A comprehensive approach for modelling horizontal diffuse radiation, direct normal irradiance and total tilted solar radiation based on global radiation under Danish climate conditions

A novel combined solar heating plant with flat plate collectors (FPC) and parabolic trough collectors (PTC) was constructed and put into operation in Taars, 30 km north of Aalborg, Denmark in August 2015. To assess the thermal performance of the solar heating plant, global radiation, direct normal irradiance (DNI) and total radiation on the tilted collector plane of the flat plate collector field were measured. To determine the accuracy of the measurements, the calculated solar radiations, including horizontal diffuse radiation, DNI and total tilted solar radiation with seven empirical models, were compared each month based on an hourly time step. In addition, the split of measured global radiation into diffuse and beam radiation based on a model developed by DTU (Technical University of Denmark) and the Reduced Reindl correlation model was investigated. A new method of combining empirical models, only based on measured global radiation, was proposed for estimating hourly total radiation on tilted surfaces. The results showed that the DTU model could be used to calculate diffuse radiation on the horizontal surface, and that the anisotropic models (Perez I and Perez II) were the most accurate for calculation of total radiation on tilted collector surfaces based only on global radiation under Danish climate conditions. The proposed method was used to determine reliable horizontal diffuse radiation, DNI and total tilted radiation with only the measurement of global radiation. Only a small difference compared to measured data, was found. The proposed method was cost-effective and needed fewer measurements to obtain reliable DNI and total radiation on the tilted plane. This method may be extended to other Nordic areas that have similar weather.
Analysis and validation of a quasi-dynamic model for a solar collector field with flat plate collectors and parabolic trough collectors in series for district heating

A quasi-dynamic TRNSYS simulation model for a solar collector field with flat plate collectors and parabolic trough collectors in series was described and validated. A simplified method was implemented in TRNSYS in order to carry out long-term energy production analyses of the whole solar heating plant. The advantages of the model include faster
computation with fewer resources, flexibility of different collector types in solar heating plant configuration and satisfactory accuracy in both dynamic and long-term analyses. In situ measurements were taken from a pilot solar heating plant with 5960 m² flat plate collectors and 4039 m² parabolic trough collectors in series in Taars, Denmark from Sep.2015 to Aug.2016. The simulated thermal performances of both the parabolic trough collector field and the flat plate collector field have a good agreement with the measured performances. The thermal performance of the hybrid solar district heating plants is also presented. The measured and simulated results show that the integration of parabolic trough collectors in solar district heating plants can guarantee that the system produces hot water with relatively constant outlet temperature. The daily energy output of the parabolic trough collector field can be more than 5 kWh/m², while the daily energy output of the flat plate collector field is less than 5 kWh/m² under Danish climate conditions. The simplified and validated TRNSYS model can be a useful tool to simulate and optimize thermal performance of solar heating plants with both flat plate and parabolic trough collectors.

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Authors: Tian, Z. (Intern), Perers, B. (Intern), Furbo, S. (Intern), Fan, J. (Intern)
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Web of Science (2017): Impact factor 4.968
Web of Science (2017): Indexed yes
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Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 2.22 SNIP 2.037 CiteScore 5.03
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 2.575 SNIP 2.602 CiteScore 5.7
Web of Science (2014): Impact factor 4.844
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 2.458 SNIP 2.556 CiteScore 5.02
Web of Science (2013): Impact factor 4.159
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.935 SNIP 2.214 CiteScore 4.25
Web of Science (2012): Impact factor 3.651
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 1.566 SNIP 2.01 CiteScore 4
Web of Science (2011): Impact factor 3.487
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
This paper proposes a simple method for estimating annual thermal performance of parabolic trough collectors (PTCs) based on a linear relation with annual DNI for a certain latitude. A case study with simulations for a novel concentrating solar collector in 316 locations for three operating temperature scenarios worldwide was carried out and showed promising results for the latitudes and continents investigated. For a certain latitude and mean operating temperature, the annual yield of a PTC was found to be linearly proportional to yearly DNI. The proposed method will serve as a simplified alternative to the steady-state and quasi-dynamic methods already used. Estimating performance based on yearly DNI can be used by design engineers to do quick preliminary planning of solar plants. Customers can also use this method to evaluate existing solar collector installations. A TRNSYS/TRNSED tool that uses a steady-state model has been developed to carry out the simulations and it has been validated against a PTC array at Technical University of Denmark (DTU). The results show that the simplified method can give reliable estimates of long-term performance of parabolic trough collectors.

**General information**

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Organisations: Department of Civil Engineering, Energy and Services, Umeå University, Absolicon Solar Collector AB 
Authors: Ahlgren, B. (Ekstern), Tian, Z. (Intern), Perers, B. (Intern), Dragsted, J. (Intern), Johansson, E. (Ekstern), Lundberg, K. (Ekstern), Mossegård, J. (Ekstern), Byström, J. (Ekstern), Olsson, O. (Ekstern)
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Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 6.04 SJR 2.232 SNIP 2.109
Web of Science (2016): Impact factor 5.589
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 2.023 SNIP 2.079 CiteScore 5.24
Web of Science (2015): Impact factor 4.801
Web of Science (2015): Indexed yes
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Scopus rating (2014): SJR 1.789 SNIP 2.791 CiteScore 5.35
Web of Science (2014): Impact factor 4.38
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.613 SNIP 2.534 CiteScore 4.49
Web of Science (2013): Impact factor 3.59
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.674 SNIP 2.242 CiteScore 3.72
Web of Science (2012): Impact factor 2.775
ISI indexed (2012): ISI indexed yes
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BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.24 SNIP 1.82 CiteScore 3.03
Web of Science (2011): Impact factor 2.216
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.35 SNIP 1.735
Web of Science (2010): Impact factor 2.072
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.302 SNIP 1.798
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.471 SNIP 1.886
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.186 SNIP 1.807
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.294 SNIP 1.797
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 1.542 SNIP 1.769
Scopus rating (2004): SJR 1.043 SNIP 1.467
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 0.879 SNIP 1.382
Scopus rating (2002): SJR 0.972 SNIP 1.467
Web of Science (2002): Indexed yes
Scopus rating (2001): SJR 0.794 SNIP 0.86
Scopus rating (2000): SJR 0.568 SNIP 0.72
Thermo-economic optimization of a hybrid solar district heating plant with flat plate collectors and parabolic trough collectors in series

Large-scale solar heating plants for district heating networks have gained great success in Europe, particularly in Denmark. A hybrid solar district heating plant with 5960 m² flat plate collectors and 4039 m² parabolic trough collectors in series was built in Taars, Denmark in 2015. The solar heating plant was used as a reference case in this study. A validated TRNSYS-GenOpt model was set up to optimize the key design parameters of the plant, including areas of both collector types, storage size, orientation of the parabolic trough collectors and so on. This study introduces a generic method to optimize the hybrid solar district heating systems based on levelized cost of heat. It is found that the lowest net levelized cost of heat of hybrid solar heating plants could reach about 0.36 DKK/kWh. The system levelized cost of heat can be reduced by 5–9% by use of solar collectors in the district heating network in this study. The results also show that parabolic trough collectors are economically feasible for district heating networks in Denmark. The generic and multivariable levelized cost of heat method can guide engineers and designers on the design, construction and control of large-scale solar heating plants.

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Web of Science (2017): Impact factor 6.377
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 6.04 SJR 2.232 SNIP 2.109
Web of Science (2016): Impact factor 5.589
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BFI (2015): BFI-level 1
Scopus rating (2015): SJR 2.023 SNIP 2.079 CiteScore 5.24
Web of Science (2015): Impact factor 4.801
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.789 SNIP 2.791 CiteScore 5.35
Web of Science (2014): Impact factor 4.38
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.613 SNIP 2.534 CiteScore 4.49
Web of Science (2013): Impact factor 3.59
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Web of Science (2013): Indexed yes
The thermal performance of solar collector fields depends mainly on the mean solar collector fluid temperature of the collector field and on the solar radiation. For Danish solar collector fields for district heating the measured yearly thermal performances per collector area varied in the period 2012–2016 between 313 kWh/m² and 577 kWh/m², with averages between 411 kWh/m² and 463 kWh/m². The percentage difference between the highest and lowest measured yearly thermal performance is about 84%. Calculated yearly thermal performances of typically designed large solar collector fields at six different locations in Denmark with measured weather data for the years 2002–2010 vary between 405 kWh/m² collector and 566 kWh/m² collector, if a mean solar collector fluid temperature of 60 °C is assumed. This corresponds to a percentage difference between the highest and lowest calculated yearly thermal performance of about 40%. This variation is caused by different weather conditions from year to year and from location to location. Approximately half of the variations of yearly thermal performances can be related to variable weather conditions.

General information
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Organisations: Department of Civil Engineering, Section for Building Energy, Danish Meteorological Institute
Authors: Furbo, S. (Intern), Dragsted, J. (Intern), Perers, B. (Intern), Andersen, E. (Intern), Bava, F. (Intern), Nielsen, K. P. (Ekstern)
A CSP plant combined with biomass CHP using ORC-technology in Bronderslev Denmark

A new CSP plant combined with biomass CHP, using ORC technology, will be built and taken into operation in Bronderslev, Denmark during spring 2017. The price for Biomass is expected to increase with more and more use of this very limited energy source and then CSP will be cost effective in the long run, also in the Danish climate. Oil is used as heat transfer fluid instead of steam giving several advantages in this application for district heating at high latitudes. Total efficiencies and costs, competitive to PV plants, are expected.

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Organisations: Department of Civil Engineering, Section for Building Energy, Section for Building Physics and Services, Aalborg CSP, Brønderslev Varme A/S, NIRAS A/S, PlanEnergi, Centro Nacional de Energías Renovables, Technical University of Denmark
Authors: Perers, B. (Intern), Furbo, S. (Intern), Yuan, G. (Ekstern), Tian, Z. (Intern), Bava, F. (Intern), Kvist, P. (Ekstern), Rothmann, J. H. (Ekstern), Neergaard, T. (Ekstern), Jensen, J. R. (Ekstern), Sorensen, P. A. (Ekstern), From, N. (Ekstern), Sallaberry, F. (Ekstern)
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ANALYSIS OF MEASURED AND MODELED SOLAR RADIATION AT THE TARS SOLAR HEATING PLANT IN DENMARK

A novel combined solar heating plant with tracking parabolic trough collectors (PTC) and flat plate collectors (FPC) has been constructed and put into operation in Tars, 30 km north of Aalborg, Denmark in August 2015. To assess the operation performance of the plant, detailed parameters, such as solar radiation, inlet and outlet temperature for the solar collector field, flow rate and pressure, ambient temperature, Wind speed and wind direction were measured. Global horizontal radiation, direct normal irradiation (DNI) and total radiation on the tilted collector plane of the flat plate collector field have been measured in Tars solar heating plant. To determine the accuracy of modeled and measured solar radiation in Tars solar heating plant, monthly comparisons of measured and calculated radiation using 6 empirical models have been carried out. Comparisons of measured and modeled total radiation on the tilted surface with different methods were also studied. The results have shown that the DTU model could he used to calculate the diffuse radiation on horizontal surface and the anisotropic models (Perez 1988 model and Perez 1999 model) with only 1% and 2% disagreement with measured data respectively were the most accurate to he used for the calculation of total radiation on the tilted collector...
Annual measured and simulated thermal performance analysis of a hybrid solar district heating plant with flat plate collectors and parabolic trough collectors in series

Flat plate collectors have relatively low efficiency at the typical supply temperatures of district heating networks (70–95 °C). Parabolic trough collectors retain their high efficiency at these temperatures. To maximize the advantages of flat plate collectors and parabolic trough collectors in large solar heating plants for a district heating network, a hybrid solar collector field with 5960 m² flat plate collectors and 4039 m² parabolic trough collectors in series was constructed in Taars, Denmark. The design principle is that the flat plate collectors preheat the return water from the district heating network to about 70 °C and then the parabolic trough collectors would heat the preheated water to the required supply temperature of the district heating network. Annual measured and simulated thermal performances of both the parabolic trough collector field and the flat plate collector field are presented in this paper. The thermal performance of both collector fields with weather data of a Design Reference Year was simulated to have a whole understanding of the application of both collectors under Danish climate conditions as well. These results not only can provide a design basis for this type of hybrid solar district heating plants with flat plate collectors and parabolic trough collectors in the Nordic region, but also introduce a novel design concept of solar district heating plants to other high solar radiation areas.
Solar district heating plants, Parabolic trough collectors, Flat plate collectors, Thermal performance

Availability of high quality weather data measurements

In the period 2016-2017 the project “Availability of high quality weather data measurements” is carried out at Department of Civil Engineering at the Technical University of Denmark. The aim of the project is to establish measured high quality weather data which will be easily available for the building energy branch and the solar energy branch in their efforts to achieve energy savings and for researchers and students carrying out projects where measured high quality weather data
are needed.

**Experimental investigations on solar heating/heat pump systems for single family houses**

In the period 2013-2017, the project “Experimental investigations on solar heat pump systems for single family houses” is carried out at Department of Civil Engineering, Technical University of Denmark. The aim of this project is to increase the knowledge of the heat and mass transfer in the combined solar heating/heat pump system type when the heat pump makes use of a horizontal ground source heat exchanger. The knowledge is gained by experimental investigations on a solar heating/heat pump system and forms the basis for improved marketed combined solar heating/heat pump systems.

**Optical losses due to tracking on solar thermal collectors**

For a wide range of operational temperatures, the solar thermal collectors can use optical concentration systems to optimize their efficiency. However, as optical concentration relies on direct solar radiation, it is necessary to use a solar tracker following the sun direction to maximize the amount of useful solar radiation received. The selection of the appropriate tracking systems matching the optical concentration factor is essential to achieve optimal collector efficiency. Otherwise, the concentrator would experience high optical losses due to the inadequate focusing of the direct solar radiation onto its receiver, regardless of its quality. This paper gives the state-of-the-art of the methodologies available to characterize the tracking error of a concentrating collector, a summary of different previous studies done in this subject and of the standardization regarding the tracking accuracy and its influence on the solar collector efficiency. The methodologies and results of the tracking accuracy, incidence angle modifier and optical losses due to tracking errors are presented in this paper for the five collectors studied.
Performance of a Solar Heating System with Photovoltaic Thermal Hybrid Collectors and Heat Pump

The energy consumption in buildings accounts for a large part of the World’s CO2 emissions. Much energy is used for appliances, domestic hot water preparation and space heating.

In solar heating systems, heat is captured by solar collectors when the sun is shining and used for heating purposes. When the solar collectors are unable to supply the heat demand an auxiliary heat source is used. Heat pumps can generate this heat. Liquid/water heat pumps have better performance than air/water heat pumps in cold climates but requires installation of a tubing system for the cold side of the heat pump. The tubes are typically placed in the ground, requires a significant land area and increase the installation cost.

A new system design of a solar heating system with two storage tanks and a liquid/water heat pump is presented. The system consists of PVT collectors that generate both heat and electricity. Heat from the collectors is transferred to a domestic hot water storage tank or to a cold storage tank, which is used as the source for the heat pump. When the heat pump charges the warm storage tank, heat is extracted from the cold storage tank, which then can be reheated by the PVT collectors. In this system, it is possible to have the high performance of the liquid/water heat pump but without the need to install tubes in the ground. The performance of the system with automated energy discharge over several months is evaluated.
and ideas on the technology. The collective research exhibits a lack of scientific publications dedicated to the drainback technology, however a significant number of patents have been published, detailing innovative technical solutions towards improvements and reliability. Based on the evaluation of drainback hydraulics, a detailed classification of this technology has been developed, with a brief description of each hydraulic typology. The operating modes have been split into three stages: filling, operation, and draining, which have been studied separately. A difference in the minimal filling velocities for a siphon development in the solar loop has been discovered in various reports. Specific features of the operation mode have been described. For the draining, existing mechanisms to initiate the emptying process have been identified and categorised. Finally, state-of-the-art hydraulic components for drainback systems have been established, with emphasis on their requirements. Based on those findings, the authors suggest potential future research paths in order to fill the knowledge gap and disseminate the drainback technology.

**General information**

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Organisations: Department of Civil Engineering, Section for Building Energy, University of Kassel
Authors: Botpaev, R. (Ekstern), Louvet, Y. (Ekstern), Perers, B. (Intern), Furbo, S. (Intern), Vajen, K. (Ekstern)
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Web of Science (2017): Indexed yes
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Scopus rating (2016): CiteScore 4.52 SJR 1.504 SNIP 1.746
Web of Science (2016): Impact factor 4.018
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
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Web of Science (2015): Impact factor 3.685
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.962 SNIP 2.671 CiteScore 4.77
Web of Science (2014): Impact factor 3.469
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BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.99 SNIP 2.85 CiteScore 4.44
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BFI (2012): BFI-level 1
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Scopus rating (2011): SJR 1.283 SNIP 2.178 CiteScore 3.19
Web of Science (2011): Impact factor 2.475
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
Laboratory Testing of Solar Combi System with Compact Long Term PCM Heat Storage

To enable the transition from fossil fuels as a primary heat source for domestic hot water preparation and space heating, solar thermal energy has great potential. The heat from the sun has the disadvantage that it is not always available when there is a demand. To solve this mismatch, a thermal seasonal storage can be used to store excess heat from the summer to the winter when the demand is higher than the supply. Installing a long term thermal storage in a one-family house needs to be compact and sensible heat storages are not suitable. A latent heat storage with a phase change material (PCM) can provide a more compact way of storing heat. Sodium acetate trihydrate (SAT) is a good candidate material as it has a relatively high heat of fusion and in addition it has the ability to supercool to room temperature without solidifying.

In this paper, results from the test of a solar combi system with a latent heat storage with SAT is presented. The SAT heat storage modules were heated to 80 °C by the solar collectors 53 times in the test period from June to November 2015 and this enabled the modules to supercool. Supercooling was achieved for 39 days for a SAT module after which 11 kWh of heat were discharged.
Tårs 10000 m² CSP + Flat Plate Solar Collector Plant - Cost-Performance Optimization of the Design

A novel solar heating plant with Concentrating Solar Power (CSP) collectors and Flat Plate (FP) collectors has been put into operation in Tårs since July 2015. To investigate economic performance of the plant, a TRNSYS-Genopt model, including a solar collector field and thermal storage tank, was established. The optimization showed that there was a synergy in combining CSP and FP collectors. Even though the present cost per m² of the CSP collectors is high, the total energy cost is minimized by installing a combination of collectors in such solar heating plant. It was also found that the CSP collectors could raise flexibility in the control strategy of the plant. The TRNSYS-Genopt model is based on individually validated component models and collector parameters from experiments. Optimization of the cost performance of the plant has been conducted in this paper. The simulation model remains to be validated with annual measured data from the plant.

General information

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Organisations: Department of Civil Engineering, Section for Building Energy, Department of Buildings and Energy, Technical University of Denmark
Authors: Perers, B. (Intern), Furbo, S. (Intern), Tian, Z. (Intern), Egelwisse, J. (Ekstern), Bava, F. (Intern), Fan, J. (Intern)
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Scopus rating (2017): CiteScore 1.44 SJR 0.495 SNIP 0.799
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.16 SJR 0.464 SNIP 0.598
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.359 SNIP 0.562 CiteScore 0.92
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.429 SNIP 0.807 CiteScore 1.09
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.42 SNIP 0.778 CiteScore 1.02
ISI indexed (2013): ISI indexed no
Web of Science (2013): Indexed yes
A new Laplace transformation method for dynamic testing of solar collectors

A new dynamic method for solar collector testing is developed. It is characterized by using the Laplace transformation technique to solve the differential governing equation. The new method was inspired by the so called New Dynamic Method (NDM) (Amer E. et al (1999) [1]) but totally different. By integration of the Laplace transformation technique with the Quasi Dynamic Test (QDT) model (Fischer S. et al (2004) [2]), the Laplace – QDT (L-QDT) model is derived. Two experimental methods are then introduced. One is the shielding method which needs to shield and un-shield solar collector continuously during test period. The other is the natural test method which doesn't need any intervention. The new L-QDT model with the shielding method are tested by TRNSYS (Klein S. et al (1988) [3]) simulation. Experiments were carried out at Technical University of Denmark by using the L-QDT method and the natural experimental method. The identified collector parameters are then compared and analyzed with those obtained by the steady state test method and the QDT test method. The results comparison shows that the L-QDT method and the natural experimental method are also valid.

It can be concluded that the new Laplace test method can obtain reasonable and accurate collector parameters under transient weather condition.

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Web of Science (2017): Impact factor 4.9
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 4.83 SJR 1.661 SNIP 2.05
Web of Science (2016): Impact factor 4.357
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Behavior of a solar collector loop during stagnation

A mathematical model simulating the emptying behavior of a pressurized solar collector loop with solar collectors with a good emptying behavior is developed and validated with measured data. The calculated results are in good agreement with the measured results. The developed simulation model is therefore suitable to determine the behavior of a solar collector loop during stagnation. A volume ratio \( R \), which is the ratio of the volume of the vapour in the upper pipes of the solar collector loop during stagnation and the fluid content of solar collectors, is introduced to determine the mass of the collector fluid pushed into the expansion vessel during stagnation, \( M_{\text{in}} \). A correlation function for the mass \( M_{\text{in}} \) and the volume ratio \( R \) for solar collector loops is obtained. The function can be used to determine a suitable size of expansion vessels for solar collector loops.
Calculated thermal performance of solar collectors based on measured weather data from 2001-2010

This paper presents an investigation of the differences in modeled thermal performance of solar collectors when meteorological reference years are used as input and when multi-year weather data is used as input. The investigation has shown that using the Danish reference year based on the period 1975-1990 will result in deviations of up to 39% compared with thermal performance calculated with multi-year the measured weather data. For the newer local reference years based on the period 2001-2010 the maximum deviation becomes 25%. The investigation further showed an increase in utilization with an increase in global radiation. This means that besides increasing the thermal performance with increasing the solar radiation, the utilization of the solar radiation also becomes better.

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Authors: Dragsted, J. (Intern), Furbo, S. (Intern), Andersen, E. (Intern), Perers, B. (Intern), Nielsen, K. P. (Ekstern)
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Drain Back systems in Laboratory and in Practice

Drain Back systems with ETC collectors are tested and analyzed in a Danish - Chinese cooperation project. Experiences from early work at DTU, with drain back, low flow systems, was used to design two systems:

1) One laboratory system at DTU. 2) One demonstration system in a single family house in Sorø Denmark. Detailed monitoring and modelling/validation of the system in the DTU lab is done, to be able to generalize the results, to other climates and loads by simulation and to make design optimizations. The advantage with drain back, low flow systems, is that the system can be made more simple with less components and that the performance can be enhanced. Also problems with long term degradation of glycol collector loops are totally avoided. A combination of the drain back and system expansion vessel was tested successfully. It is very important to achieve a continuous slope for the pipes in the collector loop to have a safe reliable operation. The components should also be designed and marked so that only one correct mounting option is possible, like forward and return pipes to/from the collector of slightly different sizes or color. Adapted installer education and training is a very important step to have success with drain back systems. Practices used in glycol systems may give serious failures.

Key-words: Drain Back, Low Flow, Solar Combi System, ETC collectors.
Long term testing and evaluation of PV modules with and without Sunarc antireflective coating of the cover glass
Two Photovoltaic (PV) modules have been manufactured by Swemodule. One with Sunarc antireflective coated glass and one without glass surface treatment. The modules have been tested at DTU during 16 months under realistic outdoor conditions. Exactly the same polycrystalline cells were used in the modules. No cleaning of the glass has been made except for removal of bird droppings and leaves on single cells that could give a very wrong comparison. The PV modules were mounted due south at 45 degree tilt angle. They were connected to the electric grid with small 250W module inverters from Involar that also realized the MPP tracking to give the maximum output of each module. The electric power output was measured both on the AC and DC side and with different measurement equipment to be sure about the accuracy in improvement. The results indicate a potential long term improvement in a system from 3% up to 6%. The improvement is best in facade and off south tilted orientations, where the better incidence angle modifier, has a larger influence. In the PV application only one side of the glass treatment is active. This reduces the possible improvement compared to solar thermal and greenhouse applications. In PV applications the slightly higher cell temperature, due to the higher transmittance of the glass for all solar wavelengths, reduces the potential electrical performance improvement.
Mathematical modelling of unglazed solar collectors under extreme operating conditions

Combined heat pumps and solar collectors got a renewed interest on the heating system market worldwide. Connected to the heat pump evaporator, unglazed solar collectors can considerably increase their efficiency, but they also raise the coefficient of performance of the heat pump with higher average temperature levels at the evaporator. Simulation of these systems requires a collector model that can take into account operation at very low temperatures (below freezing) and under various weather conditions, particularly operation without solar irradiation. A solar collector mathematical model is developed and evaluated considering, the condensation/frost effect and rain heat gains or losses. Also wind speed and long wave irradiation on both sides of the collector are treated. Results show important heat gains for unglazed solar collectors without solar irradiation. Up to 50% of additional heat gain was found due to the condensation phenomenon and up to 40% due to frost under no solar irradiation. This work also points out the influence of the operating conditions on the collector's characteristics. Based on experiments carried out at a test facility, every heat flux on the absorber was separately evaluated so that this model can represent a valuable tool in optimising the design or the thermal efficiency of the collector. It also enables the prediction of the total energy yield for solar thermal collectors under extreme operating conditions.
Side by side tests of two SDHW systems with solar collectors with and without antireflection treatment

Two low flow SDHW systems based on mantle tanks are tested side by side in a laboratory test facility for solar heating systems under the same weather and operation conditions. The systems are identical with the exception that one system is equipped with a solar collector with antireflection treated glass while the other system has a collector with a normal glass. Measurements of the thermal performance of the two systems have been carried out for a long measuring period. The thermal performances of the systems have also been calculated with a detailed simulation model. There is a good agreement between measured and calculated thermal performances for both systems. The extra thermal performance of the system with the solar collector with the antireflection treated glass cover is a strong function of the solar fraction. In sunny periods with high solar fractions the percentage extra thermal performance gained by the antireflection treatment is low. In less sunny periods with low solar fractions the percentage extra thermal performance of the system with the antireflection treated cover glass is high, typically up to 8%.

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Scopus rating (2016): CiteScore 1.16 SJR 0.464 SNIP 0.598
Simulation of a solar collector array consisting of two types of solar collectors, with and without convection barrier

The installed area of solar collectors in solar heating fields is rapidly increasing in Denmark. In this scenario even relatively small performance improvements may lead to a large increase in the overall energy production. Both collectors with and without polymer foil, functioning as convection barrier, can be found on the Danish market. Depending on the temperature level at which the two types of collectors operate, one can perform better than the other. This project aimed to study the behavior of a 14 solar collector row made of these two different kinds of collectors, in order to optimize the composition of the row. Actual solar collectors available on the Danish market (models HT-SA and HT-A 35-10 manufactured by ARCON Solar A/S) were used for this analysis. To perform the study, a simulation model in TRNSYS was developed based on the Danish solar collector field in Braedstrup. A parametric analysis was carried out by modifying the composition of the row, in order to find both the energy and economy optimum.

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Testing, development and demonstration of large scale solar district heating systems

In 2013-2014 the project "Testing, development and demonstration of large scale solar district heating systems" was carried out within the Sino-Danish Renewable Energy Development Programme, the so called RED programme jointly developed by the Chinese and Danish governments. In the project Danish know how on solar heating plants and solar heating test technology have been transferred from Denmark to China, large solar heating systems have been promoted in China, test capabilities on solar collectors and large scale solar heating systems have been improved in China and Danish-Chinese cooperation on solar heating has been improved.

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Organisations: Department of Civil Engineering, Section for Building Energy , PlanEnergi
Authors: Furbo, S. (Intern), Fan, J. (Intern), Perers, B. (Intern), Kong, W. (Intern), Trier, D. (Ekstern), From, N. (Ekstern)
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Large scale solar heating systems, Tests, Development, Demonstration, Danish-Chinese cooperation

Drain Back, Low Flow Solar Combi Systems: Design, Monitoring and Simulation

Drain Back systems with ETC collectors are tested and analyzed in a Danish - Chinese cooperation project. Experiences from early work at DTU, with drain back, low flow systems, was used to design two systems:

1) One laboratory system at DTU and 2) One demonstration system in a single family house in Sorø Denmark. Detailed monitoring and modelling of the system in the DTU lab is done to be able to generalize the results, to other climates and loads and to make design optimizations.

The advantage with drain back, low flow systems, is that the system can be made more simple with less components and that the performance can be enhanced. A combination of the drain back- and system expansion vessel was tested successfully. Small initial problems with installation and proposals for design improvements to avoid these in practice are described in the paper. Installer education and training is an important step to have success with drain back systems.

Investigations of Intelligent Solar Heating Systems for Single Family House

Three differently designed intelligent solar heating systems are investigated experimentally in a test facility. The systems provide all the needed yearly heating demand in single family houses. The systems are based on highly stratified tanks
with variable auxiliary heated volumes. The tank is a tank in tank heat storage with domestic hot water in the inner tank and space heating water in the outer tank. The total tank volume is 750 liters and the solar collector area is 9 m². The auxiliary energy supply system is based on electrical heating element(s)/heat pump and is different for all three systems. The system will be equipped with an intelligent control system where the control of the electrical heating element(s)/heat pump is based on forecasts of the variable electricity price, the heating demand and the solar energy production. By means of numerical models of the systems made in Trnsys, the control strategy of intelligent solar heating systems is investigated and the yearly auxiliary energy use of the systems and the electricity price for supplying the consumers with domestic hot water and space heating are calculated.

**General information**

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Organisations: Department of Civil Engineering, Section for Building Physics and Services

Authors: Andersen, E. (Intern), Chen, Z. (Intern), Fan, J. (Intern), Furbo, S. (Intern), Perers, B. (Intern)

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Scopus rating (2016): CiteScore 1.16 SJR 0.464 SNIP 0.598

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Scopus rating (2010): SJR 0.416 SNIP 0.91

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**Thermal performance of solar district heating plants in Denmark**

The market for solar heating plants connected to district heating systems is expanding rapidly in Denmark. It is expected that by the end of 2014 the 10 largest solar heating plants in Europe will be located in Denmark. Measurements from 23 Danish solar heating plants, all based on flat plate solar collectors mounted on the ground, shows measured yearly thermal performances of the solar heating plants placed in the interval from 313 kWh/m² collector to 493 kWh/m² collector...
with averages for all plants of 411 kWh/m² collector for 2012 and 450 kWh/m² collector for 2013. Theoretical calculations show that for temperature levels higher than about 55°C the thermal performance of a solar collector field based on concentrating tracking solar collectors is higher than the thermal performance of a solar collector field based on flat plate collectors.

It is estimated that there are potentials for further improvements of the cost/performance ratio for solar collector fields, both with flat plate collectors and with concentrating tracking solar collectors.

It is recommended to continue monitoring and analysis of all large solar heating plants to document the reliability of the solar heating plants. It is also recommended by parallel theoretical and experimental approach to investigate in detail the thermal performance of differently designed solar collector fields in such a way that their thermal performance can be determined by theoretical calculations in the future. This will be useful in connection with development of improved solar collectors for solar heating plants and in connection with optimization of future solar heating plants.

Furthermore, it is recommended to continue the development of long term heat stores for solar heating plants and to elucidate how best to integrate solar heating systems in the future energy system.

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State: Published
Organisations: Department of Civil Engineering, Section for Building Physics and Services
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A non-parametric method for correction of global radiation observations
This paper presents a method for correction and alignment of global radiation observations based on information obtained from calculated global radiation, in the present study one-hour forecast of global radiation from a numerical weather prediction (NWP) model is used. Systematical errors detected in the observations are corrected. These are errors such as: tilt in the leveling of the sensor, shadowing from surrounding objects, clipping and saturation in the signal processing, and errors from dirt and wear. The method is based on a statistical non-parametric clear-sky model which is applied to both the observed and the calculated radiation in order to find systematic deviations between them. The method is applied to correct global radiation observations from a climate station located at a district heating plant in Denmark. The results are compared to observations recorded at the Danish Technical University. The method can be useful for optimized use of solar radiation observations for forecasting, monitoring, and modeling of energy production and load which are affected by solar radiation.

General information
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Organisations: Department of Applied Mathematics and Computer Science, Dynamical Systems, Department of Civil Engineering, Section for Building Physics and Services
Authors: Bacher, P. (Intern), Madsen, H. (Intern), Perers, B. (Intern), Nielsen, H. A. (Intern)
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Global solar radiation, Observations, Correction, Quality control, Statistical clear-sky model, Solar energy
Investigations on efficiencies of HT solar collectors for different flow rates and collector tilts

Two HT solar collectors for solar heating plants from Arcon Solvarme A/S are tested in a laboratory test facility for solar collectors at Technical University of Denmark (DTU). The collectors are designed in the same way. However, one solar collector is equipped with an ETFE foil between the absorber and the cover glass and the other is without ETFE foil. The efficiencies for the collectors are tested at different flow rates and tilt. On the basis of the measured efficiencies, the efficiencies for the collectors as functions of flow rates are obtained. The calculated efficiencies are in good agreement with the measured efficiencies.

Short-term heat load forecasting for single family houses

This paper presents a method for forecasting the load for space heating in a single-family house. The forecasting model is built using data from sixteen houses located in Sønderborg, Denmark, combined with local climate measurements and weather forecasts. Every hour the hourly heat load for each house the following two days is forecasted. The forecast models are adaptive linear time-series models and the climate inputs used are: ambient temperature, global radiation and wind speed. A computationally efficient recursive least squares scheme is used. The models are optimized to fit the individual characteristics for each house, such as the level of adaptivity and the thermal dynamical response of the building, which is modeled with simple transfer functions. Identification of a model, which is suitable for all the houses, is carried out. The results show that the one-step ahead errors are close to white noise and that practically all correlation to the climate variables are removed. Furthermore, the results show that the forecasting errors mainly are related to: unpredictable high frequency variations in the heat load signal (predominant only for some houses), shifts in resident behavior patterns and uncertainty of the weather forecasts for longer horizons, especially for solar radiation.
Solar/electric heating systems for the future energy system

The project “Solar/electric heating systems in the future energy system” was carried out in the period 2008-2013. The project partners were DTU Byg, DTU Informatics (now DTU Compute), DMI, ENFOR A/S and COWI A/S. The companies Ajva ApS, Ohmatex ApS and Innogie ApS worked together with the project partners in two connected projects in order to develop solar/electric heating systems for laboratory tests. The project was financed by the Danish Agency for Science, Technology and Innovation under the Danish Council for Strategic Research in the program Sustainable Energy and Environment. The DSF number of the project is 2104-07-0021/09-063201/DSF. This report is the final report of the project. The aim of the project is to elucidate how individual heating units for single family houses are best designed in order to fit into the future energy system. The units are based on solar energy, electrical heating elements/heat pump, advanced heat storage tanks and advanced control systems. Heat is produced by solar collectors in sunny periods and by electrical heating elements/heat pump. The electrical heating elements/heat pump will be in operation in periods where the heat demand cannot be covered by solar energy. The aim is to use the auxiliary heating units when the electricity price is low, e.g. due to large electricity production by wind turbines. The unit is equipped with an advanced control system where the control of the auxiliary heating is based on forecasts of the electricity price, the heat demand and the solar energy production. Consequently, the control is based on weather forecasts. Three differently designed heating units are tested in a laboratory test facility. The systems are compared on the basis of:
- energy consumption for the auxiliary heating
- energy cost for the auxiliary heating
- net utilized solar energy

General information
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Organisations: Department of Civil Engineering, Section for Building Physics and Services, Department of Applied Mathematics and Computer Science, Dynamical Systems, Center for Energy Resources Engineering, Scientific Computing, Department of Electrical Engineering, Danish Meteorological Institute, COWI A/S, Innogie ApS
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An improved dynamic test method for solar collectors
A comprehensive improvement of the mathematical model for the so called transfer function method is presented in this study. This improved transfer function method can estimate the traditional solar collector parameters such as zero loss coefficient and heat loss coefficient. Two new collector parameters t and mfCf are obtained. t is a time scale parameter which can indicate the heat transfer ability of the solar collector. mfCf can be used to calculate the fluid volume content in the solar collector or to validate the regression process by comparing it to the physical fluid volume content if known. Experiments were carried out under dynamic test conditions and then test data were processed using multi-linear
regression method to get collector parameters with statistic analysis. A comparison of the collector parameters obtained from the improved transfer function (ITF) method and the quasi-dynamic test (QDT) method is carried out. The results show that the improved transfer function method can accurately obtain reasonable collector parameters. The influence of different averaging time intervals is investigated. Based on the investigation it is recommended to use on line calculation if applicable for the second-order differential term with 6–9min as the best averaging time interval. The measured and predicted collector power output of the solar collector are compared during a test of 13days continuously both for the ITF method and the QDT method. The maximum and averaging error is 53.67W/m² and 5.22W/m² respectively of the ITF method while 64.13W/m² and 6.22W/m² of the QDT method. Scatter and relative error distribution of the measured power output versus the predicted power output is also plotted for the two methods. No matter in either error analysis or scatter distribution, the ITF method is more accurate than the QDT method in predicting the power output of a solar collector.

In conclusion, all the results show that the improved transfer function method can accurately and robustly estimate solar collector parameters and predict solar collector thermal performance under dynamic test conditions.

**General information**

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Authors: Kong, W. (Intern), Wang, Z. (Ekstern), Fan, J. (Intern), Bacher, P. (Intern), Perers, B. (Intern), Chen, Z. (Intern), Furbo, S. (Intern)
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Web of Science (2015): Impact factor 3.685
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BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.962 SNIP 2.671 CiteScore 4.77
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Scopus rating (2011): SJR 1.283 SNIP 2.178 CiteScore 3.19
A simplified heat pump model for use in solar plus heat pump system simulation studies

Solar plus heat pump systems are often very complex in design, with sometimes special heat pump arrangements and control. Therefore detailed heat pump models can give very slow system simulations and still not so accurate results compared to real heat pump performance in a system. The idea here is to start from a standard measured performance map of test points for a heat pump according to EN 14825 and then determine characteristic parameters for a simplified correlation based model of the heat pump. By plotting heat pump test data in different ways including power input and output form and not only as COP, a simplified relation could be seen. By using the same methodology as in the EN 12975 QDT part in the collector test standard it could be shown that a very simple model could describe the heat pump test data very accurately, by identifying 4 parameters in the correlation equation found.

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Organisations: Department of Civil Engineering, Section for Building Physics and Services, SP Technical Research Institute of Sweden
Authors: Perers, B. (Intern), Andersen, E. (Intern), Nordman, R. (Ekstern), Kovacs, P. (Ekstern)
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Main Research Area: Technical/natural sciences
A tool for standardized collector performance calculations including PVT

A tool for standardized calculation of solar collector performance has been developed in cooperation between SP Technical Research Institute of Sweden, DTU Denmark and SERC Dalarna University. The tool is designed to calculate the annual performance of solar collectors at representative locations in Europe. The collector parameters used as input in the tool are compiled from tests according to EN12975, without any intermediate conversions. The main target group for this tool is test institutes and certification bodies that are intended to use it for conversion of collector model parameters (derived from performance tests) into a more user friendly quantity: the annual energy output. The energy output presented in the tool is expressed as kWh per collector module. A simplified treatment of performance for PVT collectors is added based on the assumption that the thermal part of the PVT collector can be tested and modeled as a thermal collector, when the PV electric part is active with an MPP tracker in operation. The thermal collector parameters from this operation mode are used for the PVT calculations.

General information

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Description of SCEnO-Calc (Solar Collector Energy Output Calculator), a program for calculation of annual solar collector energy output

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Development of seasonal heat storage based on stable supercooling of a sodium acetate water mixture
A number of heat storage modules for seasonal heat storages based on stable supercooling of a sodium acetate water mixture have been tested by means of experiments in a heat storage test facility. The modules had different volumes and designs. Further, different methods were used to transfer heat to and from the sodium acetate water mixture in the modules.

By means of the experiments:
• The heat exchange capacity rates to and from the sodium acetate water mixture in the heat storage modules were determined for different volume flow rates.
• The heat content of the heat storage modules were determined.
• The reliability of the supercooling was elucidated for the heat storage modules for different operation conditions.
• The reliability of a cooling method used to start solidification of the supercooled sodium acetate water mixture was elucidated. The method is making use of boiling CO2 in a small tank in good thermal contact with the outer surface of the heat storage module.
• Experience on operation of the heat storage modules was gained.

Based on the investigations recommendations for future development of a seasonal heat storage based on stable
supercooling of a sodium acetate water mixture are given.

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Scopus rating (2016): CiteScore 1.16 SJR 0.464 SNIP 0.598
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BFI (2015): BFI-level 1
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Scopus rating (2013): SJR 0.42 SNIP 0.778 CiteScore 1.02
ISI indexed (2013): ISI indexed no
Web of Science (2013): Indexed yes
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Scopus rating (2011): SJR 0.877 SNIP 1.45 CiteScore 2.42
ISI indexed (2011): ISI indexed no
Scopus rating (2010): SJR 0.416 SNIP 0.91
Web of Science (2009): Indexed yes
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Source: dtu
Source-ID: u::5639
Publication: Research - peer-review › Conference article – Annual report year: 2012

**Efficiencies of flat plate solar collectors at different flow rates**

Two flat plate solar collectors for solar heating plants from Arcon Solvarme A/S are tested in a laboratory test facility for solar collectors at Technical University of Denmark (DTU). The collectors are designed in the same way. However, one collector is equipped with an ETFE foil between the absorber and the cover glass and the other is without ETFE foil. The efficiencies for the collectors are tested at different flow rates. On the basis of the measured efficiencies, the efficiencies for the collectors as functions of flow rate are obtained. The calculated efficiencies are in good agreement with the measured efficiencies.

**General information**

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Publication date: 2012
Evaluation of long-term global radiation measurements in Denmark and Sweden

The climate, especially global radiation is one of the key factors influencing the energy yield of solar energy systems. In connection with planning and optimization of energy efficient buildings and solar energy systems it is important to know the climate data of the area where the buildings/systems are located. This study is based on yearly and monthly values of global radiation based on measurements from a climate station placed on the roof of building 119 at Technical University of Denmark in Kgs. Lyngby, from different Danish climate stations runned by Danish Meteorological Institute and from different Swedish climate stations of Swedish Meteorological and Hydrological Institute. The global horizontal radiation has been measured for a high number of years at all of these stations. The values show a tendency of increased annual global radiation, most likely due to decreased pollution of the atmosphere, increased duration of periods without clouds and/or combination of both these effects.

Twenty years of measurements from a climate station in Lyngby, Denmark show that the global radiation increase is almost 3.5 kWh/m² per year, corresponding to a growth of 7 % for the last 20 years. The global radiation variation between the least sunny year to the sunniest year is 22%. Twenty-gine years of measuring of global radiation from twelve radiation stations across Sweden shows an increase of 3.1 kWh/m² per year. The increase is 87 kWh/m², corresponding to 9 % of global radiation growth during the last 29 years. The annual global radiation varies between 838 kWh/m²/year in 1998 and 1004 kWh/m²/year in 2002 with an average radiation of 932 kWh/m²/year, corresponding to a radiation variation from the least sunny year to the sunniest year of 20 %.

General information

State: Published
Organisations: Department of Civil Engineering, Section for Building Physics and Services, Slovak University of Technology, Danish Meteorological Institute, Swedish Meteorological and Hydrological Institute
Authors: Skalík, L. (Ekstern), Luňákovičová, O. (Ekstern), Furbo, S. (Intern), Perers, B. (Intern), Dragsted, J. (Intern), Nielsen, K. P. (Ekstern), Scharling, M. (Ekstern), Carlund, T. (Ekstern)
Experimental Validation and Model Verification for a Novel Geometry ICPC Solar Collector

A novel geometry ICPC solar collector was developed at the University of Chicago and Colorado State University. A ray tracing model has been designed to investigate the optical performance of both the horizontal and vertical fin versions of this collector. Solar radiation is modeled as discrete uniform rays. Rays falling on the collector are followed as they are attenuated by various components of the collector until they are absorbed by the fin or escape. The extent to which each absorbed ray is attenuated is recorded. Modeled collector properties are transmittance and translation of a ray passing through transparent media, the size of the gap between the glass tube and fin, reflectivity of the reflective surface, absorptivity of the fin and blocking and displacement of the rays by adjacent tubes.

Presentation of the progressive animation of individual rays and associated summary graphics at the various specified incident angles provide model verification for the investigation into causes of ray attenuation and provide accounts for rays that escape.

Two fourteen tube modules were tested on Sandia National Laboratory's two-axis tracking (AZTRAK) platform. By adjusting the tracking of the platform to the desired incident angle of the sun's rays, performance of the novel ICPC solar collector at various specified angles along the transverse and longitudinal evacuated tube directions were experimentally determined. To validate the ray tracing model, transverse and longitudinal performance predictions at the corresponding specified incident angles are compared to the Sandia results.

A 100 m² 336 Novel ICPC evacuated tube solar collector array has been in continuous operation at a demonstration project in Sacramento California since 1998. Data from the initial operation of the array are used to further validate the ray tracing model.

Examples of the progressive casting of individual rays across the evacuated tube aperture width and the fit to experimental data are shown in the accompanying figures.

General information
State: Published
Organisations: Department of Civil Engineering, Section for Building Physics and Services, Colorado State University
Authors: Perers, B. (Intern), Duff, W. S. (Ekstern), Daosukho, J. (Ekstern)
Number of pages: 8
Publication date: 2012
Main Research Area: Technical/natural sciences
Electronic versions:
EuroSun2012_full-paper-SKALIK_29.6.pdf
Source: dtu
Source-ID: u::6349
Publication: Research - peer-review › Paper – Annual report year: 2012

Investigation of Thermal Performance of Flat Plate and Evacuated Tubular Solar Collectors According to a New Dynamic Test Method

A new dynamic test method is introduced. This so called improved transfer function method features on two new collector parameters. One is time term which can indicate solar collector's inner heat transfer ability and the other is a second order term of collector mean fluid temperature which can obtain fluid thermal capacitance in data processing. Then theoretical analysis and experimental verification are carried out to investigate influencing factors of obtaining accurate and stable second order term. A flat plate and ETC solar collector are compared using both the new dynamic method and a standard method. The results show that the improved function method can accurately and robustly estimate these two kinds of solar collectors.

General information
State: Published
Organisations: Department of Civil Engineering, Section for Building Physics and Services
Authors: Kong, W. (Intern), Wang, Z. (Ekstern), Fan, J. (Intern), Perers, B. (Intern), Chen, Z. (Intern), Furbo, S. (Intern), Andersen, E. (Intern), Andreas Haberle (Ekstern)
Pages: 152-161
Publication date: 2012
Measurement and modelling of a multifunctional solar plus heat pump system from Nilan: Experiences from one year of test operation.

A multifunctional solar and heat pump unit from Nilan has been installed in the Performance Test Facility (PTF) at DTU Byg Denmark. It is part of the IEA Task 44 cooperation. Multifunctional means in this case: Hot water, Air heating, Ventilation, Air heat recovery, Air filtering and Floor heating. Nilan units, with additional air cooling and CO2 control, are also available.

The unit has been in operation for more than one year. The aim has been to stress the system operation to different conditions in the lab, to learn more about the performance, but also to find possible improvements especially concerning advanced control. The operation into extreme states of high hot water demand and low air ventilation rates, has also been
done to develop and validate a TRNSYS system model. The model was developed and validated for the first period of operation mainly winter and early spring conditions. Now the system has been in operation during all seasons and a full year model could be developed and validated. The model also includes new possibilities for solar collector loop and heat pump operation control.

Model predictive control for a smart solar tank based on weather and consumption forecasts
In this work the heat dynamics of a storage tank were modelled on the basis of data and maximum likelihood methods. The resulting grey-box model was used for Economic Model Predictive Control (MPC) of the energy in the tank. The control objective was to balance the energy from a solar collector and the heat consumption in a residential house. The storage tank provides heat in periods where there is low solar radiation and stores heat when there is surplus solar heat. The forecasts of consumption patterns were based on data obtained from meters in a group of single-family houses in Denmark. The tank can also be heated by electric heating elements if necessary, but the electricity costs of operating these heating elements should be minimized. Consequently, the heating elements should be used in periods with cheap electricity. It is proposed to integrate a price-sensitive control to enable the storage tank to serve a smart energy system in which flexible consumers are expected to help balance fluctuating renewable energy sources like wind and solar. Through simulations, the impact of applying Economic MPC shows annual electricity cost savings up to 25-30%.
Optimization of pellet–solar combisystems for buildings using a DoE approach

A DoE investigation using factorial and response-surface designs to analyze a solar–pellet combisystem in Sweden to optimize the system based on energy cost was performed. The same approach was also used to examine collector output energy. Investigated parameters were: building heating load, hot tap water consumption, collector flow rate, tank size, collector area, and estimated wood pellet cost. Cost- and performance-based regression equations were derived for optimal collector area and tank size for a range of buildings, providing tools for individual building solar combisystem sizing and optimization. Tank set-point temperature and estimated future pellet price were subjected to sensitivity analysis, and the influence of solar collector parameters and tank insulation level on profitability was investigated. The results indicate that a larger than expected collector area would be profitable due to inflation and the future price of pellets, and that tank size is less important to system profitability. However, tank insulation and set-point temperature were highly significant.

Performance of solar collectors under low temperature conditions: Measurements and simulations results

The performance of four solar thermal collectors (flat plate, evacuated tube, unglazed with rear insulation and unglazed without rear insulation) was experimentally measured and simulated for temperatures below ambient. The influence of several parameters (e.g. collector inlet temperature, air temperature, condensation) is investigated under different operating conditions (day and night). Under some conditions condensation might occur and heat gains could represent up to 55% of the total unglazed collector energy by night. Two TRNSYS collector models including condensation heat gains are also evaluated and results compared to experimental measurements. A mathematical model is also under development to include, in addition to the condensation phenomena, the frost, the rain and the long-wave radiation gains/losses on the rear of the solar collector. While the potential gain from rain was estimated to be around 2%, frost heat gains were measured to be up to 40% per day, under specific conditions. Overall, results have shown that unglazed collectors are more efficient than flat plate or evacuated tube collectors at low operation temperatures or for night conditions, making them more suitable for heat pump applications.
System analysis of a multifunctional PV/T hybrid solar window

The work presented in this article aims to investigate a PV/T hybrid solar window on a system level. A PV/T hybrid is an absorber on which solar cells have been laminated. The solar window is a PV/T hybrid collector with tiltable insulated reflectors integrated into a window. It simultaneously replaces thermal collectors, PV-modules and sunshade. The building integration lowers the total price of the construction since the collector utilizes the frame and the glazing in the window. When it is placed in the window a complex interaction takes place. On the positive side is the reduction of the thermal losses due to the insulated reflectors. On the negative side is the blocking of solar radiation that would otherwise heat the building passively. This limits the performance of the solar window since a photon can only be used once. To investigate the sum of such complex interaction a system analysis has to be performed. In this paper results are presented from such a system analysis showing both benefits and problems with the product. The building system with individual solar energy components, i.e. solar collector and PV modules, of the same size as the solar window, uses 1100kWh less auxiliary energy than the system with a solar window. However, the solar window system uses 600kWh less auxiliary energy than a system with no solar collector.
Thermal behavior of a heat exchanger module for seasonal heat storage

Experimental and theoretic investigations are carried out to study the heat transfer capacity rate of a heat exchanger module for seasonal heat storage with sodium acetate trihydrate (SAT) supercooling in a stable way. A sandwich heat storage test module has been built with the phase change material (PCM) storage box in between two plate heat exchangers. Charge of the PCM storage is investigated experimentally with solid phase SAT as initial condition. Discharge of the PCM storage with the presence of crystallization is studied experimentally. Fluid flow and heat transfer in the PCM module are theoretically investigated by Computational Fluid Dynamics (CFD) calculations. The heat transfer rates between the PCM storage and the heating fluid/cooling fluid in the plate heat exchangers are determined. The CFD calculated temperatures are compared to measured temperatures. Based on the studies, recommendations on how best to transfer heat to and from the seasonal heat storage module are given.

General information

State: Published
Organisations: Department of Civil Engineering, Section for Building Physics and Services
Authors: Fan, J. (Intern), Furbo, S. (Intern), Andersen, E. (Intern), Chen, Z. (Intern), Perers, B. (Intern), Dannemand, M. (Intern)
Thermal performance of marketed SDHW systems under laboratory conditions

A test facility for solar domestic hot water systems, SDHW systems was established at the Technical University of Denmark in 1992. During the period 1992-2012 21 marketed SDHW systems, 16 systems from Danish manufacturers and 5 systems from manufacturers from abroad, have been tested in the test facility under the same realistic test conditions. The systems had different designs and sizes. Each system was tested during a long test period consisting of both a summer and winter period.

Detailed simulation models for each system were developed. The simulation models were modified and the input to the models were fitted in such a way, that the calculated thermal performance is in good agreement with the measured thermal performance, both for a typical winter period and for a typical summer period. In this way it is possible to use the simulation models to calculate the yearly thermal performance of the tested systems with weather data from the Danish Test Reference Year and with the same hot water consumption.

The tests showed that the designs of the heat storage and that the system concepts are of vital importance for the thermal performances of the systems and that neither the solar collector efficiency nor the solar collector area is influencing the thermal performance as much as the heat storage design and the system concept. The tests also showed that all the tested systems can be improved with relative simple design changes.

Based on the tests it is concluded that high thermal performances of SDHW systems are achieved by reducing the heat loss from the upper part of the heat stores to a minimum by having no pipes connected to the upper part of the tank, reducing the auxiliary volume at the top of the heat stores as much as possible, of course with consideration of the required hot water comfort, avoiding simple errors, using the low flow principle and heat stores with a high degree of thermal stratification and by using components with good thermal characteristics.
Experiences and lessons learned from 30 years of dynamic collector testing, modelling and simulation

Dynamic testing and modeling (in contrast to Steady State line of action) of solar collectors is to prefer in most climates, except for the most extreme locations with clear skies every day. A very important part of dynamic testing and modeling is not only the thermal capacitance correction, but also the split of the solar radiation absorption modeling, into beam and diffuse and the modeling of the collectors' incidence angle dependency for both beam and diffuse radiation. These optical features are in most situations more important than the accuracy of the dynamic and thermal loss part of the model. This can be seen from the statistical analyze when evaluating test data. The t-ratios i.e. the parameter values divided by their standard deviations, are generally much higher (often 10 times higher) for the optical parameters than for the thermal loss ones. There are also important details concerning solar radiation measurements for beam and diffuse including alignment of sensors and test object, that are often not considered, which will be discussed and lessons learned will be given. A misalignment of just a few degrees of the collector test stand or the solar sensors will immediately show up in a dynamic test evaluation, especially when analyzing the incidence angle modifier behavior and thermal capacitance of a collector. To achieve good results in dynamic testing it is essential to understand the basic concepts of the method and to use this understanding when designing a test rig and collecting data during a test for later analyze. It is very desirable to use a continuous parameter feedback during the test, so that the test conditions can be changed hour by hour to derive more accurate results and shorten the testing time. Such advice will be discussed in the paper. Some of these findings has not
yet reached the EN12975 standard level, and suggestions for revisions and improvements will be presented that have
general application also for non standardized testing, for example research and development testing.

**General information**
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Organisations: Section for Building Physics and Services, Department of Civil Engineering, SP Technical Research
Institute of Sweden
Authors: Perers, B. (Intern), Kovacs, P. (Ekstern), Pettersson, U. (Ekstern)
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Main Research Area: Technical/natural sciences
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http://www.swc2011.org/cms/
Source: orbit
Source-ID: 317128
Publication: Research - peer-review › Article in proceedings – Annual report year: 2011

**Experimental studies on seasonal heat storage based on stable supercooling of a sodium acetate water mixture**
Laboratory tests of a 230 l seasonal heat storage module with a sodium acetate water mixture have been carried out. The
aim of the tests is to elucidate how best to design a seasonal heat storage based on the salt water mixture, which
supercools in a stable way. The module can be a part of a seasonal heat storage, that will be suitable for solar heating
systems which can fully cover the yearly heat demand of Danish low energy buildings. The tested module has
approximately the dimensions 2020 mm x 1285 mm x 80 mm. The module material is steel and the wall thickness is 2
mm. Different methods to transfer heat to and from the module have been tested. Further, a solidification start method,
based on a strong cooling of a small part of the salt water mixture in the module by boiling CO2 in a small brass tank in
good thermal contact to the outer side of the module wall, has been tested. Tests of the long term durability of small scale
seasonal heat storage modules with different heights have been carried out in order to elucidate the maximum height of a
module resulting in a stable heat storage. Based on the studies, recommendations for the design of a seasonal heat
storage based on modules with a sodium acetate water mixture will be given.

**General information**
State: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering
Authors: Furbo, S. (Intern), Dragsted, J. (Intern), Fan, J. (Intern), Andersen, E. (Intern), Perers, B. (Intern)
Publication date: 2011

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**Heat transfer capacity of a heat exchanger module for seasonal heat storage**

**General information**
State: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering
Authors: Fan, J. (Intern), Furbo, S. (Intern), Chen, Z. (Intern), Andersen, E. (Intern), Perers, B. (Intern)
Publication date: 2011

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Links:
http://www.swc2011.org/cms/
Modelling, Measurements and Validation of a solar plus heat pump compact unit from Nilan

General information
State: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering, Technical University of Denmark
Authors: Perers, B. (Intern), Andersen, E. (Intern), Furbo, S. (Intern), Tsouvalas, A. (Ekstern)
Publication date: 2011

Models of the heat dynamics of solar collectors for performance testing
The need for fast and accurate performance testing of solar collectors is increasing. This paper describes a new technique for performance testing which is based on non-linear continuous time models of the heat dynamics of the collector. It is shown that all important performance parameters can be accurately estimated with measurements from a single day. The estimated parameters are compared with results from standardized test methods (Fischer et al., 2004). Modelling the dynamics of the collector is carried out using stochastic differential equations, which is a well proven efficient method to obtain accurate estimates of parameters in physical models. The applied method is described by Kristensen et al. (2004) and implemented in the software CTSM1. Examples of successful applications of the method includes modelling the of the heat dynamics of integrated photo-voltaic modules (Friling et al., 2009) and modelling of the heat dynamics of buildings (Madsen and Holst, 1995). Measurements obtained at a test site in Denmark during the spring 2010 are used for the modelling. The tested collector is a single glazed large area flat plate collector with selective absorber and Teflon anti convection layer. The test rig is described in Fan et al. (2009). The modelling technique provides uncertainty estimates such as confidence intervals for the parameters, and furthermore enables statistical validation of the results. Such tests can also facilitate procedures for selecting the best model to use, which is a very non-trivial task.

New tool for standardized collector performance calculations
A new tool for standardized calculation of solar collector performance has been developed in cooperation between SP Technical Research Institute Sweden, DTU Denmark and SERC Dalarna University. The tool is designed to calculate the annual performance for a number of representative cities in Europe on the basis of parameters from collector tests performed according to EN12975, without any intermediate conversions. The main target group for this tool is test institutes and certification bodies that intend to use it for conversion of collector model parameters derived from performance tests, into a more user friendly quantity: the annual energy output. The energy output calculated by the tool can be expressed either per square meter or per collector module.
A first research version is now in operation of a software package for multiple linear regression (MLR) modeling and analysis of solar collectors according to ideas originating all the way from Walletun et al. (1986), Perers, (1987 and 1993). The tool has been implemented in the free and open source program R http://www.r-project.org/. Applications of the software package includes: visual validation, resampling and conversion of data, collector performance testing analysis according to the European Standard EN 12975 (Fischer et al., 2004), statistical validation of results, and the determination of collector incidence angle modifiers without the need of a mathematical function (Perers, 1997). The paper gives a demonstration with examples of the applications, based on measurements obtained at a test site at DTU in Denmark (Fan et al., 2009). The tested collector is a single glazed large area flat plate collector with selective absorber and teflon anti convection layer. The package is intended to enable fast and reliable validation of data, and provide a united implementation for MLR testing of solar collectors. This will furthermore make it simple to replicate the calculations by a third party in order to validate the results. Finally more advanced methods can be implemented and easily shared as extensions to the package, for example methods for statistical estimation of the incidence angle modifier with non-linear functions for collectors with more complicated optics. The overall advantage of this kind of tool and analysis is that it is almost the inverse of simulation. Therefore the model and parameters will be very well validated for application in later use for system simulation, even if the test is no real system test. Also for annual collector performance calculations with a new Excel tool connected to EN 12975 (Kovacs, 2011) this built in validation gives an extra quality assurance.

Some of the main bottlenecks for the development and commercialization of photovoltaic/thermal hybrids are the lack of an internationally recognized standard testing procedure as well as a method to compare different hybrids with each other and with conventional alternatives. A complete methodology to characterize, simulate and evaluate concentrating photovoltaic/thermal hybrids has been proposed and exemplified in a particular case study. By using the suggested testing method, the hybrid parameters were experimentally determined. These were used in a validated simulation model that estimates the hybrid outputs in different geographic locations. Furthermore, the method includes a comparison of the hybrid performance with conventional collectors and photovoltaic modules working side-by-side. The measurements show that the hybrid electrical efficiency is 6.4% while the optical efficiency is 0.45 and the U-value 1.9W/m²°C. These values are poor when compared with the parameters of standard PV modules and flat plate collectors. Also, the beam irradiation...
incident on a north–south axis tracking surface is 20–40% lower than the global irradiation incident on a fixed surface at optimal tilt. There is margin of improvement for the studied hybrid but this combination makes it difficult for concentrating hybrids to compete with conventional PV modules and flat plate collectors.

**General information**

State: Published
Organisations: Lund Institute of Technology
Authors: Bernardo, L. (Ekstern), Perers, B. (Intern), Håkansson, H. (Ekstern), Karlsson, B. (Ekstern)
Publication date: 2011
Main Research Area: Technical/natural sciences

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Web of Science (2017): Impact factor 4.374
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 4.52 SJR 1.504 SNIP 1.746
Web of Science (2016): Impact factor 4.018
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.912 SNIP 2.085 CiteScore 4.61
Web of Science (2015): Impact factor 3.685
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.962 SNIP 2.671 CiteScore 4.77
Web of Science (2014): Impact factor 3.469
Web of Science (2014): Indexed yes
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Scopus rating (2013): SJR 1.99 SNIP 2.85 CiteScore 4.44
Web of Science (2013): Impact factor 3.541
ISI indexed (2013): ISI indexed yes
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Scopus rating (2012): SJR 1.605 SNIP 2.517 CiteScore 3.65
Web of Science (2012): Impact factor 2.952
ISI indexed (2012): ISI indexed yes
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BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.283 SNIP 2.178 CiteScore 3.19
Web of Science (2011): Impact factor 2.475
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.369 SNIP 2.16
Web of Science (2010): Impact factor 2.172
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.265 SNIP 2.158
Short-Term Solar Collector Power Forecasting

This paper describes a new approach to online forecasting of power output from solar thermal collectors. The method is suited for online forecasting in many applications and in this paper it is applied to predict hourly values of power from a standard single glazed large area flat plate collector. The method is applied for horizons of up to 42 hours. Solar heating systems naturally come with a hot water tank, which can be utilized for energy storage also for other energy sources. Thereby such systems can become an important part of energy systems with a large share of uncontrollable energy sources, such as wind power. In such a scenario online forecasting is a vital tool for optimal control and utilization of solar heating systems. The method is a two-step scheme, where first a non-linear model is applied to transform the solar power into a stationary process, which then is forecasted with robust time-adaptive linear models. The approach is similar to the one by Bacher et al. (2009), but contains additional effects due to differences between solar thermal collectors and photovoltaics. Numerical weather predictions provided by Danish Meteorological Institute are used as input. The applied models adapt over time enabling tracking of changes in the system and in the surrounding conditions, such as decreasing performance due to wear and dirt, and seasonal changes such as leaves on trees. This furthermore facilitates remote monitoring and check of the system.

General information
State: Published
Organisations: Mathematical Statistics, Department of Informatics and Mathematical Modeling, Section for Building Physics and Services, Department of Civil Engineering
Authors: Bacher, P. (Intern), Madsen, H. (Intern), Perers, B. (Intern)
Publication date: 2011
Solar combisystems with forecast control to increase the solar fraction and lower the auxiliary energy cost

Solar Combi systems still need quite a lot of auxiliary energy especially in small systems without seasonal storage possibilities. The control of the auxiliary energy input both in time and power is important to utilize as much as possible of the solar energy available from the collectors and also to use low backup energy prices during the day if electricity is used. The storage function and both stratified charging and extraction of heat, are very important, to separate different temperature zones in the storage. This paper describes a step towards forecast control for electricity based auxiliary energy sources. It can be either direct electric heating elements or a heat pump upgrading ambient energy in the air, ground, solar collector or waste heat from the house. The paper describes system modeling and simulation results. Advanced laboratory experiments are also starting now with three different combisystems, operating in parallel. These systems will be briefly described too.

General information
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Organisations: Section for Building Physics and Services, Department of Civil Engineering
Authors: Perers, B. (Intern), Furbo, S. (Intern), Fan, J. (Intern), Andersen, E. (Intern), Chen, Z. (Intern)
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Publication: Research - peer-review › Article in proceedings – Annual report year: 2011

Study on a tracking solar collector

General information
State: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering
Authors: Chen, Z. (Intern), Furbo, S. (Intern), Fan, J. (Intern), Andersen, E. (Intern), Perers, B. (Intern)
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Validation of a dynamic model for unglazed collectors including condensation. Application for standardized testing and simulation in TRNSYS and IDA

An improved unglazed collector model has been validated for use in TRNSYS and IDA and also for future extension of the EN12975 collector test standard. The basic model is the same as used in the EN12975 test standard in the quasi dynamic performance test method (QDT). In this case with the addition of a condensation term that can handle the operation of unglazed collectors below the dew point of the air. This is very desirable for simulation of recharging of ground source energy systems and direct operation of unglazed collectors together with a heat pump. The basic idea is to have a direct connection between collector testing and system simulation by using the same dynamic model and parameters during testing and simulation. The model together with the parameters will be validated in each test in this way. This work describes the method applied to an unglazed collector operating partly below the dew point under real dynamic weather conditions, for a long period during the autumn 2010. The validation results also show that the model can handle operation of such a collector during the night. This is a common mode of operation for this collector type in a real system.

General information
State: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering, SP Technical Research Institute of Sweden, ÅF Infrastructure
An improved solar collector model including condensation and asymmetric incidence angle modifiers

General information
State: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering
Authors: Perers, B. (Intern)
Publication date: 2010

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Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 273709
Publication: Research - peer-review › Article in proceedings – Annual report year: 2010

DETAILED MODELLING OF CHARGING BEHAVIOUR OF SMART SOLAR TANKS
The charging behaviour of smart solar tanks for solar combisystems for one-family houses is investigated with detailed Computational Fluid Dynamics (CFD) modelling and Particle Image Velocimetry (PIV) measurements. The smart solar tank can be charged with a variable auxiliary volume fitted to the expected future energy demand. Therefore the heat loss from the tank is decreased and the thermal performance of the solar heating system is increased compared to a traditional system with a fixed auxiliary volume. The solar tank can be charged either by an electric heating element situated in the tank or by an electric heating element in a side-arm mounted on the side of the tank. Detailed CFD models of the smart tanks are built with different mesh densities in the tank and in the side-arm. The thermal conditions of the tank during charging are calculated with the CFD models. The fluid flow and temperature calculations are compared to PIV (Particle Image Velocimetry) measurements of fluid flows and temperature measurements. The aim is to elucidate the temperature distribution and thermal stratification of the tank during charging. It is elucidated how the calculated temperatures in the tank are influenced by the mesh densities, the distribution of computational cells, the physical model and time steps used in the simulations. The findings of the investigations will be used as guidance for creation of CFD models for optimal design of smart solar tanks.

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Authors: Fan, J. (Intern), Andersen, E. (Intern), Furbo, S. (Intern), Perers, B. (Intern)
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Publication: Research - peer-review › Poster – Annual report year: 2010

DETAILED MODELLING OF CHARGING BEHAVIOUR OF SMART SOLAR TANKS
The charging behaviour of smart solar tanks for solar combisystems for one-family houses is investigated with detailed Computational Fluid Dynamics (CFD) modelling and Particle Image Velocimetry (PIV) measurements. The smart solar tank can be charged with a variable auxiliary volume fitted to the expected future energy demand. Therefore the heat loss
from the tank is decreased and the thermal performance of the solar heating system is increased compared to a traditional system with a fixed auxiliary volume. The solar tank can be charged either by an electric heating element situated in the tank or by an electric heating element in a side-arm mounted on the side of the tank. Detailed CFD models of the smart tanks are built with different mesh densities in the tank and in the side-arm. The thermal conditions of the tank during charging are calculated with the CFD models. The fluid flow and temperature calculations are compared to PIV (Particle Image Velocimetry) measurements of fluid flows and temperature measurements. The aim is to elucidate the temperature distribution and thermal stratification of the tank during charging. It is elucidated how the calculated temperatures in the tank are influenced by the mesh densities, the distribution of computational cells, the physical model and time steps used in the simulations. The findings of the investigations will be used as guidance for creation of CFD models for optimal design of smart solar tanks.

**General information**
State: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering
Authors: Fan, J. (Intern), Andersen, E. (Intern), Furbo, S. (Intern), Perers, B. (Intern)
Publication date: 2010

**Host publication information**
Title of host publication: Proceedings of EuroSun 2010 : International Conference on Solar Heating, Coolings and Buildings
ISBN (Print): 978-3-901425-13-4
Main Research Area: Technical/natural sciences
Smart Solar Tanks, Computational Fluid Dynamics, Particle Image Velocimetry, Charging Behaviour
Electronic versions: Jianhua_Fan_SmartSolarTank.pdf
Source: orbit
Source-ID: 272327
Publication: Research - peer-review › Article in proceedings – Annual report year: 2010

**Optimization of systems with the combination of ground-source heat pump and solar collectors in dwellings**
The use of ground-source heat pumps for heating and domestic hot water in dwellings is common in Sweden. The combination with solar collectors has been introduced to reduce the electricity demand in the system. In order to analyze different systems with combinations of solar collectors and ground-source heat pumps, computer simulations have been carried out with the simulation program TRNSYS. Large differences were found between the system alternatives. The optimal design is when solar heat produces domestic hot water during summertime and recharges the borehole during wintertime. The advantage is related to the rate of heat extraction from the borehole as well as the overall design of the system. The demand of electricity may increase with solar recharging, because of the increased operating time of the circulation pumps. Another advantage with solar heat in combination with heat pumps is when the boreholes or neighbouring installations are drilled so close that they thermally influence each other. This may lead to decreasing temperatures in the ground, which gives decreased performance of the heat pump and increased use of electricity. The net annual heat extraction from the ground is reduced by recharge from solar heat.

**General information**
State: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering, Lund University
Authors: Kjellsson, E. (Ekstern), Hellström, G. (Ekstern), Perers, B. (Intern)
Pages: 2667-2673
Publication date: 2010
Main Research Area: Technical/natural sciences

**Publication information**
Journal: Energy
Volume: 35
Issue number: 6
ISSN (Print): 0360-5442
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 5.6 SJR 1.99 SNIP 1.923
Web of Science (2017): Impact factor 4.968
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Performance of a multifunctional PV/T hybrid solar window

General information
State: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering, Lund University
Authors: Davidsson, H. (Ekstern), Perers, B. (Intern)
Pages: 365-372
Publication date: 2010
Main Research Area: Technical/natural sciences

Publication information
Journal: Solar Energy
Volume: 84
ISSN (Print): 0038-092X
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 4.89 SJR 1.615 SNIP 1.791
Web of Science (2017): Impact factor 4.374
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 4.52 SJR 1.504 SNIP 1.746
Web of Science (2016): Impact factor 4.018
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.912 SNIP 2.085 CiteScore 4.61
Web of Science (2015): Impact factor 3.685
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.962 SNIP 2.671 CiteScore 4.77
Web of Science (2014): Impact factor 3.469
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.99 SNIP 2.85 CiteScore 4.44
Web of Science (2013): Impact factor 3.541
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.605 SNIP 2.517 CiteScore 3.65
Web of Science (2012): Impact factor 2.952
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.283 SNIP 2.178 CiteScore 3.19
Web of Science (2011): Impact factor 2.475
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.369 SNIP 2.16
Web of Science (2010): Impact factor 2.172
Web of Science (2010): Indexed yes
Pressure and temperature development in solar heating system during stagnation

This paper presents an investigation of stagnation in solar collectors and the effects it will have on the collector loop. At a laboratory test stand at the Technical University of Denmark, a pressurized solar collector loop was designed to test different numbers of collectors and different designs of the pipes of the solar collector loop. During the investigation the pre-pressure of the expansion vessel and system filling pressure was changed. The investigations showed that a large pressurised expansion vessel will protect the collector loop from critically high temperatures as long as the solar collectors have a good emptying behaviour and the circulation pump is turned off during stagnation.

General information
State: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering
Authors: Dragsted, J. (Intern), Furbo, S. (Intern), Chen, Z. (Intern), Perers, B. (Intern)
Publication date: 2010

Host publication information
Title of host publication: Pressure and temperature development in solar heating system during stagnation
ISBN (Print): 978-3-901425-13-4
Main Research Area: Technical/natural sciences
Stagnation, Solar collector loop
Source: orbit
Source-ID: 272479
Publication: Research - peer-review › Article in proceedings – Annual report year: 2010

Solar Electric heating systems using smart solar tanks and variable electricity costs

General information
State: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering
Authors: Perers, B. (Intern), Furbo, S. (Intern), Andersen, E. (Intern), Fan, J. (Intern)
Publication date: 2010

Host publication information
Title of host publication: Eurosun 2010
Solfangerkreds med stor ekspansionsbeholder og fordampning i solfanger ved faretruede høje temperaturer til sikring af solfangelæske og anlæg

General information
State: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering
Authors: Dragsted, J. (Intern), Furbo, S. (Intern), Perers, B. (Intern), Chen, Z. (Intern)
Publication date: 2010

Test plant and development of tools for design of combi-heating systems for large buildings

General information
State: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering, Linnaeus University, Euronom AB
Authors: Persson, H. (Ekstern), Perers, B. (Intern), Carlsson, B. (Ekstern), Olsson, P. (Ekstern), Hjort, Å. (Ekstern)
Publication date: 2010

The covariation of heating load and solar energy production with the electricity price variations in Denmark

General information
State: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering, Technical University of Denmark
Authors: Perers, B. (Intern), Furbo, S. (Intern), Andersen, E. (Intern), Fan, J. (Ekstern)
Publication date: 2010

Theoretical study on a solar collector loop during stagnation
A mathematical model simulating the stagnation behavior of a pressurized solar collector loop with solar collectors with a good emptying behavior is developed. Based on the pre-pressure of the expansion vessel, the system filling pressure of the solar collector loop and the design of the solar collector loop, the mass of the fluid flowing into the pressurized expansion vessel and the pressures at the top part and at the bottom part of the solar collector loop during stagnation for
the solar collector loop are calculated. The theoretically calculated results are compared with experimental results. There is a good agreement between calculations and measurements. The developed simulation model is therefore suitable to determine the behavior of solar collector loops during stagnation.

**General information**

State: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering
Authors: Chen, Z. (Intern), Dragsted, J. (Intern), Furbo, S. (Intern), Perers, B. (Intern)
Publication date: 2010

**Host publication information**

Place of publication: Graz, Austria
ISBN (Print): 978-3-901425-13-4
Main Research Area: Technical/natural sciences
Solar collector loop, Stagnation
Electronic versions:

THEORETICAL STUDY ON A SOLAR COLLECTOR LOOP DURING STAGNATION 5_Ziqian Chen for Eurosun2010_.pdf
Source: orbit
Source-ID: 272660
Publication: Research › Article in proceedings – Annual report year: 2010

**Theoretical study on a solar collector loop during stagnation**

A mathematical model simulating the stagnation behavior of a pressurized solar collector loop with solar collectors with a good emptying behavior is developed. Based on the pre-pressure of the expansion vessel, the system filling pressure of the solar collector loop and the design of the solar collector loop, the mass of the fluid flowing into the pressurized expansion vessel and the pressures at the top part and at the bottom part of the solar collector loop during stagnation for the solar collector loop are calculated. The theoretically calculated results are compared with experimental results. There is a good agreement between calculations and measurements. The developed simulation model is therefore suitable to determine the behavior of solar collector loops during stagnation.

**General information**

State: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering
Authors: Chen, Z. (Intern), Dragsted, J. (Intern), Furbo, S. (Intern), Perers, B. (Intern)
Publication date: 2010
Event: Poster session presented at International Conference on Solar Heating, Cooling and Buildings, Graz, Austria.
Main Research Area: Technical/natural sciences
Solar collector loop, Stagnation
Electronic versions:

THEORETICAL STUDY ON A SOLAR COLLECTOR LOOP(Poaster) 1.docx
Source: orbit
Source-ID: 272672
Publication: Research › Poster – Annual report year: 2010

**Thermal advantage of tracking solar collectors under Danish weather conditions**

Theoretical investigations have been carried out with the aim to elucidate the thermal advantage of tracking solar collectors for different weather conditions in Kgs. Lyngby, Denmark (55.8°N), and for the weather conditions in Sisimiut, Greenland (66.9°N), just north of the arctic circle. The investigations are based on calculations with a newly developed program. Measured weather data from a solar radiation measurement station at Technical University of Denmark in Kgs. Lyngby Denmark in the period 1990 to 2002 and the Danish Design Reference Year, DRY data file are used in the investigations. The weather data used for Sisimiut are based on a Test Reference Year, TRY weather data file. The thermal advantages of different tracking strategies is investigated for two flat plate solar collectors with different efficiencies, operated at different temperature levels. The investigations show that the advantage of full tracking is in the range 40% – 90% depending on the solar collector and the operation conditions. The advantage is higher for a low efficient solar collector than for a high efficient solar collector and higher for high solar collector temperatures than for low solar collector temperatures. Further, design reference years are not suitable to elucidate the advantage by tracking.

**General information**

State: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering
THREE DIMENSIONAL RAY TRACING AND RELIABILITY ANALYSES OF A NOVEL ICPC COLLECTOR AFTER TWELVE YEARS OF OPERATION

Towards seasonal heat storage based on stable super cooling of sodium acetate trihydrate

A new concept for combisystems characterization: The FSC method
EFFICIENCY AND LIFETIME OF SOLAR COLLECTORS FOR SOLAR HEATING PLANTS
The 12.5 m² flat plate solar collector HT, today marketed by Arcon Solvarme A/S, has been used in solar heating plants in Scandinavia since 1983. The collector is designed to operate in a temperature interval between 40°C and 90°C. The efficiency of the collector has been strongly improved since it was introduced on the market. The paper will present the increase of the efficiency of the collector due to technical improvements since 1983. Further, measurements from the spring of 2009 of the efficiency of two HT collectors, which have been in operation in the solar heating plant Ottrupgaard, Skørping, Denmark since 1994 with a constant high flow rate and in the solar heating plant Marstal, Denmark since 1996 with a variable flow rate, will be presented. The efficiencies will be compared to the efficiencies of the collectors when they were first installed in the solar heating plants. The measurements are supplied with inspections of the collectors inclusive investigations of possible corrosion of the copper pipes of the absorbers of the collectors. It is shown that from 2002 to 2007 the thermal performance of solar collector has been increased by 29%, 39%, 55% and 80% for a mean solar collector fluid temperature of 40°C, 60°C, 80°C and 100°C respectively due to improvement of the collector design. The test of the two collectors shows that due to aging the Ottrupgård collector has a yearly thermal performance which is 4% lower than for the collector tested in 1991 for a solar collector fluid temperature of 45°C, while the Marstal collector has a yearly thermal performance which is 1% lower than the collector tested in 1991. With an increase of the solar collector fluid temperature to 60°C, the yearly thermal performance of the Ottrupgård collector and the Marstal collector is respectively 11% and 10% lower than the collector tested in 1991.
Projected beam irradiation at low latitudes using Meteonorm database

The quantitative analysis of beam radiation received on a solar concentrator may be understood by evaluating the projected solar height angle or profile angle along the north-south vertical plane. This means that all the sunrays projected along the north-south vertical plane will be intercepted by a collector provided the projection angle lies within the acceptance angle. The Meteonorm method of calculating solar radiation on any arbitrary oriented surface uses the globally simulated meteorological databases. Meteonorm has become a valuable tool for estimating solar radiation where measured solar radiation data is missing or irregular. In this paper we present the projected beam solar radiation at low latitudes based on the standard Meteonorm calculations. The conclusion is that there is potential in using solar concentrators at these latitudes since the projected beam radiation is more during winter periods than in summer months. This conclusion is in conformity with the design principle of solar collectors for worst case conditions. (C) 2008 Elsevier Ltd. All rights reserved.
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Solar Electric Heating for the future Energy System

General information
State: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering
Authors: Perers, B. (Intern), Furbo, S. (Intern), Andersen, E. (Intern), Fan, J. (Intern)
Publication date: 2009

Host publication information
Title of host publication: Solar Electric Heating for the future Energy System
Main Research Area: Technical/natural sciences
Conference: ISES Solar World Conference 2009, Johannesburg South Africa, 01/01/2009
Solar Energy Combisystem Electric Grid Interaction
Source: orbit
Source-ID: 256426
Publication: Research - peer-review › Article in proceedings – Annual report year: 2009

Solar Heating Research at Byg DTU

General information
State: Published
Organisations: Section for Building Physics and Services, Department of Civil Engineering
Authors: Perers, B. (Intern)
Publication date: 2008
Event: Poster session presented at Energy DTU : Internal Conference 2008, DTU Lyngby Copenhagen,
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 233813
Publication: Research › Poster – Annual report year: 2008

Projects:

IEA SHC Task 55 - Integration of Large SHC Systems into District Heating and Cooling (DHC) Networks (II)
The aim of the project is - through exchange of international knowledge - to develop and promote solar district heating plants. Denmark is in front in this field and the project gives good opportunities for promotion of Danish know how and technology. The overall objective is to increase the use of solar thermal energy throughout the world.

Project description
The project activities and expected outcomes are:
System description and design of low cost and high performance large-sized SDH and SDC systems as well as the design and evaluation of large scale seasonal storages and hybrid technologies.
Further, technical analyses of findings will be presented within a report for city district planners, dealing with the integration of solar thermal and seasonal storages. Additionally, a specific report for planners will focus on system requirements for SDH and SDC, modular conception and construction as well as the minimization of piping and losses.
Established business and financing models: Objectives here are reference calculation models of SDH and SDC as well as economical requirement definitions for new systems and markets.
Guidelines to secure low operation and maintenance efforts for very large systems including automated operational surveillance.
Advanced control systems for large-sized solar and hybrid systems.
A comparison of measured collector performances in the field, and singular collector tests in the laboratory. Results will be the basis for a validated measurement method of solar collector fields and the validation of performance guarantee procedures.
Data for the optimization of very large collector fields’ performances based on adjusted hydraulics and minimized system losses.

Promotion and technology spread of large systems in new markets through the continuation of the existing database from the IEA SHC Task 45, 48 and 49.

Country reports including case studies and feasibilities.

Department of Civil Engineering

Energy and Services

Period: 01/01/2019 → 31/12/2020
Number of participants: 7

Large solar heating plants, District heating and cooling, System integration, Solar collector field, Large heat storages, Performance analysis, Business models, System controls

Acronym: IEA Task 55

Project participant:

Fan, Jianhua (Intern)
Furbo, Simon (Intern)
Perers, Bengt (Intern)
Kong, Weiqiang (Intern)
Dragsted, Janne (Intern)
Nielsen, Elsabet Nomonde Noma (Intern)
Jensen, Adam Rasmus (Intern)

Financing sources

Source: Public research council
Name of research programme: EUDP
Project

IEA PVPS Task 16 Solar resource for high penetration

The purpose of this project is to develop better recommendations for understanding the solar energy resource in energy systems with high degree of renewable energy penetration. This is done as an international collaboration within the IEA PVPS programme.

Project description

With increasingly high penetration of PV, concentrating solar power (CSP), and solar heating plants into our energy and heating systems around the world, increased knowledge on the solar radiation potential become ever more important.

During meetings in 2015 and 2016 a detailed work plan was made for an upcoming task in the framework of the International Energy Agency Photovoltaic Power Systems Programme (IEA PVPS) to address the issues outlined above. The task entitled: “Solar resource for high penetration and large scale applications” was approved by the IEA PVPS Executive Committee in November 2016 as IEA PVPS Task 16. The task runs for three years from 2017 to 2020.

DTU will continue the work done in the IEA SHC Task 46 (2011-2016), where the focus was on the directional and temporal variability of the solar resource. Now the focus will be on how this affects the energy production in the rows of large scale solar collector and PV fields.

Department of Civil Engineering

Energy and Services

Period: 01/01/2018 → 31/12/2020
Number of participants: 6

Solar resource, high penetration renewable energy systems, Solar heating plants, PV, CSP Concentrating solar power

Acronym: IEA Task 16

Project participant:

Fan, Jianhua (Intern)
Furbo, Simon (Intern)
Dragsted, Janne (Intern)
Nielsen, Elsabet Nomonde Noma (Intern)
Perers, Bengt (Intern)
Kong, Weiqiang (Intern)

Financing sources

Source: Public research council
Development and validation of an in situ solar collector field test method
Denmark has become the front runner in the solar heating plant market with large scale solar collector fields connected to district heating systems. Solar collector fields are composed of solar collectors connected in series and in parallel. It is important that the thermal performances of solar collector fields can be predicted and that the performances are as high as expected. However, there are few studies of theoretical model and in situ test method suitable for solar collector fields. Further, so far no standards on thermal performance of collector fields are available. Thermal performance test methods and standards for single solar collectors have been developed for decades but they are quite different and cannot be directly used for solar collector fields. The knowledge and research of large solar collector field in situ tests is quite limited. In addition, improper layout and operation of large scale solar collector fields will reduce the solar heat production resulting in loss of money. Therefore scientific research for large solar collector fields is needed. The aim of this project is to develop an in situ test method for large solar collector fields to predict and evaluate its thermal performance. By means of the test method, the quality and operation of solar collector fields can be secured and optimized.

Department of Civil Engineering
Energy and Services
Period: 01/04/2017 → 31/03/2019
Number of participants: 2
Solar collector field, thermal analysis, Solar heating
Project ID: 26675
Project participant:
Perers, Bengt (Intern)
Project Coordinator:
Kong, Weiqiang (Intern)

Financing sources
Source: Private funding (private)
Name of research programme: Bjarne Saxhofs Fond
Project

Thermal performance of tracking concentrating solar collectors
theoretical calculations of thermal performance of tracking concentrating solar collectors. Different locations and temperature levels are considered.

Department of Civil Engineering
Section for Building Energy
Absolicon Solar Concentrator AB
Period: 01/11/2016 → 31/12/2016
Number of participants: 2
Concentrating solar collectors, tracking
Acronym: ABSOLICON
Project participant:
Furbo, Simon (Intern)
Perers, Bengt (Intern)

IEA Task 55 Large scale solar district heating and cooling systems
Investigations on large solar heating plants

Department of Civil Engineering
Section for Building Energy
Solar Key Int.
Aalborg CSP
Period: 01/10/2016 → 31/12/2018
Number of participants: 4
solar heating plants
Acronym: IEA Task 55
Project participant:
Furbo, Simon (Intern)
Perers, Bengt (Intern)
Tian, Zhiyong (Intern)
Huang, Junpeng (Intern)

Project

PVT/heat pump system
Measurements on a PVT/heat pump system are carried out in a laboratory test facility.

Department of Civil Engineering
Section for Building Energy
Department of Applied Mathematics and Computer Science
RACELL SAPHIRE Technologies ApS
COWI A/S
Period: 01/04/2016 → 31/07/2017
Number of participants: 3
PVT panels, heat pump, measurements

Project participant:
Furbo, Simon (Intern)
Dannemand, Mark (Intern)
Perers, Bengt (Intern)

Project

CSP (Concentrated Solar Power) plant with biomass heat and power plant and ORC system
Preparation and validation of a simulation model of the CSP (Concentrated Solar Power) plant with biomass heat and power plant and ORC system in Brønderslev. Analyses of measurements from the system in Brønderslev, and calculations with the developed model with the aim to optimize the system design and the control strategy of the plant.

Department of Civil Engineering
Section for Building Energy
Brønderslev Forsyning A/S
Aalborg CSP
PlanEnergi
Period: 07/01/2016 → 31/12/2018
Number of participants: 2
Concentrating solar collectors, ORC system, measurements, simulations

Project participant:
Furbo, Simon (Intern)
Perers, Bengt (Intern)

Project

Pilot installation of hybrid solar collectors in district heating plants
A combined tracking concentrating and flat plate collector will be developed and tested experimentally. A solar collector row with the developed solar collector will be installed in Sæby solar heating plant. The thermal performance of the collector row will be measured and compared to the thermal performance of normal flat plate collectors.

Department of Civil Engineering
Section for Building Energy
PolyCSP ApS
Sæby Varmevejr amba
Period: 01/01/2016 → 31/12/2017
Number of participants: 3
Solar collector, solar heating plant

Project participant:
IEA Task 54 Price reduction of solar thermal systems
Investigations on solar heating systems with the aim to reduce the price of the systems. Both solar domestic hot water systems and combined systems for space heating and domestic hot water supply are considered.

Department of Civil Engineering
Section for Building Energy
SolarKey Int.
Period: 01/01/2016 → 31/12/2017
Number of participants: 3
Solar heating systems, low flow systems, SDHW systems, Solar combi systems
Acronym: IEA Task 54
Project participant:
Furbo, Simon (Intern)
Perers, Bengt (Intern)
Dragsted, Janne (Intern)

Follow up on large scale storage in Denmark, Gram
In the project the performance of the pit heat storage in Gram will be followed. The monitoring results and experience for operation of storage until 2018 will be analyzed and published.

Project description
In 2014-2015 two new large heat storage have been implemented in Denmark in Vojns and Gram. The two storages have similar design. Before that, 3 large storages were implemented in Brædstrup, Marstal and Dronninglund from 2011-2013. Monitoring results from these 3 storages are analyzes in the project "Opfølgningsprogram for store varmelagre i Danmark" (EUDP 14-I, j.nr. 64014-0121) lasting until 30.06.2018.

Since the design of the pit heat storages Vojns and Gram differs from the design of the pit heat storage in Marstal and Dronninglund it is important to establish similar monitoring and analysis at least one of those storages. The performance of the pit heat storage in Gram will therefore in this project be monitored in a similar way as the performance of the storage in "Opfølgningsprogram for store varmelagre i Danmark". Especially for Gram will monitoring of the performance of new and cheaper lit construction.

SDH (Solar District Heating) Conference will be arranged in Denmark in 2016. This will be an excellent possibility to promote Danish solar solutions. Therefore support to SDH conference is included in the dissemination part of this project. 150 stakeholders from more than 20 countries are expected to participate. The intention is to arrange the conference in Billund and use Gram as the main stop at the technical tour.

Department of Civil Engineering
Energy and Services
PlanEnergi
Solites
Rambøll Danmark A/S
Kristensen Consulting
Period: 01/01/2016 → 31/12/2018
Number of participants: 5
Large scale heat storages, Long term measurement, Performance analysis
Project participant:
Fan, Jianhua (Intern)
Furbo, Simon (Intern)
Perers, Bengt (Intern)
Kong, Weiqiang (Intern)
Nielsen, Elsabet Nomonde Noma (Intern)
Follow up on large scale heat storages in Denmark

The purpose of the project is to follow the performance of two pit heat storages and one borehole storage implemented 2011-3013 in Denmark. In the project monitoring results and experiences from operation of the storages until 2018 will be analyzed and published. Project description Long term heat storages are important in the future energy system in Denmark. This can a.o. bee seen in two reports required by the Danish Energy Agency during 2013: "Status and Recommendations for RD&D on Energy Storage Technologies in a Danish Context" and "Udredning vedrørende varmelagringsteknologier og store varmepumper til brug i fjernvarmesystemet" (analyses of heat storage technologies and large heat pumps for district heating) From 2011 to 2013 three large long term storages has been implemented in Brædstrup (borehole storage), Marstal (pit heat storage) and Dronninglund (pit heat storage) connected to large scale solar heat plants and heat pumps for district heating. The monitoring programs for these storages end when the projects are finalized. But long term heat storages change performance the first years because the surrounding soil is heated up. Therefore there is a need to continue the monitoring programmes. This application has as purpose to secure a continuation of the monitoring programmes and to analyse and make the results public. Beside the application includes tests and measures that can support future storage projects. The main activity in the project is a real time publication of monitoring results at Solvarmedatadk and yearly analysis of performance of the storages. Pit heat storages has beside three problems, that the application shall solve for existing and future owners: Corrossion in in-and outlet pipes. The problem has showed up in Marstal. Effect of actions taken and future development has to be carefully supervised. Life time for the liner in Dronninglund. The liner has until now not been tested for long term durability, but the supplier has guaranteed 20 years life time by 90° C. This must be tested, because such a liner can extend the market for pit heat storages to storing heat from incineration plants, CHP and industrial processes. The durability of the insulation material in the floating lid constructions in Marstal and Dronninglund. Also here a test will show if the market can be extended. Long term heat storages can make the future district heating systems flexible, so that they can integrate fluctuating power production. In Denmark the future market is estimated to 5 mio. m³ water storages. Outside Denmark similar systems are developed. For instance a resent german study has showed a marked of 15 mio. m³ water storages and China has showed beginning interest for the technology.

Department of Civil Engineering
Energy and Services
PlanEnergi
Brædstrup Fjernvarme
Marstal Fjernvarme A/S
Dronninglund Fjernvarme
VIA University College
Solites
Period: 01/01/2016 → 31/12/2018
Number of participants: 4
Large heat storages, Solar heating plants, water pit heat storage, Borehole heat storage, Long term measurement, Performance analysis
Project participant:
Fan, Jianhua (Intern)
Furbo, Simon (Intern)
Kong, Weiqiang (Intern)
Perers, Bengt (Intern)

Financing sources
Source: Public research council
Name of research programme: EUDP
Amount: 2,900,000.00 Danish Kroner
Year of approval: 2014
Project

Solar heating plant with tracking concentrating solar collectors and flat plate solar collectors
A simulation model of the solar heating plant in Tårs is developed and validated by means of measuremnts. Measurements from the solar heating plant in Tårs are analysed.
Simulations are carried out with the validated model with the aim to optimize future solar heating plants.

Department of Civil Engineering
Section for Building Energy
Aalborg CSP
Period: 01/01/2015 → 30/11/2017
Number of participants: 3
CSP collectors, flat plate collectors, solar heating plants
Project participant:
Furbo, Simon (Intern)
Perers, Bengt (Intern)
Tian, Zhiyong (Intern)

Solvarme og energiforsyningens samfundsøkonomi, IEA SHC Task 52
Department of Civil Engineering
Section for Building Physics and Services
PlanEnergi
Aalborg University
Period: 01/04/2014 → 31/12/2017
Number of participants: 2
Project participant:
Furbo, Simon (Intern)
Perers, Bengt (Intern)

Development of PVT module for multiapartment buildings
Development of PVT module, which both can produce heat and electricity from solar radiation.
Department of Civil Engineering
Section for Building Physics and Services
RACELL SAPHIRE Technologies ApS
STO Danmark A/S
MAP Architects
Period: 01/01/2014 → 31/12/2014
Number of participants: 3
PVT module, Efficiency, Measurements
Project ID: 26395
Project participant:
Furbo, Simon (Intern)
Berg, Jakob Brinke (Intern)
Perers, Bengt (Intern)

Aluminiumsolfangere til fjernvarmen
Department of Civil Engineering
Section for Building Physics and Services
PlanEnergi
Period: 18/09/2013 → 31/12/2015
Number of participants: 2
Project ID: 26349
Project participant:
Furbo, Simon (Intern)
Experimental and theoretical investigations of combined solar heating/heat pump systems for single Family houses

Renewable energy systems based on the combination of solar heating systems and electrical driven auxiliary energy supply systems such as heat pumps are becoming very attractive solutions as the heating and cooling systems in single family houses. The combined solar heating/heat pump systems provide all the needed yearly heating and cooling demand in single family houses. The most widely used energy sources for the heat pumps are the ambient air, ground source heat exchangers or borehole heat exchangers. Heat pumps that use of ambient air as heat source need fans and these can create disturbing noise. Further, heat pumps that use ambient air as heat source run with low efficiency in cold winter periods. The heat source temperature is more stable with ground source heat exchanger or borehole heat exchanger. In systems with ground source heat exchangers or borehole heat exchangers, excess energy production from the solar collectors is also sometimes lead into the ground for recharging the ground heat source. Produced energy that cannot be directly used is usually lead into the ground in order to protect the system from overheating.

The aim of this project is to increase the knowledge of the heat and mass transfer in combined solar heating/heat pump systems that uses of a ground source heat exchanger. Such a system is installed and tested at DTU Byg.

Department of Civil Engineering
Section for Building Physics and Services
Period: 01/07/2013 → 30/06/2016
Number of participants: 5
Project ID: 26309
Project participant:
Nielsen, Elsabet Nomonde Noma (Intern)
Perers, Bengt (Intern)
Furbo, Simon (Intern)
Dandanell, Jens Martin (Intern)
Aagaard, Claus (Intern)
Project

VELUX visiting professor on solar heating

The visiting Professor Jiangong Han is doing experimental investigations on advantages gained by anti reflection treatment of PV panels and solar collectors.

Department of Civil Engineering
Section for Building Physics and Services
Period: 01/05/2013 → 12/12/2014
Number of participants: 7
Anti reflection treatment, PV panel, Solar collector
Project ID: 26296
Project participant:
Furbo, Simon (Intern)
Fan, Jianhua (Intern)
Kong, Weiqiang (Intern)
Perers, Bengt (Intern)
Han, Jiangong (Intern)
Dandanell, Jens Martin (Intern)
Aagaard, Claus (Intern)
Project

Testing, development and demonstration of large scale solar district heating system

The aim of the project is to bring advanced Danish experiences on demonstration project of solar district heating system and advanced testing technology into China, to promote the application of the large-scale solar district heating systems in China and to enhance the testing capabilities of collectors and large scale solar district heating systems. The project will promote Danish - Chinese cooperation in the RE area and stimulate future international cooperation.

Department of Civil Engineering
Section for Building Physics and Services
PlanEnergi
China National Solar Thermal Testing Centre, China Academy of Building Research
Chinese Academy of Sciences
Beijing Solar Energy Research Institute Co. Ltd
Sunda Solar Energy Technology Co., Ltd.

Period: 01/03/2013 → 30/09/2014
Number of participants: 8

RED, large scale solar heating, testing, development and demonstration
Project ID: 26293

Project participant:
Kong, Weiqiang (Intern)
Perers, Bengt (Intern)
He, Tao (Ekstern)
Wang, Zhifeng (Ekstern)
Zhu, Dunzhi (Ekstern)
Liu, Jun (Ekstern)

Project Manager, organisational:
Furbo, Simon (Intern)

Project Manager, academic:
Fan, Jianhua (Intern)

Financing sources
Source: Public research council
Name of research programme: the Sino-Danish Renewable Energy Development Programme (RED)
Amount: 3,950,000.00 Danish Kroner
Year of approval: 2012

Relations
Activities:
International Conference on Solar Heating and Cooling for Buildings and Industry

Powerpipe hybrid solar panel
A solar collector panel both producing electricity and heat will be developed and tested.

Department of Civil Engineering
Section for Building Physics and Services
Department of Energy Conversion and Storage
PowerPipe ApS
Batec Solvarme A/S
LOKE Lolland Energi

Period: 01/01/2013 → 30/06/2014
Number of participants: 3

Solar collector, Hybrid, Electricity, Heat
Project participant:
Furbo, Simon (Intern)
Fan, Jianhua (Intern)
Perers, Bengt (Intern)

Financing sources
Source: Forskningsprojekter - Miljø- og Energiminderiet
Name of research programme: EUDP programme
Amount: 489,600.00 Danish Kroner
Year of approval: 2012

**IEA Task 44 Systems Using Solar Thermal Energy in Combination with Heat Pumps**

The Task aims at optimizing combinations of solar thermal energy and heat pump, primarily for one family houses.

Department of Civil Engineering

Section for Building Physics and Services

Danish Technological Institute

Cenergia

Nilan A/S

**Ekolab**

- **Period:** 13/08/2012 → 31/05/2013
- **Number of participants:** 3
- **Solar heating, Heat pumps, Combined systems**
- **Acronym:** Task 44

**Project participant:**

- Furbo, Simon (Intern)
- Perers, Bengt (Intern)
- Nielsen, Elsabet Nomonde Noma (Intern)

**Financing sources**

- **Source:** Forskningsprojekter - Miljø- og Energiministeriet
- **Name of research programme:** EUDP programme
- **Amount:** 257,760.00 Danish Kroner
- **Year of approval:** 2012

**Combined development of compact thermal energy storage technologies**

The aim of the project is to develop a seasonal heat storage consisting of heat storage modules with a salt water mixture of sodium acetate and water. The heat storage concept is based on the advantage of stable supercooling. By using this concept the heat storage module will have no heat loss for a long period making seasonal heat storage possible. If a sodium acetate water mixture, which has a melting point of 58°C, has been fully melted during the sunny summer, it can cool down in its liquid phase to the surrounding temperature and still preserve the latent heat related to the heat of fusion. The heat storage module can be left in this state with no heat loss until a heat demand occurs in the house in the winter, in which case solidification is activated, the heat of fusion is released, and the heat storage temperature increases almost immediately to the melting point.

The developed heat storage will be a part of a demonstration solar heating system which is intended to cover the total yearly heat demand and hot water consumption of a low energy one family house.

Department of Civil Engineering

Section for Building Physics and Services

Technische Universität Graz

Nilan A/S

**Velux A/S**

- **Period:** 01/04/2012 → 31/03/2016
- **Number of participants:** 8
- **Development, Demonstration, Seasonal heat storage, PCM, Supercooling**
- **Acronym:** COMTES

**Project participant:**

- Furbo, Simon (Intern)
- Fan, Jianhua (Intern)
- Dragsted, Janne (Intern)
- Chen, Ziqian (Intern)
- Dannemand, Mark (Intern)
- Nielsen, Elsabet Nomonde Noma (Intern)
- Perers, Bengt (Intern)
- Berg, Jakob Brinkø (Intern)
Financing sources
Source: EU research programme (public)
Name of research programme: seventh framework programme
Amount: 4,428,000.00 Danish Kroner
Year of approval: 2012

Project

Sustainable energy
The aim of the project is to carry out research and education activities on Sustainable Energy within the SDC Center. The SDC Center is a joint project on education and research between the eight Danish universities, the Danish Ministry of Science, Technology and Innovation, the University of the Chinese Academy of Sciences (UCAS) and the Chinese Academy of Sciences (CAS). The overall aim of SDC is to promote and strengthen collaboration between Danish and Chinese research and learning environments for the benefit of both countries.

Department of Civil Engineering
Section for Building Physics and Services
Period: 01/07/2011 → 31/12/2013
Number of participants: 5
Sustainable Energy, Sino-Danish Research and Education Center, Solar Energy
Project ID: 26192
Project participant:
Fan, Jianhua (Intern)
Furbo, Simon (Intern)
Nielsen, Elsbet Nomonde Noma (Intern)
Perers, Bengt (Intern)
Chen, Ziqian (Intern)

IEA Task 45 Large Solar Heating & Cooling Systems
Large Solar thermal Systems (> 0,5MW) have enormous potential for fossils and CO2 reduction. International large solar thermal plants are getting more importance in heat production for feeding district heat networks, industrial processes and thermal driven chillers. Numerous projects in Europe (especially in Denmark), China and Arab area emphasize this trend impressively. Beneath the large potential large solar thermal installations have been proven to be economical and sustainable. Feeding the local district heat network with exceeding energy is reasonable and has been demonstrated extensively in Denmark and also Austria very effective. The central problem of solar thermal plants is that there is selective know-how available for different system parts, but most important issues like overall system concepts, collector fields, storages, heat pumps for lowering temperature and more storage density, monitoring concepts and efficient operating control, financing models etc. have no proven and harmonized standards. So potential for economics of scale and cost reduction for large scale solar thermal plants could not build advantages so far. Also a structured technology development on international level is not given until now. Central aim of Task 45 is to connect the most substantial players through analysis, discussion of implemented and future projects and simulation based optimization of components and systems, as well as the development of components and systems standards beneath considerable cost reduction potential at coincidental increased system efficiency to reach the next generation of large solar thermal installations. The planned transfer to central players and stakeholders is essential for sustainable impact the current market development. Facing the increasing demand and the enormous potential of large solar thermal plants the need for competent and independent answering of these questions is given and will be handled in Task 45. Department of Civil Engineering is the subtask A leader of the project. SUBTASK A "Collectors and collector loop" serves the need for research, development and/or optimization on: • Components for solar collector fields • Design of solar collectors for different applications • Thermal performance of solar collectors for different volume flow rates, collector tilts and solar collector fluids • Control strategy for solar collector fields • Requirements and test methods for solar collector loop pipes • Requirements on hydraulic design of solar collector fields • Precautions for safety and expansion • Guaranteed performance of solar collector fields • Description of further needed research on solar collector fields • Contribution on planning and installation of solar collector fields for design handbook

Section for Building Physics and Services
Department of Civil Engineering
PlanEnergi
Marstal Fjernvarme A/S
Brædstrup Fjernvarme
Test facility for air collectors

1. Objective of the project Renewable energy systems based on air solar collectors are used for dehumidification of buildings and heating of ventilation air for buildings. The aim of the project is to increase the knowledge of the heat and mass transfer in air solar collectors. This knowledge is the basis for improved marketed air solar collectors. 2. Background Air solar collectors are in Denmark installed in large numbers in summer houses with the aim to improve the indoor climate by dehumidification. The air solar collectors have integrated PV modules which provide electricity for integrated ventilation fans. In this way outdoor air is in sunny cold periods heated in the solar collector and by means of the fan blown into the houses. This kind of systems can also be used for heating of ventilation air. The system can also be extended with an additional ventilation fan which is placed on the north and shaded side of the building. When the temperature inside the building gets too high, a control system turns off the ventilation fan on the south and sunny side and turns on the ventilation fan on the north side. In this way cold air from the shaded part of the building can be used to cool down the building. Marketed air solar collectors are today designed based on manufacturer’s practical experience with special focus on the manufacturing process, the installation process and the operation of the system. Detailed knowledge of the thermal behaviour inclusive details on the heat and mass transfer in the air solar collector during operation is only to a small extent the basis for the design of the air solar collectors. Several companies in Denmark manufacture this kind of solar collectors, for instance Solar Venti A/S, Ans Solvarme and Dansolar and consumers must rely on product information given by manufactures. There is a lack of detailed knowledge in this field, and there are no impartial institutes with test facilities for air collectors in Denmark. Further, there are no international standard test methods available for air solar collectors. 3. Project activities This project will establish the first part of the basis for development of air solar collector systems for dehumidification of buildings and heating of ventilation air for buildings. The first part contains the following activities: Establishing of a test facility for side-by-side tests of air solar collectors, Testing the efficiency of a marketed air solar collector and Contribute to development of test methods for air solar collectors within the international energy agency framework program, Task 43

Optimization of solar heating and water heating combisystems applied in buildings

The project will be carried out by Beijing Solar Energy Research Institute Co. Ltd, China and Department of Civil Engineering, Technical University of Denmark. The Chinese partner will focus investigations on flat plate solar collectors and the Danish partner will focus on evacuated tubular solar collectors. The thermal performance of the different collectors will be compared both for Danish and Chinese climate. The Chinese partner will focus on traditional designed heat stores without a high degree of thermal stratification. The Danish partner will focus on highly stratified heat stores with built in inlet stratification devices. It will be elucidated how much the thermal performance will be improved for solar combi systems with advanced stratified heat storages instead of normal heat storages with limited thermal stratification both with Danish and Chinese weather data. Laboratory tests of solar combi systems, development of TRNSYS simulation models for solar combi systems and validation of the simulation models will be carried out. Solar combi systems will be developed based on TRNSYS calculations both for Danish and Chinese weather data and one family houses. The long term thermal performance of solar combi systems installed in demonstration houses in China and in Denmark will be measured.
Section for Building Physics and Services

Department of Civil Engineering

Period: 01/03/2010 → 31/12/2013

Number of participants: 5

Project participant:
Chen, Ziqian (Intern)
Fan, Jianhua (Intern)
Nielsen, Elsabet Nomonde Noma (Intern)
Perers, Bengt (Intern)

Project Manager, organisational:
Furbo, Simon (Intern)

Financing sources

Source: Forskningsrådene - Andre
Name of research programme: Forskningsrådene - Andre
Amount: 3,965,378 Danish Kroner

Project:

Dansk deltagelse i IEA Task 44: Systems using solar thermal energy in combination with heat pumps

Section for Building Physics and Services

Department of Civil Engineering

Danish Technological Institute

Ellehauge og Kildemoes ApS

Nilan A/S

Period: 12/02/2010 → 31/03/2011

Number of participants: 3

Project participant:
Perers, Bengt (Intern)
Furbo, Simon (Intern)

Project Manager, organisational:
Nielsen, Elsabet Nomonde Noma (Intern)

Financing sources

Source: Forskningsprojekter - Miljø- og Energiministeriet
Name of research programme: Forskningsprojekter - Miljø- og Energiministeriet
Amount: 231,984.00 Danish Kroner

Project:

Kvalitetssikring af solvarme, fase 3

Department of Civil Engineering

Period: 01/04/2009 → 31/03/2010

Number of participants: 4

Project participant:
Dragsted, Janne (Intern)
Chen, Ziqian (Intern)
Perers, Bengt (Intern)

Project Manager, organisational:
Furbo, Simon (Intern)

Financing sources

Source: Forskningsprojekter - Miljø- og Energiministeriet
Name of research programme: Forskningsprojekter - Miljø- og Energiministeriet
Amount: 218,000.00 Danish Kroner

Project
Solar/electric heating systems in the future energy system

The two most powerful renewable energy sources are solar and wind energy. It is expected that an increasing part of our electricity consumption in the future will be covered by wind farms. This will result in an increased number of windy periods with a surplus of electricity and thereby a low electricity price. A concept where individual solar heating systems optimised for making use of electricity produced by wind turbines in these periods can facilitate the introduction of wind energy in large scale into the energy system and thereby contribute to increasing the part of our energy consumption covered by renewable energy sources. The heat is produced by the solar heating system and by the electric heating element(s)/heat pump, which, if possible, only should be in operation in periods where the solar heating system cannot fully cover the heat demand and where the electricity price is low, e.g. in windy periods with a high electricity production from wind turbines. The unit is equipped with a smart heat storage (variable auxiliary volume) and a smart control system based on prognosis for the electricity price, the heat demand of the house, the solar heat production of the solar heating system and weather forecasts. The project will elucidate how best to design an individual heating unit for one family houses based on the above principles. It is also elucidated how suitable the heating unit is for the home owner and for our future energy system. Different designs of the heating unit and the control system will be investigated and the most promising solutions tested experimentally. It is expected that the heating unit is more cost efficient than traditional solar heating systems and that it can be an attractive alternative to oil- and natural gas boilers, both from an economy and environmental point of view.
Competitive Solar Heating Systems for Residential Buildings

Department of Civil Engineering
Period: 15/12/2003 → 15/08/2007
Number of participants: 5
Phd Student:
Thur, Alexander (Ekstern)
Main Supervisor:
Furbo, Simon (Intern)
Examiner:
Schultz, Jørgen Munthe (Intern)
Jordan, Ulrike (Intern)
Perers, Bengt (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Offentlig finansiering
Project: PhD