Final report – Superior Inlet Stratifier

Publicized Version

1.1 Project details

Project title	Superior Inlet Stratifier
Project identification (program abbrev. and file)	64014-0122
Name of the programme which has funded the project	EUDP 14-l
Project managing company/institution (name and address)	EyeCular Technologies ApS Fruebjergvej 3 – 2100 Copenhagen Martin Spanggaard
Project partners	DTU-byg Brovej, bygning 118, 2800 Kgs. Lyngby Simon Furbo
CVR (central business register)	35 53 43 77
Date for submission	30.09.2017

Note:
This version of the report was altered to comply with confidentiality demands and non-disclosure agreements of customers. Some of the names and terms were replaced by (-confidential-). Paragraph 1.5.6 was removed entirely, as it contained sensitive customer related information.

1.2 Short description of project objective and results

Projektets hovedmål er:

a) At færdiggøre prototypens udvikling/produktion af NewTech

Udvikling og afprøvning af forskellige monteringssystemer, resulterede i en hensigtsmæssig fjederopspændingsløsning der nu er implementeret.

b) At demonstrere NewTechs unikke egenskaber og karakteristika for markedet

Undersøgelser af forskellige designede polymerfilmbaserede lagdelingsindløbsrør, fastlagde de mest hensigtsmæssige designmetoder for lagdelingsindløbsrør. To små brugsvandssolvarme-anlæg blev testet side om side i laboratoriet, hvor en standardtank blev sammenlignet med en tank der var udstyret med et lagdelingsindløbsrør. Den årlige termiske ydeevne af systemet med lagdelingsindløbsrøret er ca. 8% højere end referencen. Den forventede levetid for lagdelingsindløbsrøret i solvarmeanlæg er mere end 20 år.

c) At skabe de første kunderelationer, samt at eksponere NewTech markant på markedet

Takket være udviklingsprojekter med industrielle partnere, tilpasningen til markedet, publikationer og tilstedeværelse på messer, er EyeCular i øjeblikket i en test- og udviklingsfase med forskellige virksomheder fra hele Europa.

The main objectives and results of the project are:

a) To finalize the prototype development/production of NewTech.

Developing and testing different mounting systems, let to a suitable spring-borne solution which is now implemented.

b) To demonstrate the superior capabilities and characteristics of NewTech to the market.

Investigations of differently designed polymer film based stratification inlet pipes, showed how best to design the inlet stratifier. Two small solar domestic hot water systems were tested side by side in the laboratory comparing a standard tank to the other equipped with an inlet stratifier. The yearly thermal performance of the system with the inlet stratifier is about 8% higher than the thermal performance of the reference system. The expected life time of the inlet stratifier in solar heating systems is more than 20 years.

c) To create the first customer relationships, as well as making significant exposure of NewTech to the market

Owing to the development projects with industrial partners, the adaption to the market, publications and presence on trade fairs, EyeCular is currently in a testing- and development phase with different companies from all over Europe.

1.3 Executive summary

Experimental investigations of differently designed polymer foil based stratification inlet pipes used to establish thermal stratification in hot water stores were carried out. Inlet stratifiers with different polymer materials, foil thicknesses, inlet arrangements and number of foil layers were included in the investigations with different volume flow rates and temperature conditions in a laboratory test tank. Besides the thermal performance, cost issues and life time issues were also included in the investigations. The investigations elucidated the best design of the inlet stratifier for different volume flow rates. The thermal performance of the developed polymer foil based inlet stratifiers were improved compared to the thermal performance of other marketed inlet stratifiers. Developing NewTech moreover entailed the choice of a suitable mounting system with regards to industrial scale feasibility, durability and stability.

Two small solar domestic hot water systems were tested side by side in a laboratory test facility for solar heating systems under realistic operation conditions. A reference solar heating system equipped with a standard solar hot water tank and a system with a hot water tank with the new inlet stratifier. Apart from the heat storages, the systems were identical. The yearly thermal performance of the system with the inlet stratifier is about 8% higher than the thermal performance of the reference system. Further, the durability of the developed inlet stratifier was investigated by accelerated durability tests in a laboratory test facility. One inlet stratifier was installed in a domestic hot water tank and one inlet stratifier was installed in a heat storage with "technical" water. The investigations showed that the expected life time of the inlet stratifier in solar heating systems is more than 20 years.

The results were used in connection with EyeCular's efforts to bring the developed inlet stratifiers into heat storages for the solar heating and heat pump market. The results provide evidence of NewTechs durability, functionality and competitiveness. With the help of industrial partners, recent developments were tested at their facilities to receive feedback and include it in the following development activities. The collaboration with industrial partners also facilitated to create exposure and enter the solar thermal and heat pump market. Receiving continuous feedback from industrial

partners, EyeCular improved the effectivity of the stratifier and increased its flow rate to 40 l/min. Thereby the heat pump market was unlocked with a second target group, raising the likelihood of successful commercialisation.

1.4 Project objectives

The main objectives of the project are already briefly described in point 1.2. In the following the milestones and derivation from these shall be outlined. It has to be mentioned that the project was extend two times first 7 months and secondly for 6 months. The side-by-side where more challenging and took more time than expected.

The project deliverables are subdivided into four project milestones (M) and three commercial milestones (CM). In the following, the Milestones are briefly described and their planned deadline (PD) and completion date (CD) is indicated (PD → CD):

M1: Durability test initiated (01.2015 → 03.2015)
The completion of this milestone will be the first prototype that meets the requirements for use in a domestic hot water storage tank containing hard water and is therefore the first prototype that can be durability tested.
The objective of this Milestone was met on March 2015.

M2: Customer testing initiated (07.2015 → 11.2015)
The second major milestone in the present project is to initiate testing at customer's facilities
The objective of this Milestone was met in November 2015.

M3: Proof of durability (12.2015 → 03.2017)
The completion of this milestone is expected to document NewTech's long-term durability regarding to lime deposit and regarding to other particles.
The objective of this milestone was met in March 2017. As the overall project duration was extended for a total of 13 months, it was decided to let the durability test run for as long as possible, to get as extensive results as possible.

M4: Commercialization plan and final reporting (09.2016 → 09.2017)
The final reporting is completed at the end of the project September 2017 as planned.

CM1: Presentation at Intersolar Europe2015 and other trade fairs (06.2015 → 03.2017)
The trade fair launch jointly with an I-partner was postponed due to delays in customer testing and commercialization. But the launch was though changed to the higher esteemed trade fair "International Sanitary and Heat fair" (ISH2017).
The objective was met and also included other trade fairs in 2014 – 2017.

CM2: Update of EyeCular Business Plan (12.2015 → 03.2018)
Feedback from the market which is expected to be received October 2017 – March 2018, is crucial to the content of EyeCular's Business plan.

CM3: Signed agreement with first industrial partner (06.2016 → 02.2017))
The signed agreement will work as declaration of intent, describing a framework agreement (prices, delivery etc.) and when EyeCular expects to be able to deliver the first order. The signed agreement should also contain a description of the manufacturer's go-to-market strategy regarding e.g. re-engineering of their product portfolio to fit with the stratifier.
The objective was met when signing the first agreement with Bruns Heiztechnik February 2017.

1.5 Project results and dissemination of results

1.5.1 Prototype development and maturing of NewTech

Several factors were believed to have importance for the performance of NewTech such as material, material thickness, number of layers and the design itself in terms of width and additional cape inside etc.

The tests the first 1½ years were carried out in a transparent polymer test tank with an inner diameter of 240 mm and a height of 1500 mm, see Figure 1. The test tank consists of two cylindrical polymer cylinders separated by an air gap of 25 mm to reduce the heat loss from the tank.

The temperatures of the water at different levels inside the tank were measured by 12 copper/constantan thermocouples, type TT, see Figure 1. The test facility allowed the water to be circulated from the bottom of the tank through a heat source and then back into the tank through the stratifier. The volume flow rate and the temperature of the incoming water were kept constant during a test.

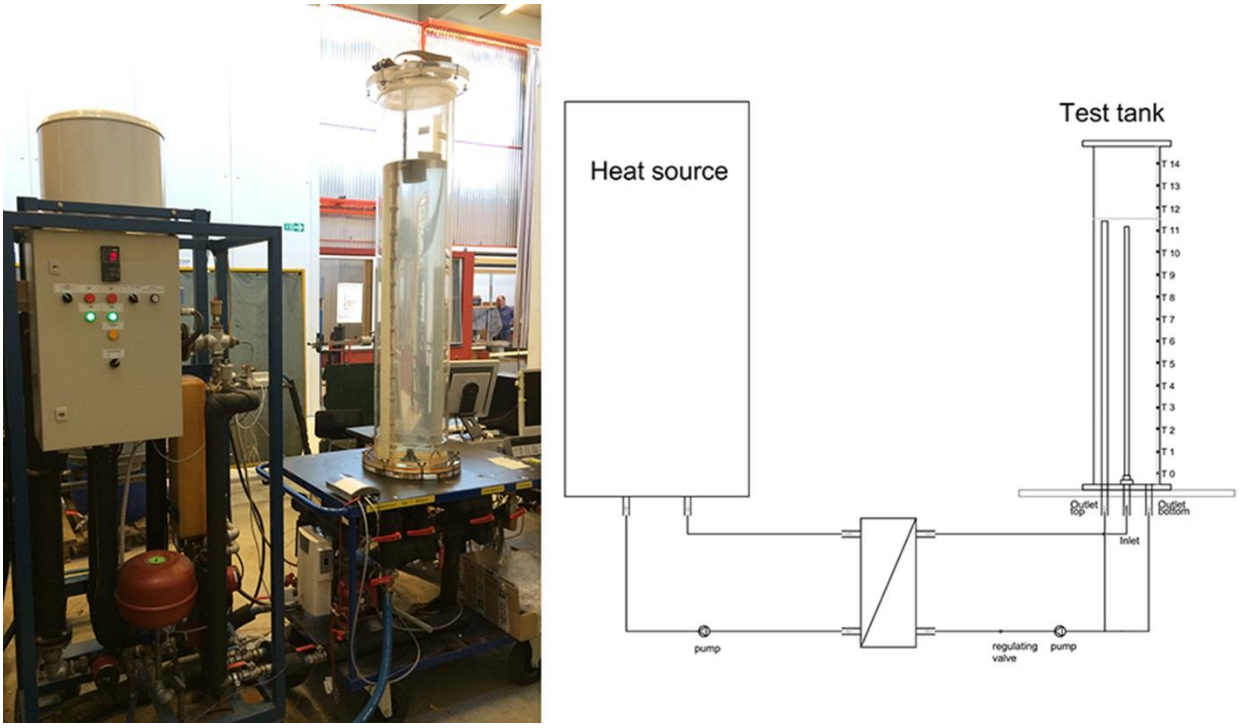

Figure 1. Photo and schematic sketch of polymer test tank with an inlet stratifier connected to a heat storage test facility. The tank has 15 temperature sensors.

The tank was filled with 54 l of water and the entire volume was exchanged during each test. There was air above the water inside the tank, as shown on the schematic sketch in Figure 1.

The tank was heated from a uniform cold temperature of about 20 °C, and the measurements were recorded with a time step of 10 seconds.

All tests started as soon as the warm water from a previous charge test had been replaced by cold water, so that the warm polymer walls only had limited time to release the heat stored in the walls. This assured that all tests were carried out starting with warm tank walls and ending with warm tank walls, and consequently assured energy balance in the tests.

The choice of material for testing was conducted in cooperation with the Technological Institute (TI), which resulted in the closer choice of the material ETFE and mPTFE. The following tests had the purpose to compare ETFE and mPTFE to PP as the baseline material of the original NewTech invention/ prototype.

The materials tested are ETFE, mPTFE and PP, see Figure 2, Figure 3 and Figure 4. The tests are carried out at flowrates of 1, 2, 4 and 6 l/min.

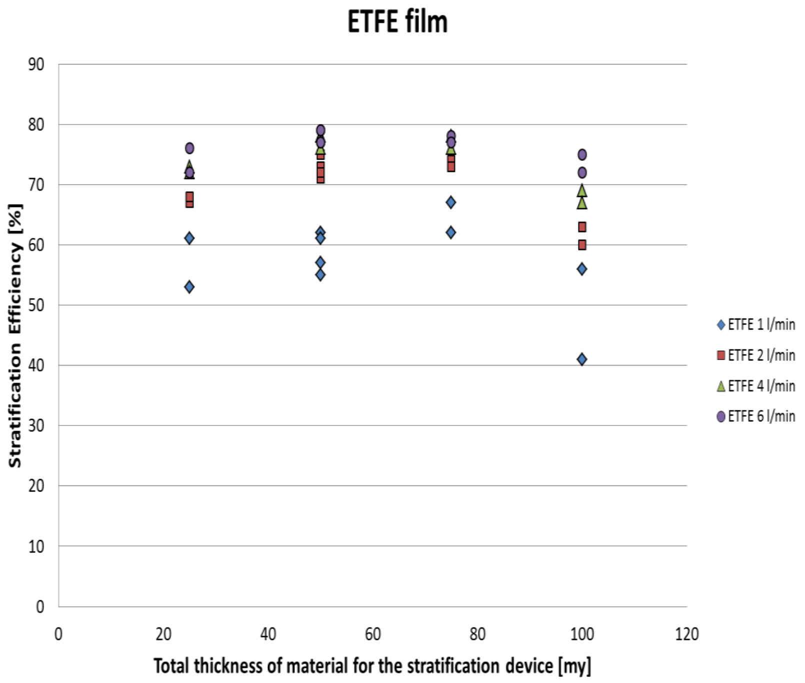

Figure 2 The performance of the material ETFE and thickness.

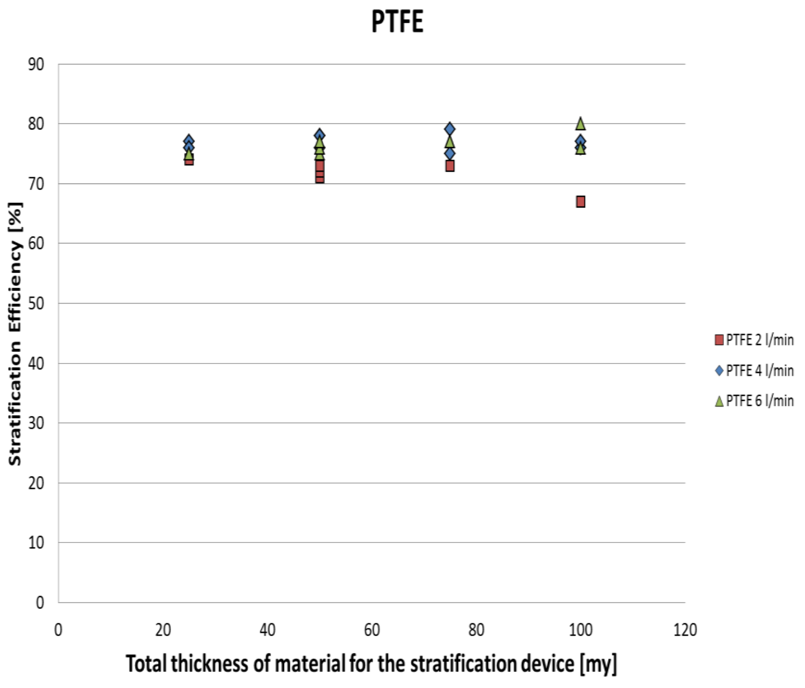

Figure 3 The performance of the material mPTFE and thickness.

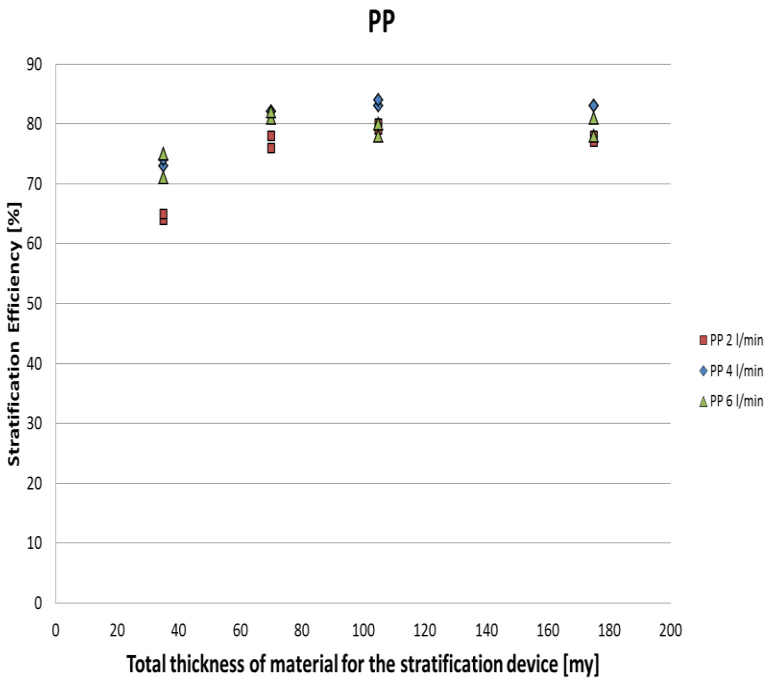

Figure 4 The performance of the material PP and thickness.

The results show that a stratifier in PP will give the best results in terms of stratification efficiency. However, the durability of PP over time is poor (according to TI) which is why mPTFE was initially chosen as the preferred material.

The tests also showed that the performance of mPTFE was less influenced by flowrate and thickness.
Even though mPTFE performed better, ETFE was finally chosen due to its combination of higher weldability, better process ability and price competitiveness. Especially the price competitiveness contributed to choosing ETFE, as this would facilitate the commercialisation of the stratifier. Based on that decision several samples from different producers and thicknesses were evaluated. Eventually, the thickness of 50µm of the German producer Nowofol was decided upon, due to a high durability and functionality.

Test of different inlet stratifiers:
Based on the results from the previous investigations, a NewTech stratifier was produced by EyeCular in order to compare the performance of this stratifier to that of a Solvis stratifier The Solvis solution is a rigid plastic pipe with holes along the pipe. Flaps in front of them establish a one-way valve function.
The tested stratifiers are shown in Figure 5.

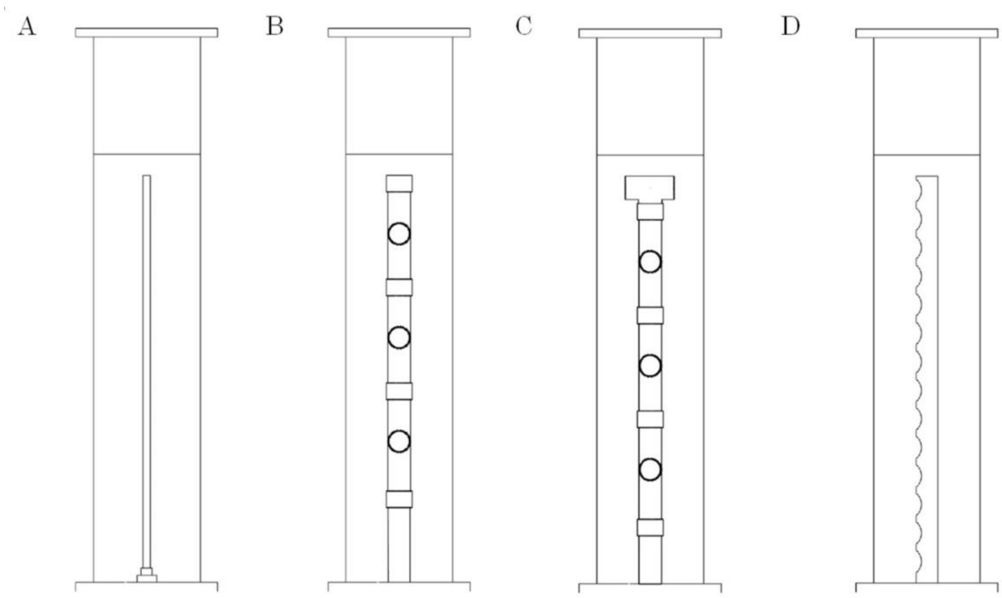

Figure 5. Tested inlet stratifiers. From left to right: PEX pipe, Solvis without T-pipe, Solvis with T-pipe and EyeCular Technologies stratifier.

The stratification efficiency is defined in the paper "Thermal stratification built up in hot water tank with different inlet stratifiers" published in the journal Solar Energy. Figure 6 shows the stratification efficiencies for 12 tests. The stratification efficiencies after a full replacement of the water volume in the 54 l tank ranged from 68% to 92% with the highest efficiencies for the PEX pipe with 92 % at 2 l/min. The thermal stratification for the SOLVIS stratifiers was delayed because of the relatively large water content in the stratifier (about 3 l), which is seen for all flowrates in Figure 6. The stratification efficiencies are higher for 4 l/min than for 2 l/min and 1 l/min.

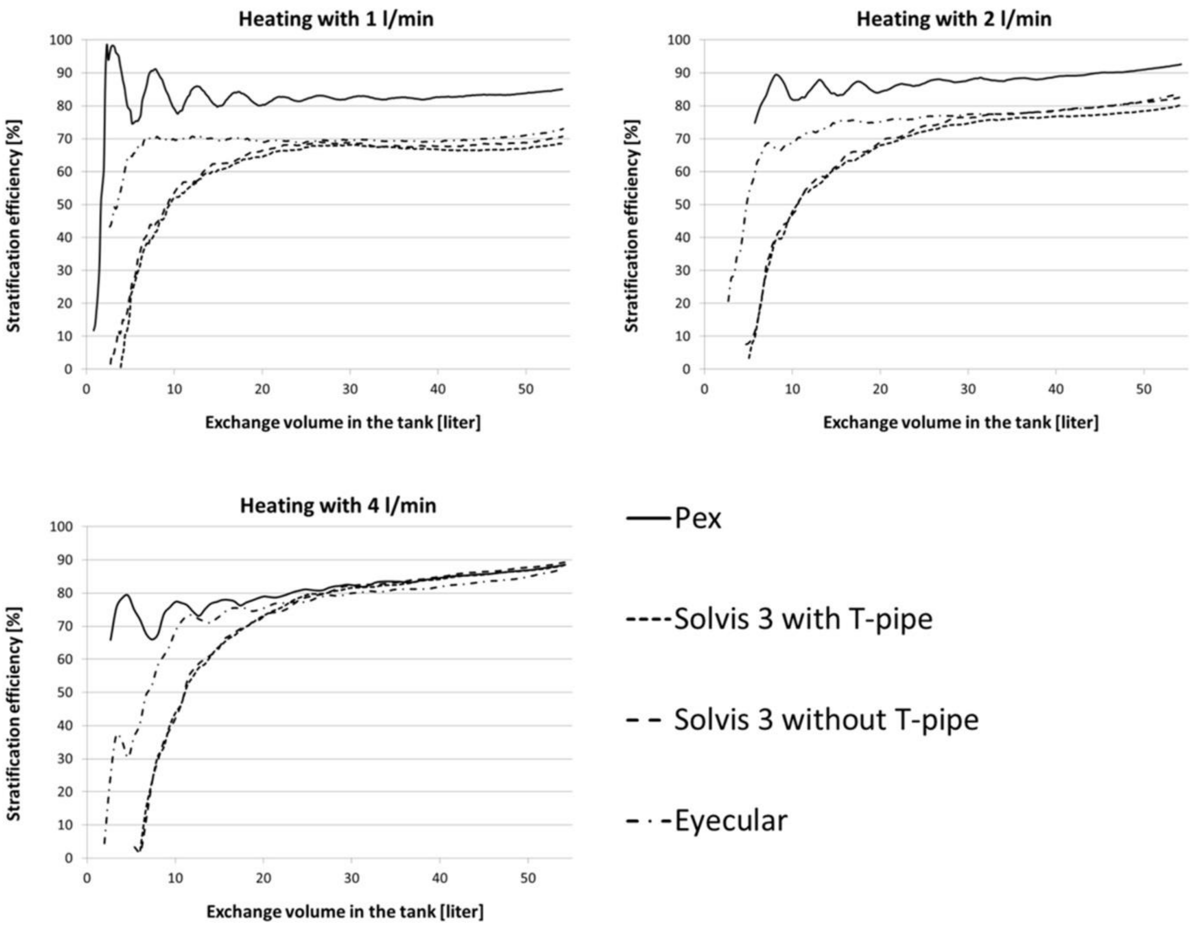

Figure 6. Stratification efficiencies during charge tests for four different inlet stratifiers with a volume flow rate of 1 l/min, 2 l/min and 4 l/min.

The stratification efficiencies of the SOLVIS stratifiers and the EyeCular stratifier were similar, see Table 1. The PEX pipe has as expected the best stratification efficiency at 1 l/min and 2 l/min. At 4 l/min the SOLVIS stratifier has a slightly higher efficiency than the PEX pipe.

The SOLVIS stratifiers and the EyeCular stratifier both performed well at the tested flow rates. At 1 l/min and 2 l/min the best result is achieved with the stratifier from EyeCular, see Table 1. At 4 l/min the best result is with the SOLVIS stratifier without the T-pipe. Of the two SOLVIS stratifiers the one without the T-pipe performs the best compared with the one with the T-pipe, see Table 1.

Table 1 Stratification efficiency after a full replacement of the water volume at flow rate 1 l/min, 2 l/min and 4 l/min.

Tabel 1: Stratification Efficiency of Test Devices

	Flowrate		
	1 l/min	2 l/min	4 l/min
Pex - reference	85 %	92 %	88 %
Solvis with T-pipe	68 %	80 %	88 %
Solvis without T-pipe	70 %	82 %	89 %
EyeCular	72 %	83 %	87 %

1.5.2 Side-by-side testing

Two small solar domestic hot water systems are installed side by side in the solar heating test facilities at the Technical University of Denmark (DTU), Lyngby, Denmark. The systems are identical, with the exceptions of the stratification device and the heat exchanger methods, see Figure 7.

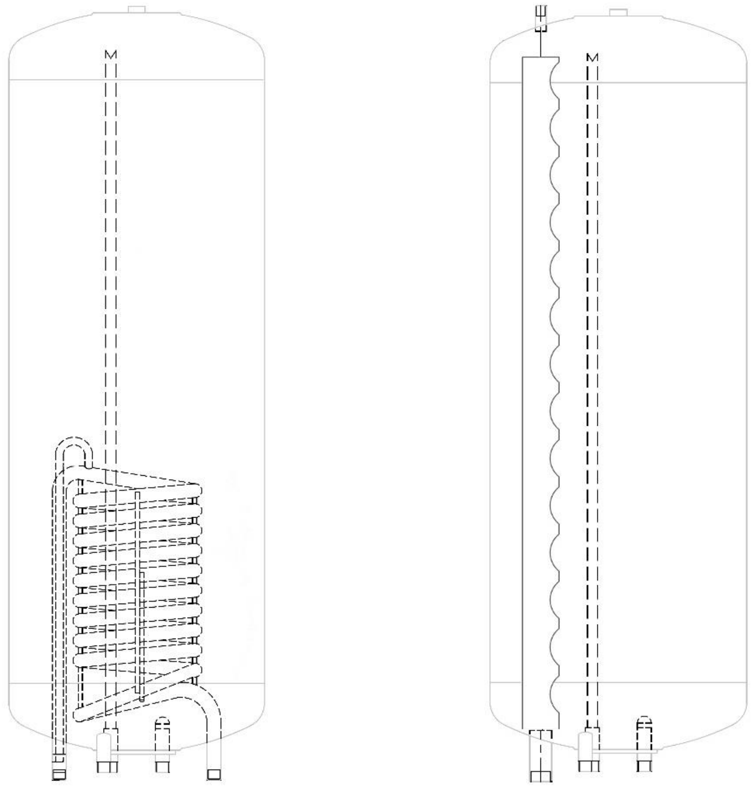

Figure 7 Sketches of the two tanks in the SDHW systems.

The solar collectors for each system have an aperture area of 2.36 m², see Figure 8. The solar collectors are facing south with a tilt of 45°. The data of the collectors are given in Table 2.

Table 2: Data for solar collectors used in the two SDHW systems

Collector type	TLP ACR 2600, Hewalex, Poland
Maximum efficiency	0.827
First order heat loss coefficient	3.247 W/m²K
Second order heat loss coefficient	0.020 W/m²K²
Incidence angle modifier for an incidence angle of 50°	0.94

The daily hot water consumptions for each system is 135 liters heated from 20 °C to 50°C, corresponding to approximately 4.5 kWh. The daily hot water consumption is tapped at 7 am, at noon and at 7 pm in three equal volumes. The tanks, which are produced by METRO THERM A/S, Denmark, have volumes of 255 l, see Figure 7.
One of the systems is a typical marketed small solar domestic hot water system with a built-in heat exchanger spiral in the hot water tank.
The other system has an identical tank but without the spiral heat exchanger. This tank is equipped with a polymer film inlet stratifier developed by EyeCular Technologies ApS.
The specific stratifier model applied in the present test is developed for low flow solar combi systems with flows rates from 2 - 4 l/min. If operated at lower flow rates than 2 l/min, the efficiency of this specific stratifier model will, decrease due to heat loss from the stratifier. Unfortunately, EyeCular had at this point not yet developed a stratifier for flow rates below 2 l/min, let alone a flow rate of 0.5 l/min.
An optimized low flow system operates at a flow rate of 0.15 – 0.20 l/min/m² solar collector. In the present test, the low flow system should therefore ideally be operating at a flow rate of approx. 0.5 l/min. Higher flow rates than 0.5 l/min will reduce the thermal performance of the system somewhat. DTU and EyeCular decided upon a compromising flow rate of 1.0 l/min, still knowing, that this flow rate is not ideal for the stratifier nor the system.
The solar heat is transferred from the solar collector fluid to the DHW water through an external flat plate heat exchanger.

Figure 8 Pictures of the storage tanks and solar collectors in the two SDHW systems.

In both systems the circulation pumps are controlled by differential thermostats based on temperature sensors measuring temperature differences between the outlet from the solar collectors and the bottom of the tanks.
Figure 9 shows the result and as expected the relative performance increases with a decreasing solar fraction. The measurements show that the thermal performance of the system with the stratification device is up to 10 % higher than the thermal performance of the spiral tank system at solar fractions between 40-50 %.

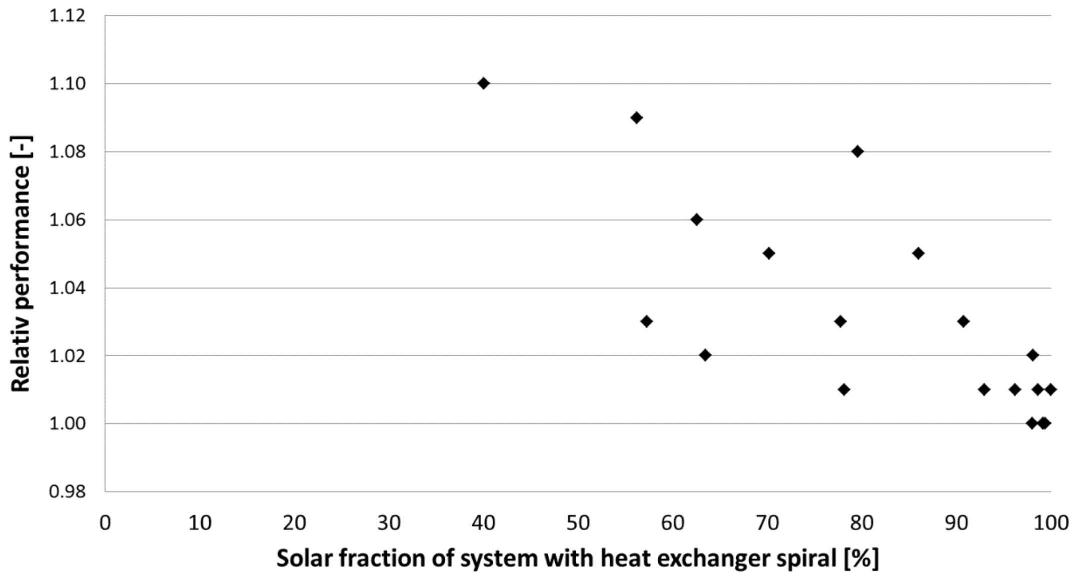

Figure 9 Weekly relative performance of system with stratification device as function of the weekly solar fraction of the spiral tank system

1.5.3 Lifetime testing of the NewTech

The lifetime of inlet stratifiers installed in hot water tanks for solar thermal systems can be influenced by a large number of factors. It is therefore challenging to estimate the lifetime and even to evaluate the lifetime based on accelerated lifetime tests. Particularly the tank design and the operation of the tank will strongly influence the lifetime.
In **solar domestic hot water tanks** the lifetime may be influenced by the quality of the domestic water. The lifetime might be shorter in regions with hard water with high levels of lime content, than in regions with softer water.
In **solar buffer stores** with technical water the lifetime is expected to be higher than the lifetime in solar domestic hot water tanks. Most likely the lifetime in solar buffer tanks the water will be mostly influenced by the amount of dirt and rust accumulating in the storage.
It is expected that the duration of periods with high storage temperatures will influence the lifetime. For increasing duration with high temperatures, the lifetime is expected to decrease.
However, for **solar domestic hot water tanks** it is estimated that the lifetime first of all is influenced by the quantity of lime deposits in the tank. The lime deposits in the tank will be strongly related to the domestic hot water consumption and therefore also to the energy transferred to the tank.
Further, it is assumed that the lifetime in **solar buffer stores** without constant feed of new fresh lime containing water, is primarily influenced by the water volume passing through the inlet stratifier.
The durability of two identical inlet stratifiers from EyeCular has been tested in a laboratory test facility at Department of Civil Engineering, Technical University of

Denmark. One of the inlet stratifiers was tested in a domestic hot water tank and the other inlet stratifier was tested in a hot water buffer tank without replacement of the water. The operation of the heat stores has been accelerated compared to the operation of the heat stores in solar heating systems. In this way, the lifetime of the stratifiers in different solar heating storages can be evaluated by the tests.

The tests were conducted at the Technical University of Denmark in Kgs. Lyngby, Denmark. In Kgs. Lyngby the domestic water is classified as "hard" with a high level of mineral content. The hardness is 21 dH (1 dH = 0.05603 mg/l), which is harder than domestic water in most other parts of Denmark.

Figure 10 and *Figure 11* shows schematic sketches of a domestic hot water tank and a buffer tank with water connected to a laboratory test facility. The monitoring equipment is shown as well. Both hot water tanks are equipped with an inlet stratifier from EyeCular. The inlet stratifiers are made of a high performance flexible polymer film, with a number of openings along its vertical axis. Each tank has a volume of 400 l and is insulated with 100 mm of mineral wool.

The hot water tanks can be heated by the test facility by circulating cold water from the bottom of the tanks through heat exchangers and back into the tank though the inlet stratifier.

The domestic hot water tank can be discharged by tapping hot water from the top of the tank while cold fresh water enters the bottom of the tank. The buffer tank with water can be discharged by pumping hot water from the top of the tank through a heat exchanger, where the water is cooled, and then circulated back to the bottom of the tank. Figure 12 show a photo of the two tanks and the test facility.

By means of energy meters the energies charged to and discharged from the tanks are also determined.

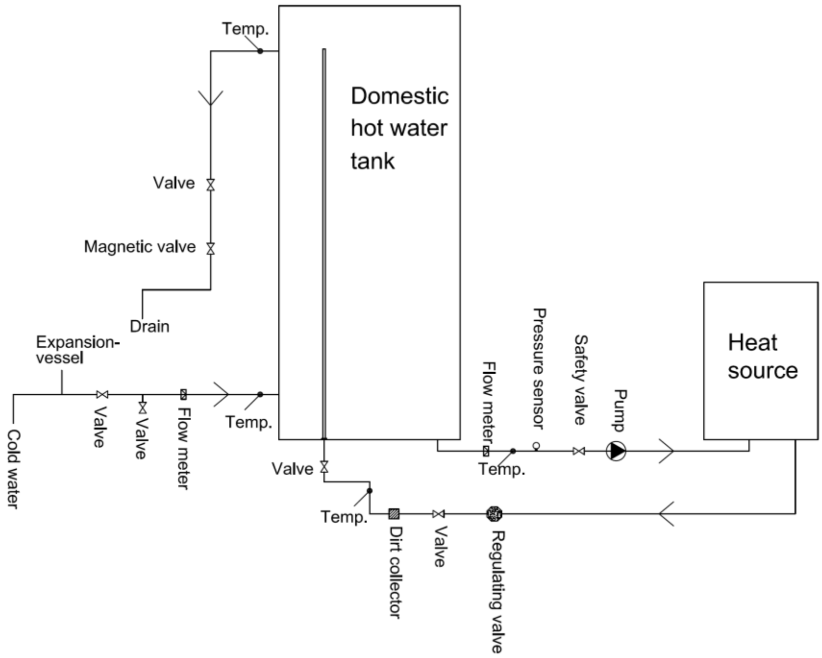

Figure 10 Schematic sketch of domestic hot water tank connected to test facility.

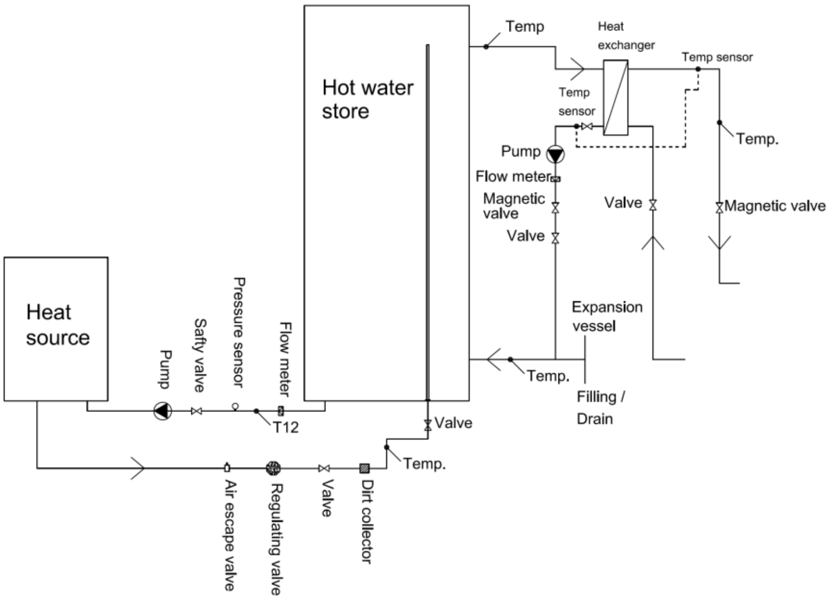

Figure 11 Schematic sketch of buffer tank with water connected to test facility.

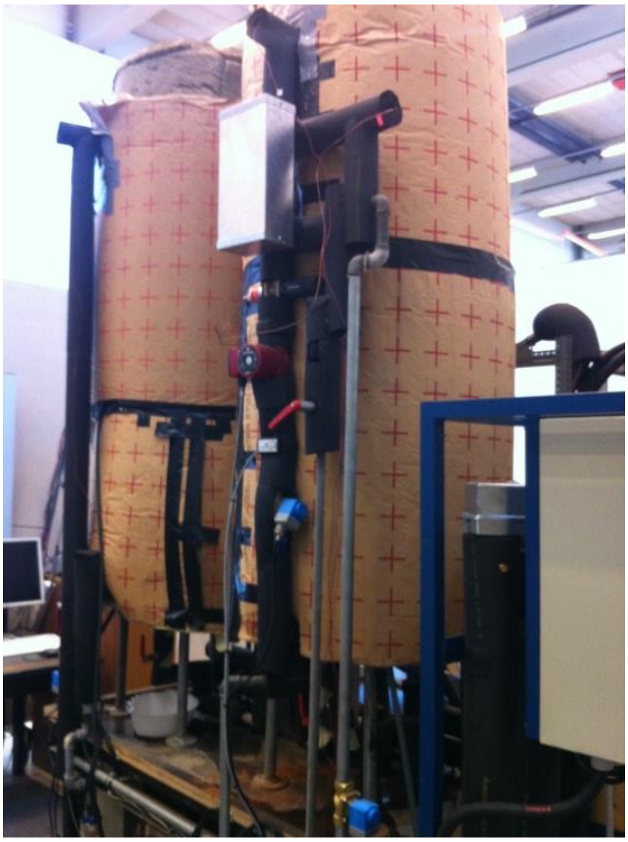

Figure 12 Photo of the two tanks and the test facility. Hot water tank (left) and hot waterstore (right).

The tanks are charged and discharged automatically in a repetitive manner by the use of LabView. The tanks are heated by hot water flowing into the tanks through the inlet stratifiers with a volume flow rate of about 4 l/min. The inlet temperatures are 70 - 75°C for the domestic hot water tank and 65 - 70°C for the buffer storage. The duration of the charge periods are 90 min.
The durability tests started March 13, 2015 and ended on March 20, 2017, with more than 5.000 charge/discharge cycles carried out.

The charge/discharge during the 2 years are shown for both tanks on Figure 13 and Figure 14. It is here evident that the stress the stratifiers are subjected to during the two years does not affect the performance of the stratifiers.
The energy transferred to the domestic hot water tank during one charge period is approximately 20 kWh, and the water volume which has passed though the inlet stratifier during one charge period in the hot water store is between 330 - 360 l.
As mentioned in the introduction, it is assumed that, the lifetime of inlet stratifiers in domestic hot water tanks are first and foremost influenced by the energy transferred to the tank and that the lifetime of inlet stratifiers in buffer tanks with water first and foremost are influenced by the water volume passing through the inlet stratifier.

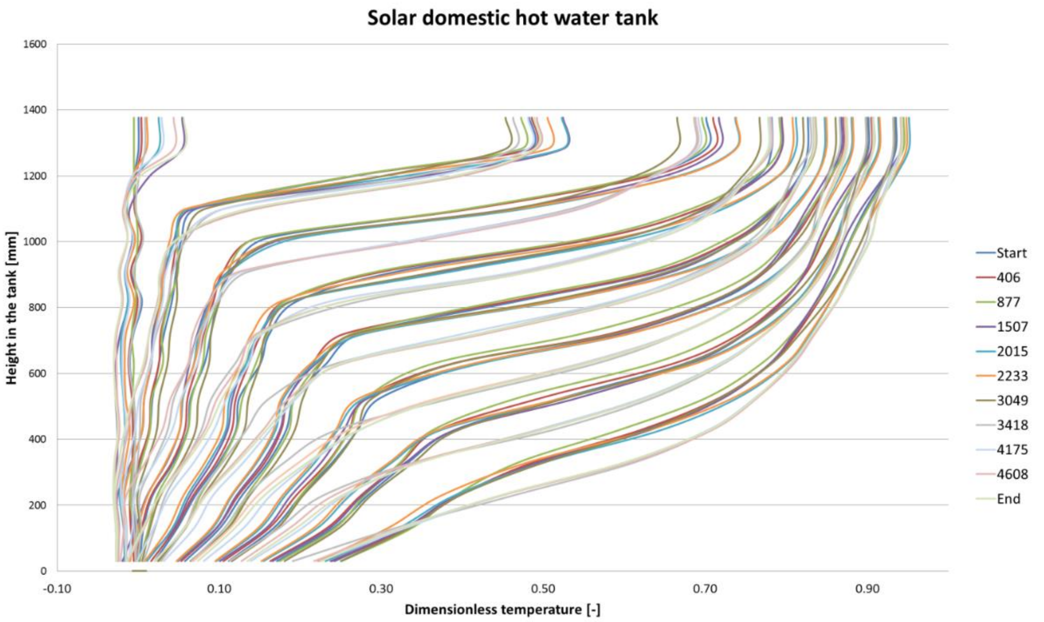

Figure 13 Temperatures for the domestic hot water tank for selected charge periods during the two years of testing.

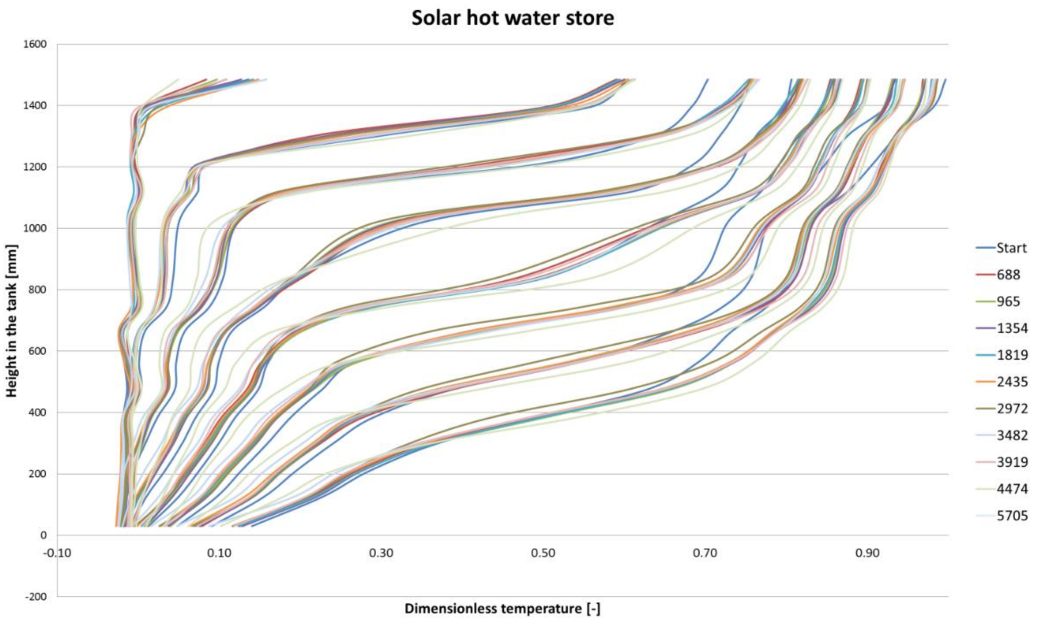

Figure 14 Temperatures for the buffer tank for selected charge periods during the two years of testing.

In Denmark, the typical yearly domestic hot water consumption in a one family house is about 1,700 kWh. The energy quantity transferred to the domestic hot water tank

during the two years of testing is 118,829 kWh. The energy transferred to the domestic hot water tank therefore corresponds to about 70 years of operation in Denmark. In Germany, the typical yearly hot water consumption in a one family house is about 5.800 kWh. The energy transferred to the domestic hot water tank therefore corresponds to about 20 years of operation in Germany.
A suitable volume flow rate in a solar heating system with a buffer storage with thermal stratification is about 0.15 l/min per m² solar collector. The yearly duration of periods with pump flow operation for solar heating systems is about 2.000 hours. The total water volume passing through the inlet stratifier in the buffer tank during the two years of testing is 1.971.617 l. This water volume therefore corresponds to about 18 years of operation for a 6 m² solar heating system and to about 5.5 year of operation for a 20 m² solar heating system.

1.5.4 Mounting solutions

To effectively respond to customer's feedback, EyeCular decided to develop its own test stands. In the course of this project the test stands were used to conduct functionality tests, increase the flow rate and develop the mounting method of NewTech. 3 different mounting systems for comparative testing have been developed: A float-, rod-, and spring -born mounting method.
Float Solution:
The first mounting solution for NewTech was a float, in the course of time consisting of different materials, that was drifting inside the tank thereby keeping NewTech stable and under tension. After thorough investigations of polymers, stainless steels, other steels and solid materials, it was not possible to find a solution which had a high likeliness of being able to sustain a sufficient buoyancy throughout the lifetime of the hot water tanks for a commercializeable cost. The concept was for that reason eventually dropped.
Direct feedback from customers, considering production- feasibility led to the choice of the spring-born method. Possible producers of springs and mounting tools have been researched and contacted. Surpassing different versions, the final version of the topspring is now mounted in a female ½" connection on the upper side of the tank, whereas the feedpipe for charging the stratifier is fixed inside a 2" connection from the side of the tank. The upper ½ "connection is only used to fasten the top spring pulling the stratifier up and keep it under tension. The 2" connection at the bottom, on the other hand, accommodates the feed pipe. One big advantage of this method is the ability to mount NewTech in a readily produced tank from the outside through the connections within less than a minute. From a production process viewpoint, this is a huge competitive advantage to other stratification technologies, that have to be welded/ fixed in the open tank. See the following drawing for specifics:

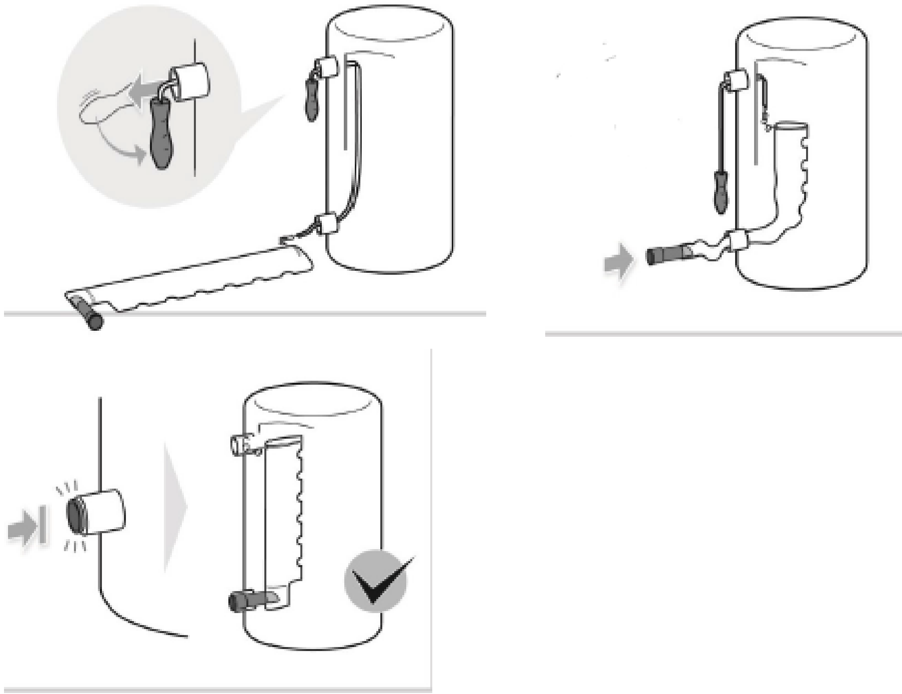

Figure 15: Mounting Method of NewTech (2017)

1.5.5 *Increase of flow rate and change of target group*

Due to the different demands of the below mentioned industrial partners (I-Partners, NewTech has been further developed, to accommodate flowrates of up to 40 l/min. This commenced the continued collaboration with three of the customers. It moreover facilitated to penetrate the market segment of heat pump systems up until 16 kW and higher (with several stratifiers installed), requiring higher flow rates for stratifiers.

The latest innovation of EyeCular technologies is the development of a Stratifier with 2 and more flaps. The picture below shows the 2-sided stratifier that is currently tested with a customer. However, have prototype of a 4 -sided and 6- sided stratifier already been developed in house. Even more flaps are envisaged and will be produced. Using more flaps than one decreases the water velocity in each opening, which is even more beneficial for effective stratification. The flowrate will also be increased until up to 80 l/min.

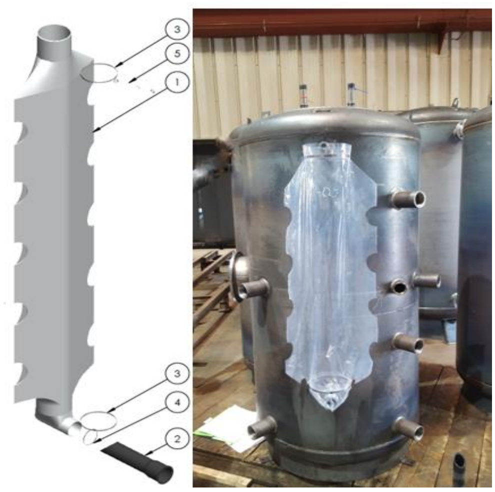

Figure 16: Double Sided Stratifier - Drawing and Installation at a customer

1.5.6 *Testing and Feedback from Industrial Partners*

For acquiring feedback on the feasibility and the capability of the system, several industrial partners were cooperated with. Due to the long duration of their testing initiation and continuous interest on NewTech, the project duration was extended.
Summary of Collaborations:

- Due to confidentiality concerns, the following paragraph was removed in the publicised version of the report. If authorized, ask the Danish Energy Agency for access to the original report. –

1.5.7 Dissemination and publication

DTU

Article in Solar Energy: *'Thermal stratification built up in hot water tank with different inlet stratifiers', Volume 147, 1 May 2017.*

DTU report: *Durability tests of inlet stratifiers from: EyeCular Technologies ApS: Final results after 2 years of accelerated stress tests, Report SR 17-01*

Presentation of the paper*: "Advantages using inlet stratification devices in solar domestic hot water storage tanks"* at EUROSUN 2016 Conference in Palma de Mallorca

Presentation of *"Investigations of stratification in a mantle tank and a tank with flexible inlet stratifier"* at International Renewable Energy Storage Conference in Dusseldorf 2017

Presentation of solar heating system with tank with EyeCular inlet stratifier at IEA Task 54 meeting in Rapperswil May 2017.

Presentation to students at the Technical University of Denmark (2017)

EYECULAR APS

Basics of thermal Stratification in solar thermal systems: Spanggaard, M., Schwaner, T. (2015)

The article compiled by EyeCular Technologies, elaborates on the principles of thermal stratification and implications for solar thermal systems. Five main advantages of stratified solar thermal systems were found: An increased utilization of collectors, due to lower feed temperatures; reduced heat loss from equipment through a lower average temperature; more often comfort temperature through the prevention of mixing in the top zone; Less lime scaling due to less water volume circulating in a stratified tank; smaller tanks are needed for providing a steady comfort temperature.

Heat Pump Systems - Quantification of energy savings: Svindt, A. (2016)

This paper, created by EyeCular Technologies, investigates the implications of stratification for a heat pump system, while also quantifying the costs of energy savings due to improvements. The paper is based on research by the swiss research institute SPF and a test setup by EyeCular. The baseline system, a heat pump system with a fixed inlet was compared to a stratified one by EyeCular. The outcome was a COP increase of 19% for the stratified system resulting in a 16% (= 211€) heating cost reduction for a standard 1-family household with a yearly consumption of 15.000 kWh.

Technical Summary – StratiFlex by EyeCular: Arnold, F., Svindt, A., Spanggaard, M. (2017)
This technical summary, compiled by EyeCular, summarizes all components of NewTech (StratiFlex) including durability certificates, test results and drinking water approval. The first part summarized the durability of ETFE for the film, PP-R for the feedpipe and Duplex steel for the expanders. The second part compiles the function durability, tested by DTU in DHW and technical water. The last part summarizes drinking water approvals for all materials used. The intention of producing such a summary was to be able to present an evidence for the durability, functionality and suitability of NewTech as a reliable component of a commercialized product. EyeCular especially wanted to respond to repeated concerns of customers regarding the durability in operation. This facilitated the marketing and commercialization process already, as credible evidence for a quality product can be presented.

<u>Trade fairs and marketing measures:</u>

Speaking from experience we know that a technology like NewTech can attract many curious companies and private persons. EyeCular also actively approached companies on fairs to talk to them about the advantages of stratification and their existing systems. Trade fairs, such as the MCE in Milan 2016, the IFH Intherm in Nürnberg in April 2016 and the ISH in Frankfurt in March 2017 formed the most important forums for EyeCular's trade fair activities. The Milano fair created relationships to the companies *(-confidential-)*, whereas Nürnberg initiated the contact to *(-confidential-)* and Bruns. Both of which we are in a good research and development process with. On ISH 2017 EyeCular launched on the market, exhibiting together with Bruns. They tested NewTech in their systems thoroughly and presented the positive stratification efficiency to their clients on ISH. The first Heat Pump tank combination will be launched with *(-confidential-)* and Bruns in Summer 2018. Other development projects with Bruns clients are currently initiated.
ISH 2017 also managed to tighten relationships with *(-confidential-)*.
The fast testing in September-October 2017 and application process with *(-confidential-)* is a direct result of the excellent communication and planning on ISH. The second development project with the application case *(-confidential-)* with *(-confidential-)* was also facilitated by constructive conversation and successful networking on the fair.

1.6 Utilization of project results

Many of the project outcomes were already utilized in the form of paper publications, conference presentations, trade fair exhibitions. The test results are the foundation of the NewTech version that we see today, which is already in the phase for commercialization. The fastest pace and the biggest likelihood for industrial scale commercialization are in cooperation with the companies mentioned in section 4, in compliance with the indicated market launch dates. As already mentioned, has the EUDP project enabled to finalize a product with durable materials, feasible mounting methods, and fruitful industrial cooperation. The stratification efficiency and energy savings of NewTech, also in comparison to competing products was proven; the right materials chosen; the durability ensured. A main step was furthermore the improvement of NewTech for flowrates to 40l/min, which enabled responding to market dynamics and opening to the heat pump sector as an additional target group. Developing different mounting methods based on feedback from the industrial partners, managed to shape the implementation of NewTech as industrially feasible as possible. All these improvements and tests developed NewTech to a stratification device that is

unique in terms of stratification efficiency, price-competitiveness and durability. EyeCular has not yet seen a technology that can compete in all three regards with NewTech. Thereby, the commercialization and canvassing of clients will be extended beyond the abovementioned cases. NewTech will in this perspective be sold to OEMs and system manufacturers as an additional part, that is assembled into hot water storage tanks. With the specific connection requirements, tanks must be re-engineered to accommodate NewTech. Specific modification of tanks for NewTech has also been shown to achieve better system performances. EyeCular is and will therefore be part of the redevelopment process in cooperation with their customers. Competition to NewTech is given by technologies like *(-confidential-)*. However, are none of these systems as temperature sensitive, easy to install and first and foremost inexpensive.
With this competitive advantage, EyeCular has a good foundation to commercialize NewTech in the future. According to the 2017 Technavio market report, the global air-sourced heat pump market is expected to grow with more than 10% yearly within the next 5 years. EyeCular will accordingly focus on addressing heat pump clients, while also keeping up the collaboration with interested solar thermal technology producers. As soon as the solar thermal market in Europe recovers, the available R&D budget of clients will increase and EyeCular will be able to also work with Solar systems to the same extent.

EyeCular has applied for several patents for NewTech and is in the process of approval.
The project results of developing a product for heating systems, achieving significant energy savings, responds to the need for energy efficient, and low-carbon heating technologies, to meet national (Energy 2050), European (2030 climate and energy framework) and global (EU INDC to COP 21) CO2 reduction commitments.
With NewTech making solar thermal energy more efficient, it supports the aim of creating cost effective and cost competitive renewable energy sources.

In the case of solar energy, the stratifier achieves this in different ways:

1) By establishing thermal stratification in solar tank during periods with collector operation, the comfort temperature for DHW and heating is provided more often. Less use of auxiliary energy from e.g. fossil sources is needed to provide the comfort temperature.
2) The stratifier increases the timespan where the solar system can "harvest" energy from the sun – also in morning and evening hours. Again, less auxiliary energy is needed.
3) Through preventing mixing, the average temperature in the system is lower, wherefore heat losses in pipes and appliances are also lower, increasing the overall thermal performance of the system.

In the case of heat pumps, the following benefits of stratification have been observed:

1) Through a lower average feed temperature, the electricity consumption of the heat pump compressor is reduced, increasing the COP of the system up to 20%. Less auxiliary energy is needed to cover the energy demand of households.
2) Similar to point 1 for solar systems, the comfort temperatures can be offered more often, decreasing the need for auxiliary energy.
3) Similar to point 3 for solar systems, the average temperature in the system is reduced, decreasing heat losses.

Improving the performance of heat pump systems, NewTech is decreasing the dependence from fossil fuels, even more with the share of renewable energy in the electricity grid growing. With heat pumps only using electricity, the possibility of including heat pumps and storage tanks into smart grids can provide energy storage capacity and outbalance production/demand variability. Especially facing Denmark's dominating electricity production by wind power of over 40%, this can be an asset.

The project's knowledge has been passed on to the swiss institute SPF in Rapperswill, in form of a presentation. See the dissemination paragraph.

1.7 Project conclusion and perspective

As previously mentioned, the EUDP project facilitated developing a unique, commercialisable product, significantly increasing the performance of solar thermal and heat pump systems. Regardless of NewTech's proof of concept, the market introduction of such a product is time intensive. It takes work convincing companies of the necessity of such a product, and even when that step is surpassed starting to initiate an R&D project with them. The EUDP project was started with little interaction between research and market, resulting in a product that needed several changes and adaptions according to customer demands. The main take-away for EyeCular Technologies here is, that products should be developed on request from the market. This was even enhanced by the market's limited knowledge of thermal stratification and a rather stubborn attitude regarding innovation of European heating systems manufacturers. EyeCular has however faced and countered these challenges well and is currently progressing fast with customers and planned sales in mid-2018.

Annex

1. Structural change of the project
2. Durability tests for inlet stratifiers
3. StratiFlex Technical Summary
4. Thermal stratification built up in hot water tank with different inlet Stratifiers
5. 2016 Euro Sun final paper
6. Stratification in solar thermal systems
7. Heat Pump Systems – Quantification of energy savings