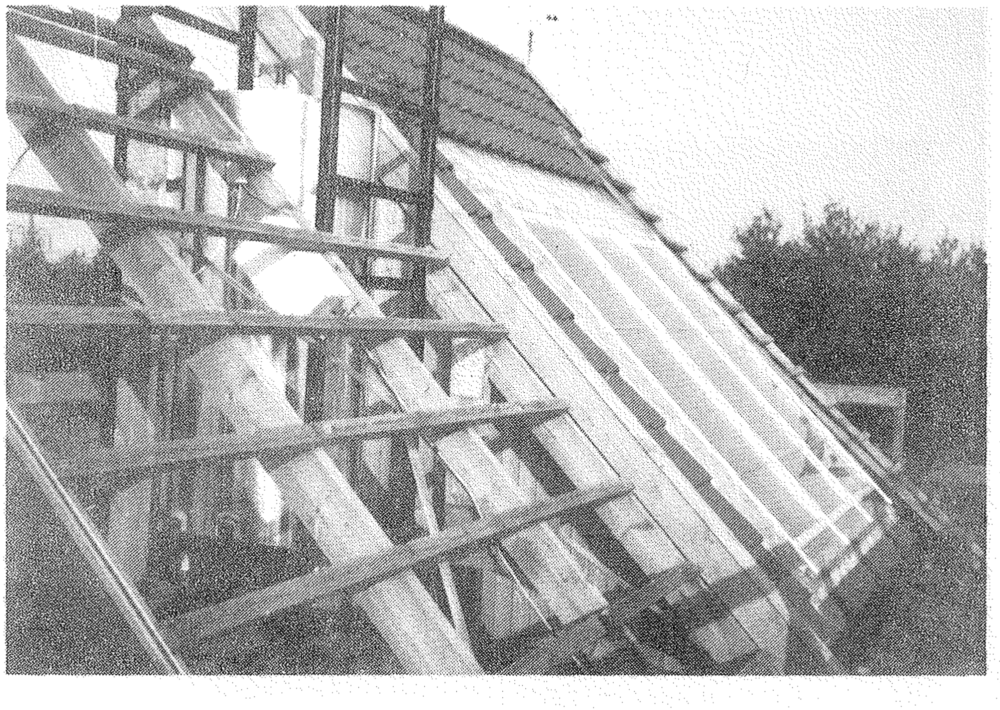
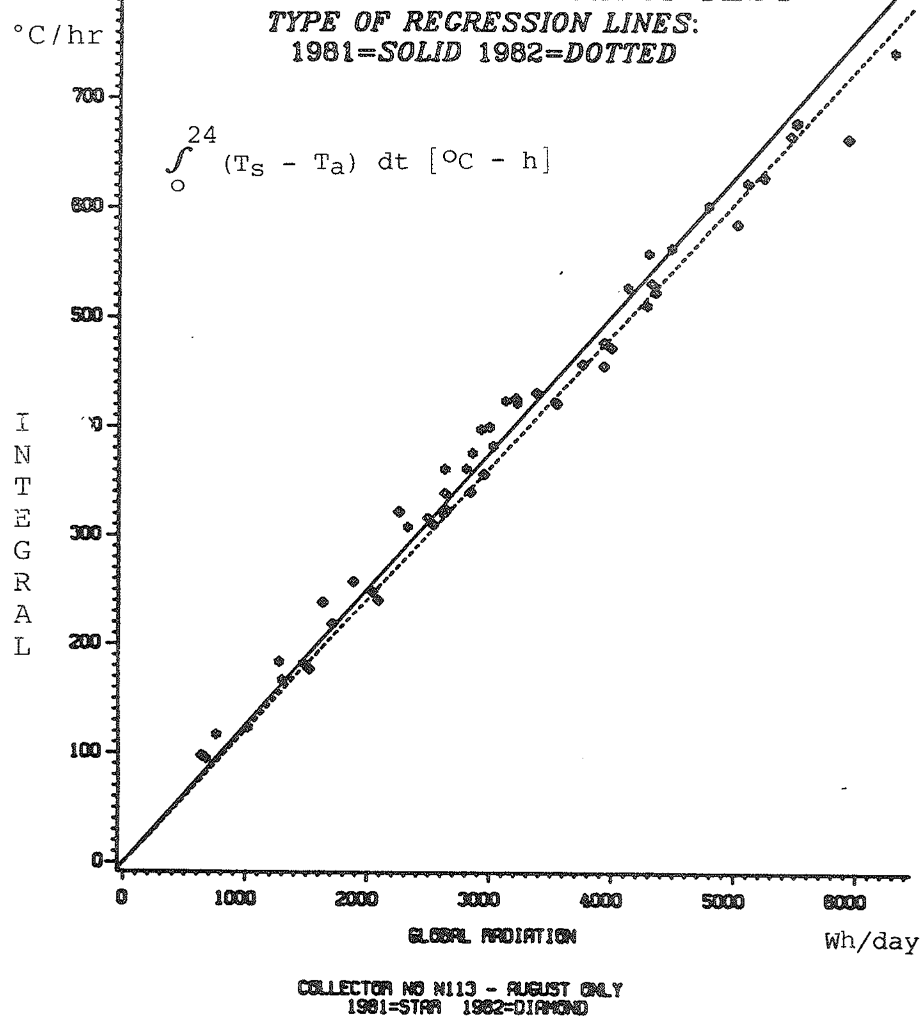


Fig. 3.2.2 Outdoor exposure test at the Thermal Insulation Laboratory. Inspections were performed with one months interval. Also a roof integrated solar collector was tested, one in stagnation and one in operation.



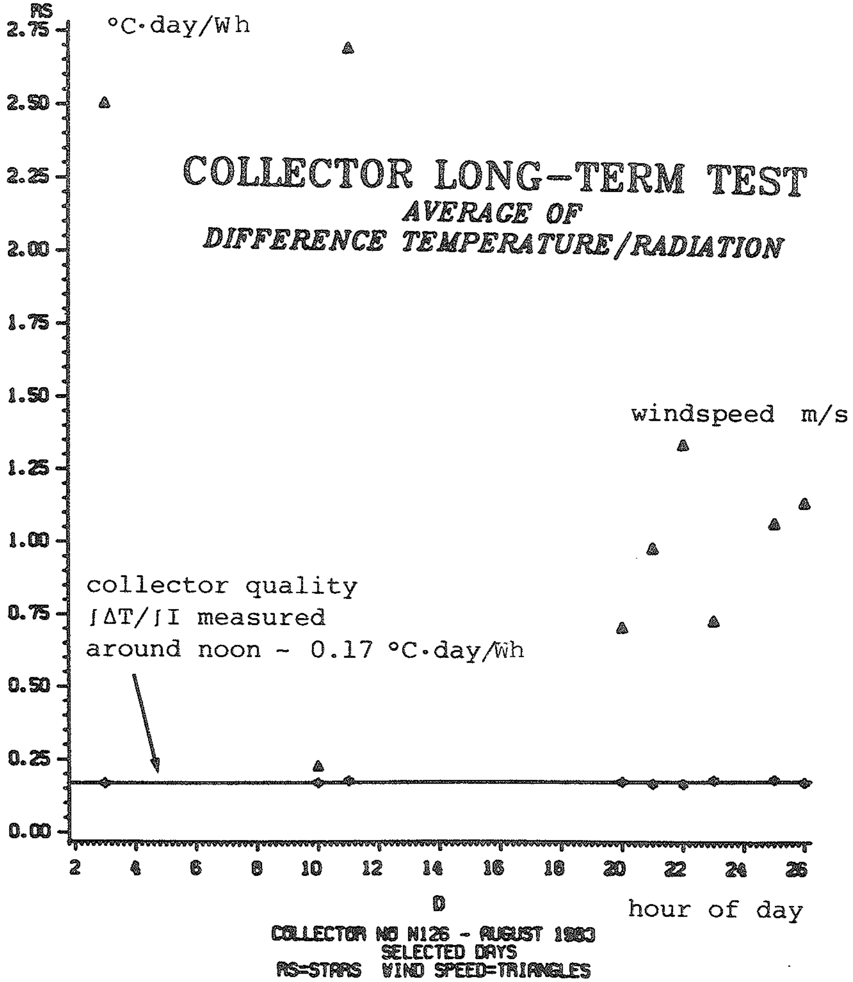


Fig. 3.2.3 Example of analysis of outdoor exposure data performed at the Thermal Insulation Laboratory. To the right is shown the ratio of $T_s - T_a$ and I around noon on sunny days in August 1983. ∫ΔT divided by ∫I can be used as a measure of collector quality as it is the same as $(\tau\alpha)_e / U_L$. For the mentioned collector, this value increased during the years. In 1981 it was 0.16, in 1982 0.17 and in 1983 it was measured between 0.17 and 0.18. In the same period the polyurethane backside insulation became very brown.
To the left is an example of a Birnbreier analysis for another collector. The collector quality meassured as ∫ΔT divided by I is here reduced from 0.13 to 0.125 °C·day/Wh.

3.3 Identification of Problems with Moisture and Condensation in the Outdoor Exposure Test

As part of the outdoor exposure test of solar collectors at the Thermal Insulation Laboratory, monitoring of moisture and relative humidity were performed during different periods of the year.

The following quantities were measured hourly:

ambient air:	temperature, relative humidity, wind speed
collector, air space between glass and absorber:	temperature, relative humidity
collector, insulation material:	temperature, relative humidity

The saturation pressure is calculated by the expression:

$$P_s = e^{(25.876 - 5316/T^{o}K)} \quad [Pa]$$

and the moisture content in the air, grams of water per kilo dry air is then calculated as:

$$x = 622 \cdot \left(\frac{RH \cdot P_s}{P - RH \cdot P_s} \right)$$

[x]: gram water/kilo dry air

[RH]: RH %, [P]: Pa

where RH is the relative humidity, P_s is the saturation pressure at a certain temperature and P is the total pressure.

The ventilation rate of the solar collector is known from the indoor qualification test. We also know that the actual ventilation is a function of wind pressure and the chimney effect of the collector.

The type of ventilation is evaluated as shown in fig. 1.2.6 in chapter 1.2.

Analyses of RH and x as a function of time are performed for different kinds of days and for different solar collectors.

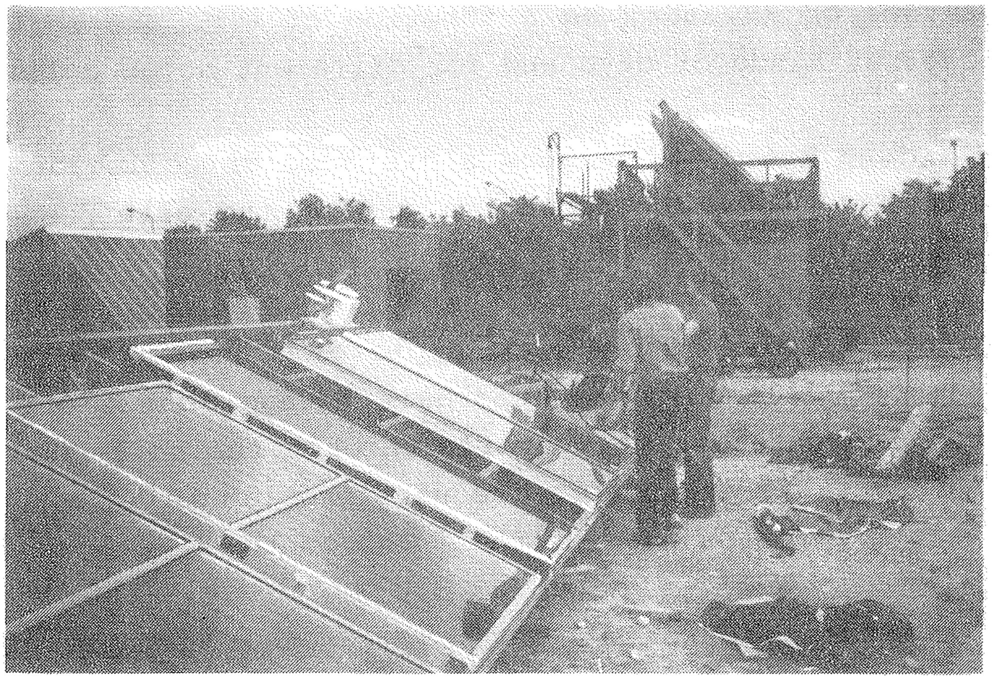
In fig. 3.2.4 is shown how a "wet" solar collector typically would have heavy condensation during the afternoon when the glass is cooled.

In fig. 3.2.5 is shown an example of a roof integrated solar collector with corroded absorbers because humid air from the house is vented to the outside through the collector. Unfortunately, this is quite a frequent problem in houses where the loftroom is often used by the inhabitants.

In the same figure is also shown another example of a solar collector with condensation still present in the afternoon. If it is a rainy and very humid day, this might be the case for many solar collectors. However, in cases of good quality solar collectors with protected ventilation holes in the top and at the bottom of the collector, the chimney effect was, in most cases, able to remove the condensation in only one hour in the morning.

In fig. 3.2.6 is shown measured stagnation temperatures and relative humidity in four different solar collectors, A, B, C and D, in March 1983. Relative humidity is measured for the ambient air (1) in the insulation material near the absorber (2) and in the air space between absorber and glass (3).

Collector A is a good collector which seldom forms condensation. The collector case is almost hermetic, but with drilled holes in the back plate. The relative humidity during a sunny day is very low, 10-20% RH for the air space while the relative humidity for the insulation material is higher than for the ambient air.



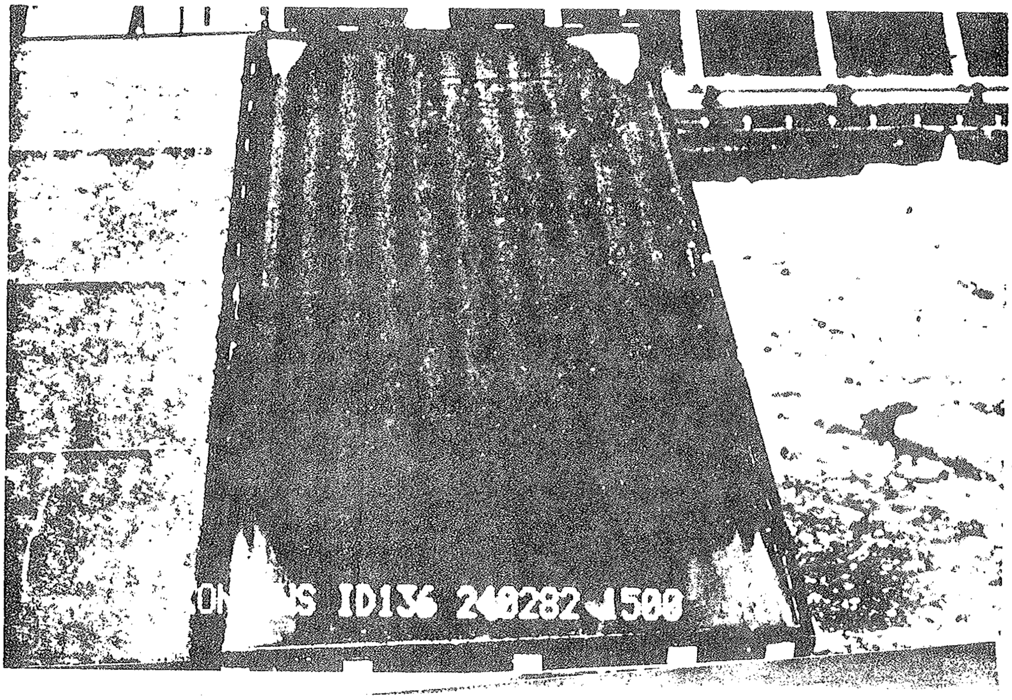
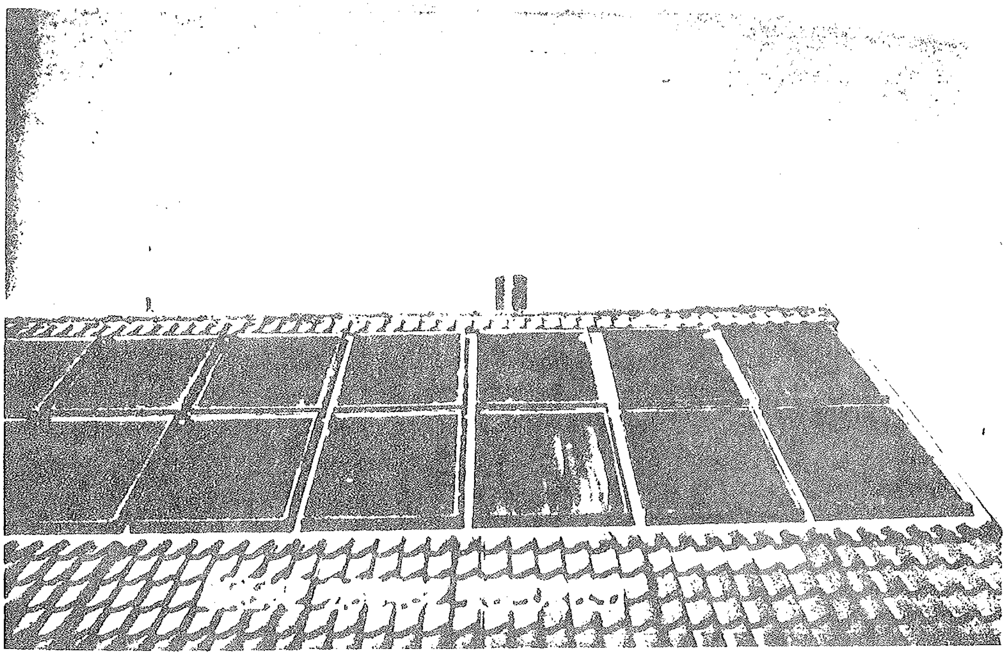


Fig. 3.2.4 Before the outdoor exposure test at the Thermal Insulation Laboratory, the collectors were shielded with plastic foil, (above). An example of typical condensation in "wet" collector during the afternoon when solar insolation is decreasing, (below).



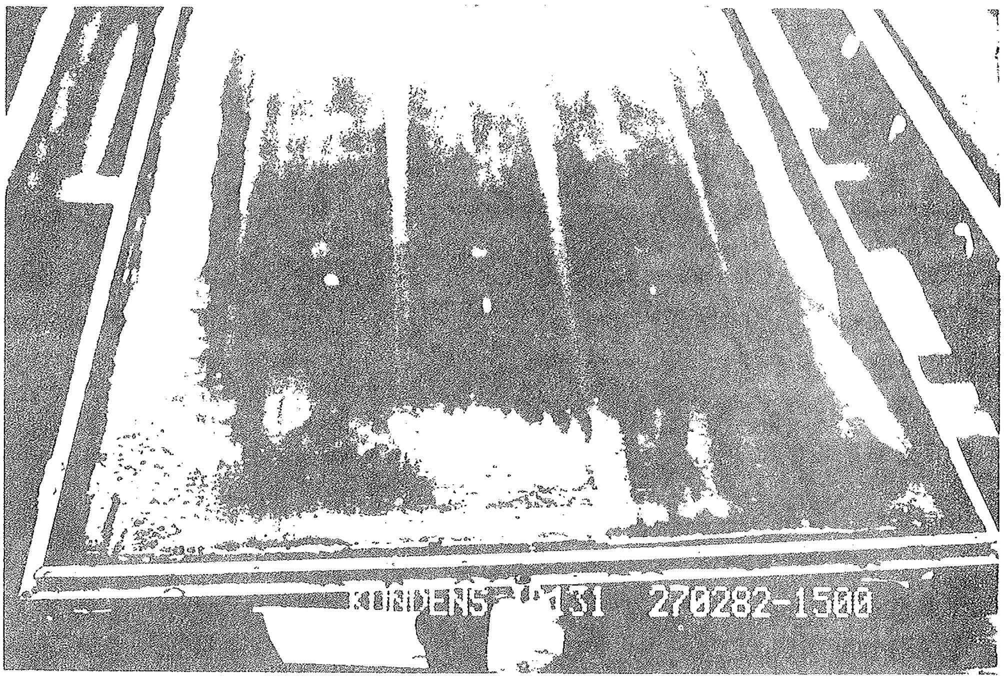
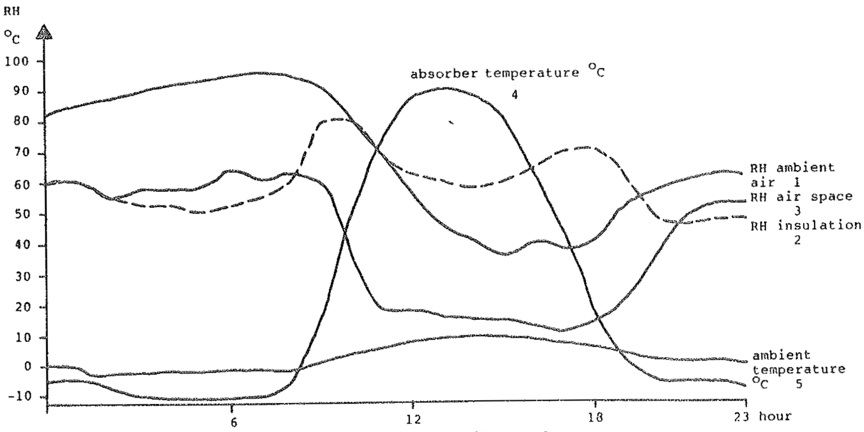
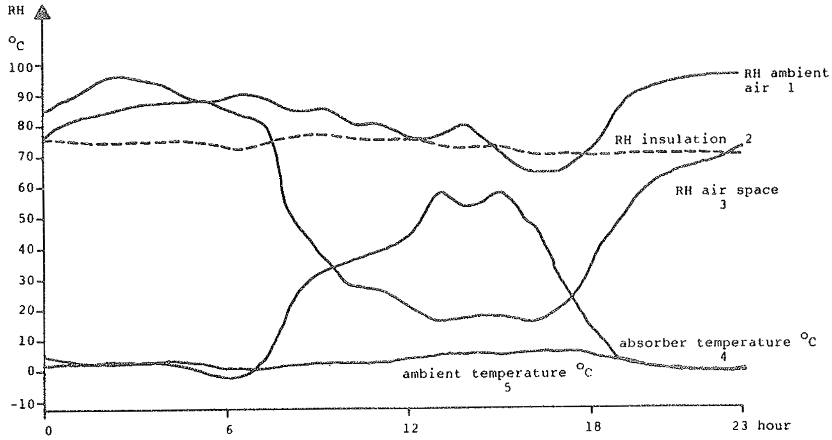


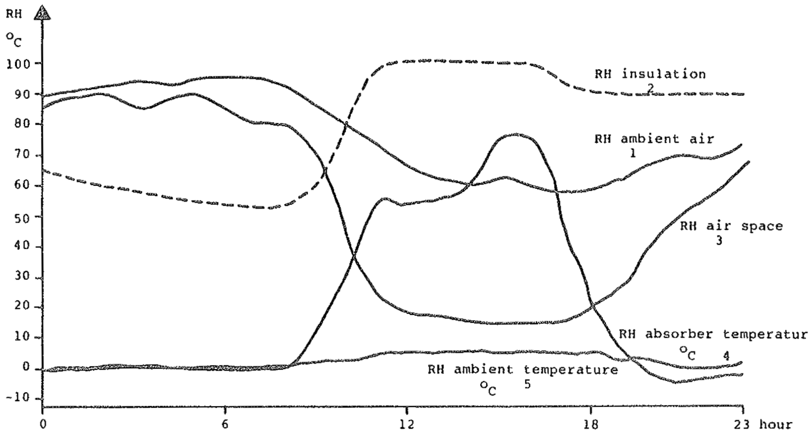
Fig. 3.2.5 Qualification testing of solar collectors at the Thermal Insulation Laboratory, incl. frequent inspections of operational solar heating systems using the same collectors. Here is an example of heavy corrosion due to humid air from the houses which is ventilated out through the collector. Below is shown an example of internal condensation in a "wet" collector on a rainy afternoon.



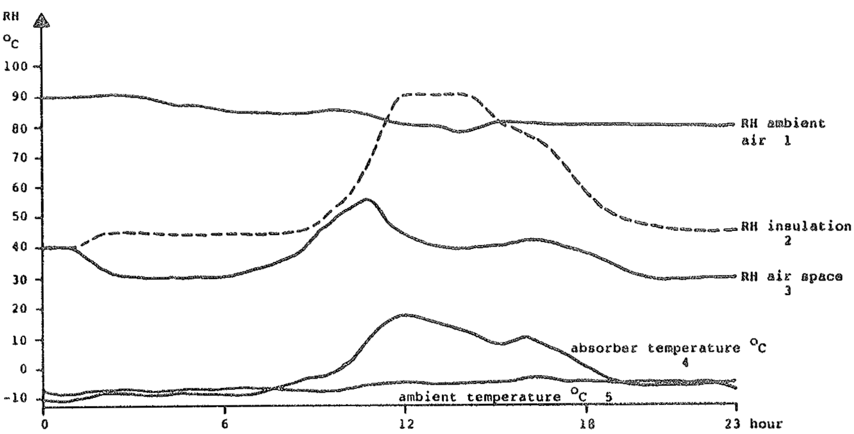
March 12, 1983, collector A



March 22, 1983, collector B



March 26, 1983, collector C



March 16, 1983, collector D

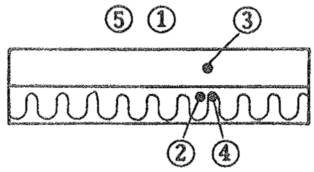


Fig. 3.2.6

Relative humidity (RH) and stagnation temperatures measured for four different solar collectors in March 1983 at the Thermal Insulation Laboratory in Denmark.

RH is measured for the ambient collector air space between absorber and glass and for the insulation material near the absorber.

Collector A has a very good performance, always with low values of air space RH, and thus only seldom condensation on the glass cover.

Also note that the relative humidity of both air space and insulation are well below that of the ambient air during the night. This means that it is difficult for condensation to be formed on the inside of the glass cover, even when this is some degrees below the ambient temperature during the night.

For collector B, the air space RH is also low during the day, but during the night it is near to the ambient air because of direct ventilation.

In the case of collector C and D, it is seen that the RH for the insulation comes near to 100% during the day. Especially, collector D is not raintight with the result that the insulation most probably is wet much of the time.

For the good collector A, there was also a rise in RH of the insulation during the day, but still far from 100%.

4. INNOVATIVE SOLAR COLLECTOR QUALIFICATION TESTS

4.1 Presentation of the Swiss Testing Method to determine the Quality and Durability of Solar Collectors

The described method is a draft Swiss Standard (SN 165003/3). [21].

The philosophy of the procedure is to include, in one single test, every important load which may occur in practical operation of solar energy systems. The solar collectors are exposed outdoors to the following well defined load conditions:

- high temperature stagnation test
- external thermal shock test
- internal thermal shock test
- rain penetration test
- thermal cycling test

In addition, during operation of the pump, the internal pressure is kept beyond the normal operational pressure, thus an absorber pressure and absorber leak test are also included in this procedure.

The test cycle is shown in fig. 4.1.1.

At least two solar collectors of the same manufacture should be exposed together, mounted on the outdoor test facility according to the prescription of the manufacturer. Also fittings and joints are to be used according to the manufacturer's installation guide, thus the test procedure includes a small collector field similar to those in use conditions.

The test period lasts one year and has to begin in summer between the middle of July and the middle of August.

During the test period, the following quantities are to be measured:

- ambient temperature
- irradiance on the collector plane (global and diffuse)
- wind velocity
- inlet and outlet temperature of each collector
- flow rate
- stagnation temperature of each collector

Based on these data, during given time intervals, the following collector parameters are to be determined:

- optical efficiency for direct and diffuse radiation perpendicular to the collector plane
- thermal heat loss coefficient
- stagnation parameter (representing the stagnation temperature under certain boundary conditions)

The test results include on one hand the descriptions of the visual changes including cases of damages as eg. broken covers, and on the other hand the monthly averages of the collector parameters.

A calculation method allows an assessment of the quality level and an estimation if the collector is capable to achieve a minimal lifetime of 15 years under normal operation conditions.

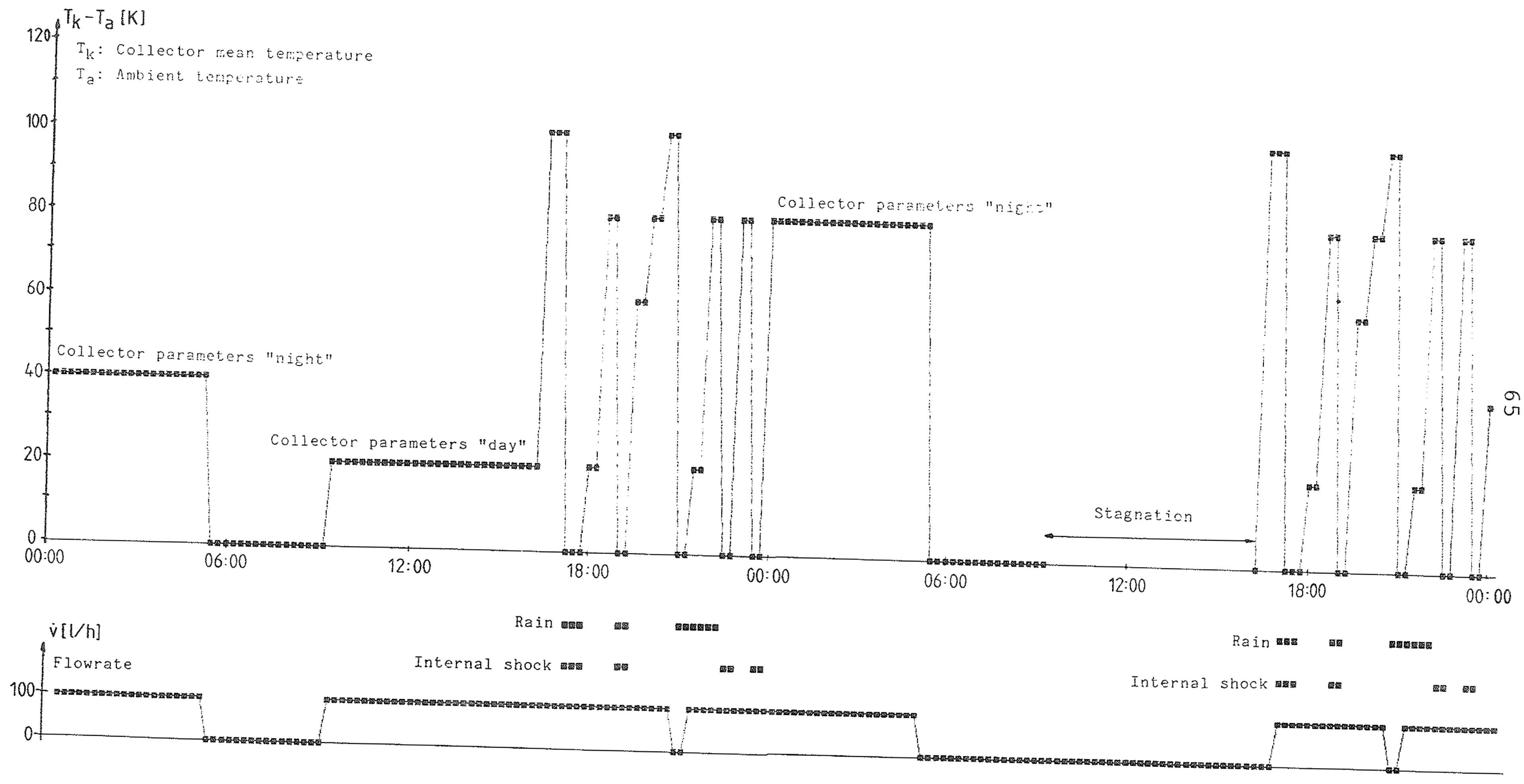


Fig. 4.1.1. Test cycle. (Swiss Testing Method in development).

4.2 Qualification testing of solar collector primary circuit corrosion and control system

It is important to focus more on qualification testing of the solar collector primary circuit. As reported in chapter 1, solar collector failures are often reported in connection with the function of the collector primary circuit, especially with respect to freezing, air locks, boiling and corrosion. Freezing problems have been mentioned in the previous chapters.

In [7], [8], [9] and [22] there is a discussion on important aspects in connection with the problem of how to avoid corrosion in the solar collector primary circuit. In [7] J.G. Avery and J.J. Krall discuss the need for maintenance of the heat transfer fluid in active solar systems. They recommend to use 50% inhibited glycol in water if there is a risk of frost, to avoid both freezing and corrosion. In systems with stainless steel, less than 100 ppm of chloride in the water should be used. Periodic monitoring and maintenance of heat transfer fluid (glycol %, pH factor, reserve alkalinity) should be performed, for example once a year, the last two by indicator strips or laboratory analysis.

In [9] from Deutsche Gesellschaft für Chemisches Apparatewesen e.V. (Dechema) it is recommended to avoid under-pressure and leakages in closed systems in order to avoid diffusion of oxygen into the system and also to avoid the use of plastic and rubber in systems with metal. Furthermore, they recommend to avoid stagnation of the solar collector in case of repair or in case of winter-stop of the solar collector.

In [8] it is stated that it should be possible to assure a long lifetime for the primary circuit if the mentioned conditions are incorporated in the solar design.

It is the general understanding that long time boiling should be avoided for the primary circuit if frost protection with glycol is used. If the pH value has dropped more than from 8 to 7, it will be necessary to change the heat transfer fluid and this can be very costly. From this point of view it seems to be an important task for solar system designers to incorporate means to avoid boiling or at least limiting the damage for example by stopping the pump and installing an alarm as indication in a drain-back system. Since air locks can often lead to bad flow distribution and thus start a boiling, it is important to assure that there are no air locks and that the flow distribution is in order. A qualification test of the primary circuit to assure that boiling will not occur, might be worthwhile because of these aspects.

Perhaps one can also rely on a check of these things as part of the inspection of new solar systems, for example by use of the IEA inspection format [23].

4.3 Qualification testing of Mega solar collectors and site-built roof integrated solar collectors

Mega solar collectors

Mega solar collectors are large collectors for mounting on outdoor stands, for example for district heating systems. An example of a 12 m^2 Mega solar collector, 2x6 m, and produced in Sweden, is shown in fig. 4.3.1.

The solar collector modules are too big to be tested in indoor solar simulators. At present both efficiency tests and qualification tests are being performed outdoors.

Procedures on how to construct a sample collector, which could be tested indoors, would be of great value.

If the ambitious plans for using Mega collectors in large installations with between 1000 and 10,000 m^2 of collector area are to be realized on a commercial basis, development of appropriate testing procedures will be necessary.

Site-built roof integrated solar collectors

Fig. 4.3.2 shows an example of a site-built roof integrated solar collector which has been used with success in new building projects in Denmark and Sweden. At present there is no agreed upon method for performing qualification test of this solar collector. Testing of sample collectors could be a possible method in this connection.

Another important aspect for roof integrated and building integrated solar collectors in general is to perform tests and have demands for resisting fire hazards. This would not be a problem with the already mentioned solar collector, but for solar collectors, where either the wood construction in the roof is used as part of the collector or where wood is used in construction, it is a question which wood temperatures can be accepted. For continuous temperatures, 80°C as a maximum would be normal, but in solar collectors the temperatures will vary a lot over the time. Fire experts are of the opinion that wood does not burn before the temperature is well over 300°C, and even in this case only when ignited by a spark. Further testing will be necessary to identify the safety levels of temperatures in wood constructions.

In fig. 4.3.3 is shown an example of how Mega and site-built roof integrated solar collectors are integrated in e new Total Energy Building Project in Denmark. A more frequent use of this technology in new-built housing will be possible only if reliable qualification test measures and demands for the technology have been developed. [24].

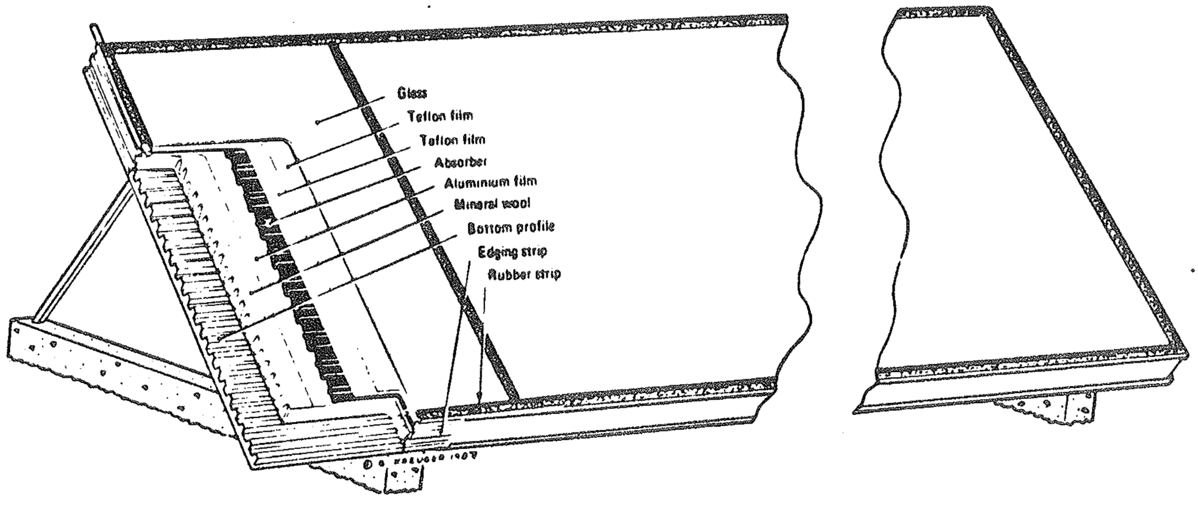


Fig. 4.3.1 12 m² Mega solar collector developed for effective operation at district heating temperatures of 60-80°C. Installed cost in Denmark in 1988, incl. primary circuit, is 240 US$ per m².

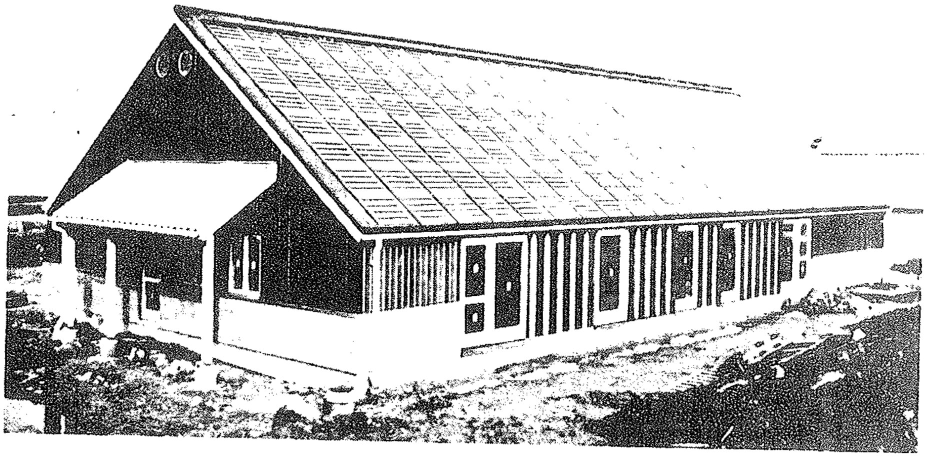
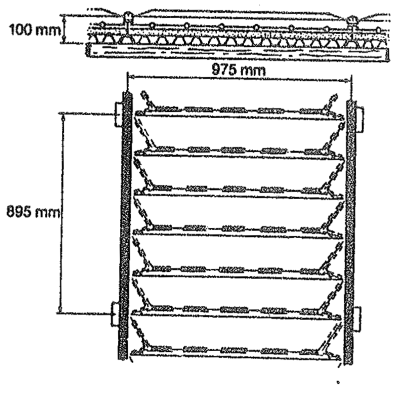


Fig. 4.3.2 Site-built roof integrated solar collectors of this design have been a success in Denmark and Sweden. The photo shows a 160 m² solar collector used in a Nordic Demonstration Project in Ballerup, Denmark.



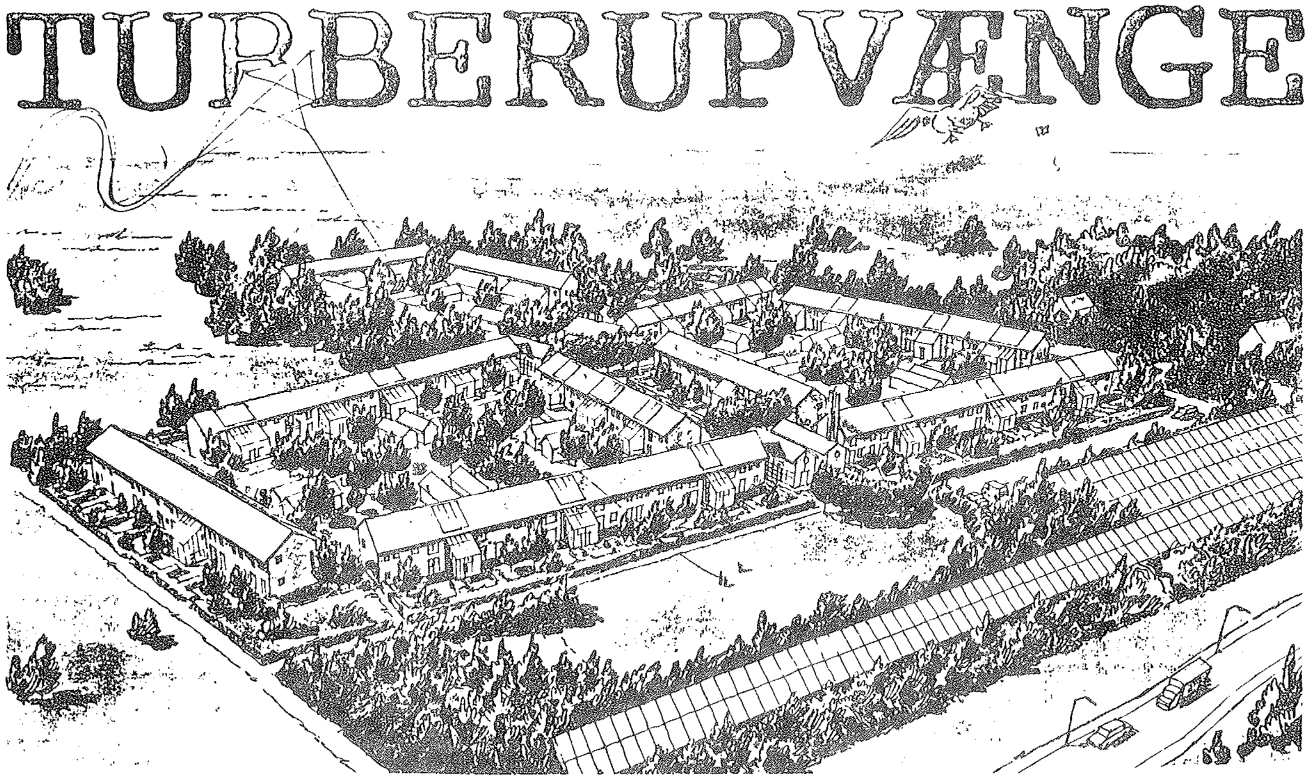


Fig. 4.3.3. A Total Energy Project in Denmark with integration of roof integrated solar collector and Mega solar collector on the ground was realized during 1989 in Herlev, Denmark, partly funded by the EEC and the Energy council in Denmark.

A low energy design for the houses is used together with local solar heating systems for DHW. Besides 1050 m^2 Mega collectors are heating a 3000 m^3 seasonal storage, buried in the ground, to 80°C during the summer. All heating demand for the 92 houses is covered alone from the seasonal storage until December. From here on, a small heat pump is taking the rest of the energy out of the storage, cooling it down to 10°C in April. The total savings of natural gas is 80% compared to normal Danish standard, leading to an expected use of natural gas for heating limited to 35 kWh per m^2 house per year.

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