Final report

1.1 Project details

Project title	Participation in IEA ECES Annex 31, Energy Storage
Project identification (program abbrev. and file)	64014-0505
Name of the programme which has funded the project	
Project managing company/institution (name and address)	Danish Building Research Institute, A.C. Meyers Vænge 15, 2450 Copenhagen SW
Project partners	Danish Building Research Institute
CVR (central business register)	29102384
Date for submission	26-03-2018

Please note that, when this document was written (March 2018), the final report of the IEA ECES Annex 31 was not available yet.

1.2 Short description of project objective and results

The *IEA-ECES* Annex 31 aims to develop efficient and reliable design approaches and operating strategies for storage in conjunction with thermal and electrical energy produced on-site in buildings/districts, and to support intermittency in the external grid. In general, the main objective of Annex 31 can be subdivided into five specific themes:

- To assess the technical potential and total performance of energy storage systems in energy efficient buildings and districts;
- To develop methods and tools to evaluate and optimize the total performance (energy, environmental, and economical) of whole systems;
- To develop efficient and advanced control algorithms and/or strategies for the operation of whole systems located in different climatic conditions and energy markets;
- To develop and provide design guidelines for integrating energy storage into energy efficient buildings and districts;
- To demonstrate and disseminate the knowledge and experience acquired in this Annex through case studies and validated demonstration projects.

The project has achieved the following outputs:

- The fundamentals of energy storage technologies at component, building and district level are provided by means of modelling approaches, available tools and state-of-the-art examples.
- Best practices for controlling energy storage systems at building level are presented, including classic control, intelligent control, advanced control and model-free control.
- Tools for optimization are elaborated, and examples based on some recent studies are provided to show how the optimization can be applied for energy storage in buildings and districts.
- Key performance indicators (KPIs) are introduced in order to evaluate the effectiveness of energy storage technologies in building and district applications.

IN DANISH

IEA-ECES Annex 31 har til formål at udvikle effektive og pålidelige designmetoder og driftsstrategier for lagring i forbindelse med varme og elektrisk energi produceret på stedet i bygninger/distrikter, og at understøtte intermittens i det eksterne net. Generelt kan hovedformålet med bilag 31 opdeles i fem specifikke temaer:

- At vurdere energilagringssystemers tekniske potentiale og samlede ydeevne i energieffektive bygninger og distrikter
- At udvikle metoder og værktøjer til evaluering og optimering af den samlede ydeevne (energi, miljø og økonomi) af systemer i helhed
- At udvikle effektive og avancerede kontrolalgoritmer og/eller strategier til drift af systemer i helhed under forskellige klimatiske forhold og energimarkeder;
- At udvikle og udarbejde designretningslinjer for integration af energilagring i energieffektive bygninger og distrikter;
- At demonstrere og formidle den viden og erfaring, der er opnået i dette annex gennem casestudier og validerede demonstrationsprojekter.

Projektet har resulteret i:

- Grundlagene for energilagringsteknologier på komponent-, bygnings- og distriktsniveau er stillet til rådighed i form af modelleringsmetoder, tilgængelige værktøjer og avancerede eksempler.
- Best practice til styring af energilagringssystemer på bygningsniveau er præsenteret, herunder klassisk kontrol, intelligent styring, avanceret styring og modelfri styring.
- Værktøjer til optimering er udfærdiget, og eksempler baseret på nyere undersøgelser er givet for at vise, hvordan optimeringen kan anvendes til energilagring i bygninger og distrikter.

- Nøgleindikatorer (Key Performance Indicators) er introduceret med henblik på evaluering af effektiviteten af lagringsteknologier til energilagring i bygninger og distrikter.

1.3 Executive summary

Thermal energy storage has many applications with typical aims to decrease design power for heating and cooling of a building or a district heating or cooling system, and to improve their energy performance. Energy storage solutions often complement energy efficiency and renewable energy measures; the higher the energy performance level, the more attractive and competitive the storage solutions became. However, many technical solutions require the use of storage solutions independently of an energy performance level of a building. Well known examples are solar thermal systems, which can barely operate without integration of buffer tanks. Another example is domestic heat pumps, which always include hot water tanks in order to operate at a reasonable capacity. In these examples, thermal energy storage can occur in a short period of time, however, in a seasonal thermal energy storage format at either building or district level, a high capacity storage tanks or a ground heat exchangers are required.
Storage solutions have many positive features, but as always there are some associated cons. Every storage solution causes losses, which are to be accounted in a similar fashion with generation, distribution and emission losses of heating and cooling systems. Though storing energy will always mean a higher energy use, it only can serve as a practical solution in the case of having access to abundant and free/cheap energy sources or in the case of remarkable installed heating or cooling capacity saving. There are size requirements and cost implications, implying that storage solutions will need relevant calculation and optimization tools as well as robust technical solutions to break through in markets. Control, automation and simulation are also essential research questions in the development of storage technologies. If one is not able to simulate and evaluate a system performance beforehand, it is better not to build it, because it is much easier to solve problems in virtual cases.
The IEA ECES Annex 31 addresses the integration, control and automation of energy storage with buildings, districts, and/or local utilities. The focus was on the development of design methods, optimization and control tools related to predicting, operating, and evaluating the performance of buildings and districts when energy storage is available

The project was carried out between 2014 and 2017 though the collaboration of 17 research institute from 11 countries.

To address the specific Annex objectives, the research and development work in the Annex was divided in a number of tasks provided below:

TASK A: Methodologies and tools for the evaluation of combined various energy storage and saving techniques

TASK B: Methodologies and tools to optimize the total performance (energy, environmental, and economical) of whole system

TASK C: Efficient and advanced control algorithms for energy storage applications

TASK D: Demonstration/Case studies

A total of eight expert meeting were organized throughout the project:

Lyon	France	18-20th June 2014
Milan	Italy	16-17th Oct 2014
Torino	Italy	7th May 2015
Nanjing	China	26-28th Oct 2015
Aalborg	Denmark	26th May 2016
Seoul	South Korea	27th Oct 2016
Palermo	Italy	25th May 2017
Montreal	Canada	14th Nov 2017

1.4 Project objectives

Research in the area of design and analysis of energy efficient buildings and districts is inherently interdisciplinary. The current research approach to energy efficiency, though multidisciplinary in principle, is hindered by the lack of effective tools, methodologies, and demonstrations that address interdisciplinary aspects of the effective integration of storage systems in buildings and districts. In addition, the concept of energy use and storage integration with renewable energy technologies for buildings and districts requires not only optimization, but also accurate forecasting and control strategies to simultaneously predict and react to future energy demand as well. This allows an appropriate orchestration of energy conversion systems and storage to maximize overall performance of the systems.
Therefore, the IEA-ECES Annex 31 aims to develop efficient and reliable design approaches and operating strategies for storage in conjunction with thermal and electrical energy produced on-site in buildings/districts, and to support intermittency in the external grid.

1.5 Project results and dissemination of results

The main findings of each task are described in the following, and these are included in the IEA final report of Annex 31, which is currently under development.

TASK A: Methodologies and tools for the evaluation of combined various energy storage and saving techniques.

This task aimed to assist the integration of thermal energy systems in low energy buildings and district by providing modelling approaches, available tools and examples. In particular, with regards to component/building level, methods to predict energy demand profiles in relation to energy storage systems are introduced and a total of nine examples are presented. These are:

- Simplified building load prediction
- Electrically heated floor
- Triplex tube heat exchanger with PCM
- Shell and tube heat exchanger with PCM
- Air-PCM heat exchanger
- Water-PCM heat exchanger
- Thermally activated wall panels containing PCM

- High-temperature cooling system with PCM
- Borehole heat exchanger

Regarding the district level, the fundamentals of available energy resources, distribution network and user demand profiles were introduced. In addition, available tools for district energy analysis were presented, and two examples were provided. There are:

- Simplified district load prediction: inter-model comparison
- Simplified district load prediction: WWH case study

SBi/AAU contributed to Task A by developing a mathematical model of novel PCM-based heat exchanger to be integrated into high-temperature cooling systems.

TASK B: Methodologies and tools to optimize the total performance (energy, environmental, and economical) of whole system

This task aimed to provide optimization techniques for energy storage systems. A detailed review of the most common methods (deterministic, stochastic and hybrid) is presented. Algorithms, objective functions and decision parameters are elaborated. In addition, a list of available tools for optimization problems is introduced. Examples at building and district level were collected.

TASK C: Efficient and advanced control algorithms for energy storage applications

This task aimed to describe best practices for controlling energy storage systems. These include: (1) classical control (mainly ON/OFF and PID), (2) soft or intelligent control (based on historical data) and (3) hard or advanced control (based on a building model).
In addition, a fourth category named "model-free control" was also presented. In the case of predictive control, classical controllers as PID cannot be implemented apart from a predictive algorithm. Consequently, supervisory control strategies have been proposed based on some features (weather parameters with sometimes building and/or storage parameters) to control the storage system, without using building model or historical data. This is the reason why they are presented as "model-free control".
It is worth mentioning that, as a subcategory of advance control, model predictive control (MPC) was also described. Among all control methods for thermal storage applications, MPC control received considerable attention, due to its satisfactory performance.

TASK D: Demonstration/Case studies

This task aimed to evaluate the effectiveness of energy storage technologies in building/district applications through a set of key performance indicators (KPIs).
These KPIs allowed the assessment of the energy storage systems applied to the case studies analysed in this task. A total of ten demonstration case studies were described.

Dissemination

The results achieved in the Annex were presented in several special scientific tracks at national and international conferences. In addition, a Special Issue of the Journal "Energy and Building" was released in relation to the Annex 31 project. Another Special Issue is currently under released for the Journal "Sustainable cities and societies".

1.6 Utilization of project results

Presently, designers use guidelines developed for passive solar buildings to design energy efficient buildings where the focus is on the design of a well-insulated and airtight building envelope populated with energy efficient systems and controls. Then, the building is connected with appropriate sources of energy either directly or through a district energy network. There is a lack of guidance on the effective integration and operation of energy storage at building or district level.
Therefore, the methods and tools provided by Annex 31 can support designers in applying a more comprehensive and integrated approach for the design of low energy buildings and districts which incorporate energy storage technologies.

1.7 Project conclusion and perspective

IEA-ECES Annex 31 developed efficient and reliable design approaches and operating strategies for storage in conjunction with thermal and electrical energy produced on-site in buildings and districts. This was done by focusing on modelling techniques, control algorithms, optimization methods and state-of-the-art examples and case studies.

Recommendations for the future work

The following points present the recommendations for future research:

- Building level modeling: the existing comprehensive models are already well-established and saturated. However, the discrepancies between the simulations and real case scenarios can be further reduced. In this context, it is recommended to upgrade the existing models so that users can easily model the buildings within the urban setting (as opposed the existing stand-alone approach).
- District level modeling: despite development of several tools for district level modeling, existing models lack the capability of modeling the entire elements of a DHS (i.e. energy resources, distribution network as well as demand profile prediction). In addition, data collection and processing for large-scale communities (city or regional level) are very computationally intensive or even not feasible. Therefore, developing a smart systematic approach which can easily gather data from different sources (i.e. city databanks, utility industries, etc.) and then model the entire district system is required.
- Optimization: Existing optimization approaches are either focused on energy mapping or equipment sizing. Hence, a simplified dynamic optimization ap-

proach which can simultaneously optimize both of them at the design stage is currently missing.

- Key performance indicators: more precise and standardized monitoring procedures are needed to have a comprehensive view of the benefits related to energy storage in buildings/districts. In this sense, the developed KPIs allow to push for more detailed and widespread assessments in the future

Annex

Special Issue on “Energy and Buildings”
https://www.sciencedirect.com/journal/energy-and-buildings/vol/106