Interim report – WP3

Smart energy buildings

Reporting months: July 2018 – June 2019

Photo: By & Havn / Ole Malling

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Work package aims and objectives

The objective is to provide a new understanding of low-energy buildings with their occupants and users as active energy-flexible elements in a smart energy system, and to develop and showcase associated novel control solutions for smarter operation and monitoring of energy in modern buildings.

The aim is to provide a new understanding of the possibilities that arise from using low energy buildings of Nordhavn - with their occupants and users - as active components in the future smart energy system. The consumer side will be investigated to see if low or flexible energy consumption is feasible without loss of comfort due to actively controlled living and working spaces.

Objectives include development and verification of smart energy building models and simulations, design of predictive controllers based on the models and simulations and the implementation and operation of the controls developed. The work package will provide at least two smart buildings as an integrated part of a smart energy infrastructure experiment by WP5, WP6, WP7 and WP8. Furthermore appropriate simulation models for analysing smart energy buildings in the energy system will be developed.

Two PhD projects and one Post Doc project will be conducted mainly within the framework of WP3. These research activities will have their main focus in task T3.3 and T3.4. A short summary of the activities is given in the respective task descriptions.

Overall progress of the work towards WP Objectives

Work on structuring the data by adding metadata and data quality check has been carried out in collaboration with WP2 in order to make the data accessible for the researchers. The DMS (Data Management System) was further developed and it is now possible to both receive data from buildings and to send back set-point changes for control. This enabled the implementation of the real-life demonstration of flexible space heating supply, which was carried out this year in Sundmolehusene in 13 apartments with KNX installations. Measurements of the effect on the indoor climate were included in the study both by direct measurements and by interviews where residents' experience of changes in the heat supply was recorded.

On the research side, an Assistant Professor, several PhD and Master students are well integrated in the project. They have worked on the above mentioned demonstration as well as building modelling, studying the flexibility potential of buildings in relation to heat and electricity consumption, the effect of building design and considered the influence of occupant behaviour. The research has led to a PhD thesis, seven journal articles, six conference papers, along with participation in several conferences and seminars. Moreover, four student theses have been based in this WP.

Status and activities in the WP tasks

The following activities performed are in relation to tasks: **Task 3.2 Active prosumers, Task 3.7 Installation and operation of building management system and Task 3.8 Building real-time flexibility performance**

- In collaboration with WP2, work has been done on structuring (metadata) of data, data quality and analysis from different buildings: Frihavnstårnet, Copenhagen International School (CIS) and Sundmolehusene.
- Identification of problems with the solar cell system in Copenhagen International School (CIS). Balslev has concluded a commercial agreement with CIS on technical advice and assistance regarding the establishment of filter for reducing electrical noise generated by the solar cell system.
- In collaboration with WP2, the DMS (Data Management System) has been further developed and it is now possible both to receive data from buildings and to send back set-point changes, which is a prerequisite for the implementation of the flexible space heating supply demonstration.
- A significant amount of work this year has been put on designing, testing and executing a real-life demonstration on flexible space heating supply. The demonstration was implemented in Sundmolehusene in selected apartments with KNX installations. Measurements of the effect on the indoor climate were included in the study both by direct measurements and by interviews where residents' experience of changes in the heat supply was recorded.
  During the heating season 2018/2019 tests were conducted on the possibility of consuming district heating in a flexible manner that facilitates the operation of the district heating system by reducing consumption during the morning peak load period. Some of the residents complained about not being properly informed. An increased effort in improving the communication with the residents created a good relationship, which has been maintained. The demonstration showed that the apartments can deliver the same reduction of district heating use at the desired time periods via their smart installations as when the reduction is made on the central heat exchanger with additional benefit to both system efficiency and resident comfort.
  With this work WP3 contributes significantly to Use Case 26, which coordinates two sources of flexibility in the district heating: on building level and on apartment level. This work is, eventually, a key contribution to the milestone M7, which deals with the use of the intelligent buildings in an integrated energy system context.
- Work has been done to produce so-called "dashboards" and other visualizations so that energy consumption and indoor climate can be monitored in real time.

Task 3.3 Smart energy buildings and user behaviour

Completion of PhD project on “Models for flexible operation of buildings in district energy system Nordhavn”. The aim of the work was to investigate the physical potential of low-energy buildings to facilitate flexible heating operation by using the thermal mass of the buildings as heat storage, while maintaining thermal comfort. The thermal behavior of low-energy buildings was analyzed in detail and the physical potential for energy flexibility was determined, identifying the influential factors. The operational flexibility potential of low-energy buildings was investigated via simulations. And methodologies were proposed that made it possible for the heating system to be operated in such a way as to meet the

flexibility requirements of the local district heating system. In addition, creating realistic daily profiles of household electricity demand was undertaken as the basis for flexibility modelling of electricity household loads, i.e. rescheduling the use of domestic appliances and electricity-based heating systems.

Task 3.4 Smart building modelling
Modelling work has been done to investigate the thermal energy flexibility that a local district heating network can realistically provide to the district heating system. The model takes into account the thermal characteristics of buildings in the area, occupants' comfort and current heat market setup. The case study was based on the district heating network in Nordhavn. Two methods of control were applied: schedule-based and price-based indoor temperature set point control.

Deliverable status

D #	Deliverable title	Planned completion month	Status **1** = on schedule **2** = completed **3** = delayed
D3.3 and D3.4c	Designing for thermal flexibility with temporary recommendations to future building Regulations	July 2019	**3**
D3.4a	State of art model for energy system integration, applied in scenario model in cooperation with other tasks	August 2019	**3**
D3.4b	Findings published in scientific publications	July 2019	**1**
D3.7	Functional installation of Smart energy-flexible building management system in the buildings recruited by T3.1. Commissioning report	June 2019	**2**
D3.8b	Functional performance indicators in showroom and partner locations	June 2019	**1**

Delivery D3.3 and D3.4c will be integrated in one report.

Dissemination
In addition to the scientific publications and thesis, the WP has hosted several delegations, both national and international. Speaking engagements for public events and panel debates have been carried out by members of the WP group based on the work carried out during the last year, and the WP has been an active participant in the sustainability festival recently held in the Nordhavn area.

Publications:

PhD thesis:

Foteinaki, K. (2019), 'Models for flexible building operation in the Nordhavn district energy system', Department of Civil Engineering, Technical University of Denmark.

Journal Articles:

Published

Foteinaki, K., Li, R., Heller, A. and Rode, C. (2018) 'Heating system energy flexibility of low-energy residential buildings', *Energy and Buildings*. Elsevier B.V. doi: 10.1016/j.enbuild.2018.09.030.

Hu, Maomao; Xiao, Fu; Jørgensen, John Bagterp; Li, Rongling. Price-responsive model predictive control of floor heating systems for demand response using building thermal mass. In: Applied Thermal Engineering, Vol. 153, 2019, p. 316-329.

Cai, Hanmin; Ziras, Charalampos; You, Shi; Li, Rongling; Honoré, Kristian; Bindner, Henrik W. Demand side management in urban district heating networks. In: Applied Energy, Vol. 230, 2018, p. 506-518.

Wang, Andong; Li, Rongling; You, Shi. Development of a data driven approach to explore the energy flexibility potential of building clusters. In: Applied Energy, Vol. 232, 2018, p. 89-100.

Li, Rongling; You, Shi. Exploring Potential of Energy Flexibility in Buildings for Energy System Services. In: C S E E Journal of Power and Energy Systems, Vol. 4, No. 4, 2018, p. 434-443.

Barthelmes, V.M.; Li, R.; Andersen, Rune Korsholm; Bahnfleth, W.; Corgnati, S.P.; Rode, Carsten. Profiling Occupant Behaviour in Danish Dwellings using Time Use Survey Data. In: Energy and Buildings, Vol. 177, 2018, p. 329-340.

Zong, Yi ; Su, Wenjing ; Wang, Jiawei ; Rodek, Jakub Krzysztof ; Jiang, Chuhao ; Christensen, Morten Herget ; You, Shi ; Zhou, You ; Mu, Shujun. Model Predictive Control for Smart Buildings to Provide the Demand Side Flexibility in the Multi-Carrier Energy Context: Current Status, Pros and Cons, Feasibility and Barriers. In: Energy Procedia, vol: 158, pages: 3026-3031. Presented at: 10th International Conference on Applied Energy 2019. DOI: https://doi.org/10.1016/j.egypro.2019.01.981

Submitted

Foteinaki, K., Li, R., Péan, T., Rode, C. and Salom, J. (2019) 'Evaluation of energy flexibility of low-energy residential buildings connected to district heating'. *Submitted to Energy and Buildings, under revision.*

Foteinaki, K., Li, R., Rode, C. and Andersen, R. K. (2019) 'Modelling household electricity load profiles based on Danish time- use survey data'. *Submitted to Energy and Buildings, under review.*

Conference papers:

Foteinaki, K., Li, R., Heller, A., Christensen, M. H. and Rode, C. (2019) 'Dynamic thermal response of low-energy residential buildings based on in-wall measurements'. Published in the proceedings of 13th REHVA World Congress CLIMA 2019. Bucharest, Romania.

L. Sarran, M. H. Christensen, C. A. Hviid, A. M. Radoszynski, C. Rode, P. Pinson, Data-driven study on individual occupant comfort using heating setpoints and window openings in new low-energy apartments-preliminary insights, Published in the proceedings of 13th REHVA World Congress CLIMA 2019. Bucharest, Romania.

Rongling Li, Kyriaki Foteinaki, Christian Finck, Morten Christensen, Shi You. On the energy flexibility in buildings: from components to building cluster. Accepted to SBE19 conference, Tokyo, Japan.

Lucas Beltram, Morten Christensen, Rongling Li. Demonstration of heating demand peak shaving in smart homes. Submitted to CISBAT 2019 conference, Lausanne, Switzerland.

Rongling Li, Morten Christensen. Heating demand peak shaving in smart homes. To be presented at EnergyLab Nordhavn Session in Smart Energy Systems International Conference, Copenhagen, Denmark.

Hanmin Cai, Rongling Li, Shi You, Jan Eric Thorsen, Kristian Honoré. Flexibility in integrated energy system: experimental insights from EnergyLab Nordhavn project. To be presented at EnergyLab Nordhavn Session in Smart Energy Systems International Conference, Copenhagen, Denmark.
Jiang, Chuhao ; Zong, Yi ; Su, Wenjing ; Qi, Zhiyuan. Exploring the Demand Side Flexibility of a New Residential Building. Published in the proceedings of the 2nd International Symposium on Computer Science and Intelligent Control 2018. DOI: https://doi.org/10.1145/3284557.3287305

Next steps

- Completion of PhD project on "Implementation of flexible operational schemes for buildings in a district with smart energy systems".
- Publication of due deliverable reports.
- Final report for WP3.

Quality Assurance

Status of deliverable		
Action	By	Date
Sent for review	Palle Holdt	28.05.2019
Reviewed	Carsten Rode	11.06.2019
Approved	WPL	21.06.2019

Author	Reviewer	Approver
Kyriaki Foteinaki & Morten Herget Christensen	Carsten Rode	WPL

The project "EnergyLab Nordhavn – new urban energy infrastructures" will develop and demonstrate future energy solutions. The project utilizes Copenhagen's Nordhavn as a full-scale smart city energy lab and demonstrates how electricity and heating, energy-efficient buildings and electric transport can be integrated into an intelligent, flexible and optimized energy system. The project participants are: DTU, City of Copenhagen, CPH City & Port Development, HOFOR, Radius, ABB, Balslev, Danfoss, CleanCharge, METRO THERM, Glen Dimplex and the PowerLab facilities. The project is supported by EUDP (Energy Technology Development and Demonstration Programme), grant 64014-0555 and runs from 2015-2019.

Version Control

Version	Date	Author	Description of Changes
01	28.05.2019	Kyriaki Foteinaki & Morten Herget Christensen	Interim report created
	11.06.2019	Carsten Rode	Review
	12.06.2019	Kyriaki Foteinaki	Implemented changes/additions