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.
Energy demand flexibility in buildings and district heating systems – a literature review

With the growing share of fluctuating renewable energy sources in our energy systems, providing sufficient flexibility on the demand side is becoming more and more important – also in the context of the emergence of Smart Grids. However, it will be difficult to achieve this by concentrating on electricity-only solutions. So, the next step is to focus on electricity-thermal solutions (e.g. heat pumps, electrical heating and cooling) and thermal system components. Here district heating and the building stock are important contributors due to their large share of energy demand. This literature review focuses on energy flexibility in context of heat demand in buildings and district heating systems. First, the theory regarding definitions of energy flexibility found in the literature, its quantification methods and indicators is discussed. Due to a lack of literature on the heating side, most of the theory in this review is based on electrical solutions. Then, the connection between electrical and thermal energy systems is described and the importance of integrated systems approach is explained. A schematic of flexibility sources in the built environment is proposed and technological solutions found in literature on buildings and district heating are presented based on the proposed framework.

General information
State: Accepted/In press
Organisations: Department of Civil Engineering, Energy and Services, Section for Building Energy, Materials and Durability, Section for Indoor Climate and Building Physics

Bibliographical note
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Source: FindIt
Source-ID: 2434709223
Publication: Research - peer-review › Journal article – Annual report year: 2018
Estimation of temperature setpoints and heat transfer coefficients among residential buildings in Denmark based on smart meter data

Thermal comfort preferences of occupants and their interactions with building systems are top influential factors of residential space heating demand. Consequently, housing stock models are sensitive to assumptions made on heating temperatures. This study proposes a heat balance approach, inspired by the classical degree-day method, applied to an extensive urban dataset. The goal of this analysis is to determine heterogeneous characteristics, such as temperature setpoints of heating systems and thermal envelope characteristics from an overall population of residential buildings. Measured energy data are utilized for the purpose of the study from the city of Aarhus, Denmark, where the energy usage for heating of circa 14,000 households was monitored over time via smart meters. These data are combined with actual weather data as well as data extracted by a national building database. Using linear regression and heat balance models, temperature setpoints for the whole dataset are determined with a median and average of 19 °C and 19.1 °C, respectively. Furthermore, building related characteristics such as thermal and ventilation losses per building and overall heat transfer coefficients are extracted at urban scale. The reliability of the method over its complexity is discussed with regards to the big sample that has been applied to. In general, the overall performance of the approach is satisfactory achieving a coefficient of determination with an average of 0.8, and is found to be in line with previous findings, considering also the high uncertainty associated with building-related input parameters. The extracted setpoint distribution should be transferrable across Scandinavia.
Experience from a practical test of low-temperature district heating for space heating in five Danish single-family houses from the 1930s

The efficiency of district heating systems is greatly affected by network supply and return temperatures. However, the opportunities to lower the temperatures and thereby increase network efficiency are restricted by customer installations. Very little is known about the customer installations, because heating system operation is only rarely monitored in detail.
this study, we therefore investigated the operation of the heating systems in five houses. The study had two aims: first to
investigate how much of the heating season the houses could be heated with supply temperatures as low as 55 °C, and
second to investigate whether occupant behaviour and heating system malfunctions caused unnecessarily high return
temperatures. The results showed that all the houses were compatible with low-temperature supply, and in two of the
houses return temperatures were even as low as the preferred 25–30 °C. Two main causes were found for unnecessarily
high return temperatures in the remaining houses: a few radiators were found to be too small, and thermostatic radiator
valves did not always ensure proper water mass flow. In conclusion, if these errors were corrected, the study indicates that
it would be possible to heat the investigated houses with district heating temperatures of 55/30 °C.

General information
State: Published
Organisations: Department of Civil Engineering, Energy and Services, Section for Building Energy
Authors: Østergaard, D. S. (Intern), Svendsen, S. (Intern)
Number of pages: 10
Pages: 569-578
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Main Research Area: Technical/natural sciences

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Scopus rating (2017): CiteScore 5.6 SJR 1.99 SNIP 1.923
Web of Science (2017): Indexed yes
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Scopus rating (2016): CiteScore 5.17 SJR 1.974 SNIP 1.823
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Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
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ISI indexed (2013): ISI indexed yes
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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
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.712 SNIP 2.46
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.663 SNIP 2.357
Web of Science (2009): Indexed yes
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Scopus rating (2008): SJR 1.103 SNIP 1.438
Scopus rating (2007): SJR 0.902 SNIP 1.434
Neural network based predictive control of personalized heating systems

The aim of a personalized heating system is to provide a desirable microclimate for each individual when heating is needed. In this paper, we present a method based on machine learning algorithms for generation of predictive models for use in control of personalized heating systems. Data was collected from two individual test subjects in an experiment that consisted of 14 sessions per test subject with each session lasting 4 h. A dynamic recurrent nonlinear autoregressive neural network with exogenous inputs (NARX) was used for developing the models for the prediction of personalized heating settings. The models for subjects A and B were tested with the data that was not used in creating the neural network (unseen data) to evaluate the accuracy of the prediction. Trained NARX showed good performance when tested with the unseen data, with no sign of overfitting. For model A, the optimal network was with 12 hidden neurons with root mean square error equal to 0.043 and Pearson correlation coefficient equal to 0.994. The best result for model B was obtained with a neural network with 16 hidden neurons with root mean square error equal to 0.049 and Pearson correlation coefficient equal to 0.966. In addition to the neural network models, several other machine learning algorithms were tested. Furthermore, the models were on-line tested and the results showed that the test subjects were satisfied with the heating settings that were automatically controlled using the models. Tests with automatic control showed that both test subjects felt comfortable throughout the tests and test subjects expressed their satisfaction with the automatic control.

General information
State: Published
Organisations: Department of Civil Engineering, Energy and Services, Eindhoven University of Technology
Authors: Katić, K. (Ekstern), Li, R. (Intern), Verhaart, J. (Ekstern), Zeiler, W. (Ekstern)
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Main Research Area: Technical/natural sciences

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Volume: 174
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Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 4.64 SJR 2.055 SNIP 1.968
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Ultra-low temperature district heating system with central heat pump and local boosters for low-heat-density area: Analyses on a real case in Denmark

Low temperature district heating (DH) system gives easier access to the renewable energy as heat sources and improves the heat distribution efficiency. From the exergy point of view, low DH supply temperature also better matches the exergy demand of space heating and domestic hot water. It is more beneficial to operate district heating system under lower...
temperature level for the heat-sparse area where the distribution losses accounts for a large proportion in the total heat supply. In this study, the actual performance of a case ultra-low temperature district heating (ULTDH) system in Denmark was investigated based on long-term measurements. The system combines the central heat pump and local boosters, while the impact of such configuration on the overall system performance was analysed. The energy, exergy and economy performances of the case system were compared to medium temperature district heating system (MTDH) and low-temperature district heating system (LTDH). The results show that the LTDH system without supplementary heating has the highest energy and exergy efficiency. While the ULTDH system has better performance compared to the MTDH system in energy, exergy and economy due to substantial savings from the distribution heat loss.
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)
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.

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.

Highly Efficient and Simplified Thermodynamic Cycle with Isolated Heating and Cooling – Cost Optimized
The project will develop a new combined heating/cooling system that efficiently and continuously produces hot and/or cold water with up to 30 % larger efficiency that conventional heat pump and cooling systems and generates a possibility of accumulating heat and/or cooling.

Depending on the operating conditions, an efficiency improvement of 10-50 % is shown in a completed EUDP project by employing the tank system for heating. An additional increase of 15 % is expected to be achieved by simultaneous use of the tank system for cooling also. A further advantage of the concept is the possibility of accumulation hot and cold water.

A major performance improvement can be achieved. However, it is also shown that costs of the technology provide some challenges. By studying the framework of the technology, both the temperature operating range and the economy when using this system could be increased significantly.
Thus, the focus of the ISECOP project is the development of components and the control system to achieve optimal interaction between the heat pump, the heat storage and the heat consumption. Indeed, it will be possible to construct certain essential components, e.g. the compressor, in a simpler way (e.g. without capacity control) by using the ISECOP concept.

Department of Civil Engineering
Energy and Services
Danish Technological Institute
Department of Mechanic Engineering, Technical University of Denmark
Vengcon
Alfa Laval Corporate AB
METRO THERM A/S
Svedan Industri Køleanlæg
CHR Møller
Egå smedegård og maskinfabrik

ARLA FOODS AMBA
Period: 01/01/2018 → 31/12/2020
Number of participants: 4
Heating and cooling, Heat pumps, Heat storages, CFD calculations, Trnsys simulations
Acronym: ISECOP
Project participant:
Fan, Jianhua (Intern)
Furbo, Simon (Intern)
Andersen, Elsa (Intern)
Kong, Weiqiang (Intern)

Financing sources
Source: Public research council
Name of research programme: EUDP
Web address: https://ens.dk/
Amount: 5,950,000.00 Danish Kroner
Year of approval: 2017

European Committee for Standardization (CEN) Project ECOTEST
This project is funded by European Committee for Standardization (CEN) under the following EU regulations:
Supplementing Directive 2010/30/EU of the European Parliament and of the Council with regards to the energy labelling of space heaters etc.
Supplementing Directive 2010/30/EU of the European Parliament of the Council with regard to the energy labelling of water heaters etc.
The project is focused on evaluation of the standards used and measurement reproducibility of EU laboratories for the application of Ecodesign requirements and labelling of heating and hot water production appliances.
There are eight work packages:
• WP 1 Emissions - CEN/TC 238 (including sound power level)
• WP2 Uncertainty calculation method of the emissions, efficiency and all other parameters and common protocols for the INTER-COMPARISON + uncertainties
• WP3 Ecodesign testing of sanitary hot water work package with CEN/TC 109
• WP4 Work package with CEN/CENELEC JWG FCGA (on mCHP)
• WP5 Work package with CEN/TC 299 (on gas heat pump)
• WP6 Work package with CEN/TC 57 (fuel oil boilers)
• WP7 Work package with CEN/TC 113 (electrical heat pumps)
• WP8 Work package with CEN/TC 312 (solar heaters)
Overall objectives:
1: EVALUATION OF EU LABORATORIES: “to provide for each parameter measured for the application of (EU) No 811/12/13/14 2013 and each appliance a value of the inter-laboratory reproducibility obtained with the test procedures of the corresponding standard developed”
2: EVALUATION OF EU STANDARDS: “to propose improvements of the procedures from the standards”
3: EVALUATION OF EU market surveillance TOLERANCES: “to propose for all parameters and appliances tested a value of a reasonable tolerance that shall be used for the market surveillance”.

Department of Civil Engineering
Energy and Services
Danish Gas Technology Centre A/S
Instytut Nafty I Gazu – Państwowy Instytut Badawczy
KIWA Gastec Netherlands
DVGW-Forschungsstelle EBI
Centre Technique des Industries Aérauliques et Thermiques
IGE-HLK
APPLUS Laboratories
IMQ
KIWA Italy
Technological Centre for the Metal Working Industry
Institute for Solar Technologies SPF
Institute of Thermodynamics and Thermal Engineering ITW
Refrigeration and Heat Pump Technology, Danish Technological Institute
AIT Austrian Institute of Technology GmbH
Wärme-pumpen-Testzentrum Buchs
Fraunhofer Institute for Solar Energy Systems ISE
Politecnico di Milano
TÜV Rheinland Energy GmbH
TÜV SÜD Industrie Service GmbH
Period: 02/10/2017 → 31/12/2018
Number of participants: 5
European Committee for Standardization (CEN), EcoDesign, EU Reference Laboratory, Space heating, Water heaters
Acronym: ECOTEST
Project participants:
Fan, Jianhua (Intern)
Fürbo, Simon (Intern)
Andersen, Elsa (Intern)
Dragsted, Janne (Intern)
Kong, Weiqiang (Intern)

Financing sources
Source: Public research council
Name of research programme: European Committee for Standardization (CEN)

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 Bredstrup, Marsal 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 indtil 30.06.2018.

Since the design of the pit heat storages Vojns and Gram differs from the design of the pit heat storage in Marsal 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 form 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)
Andersen, Elsa (Intern)

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

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 2011-2013 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. be 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 that three problems, that the application shall solve for existing and future owners: Corrosion 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
Solar Heat Integration NEtwork

Large solar heating systems are decisive to cover a major part of European low temperature heat demand by solar energy and therewith to meet European policy aims. However, today only a negligible share of solar heating systems installed in Europe are large units due to manifold technical and socio-economic obstacles. The challenge of solar thermal technology and the overall objective of the proposed initial training network is to supply heat in larger solar heating systems for applications like industrial processes, to feed-in into district heating networks, or sorption drying and cooling. The obstacles will be approached with an innovative inter-disciplinary consortium, including 13 PhD students. Six universities and five private sector participants from six different European countries will provide research and training in cooperation with four associated partners from the private sector. The SHINE project will cover detailed new experimental material-, component- and system studies, system integration analysis and numerical optimization, as well as chemical investigations on storage materials. A close cooperation with industry will ensure fast exploitation of the results. With the SHINE network, the critical mass of PhD students will be gathered on a European level to offer a specialized and structured PhD course programme of large solar heating systems. After the end of SHINE, the key course modules will be offered as a standard curriculum of European PhD education in solar thermal in the long term. The SHINE students will face excellent job perspectives, they will have a sound background in energy economics and complementary skills, regarded as important skills to reach a breakthrough of solar thermal technology.

The project consists of eight work packages:
- WP1: District Heating
- WP2: Industrial Process Heat
- WP 3: Advanced Storage Concepts: Open sorption processes
- WP4: PhD Courses
- WP5: Workshops
- WP6: Dissemination
- WP7: Cooperations
- WP8: Management

Department of Civil Engineering
Energy and Services
Section for Building Physics and Services

UNIVERSITAET KASSEL
FSAVE Solartechnik GmbH
Hogskolan Dalarna Falun Dalarna
AEE - INSTITUT FUR NACHHALTIGE TECHNOLOGIEN
University of Applied Sciences Rapperswil
Vela Solaris AG
UNIVERSITAET INNSBRUCK
Universitat de les Illes Balears
SAMPOL INGENIERIA Y OBRAS S.A.
STEINBEIS GMBH & CO. KG FUER TECHNOLOGIETRANSFER
Period: 01/10/2013 → 30/04/2018
Number of participants: 3
solar heating plants, District Heating, Industrial processes, New storage concept, PhD Training
Acronym: SHINE
Number of related Ph.D. students: 13
Project participant:
Fan, Jianhua (Intern)
Furbo, Simon (Intern)
Bava, Federico (Intern)

Financing sources
Source: Public research council
Name of research programme: Marie Curie Initial Training Networks
Web address: https://cordis.europa.eu/project/rcn/109061_en.html
Amount: 3,461,561.30 Euro
Year of approval: 2013

Activities:

Chairman of PhD Assessment Committee
Period: 17 Sep 2018
Toke Rammer Nielsen (Internal examiner)
Department of Civil Engineering
Energy and Services
Degree of recognition: International
Activity: Examinations and supervision › Internal examination

Energy and Buildings (Journal)
Period: Jul 2018
Toke Rammer Nielsen (Reviewer)
Department of Civil Engineering
Energy and Services
Degree of recognition: International

Related journal
Energy and Buildings
0378-7788
BFI (2018): BFI-level 2, Scopus rating (2017): CiteScore 4.96 SJR 2.061 SNIP 2.12, ISI indexed (2013): ISI indexed yes,
Web of Science (2018): Indexed yes
Central database
Activity: Research › Peer review of manuscripts

Reduktion af risiko for overtemperatur i forbindelse med facaderenovering
Period: 11 Jun 2018
Toke Rammer Nielsen (Guest lecturer)
Department of Civil Engineering
Energy and Services
Degree of recognition: National

Related event

VEB-dagen
11/06/2018 → 11/06/2018
Taastrup, Denmark

Activity: Talks and presentations › Talks and presentations in private or public companies and organisations