Final report

1.1 Project details

Project title	IEA Task 54 Price reduction of solar thermal systems
Project identification (program abbrev. and file)	Task 54
Name of the programme which has funded the project	EUDP
Project managing company/institution (name and address)	Department of Civil Engineering, Technical University of Denmark. Brovej, building 118, 2800 Kgs. Lyngby
Project partners	SolarKey Int.
CVR (central business register)	30 06 09 46
Date for submission	19/3-2018

1.2 Short description of project objective and results

The main aim of the project is to reduce the price of solar heating systems. The project is the Danish part of the International Energy Agency SHC Programme Task 54 project Price reduction of solar thermal systems with focus on:
- Contributions to the international project: A joint method to determine Levelised Cost of Heat for solar heating systems was developed. The method is the basis for fair comparisons of different solar heating systems
- Low flow solar heating systems with a heat storage with a polymer inlet stratifier creating a good thermal stratification in the heat storage. The system has lower levelised cost of heat than traditional solar heating systems
- Investigations on inexpensive heat stores consisting of pressureless plastic tanks with built in standard hot water tanks.

Projektets overordnede formål er at billiggøre solvarmeanlæg. Projektet udgør den danske del af IEA (International Energy Agency) SHC (Solar Heating & Cooling) Programme Task 54 projektet Price reduction of solar thermal systems med fokus på:
-Deltagelse i det internationale projekt. Blandt andet blev der bidraget til udvikling af en fælles metode til bestemmelse af varmeprisen for solvarmeanlæg. Metoden er værdifuld ved sammenligning af forskellige solvarmeanlæg
-Low flow solvarmeanlæg med varmtvandsbeholder med polymer stratifikationsindløbsrør der opbygger en god temperaturlagdeling i beholderen. Anlægget har en lavere varmepris end traditionelle solvarmeanlæg
-Undersøgelser af billige varmelagre bestående af trykløse plastbeholdere med indbyggede standard varmtvandsbeholdere.

1.3 Executive summary

The project is the Danish part of the IEA (International Energy Agency) SHC (Solar Heating & Cooling) Programme Task 54 project Price reduction of solar thermal systems. Contributions to the international project were given. A new joint method to determine levelised cost of heat for solar heating systems was developed together with partners from the project. A questionnaire on installation of solar heating systems was prepared and filled in in a coop-

eration with the Danish solar heating association. Based on the questionnaire, current obstacles for an efficient and time saving installation of solar heating systems were identified.

Investigations of a low flow solar domestic hot water system with a hot water tank with a polymer inlet stratifier creating a good thermal stratification in the hot water tank was investigated in parallel with a traditional solar domestic hot water system. The inlet stratifier is manufactured by EyeCular Technologies ApS. The system with the tank with the inlet stratifier has a somewhat lower levelised cost of heat than traditional solar heating system.

Theoretical investigations on heat stores consisting of pressureless plastic tanks with a built in standard hot water tank were carried out. A good thermal stratification can be achieved in the heat stores under typical operation. Therefore solar heating systems with such heat stores will have high thermal performances. Further, such heat stores can also be economically attractive compared to traditional solar heat storages.

It is expected that the project results will motivate manufacturers to develop improved marketed solar heating systems with reduced levelised cost of heat and that these systems will be so attractive that the market for individual solar heating systems for buildings will increase.

1.4 Project objectives

The overall aim of the project is to reduce the price of solar heating systems. The price reduction shall be achieved by use of simplified system designs, cost-efficient materials, standardized and prefabricated easy to install components and reduced maintenance and operation costs.

The project is the Danish part of the International Energy Agency SHC Programme Task 54 project Price reduction of solar thermal systems for the period 2016-2017. The work includes participation in the following subtasks:

Subtask A: Market success factors and cost analyses

Subtask B: System design, installation, operation and maintenance

Subtask C: Cost-efficient materials, production processes and components

Subtask D: Information, dissemination and stakeholder involvement

Danish participants attended the four experts meetings during 2016-2017. A workshop was organised to inform the Danish solar industry about the project and about the activities of the international partners.

The Danish activities were both on solar domestic hot water systems and on solar combi systems with special focus on:

- Contributions to the international project. Among other things, a joint new method to determine Levelised Cost of Heat for solar heating systems was developed. Further, an info sheet on the method was prepared. The method can be used to make a fair comparison of different solar heating systems. Further, to get an idea of the final part of the value chain, a questionnaire on the installation effort to make cost structures more transparent was launched. The questionnaire helped to understand current obstacles for an efficient and time saving installation of solar heating systems. The installation questionnaire was filled in with Danish experience in cooperation with the Danish solar heating association.

- Investigations on a low flow solar domestic hot water system with a hot water tank with a polymer inlet stratifier creating a good thermal stratification in hot water tank. The system was investigated in parallel with a standard solar domestic hot water system. The low flow system has a somewhat lower levelised cost of heat than the standard solar heating systems

- Theoretical investigations on heat stores consisting of pressureless plastic tanks with a built in standard hot water tank. Such heat stores can be economically attractive compared to traditional solar heat storages, and the investigations indicate that solar heating systems with these heat stores can have high thermal performances.

The milestones agreed upon were fulfilled:
A.1: Definition of reference system. A Danish reference system was defined.
A.2: Cost analyse of reference system. The analyse was carried out in cooperation with the Danish solar heating association.
A.6: The boundary conditions for the Danish systems were defined.
Based on the above mentioned milestones an info sheet on the Danish reference system was worked out.
B.1: Definition of standard components. Standard components were defined.
C.1: Methods for cost reduction. Investigations on two approaches were carried out: Low flow solar heating systems with hot water tanks with a polymer inlet stratifier and inexpensive heat storages based on pressureless polymer tanks with a built in standard domestic hot water tank. An info sheet on a low flow solar domestic hot water system with a hot water tank with a built in inlet polymer stratifier from EyeCular Technologies ApS was worked out.
D.1: Participation in international workshop. Workshop attended in Linz, Austria, October, 2017.
D.2: Danish workshop. Workshop with information on the project arranged December 14, 2017 at the Technical University of Denmark, Kgs. Lyngby with 23 interested participants.
D.5 Homepage. Contributions prepared to the project homepage: http://task54.iea-shc.org/
D.6: Newsletter. Contribution prepared to project newsletter.

The project was carried out as originally planned.

1.5 Project results and dissemination of results

The project is the Danish part of the IEA (International Energy Agency) SHC (Solar Heating & Cooling) Programme Task 54 project Price reduction of solar thermal systems. Contributions to the international project were given.

To evaluate the cost of heat produced by solar heating systems is an important step in order to compare this technology with other energy systems. Whereas in the power sector the cost of produced electricity is systematically used to compare different solutions, there is so far no clear methodology applicable to the heat sector. Therefore a new joint method to determine levelised cost of heat for solar heating systems was developed together with partners from the project. The FRoNT project [1] laid the foundations for a general method applicable to every heating technology.

Based on [1] and [2] the levelized cost of heat for solar heating systems can be derived from the following formula:

$$LCOH = \frac{I_0 + \sum_{t=0}^{T} \frac{C_t(1-TR) - DEP_t \cdot TR - S_t - RV}{(1+r)^t}}{\sum_{t=1}^{T} \frac{E_t}{(1+r)^t}}$$

where:

LCOH: Levelised cost of heat, €/kWh

I0: Initial investment, €

Ct: Operation and maintenance costs (year t), €

TR: Corporate tax rate, %

DEPt: Asset depreciation (year t), €

St: Subsidies and incentives (year t), €

RV: residual value, €

Et: Saved final energy (year t), kWh

r: Discount rate, %

T: Period of analysis, year

The calculation of the LCOH for solar heating systems requires the definition of a reference "conventional heating system". This reference is a theoretical heating system which would supply the same amount of energy to the end user as the solar heating system, but without solar assistance. More information on the developed method are given in [3] and [4].

A questionnaire on installation of solar heating systems was prepared and filled in in a cooperation with the Danish solar heating association. Based on the questionnaire, current obstacles for an efficient and time saving installation of solar heating systems were identified.

Investigations of a low flow solar domestic hot water system with a hot water tank with a polymer inlet stratifier creating a good thermal stratification in the hot water tank was investigated in parallel with a traditional solar domestic hot water system. The inlet stratifier is manufactured by EyeCular Technologies ApS. Figure 1 show schematically sketches of the traditional solar heating system (left) and of the low flow solar heating system with the hot water tank with the inlet stratifier (right).

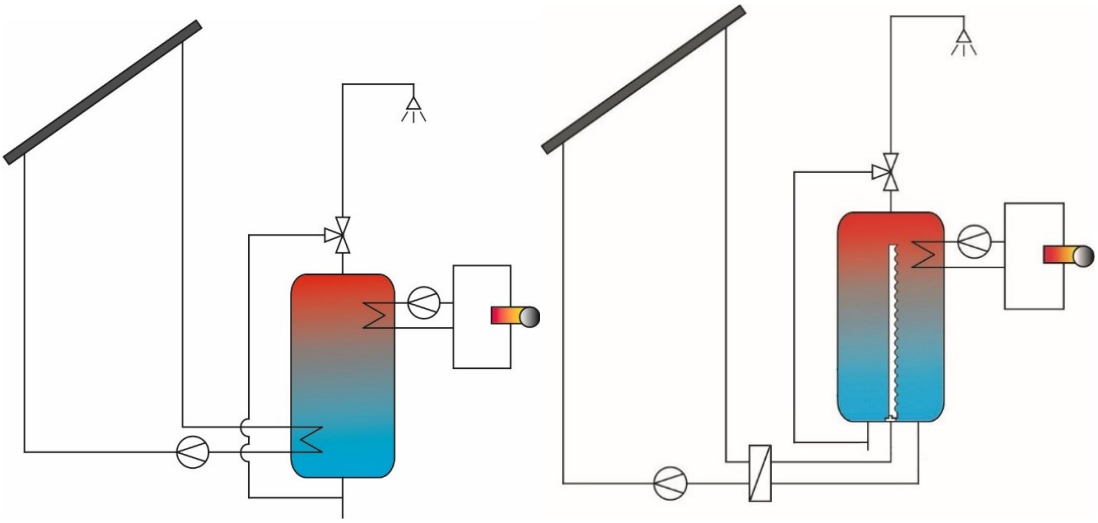


Figure 1. Schematically sketches of investigated solar heating systems.

The system with the tank with the inlet stratifier has a somewhat lower levelised cost of heat than the traditional solar heating system. More information on the investigations are available on the info sheets and in the project newsletter available on the project homepage [5], [6].

Theoretical investigations on heat stores consisting of pressureless plastic tanks with a built in standard domestic hot water tank were carried out. The investigations were carried out by means of CFD (Computational Fluid Dynamics) calculations using ANSYS. Figure 2 shows the mesh used in the calculations for the heat storage consisting of an outer polymer tank and an inner domestic hot water tank. Water circulating through the outer tank, with the inlet in the middle on the left hand side and the outlet at the bottom at the right side, transfer solar heat to the heat storage. A volume flow rate of 0.6 l/min, a constant inlet temperature of 60°C and a uniform start temperature for the heat storage of 10°C are assumed. Figure 3 show calculated water velocities in the heat storage and figure 4 show calculated temperatures in the heat storage after 0, 1, 2, 3, 4, 5, 6 and 7 hours of the heating.

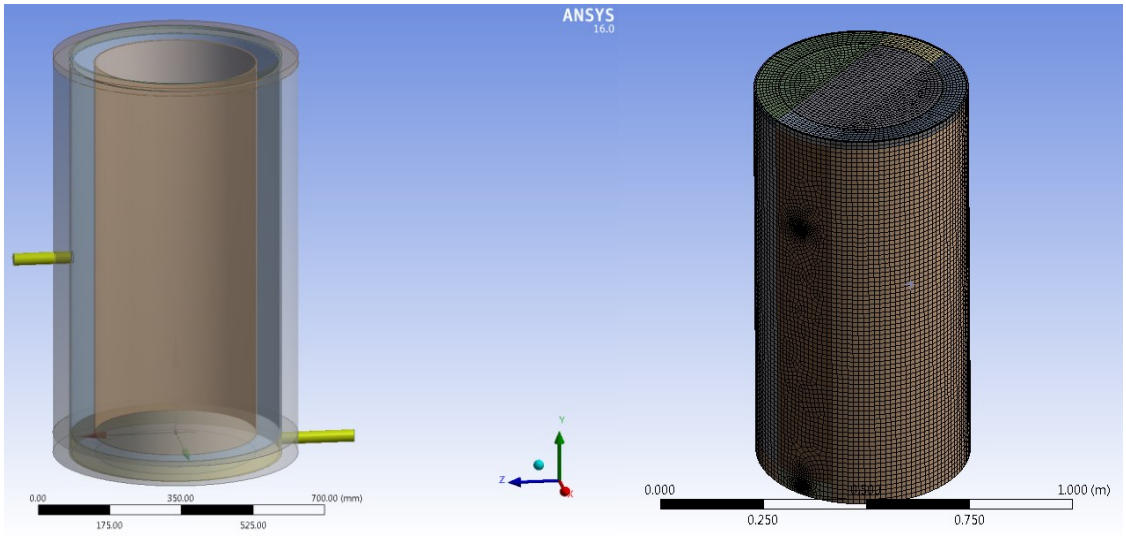


Figure 2. Mesh of tank in tank heat storage.

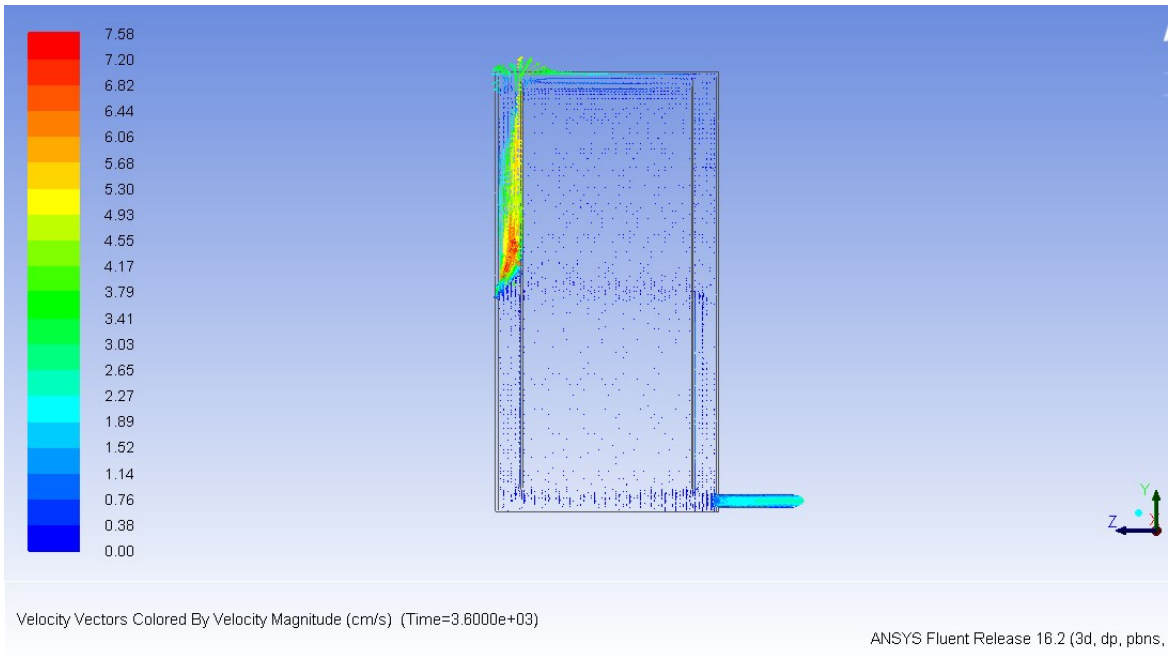
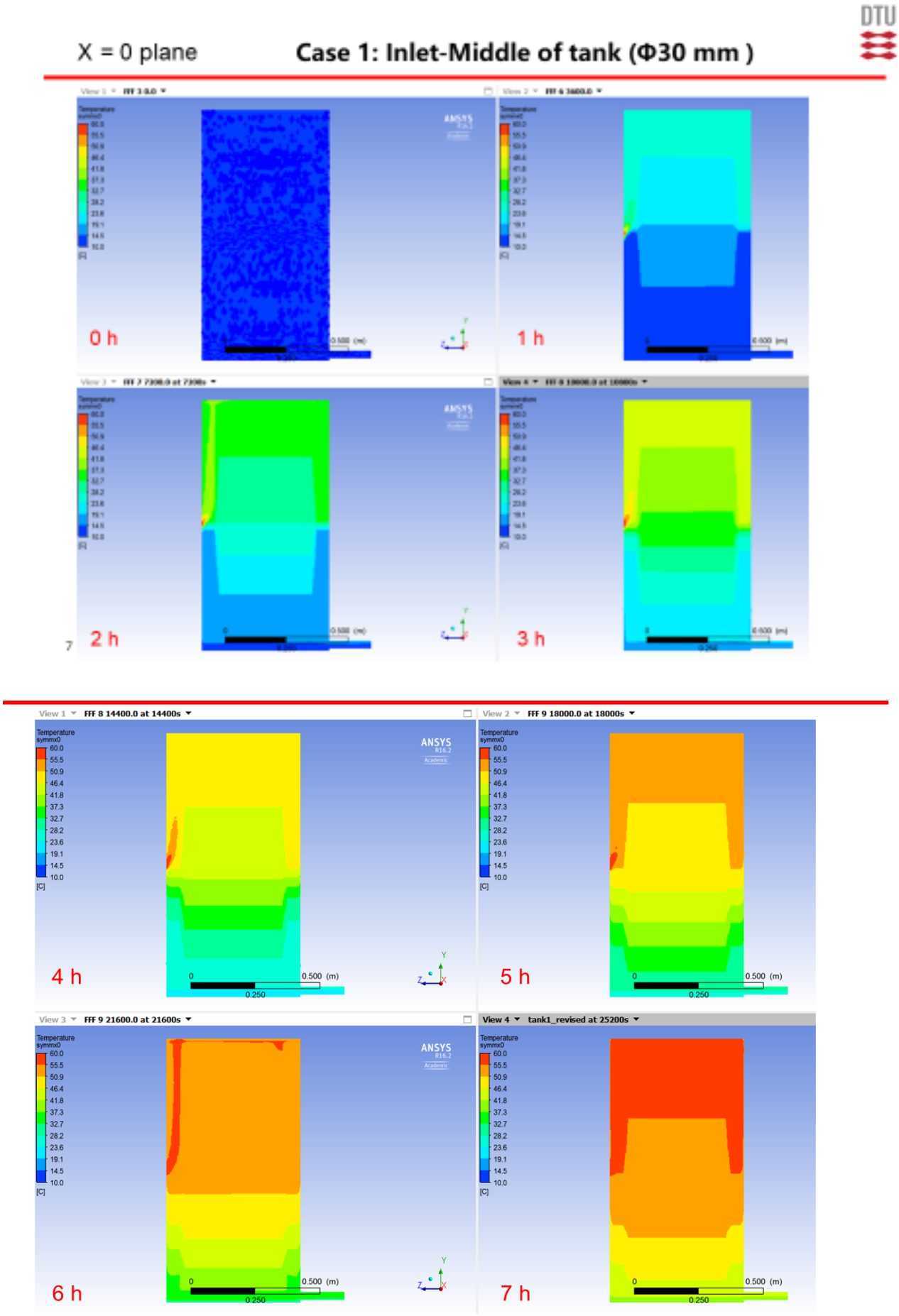


Figure 3. Water velocities in the heat storage during charge.



Figur 4. Heat storage temperatures during charge.

From figure 4 is seen that a good thermal stratification can be achieved in the heat storage under typical operation. Therefore solar heating systems with such heat stores will have high thermal performances. Further, such heat stores can also be economically attractive compared to traditional solar heat storages. More information on the investigations will be available soon [7].

It is expected that the new developed method to determine levelised cost of heat for solar heating systems will be used in the future, not only to make a fair comparison of differently designed solar heating systems. It is also expected that the method can be further developed, so that it can be used for fair comparisons of different energy systems covering our heat demand.

Further, it is expected, that the analyses of the questionnaire on installation of solar heating systems will motivate manufacturers to develop prefabricated easy to install components for solar heating systems. Such components are of vital importance in order to make solar heating systems economically attractive for consumers.

It is also expected that manufacturers based on the investigations of the low flow solar domestic hot water system with the hot water tank with the inlet stratifier will be motivated to further develop solar heating systems making use of the attractive low flow principle and hot water tanks with a high degree of thermal stratification. Such systems will have a much lower levelised cost of heat than traditional solar heating systems marketed today.

Finally, it is expected that manufacturers will be inspired by the investigations of the heat storages consisting of pressureless plastic tanks with a built in standard domestic hot water tank. Use of polymer heat storages offer a potential for decreased costs of solar heating systems and consequently decreased levelised cost of heat for solar heating systems.

The objectives of the project were realised. The main reasons for high levelised cost of heat for individual solar heating systems for buildings were identified. Also, ways to reduce the levelised cost of heat for solar heating systems were pointed out. Solar heating systems with reduced levelised cost of heat can be achieved by use of simplified system designs, by use of the attractive low flow principle, by use of cost-efficient materials such as polymers, by use of standard components and prefabricated easy to install components and by use of system designs with reduced maintenance and operation costs. Hopefully, manufacturers will be inspired by the project results in connection with their efforts to develop improved marketed solar heating systems.

So far no increased turnover, exports or employment resulted from the project. It is expected that manufacturers using the project results can develop improved solar heating systems resulting in an increased number of installed solar heating systems. This can in the future result in increased turnover, exports and employment.

The project results were disseminated on the project homepage inclusive info sheets, by means of project newsletters, by a presentation at the OTTI - 27. Symposium Thermische Solarenergie Conference in Bad Staffelstein, Germany in 2017 and at a workshop at the Technical University of Denmark in 2017. Further, a paper on the developed method to determine levelised cost of heat for solar heating systems is under preparation in a cooperation with the project partners for a scientific journal [8]. Finally, a paper on the investigations of the tank in tank heat storage is also under preparation for a scientific journal.

1.6 Utilization of project results

The joint method to determine the levelised cost of heat is valuable not only by comparison of different solar heating systems. The method will in the future also be used to determine the suitablility of different energy systems to cover heat demands.

Further it is expected, that manufacturers will be inspired by the project results in connection with their efforts to develop improved marketed solar heating systems with reduced levelised cost of heat. This can result in an increased number of installed solar heating systems contributing to a sustainable energy future.

No patents resulted from the project. PhD students have not been working in the project.

1.7 Project conclusion and perspective

The main reasons for high levelised cost of heat for individual solar heating systems for buildings were identified.

Ways to reduce the levelised cost of heat for solar heating systems were pointed out.

Solar heating systems with reduced levelised cost of heat can be developed by use of simplified system designs, by use of the attractive low flow principle, by use of cost-efficient materials such as polymers, by use of standard components and prefabricated easy to install components and by use of system designs with reduced maintenance and operation costs.

Hopefully, manufacturers will be inspired by the project results in connection with their efforts to develop improved marketed solar heating systems.

References

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[7] Deng, J., Tian, Z., Fan, J., Furbo, S., 2018. Establishment of thermal stratification during heat charge in a tank-in-tank unit with an outer plastic tank as a cost-efficient DHW storage. Will be submitted to Solar Energy.

[8] Louvet, Y., Fischer, S., Furbo, S., Mugnier, D., Philippen, D., Ramschak, T., Vajen, K., 2018. Economic comparison of reference solar thermal systems for households in five European countries. Will be submitted to Solar Energy.

Annex

Project homepage: http://task54.iea-shc.org/about-project
Project information, reports, papers, publications, info sheets, newsletters etc. are available on the homepage.
The international project will continue until the end of 2018.

Presentations from the workshop at the Technical University of Denmark available on the homepage:
http://www.solvarme.byg.dtu.dk/research/research-projects/project-presentations