Interim report – WP3

Reporting months: July 2017 – June 2018

Photo: By & Havn / Ole Malling

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Overall progress of the work towards WP Objectives

Installation of building automation systems has been completed. Work on structuring the data by adding metadata has been carried out in collaboration with WP2 in order to make the data accessible for the researchers.
On the research side, a Post Doc, several PhD and Master students are well integrated in the project. They have mainly worked on building modelling and studies of possibilities to utilize the building flexibility with relations to heat and electrical consumption and studies of thermal designs in smart buildings and the effect that will have on consumer behaviour.
The research has led to fourteen conference papers and eleven journal articles, along with participation in several conferences and seminars. Also six student theses have been based in this WP.

Selected results and task activities in the reporting period

- The building recruitment process has been finalized
- The building automation system (KNX) has successfully been installed in all recruited buildings.
- 11 journal articles (four published, two accepted and five submitted). Two more journal articles are ready to be submitted.
- 14 conference papers (12 published and two submitted)
- Six student theses

Status and activities in the WP tasks

Task 3.1 Recruiting of buildings

Recruitment of buildings for carrying out the planned demonstrations in WP3 has been finalized. The recruited buildings are:

- Sundmolen, building plot 5.03 (CASA)
- Frihavnstårnet, building plot 1.13 (Kornaksen A/S)
- Terra Nova, building plot 1.07 (KPC)
- CIS, building plot 4.01 (Ejendomsfonden Copenhagen International School)

The number of recruited buildings is considered to be sufficient for carrying out the WP3 demonstrations that are necessary for the project.

Task 3.2 Active prosumers

In Task 3.2, the potential for using building flexibility in relation to heat and electricity consumption, and the consequences for the users (prosumers) are being studied.
The systems that allow for data collection and control of the buildings have been designed and installed. Demonstrations that use the buildings as active control elements are being planned pending final completion of

- Implementation of suitable algorithms (this WP)
- Data Management System (WP2)
- Integrated control schemes (WP8)

All installations in the recruited buildings have been finished. A meeting with the residents in Sundmolehusene has been carried out. The purpose of the meeting was to inform them

about the project and functionality of the installed systems and how they are operated. At the meeting questionnaires were handed out. Upcoming interviews are being planned.

Tests and measurements have been carried out in Frihavnstårnet in connection with the building modelling as Master projects.

Task 3.3 Smart energy buildings and user behaviour
In Task 3.3, thermal design of smart buildings and the influence of user behaviour are being studied.

Study: *Heating system energy flexibility of low-energy residential buildings*
The aim of this study was to quantify the flexibility potential for low-energy residential buildings according to current building regulations, to identify their role in the future energy system and to discuss possible flexibility services that could be offered to the energy system.

Study: *Flexibility potential of low-energy residential buildings as short term thermal energy storage in the district heating system*
The purpose of the study was to evaluate the potential for load shifting of residential buildings. Different control signals were used, coming from the district heating (DH) side and acting as drivers for the heat supply of the building, in order to offer flexibility to the DH network. The signals considered typical peak hours and marginal heat production costs, without compromising the thermal comfort of occupants.

Task 3.4 Smart building modelling
In Task 3.4, models for integration of energy systems in smart buildings are being studied.

Study: *Flexibility potential of a thermal energy system in a low-energy district*
The main aim of this task is to evaluate the flexibility potential that can be obtained for the district heating system by considering both the buildings and the district heating grid as potential flexibility sources. Models of the different system components were built, and currently the focus is on debugging and calibrating the components. This work is intended to be submitted to a journal in the early autumn 2018.

Task 3.5 Control of energy building microgrid
In Task 3.5, algorithms for building management systems (model predictive control algorithms) are developed. During the period, development and test of algorithms for the building management system based on measurements from Frihavnstårnet have been done, resulting in two Master projects finalized in August 2017. In this task, several Journal and Conference papers have been produced.
Based on the collected data of the Frihavnstårnet building and the District Heating data from HOFOR, the following subtasks were carried out as planned.

1. Data-driven heat dynamic models of the zones (e.g. room, apartments, floors and the whole building) were built and evaluated;
2. Architectural design of a hierarchy Model Predictive Control (MPC) based optimal Building Energy Management Systems (BEMS) for the floor heating was conducted;

A proof-of-concept simulation study was done by implementation of an Economic MPC controller (EMPC) for BEMS including a preliminary study on smart start of appliances (e.g. washing machines and dish washers) to provide grid ancillary services.

Task 3.6 Software and hardware development and Task 3.7 Installation and operation of building management system

In Task 3.6 and 3.7 software and hardware for smart building management systems (BMS) has been developed together with installation and operation of these. During the period, a weather station for local data and an interface for integration of BMS at the Copenhagen International School was installed.

Task 3.8 Building real-time flexibility performance

The purpose of Task 3.8 is to develop and visualize a flexibility performance indicator. The aim is to categorize the heat flexibility of dwellings and to develop an applicable energy flexibility indicator to use in the operation of district heating grids. Predictive models for a variety of building types have been developed.

Models of the distribution network of a district heating grid are also developed in collaboration with project partners to realize low temperature district heating. These models are tools for district heating suppliers to utilize building thermal autonomy as a service to eliminate the use of peak load boilers and reduce CO_2 emission in heat production.

Studies on a data-driven approach for modelling energy flexibility of buildings and communities as well as user activity simulation for Danish dwellings using Time Use Survey data were conducted.

Deliverable status

D 3	Deliverable title	Planned or accomplished completion month	Status **1** = on schedule **2** = completed (Confidential / Public) **3** = delayed
D3.1a	Screening of potential buildings finished	Feb. 2017	2 (C)
D3.1b	Contractual agreement in place and installation of meters etc. initiated	Feb. 2017	2 (C)
D3.2a	Prosumer analysis report	Dec. 2017	2 (P)
D3.2b	Design documentation for end user interaction system	July 2017	2 (C)
D3.2c	Implementation of end user interaction system	Oct. 2017	3 Anticipated 15.06.2018
D3.3	Report: Designing for thermal flexibility with temporary recommendations to future building Regulations	Aug. 2017	3 Anticipated 13.07.2018
D3.4a	State of the art model for energy system integration, applied in scenario model in cooperation with other tasks	Oct. 2017	3 Anticipated 31.10.2018
D3.4b	Findings published in scientific publications	Dec. 2017	3 Anticipated 31.10.2018
D3.4c	Findings published in a public report with final recommendations to future building code	Sep. 2018	1
D3.5a	Algorithms suitable for implementation in BMS/EMS	Sep. 2017	2 (C)
D3.5b	Proof of concept test of microgrid controller	May 2018	2 (C)
D3.6	Working prototype of complete smart energy building control system unit suitable for installation as described in task 3.7	July 2017	2 (C)
D3.7	Functional installation of Smart energy-flexible building management system in the buildings recruited by T3.1. Commissioning report	Dec. 2017	3 Anticipated 13.07.2018
D3.8a	Conceptual description of indicators and interfaces	July 2017	2 (P)
D3.8b	Functional performance indicators in showroom and partner locations	March 2018	3 Anticipated 28.09.2018

Dissemination

Publications (Journal and conference papers):

Journal Articles:

Published

Finck, Christian; Rongling Li; Kramer, Rick; Zeiler, Wim. “Quantifying demand flexibility of power-to-heat and thermal energy storage in the control of building heating systems”. In: *Applied Energy*, Vol. 209, 2018, p.409-425

Rongling Li; Dane, Gamze; Finck, Christian; Zeiler, Wim. “Are building users prepared for energy flexible buildings—A large-scale survey in the Netherlands”. In: *Applied Energy*, Vol. 203, 2017, p.623-634

Zong, Yi ; Awadelrahman, M. A. Ahmed ; Wang, Jiawei ; You, Shi ; Træholt, Chresten ; Xiao, Xianyong, “Enhancing Wind Power Integration through Optimal Use of Flexibility in Multi-Carrier Energy Systems from the Danish Perspective”, in journal: *World Journal of Engineering and Technology* (ISSN: 2331-4249), vol: 5, issue: 4, pages: 78-88, 2017, http://file.scirp.org/Html/79551_79551.htm

Wang, Jiawei; Zong, Yi; You, Shi and Træholt, Chresten, “A review of Danish integrated multi-energy system flexibility options for high wind power penetration”, in journal: *Clean Energy* (ISSN: 2515-4230) (DOI: http://dx.doi.org/10.1093/ce/zkx002), vol: 1, issue: 1, pages: 23-35, 2017

Accepted

Rongling Li and Shi You. “Exploring energy flexibility potential of buildings for energy system services”. Accepted for *Journal of Chinese Society for Electrical Engineering*

Katarzyna M. Luc, Alfred Heller, Carsten Rode, “Energy Demand Flexibility in Buildings and District Heating Systems - a Literature Review”, *Advances in Building Energy Research*, accepted

Submitted

Rongling Li, Andong Wang and Shi You. “Development of a data driven approach to explore the energy flexibility potential of building clusters”. *Applied Energy*, under revision

Hanmin Cai, Charalampos Ziras, Shi You, Rongling Li, Kristian Honoré and Henrik W. Bindner. “Demand side management in urban district heating network: centralized solution”. *Applied Energy*, under review

Rongling Li, Tobias Weiss, Yunran Chen, Carsten Rode and Anders Stockmarr. “Energy flexibility in dwellings: predicting heating flexibility from weather forecasts”. *Sustainable Cities and Society*, under revision

Verena M. Barthelmes, Rongling Li, Rune K. Andersen, William Bahnfleth, Stefano P. Corgnati and Carsten Rode. “Profiling occupant behaviour and occupancy in Danish dwellings using Time Use Survey data”. *Energy and Buildings*, under revision

Kyriaki Foteinaki, Rongling Li, Alfred Heller and Carsten Rode. “Heating system energy flexibility of low-energy residential buildings”. *Energy and Buildings*, under review

To be submitted
Rongling Li, Xiufeng Liu and Per Sieverts Nielsen. “Dynamic labeling of building energy load profile in smart cities”. To be submitted to to *Applied Energy*

Maomao Hu, Rongling Li, Fu Xiao, John Bagterp Jørgensen and Henrik Madsen. ”Model predict control of residential floor heating systems using dynamic electricity prices”. To be submitted to to *Applied Energy*

Conference papers:

Published
Rongling Li, Yunran Chen and Carsten Rode. “Heat Flexibility as a Function of the Outdoor Climate: A Study of Danish Dwellings”. *COBEE2018 Conference*, February 2018.

Verena M. Barthelmes, Rongling Li, Rune K. Andersen, William Bahnfleth, Stefano P. Corgnati and Carsten Rode. “Profiling Occupant Behaviour in Danish Dwellings using Time Use Survey Data - Part I: Data Description and Activity Profiling”. *COBEE2018 Conference,* February 2018

Verena M. Barthelmes, Rongling Li, Rune K. Andersen, William Bahnfleth, Stefano P. Corgnati and Carsten Rode. “Profiling Occupant Behaviour in Danish Dwellings using Time Use Survey Data - Part II: Time-related Factors and Occupancy”. *COBEE2018 Conference*, February 2018

Rongling Li, Feng Wei, Yang Zhao and Wim Zeiler. “Implementing Occupant Behaviour in the Simulation of Building Energy Performance and Energy Flexibility: Development of Co-Simulation Framework and Case Study”. Paper for *Building Simulation 2017 Conference*, August 2017, San Francisco USA

Finck, Christian; Rongling Li; Zeiler, Wim. “Performance maps for the control of thermal energy storage”. Paper for *Building Simulation 2017 Conference*, August 2017, San Francisco USA

Gianniou, P., Foteinaki, K., Heller, A., & Rode, C. (2017). ”Intelligent Scheduling of a Grid-connected Heat Pump in a Danish Detached House”. In Proceedings of *Building Simulation 2017*, San Francisco, United States.

Sarran, L., Foteinaki, K., Gianniou, P., & Rode, C. (2017). “Impact of Building Design Parameters on Thermal Energy Flexibility in a Low-Energy Building”. In Proceedings of *Building Simulation 2017*, San Francisco, United States.

Zilio, E., Foteinaki, K., Gianniou, P., & Rode, C. (2017). “Impact of Weather and Occupancy on Energy Flexibility Potential of a Low-energy Building”. In Proceedings of *Building Simulation 2017*, San Francisco, United States.

Wang, Jiawei; You, Shi ; Zong, Yi; Træholt, Chresten “Energylab Nordhavn: An integrated community energy system towards green heating and e-mobility” part of: Proceedings of 2017 *IEEE Transportation Electrification Conference and Expo*, (ISBN: 978-1-5386-2894-2), pages: 1-6, 2017, IEEE, Presented at: 2017 IEEE Transportation Electrification Conference and Expo, Asia-Pacific, 2017, Harbin,China

Yu, Xingji; You, Shi; Jiang, Yuewen; Zong, Yi and Cai, Hanmin, “An evolving experience learned for modelling thermal dynamics of buildings from live experiments: the Flexhouse story” in journal: Energy Procedia (ISSN: 1876-6102), vol: 141, pages: 233-239, 2017. Presented at: *4th International Conference on Power and Energy Systems Engineering* (CPESE 2017), 2017, Berlin.

Li, Rongling; Wang, Jiawei; Zong, Yi; Foteinaki, Kyriaki; Rode, Carsten, “Enhancing demand side flexibility in Nordhavn buildings for integrated multi-energy systems”, part of: Book of Abstracts, *Sustain 2017*, 2017, Technical University of Denmark (DTU), Presented at: Sustain 2017, 2017, Kgs. Lyngby

Ahmed, Awadelrahman M. A.; Zong, Yi; et al., “Potential Energy Flexibility for a Hot-Water Based Heating System in Smart Buildings via Economic Model Predictive Control “, part of: Proceedings of *2017 International Symposium on Computer Science and Intelligent Controls* (ISBN: 978-1-5386-2941-3), pages: 1-5, 2018, IEEE, Presented at: *2017 International Symposium on Computer Science and Intelligent Controls*, 2017, Budapest.

Submitted

Yi Zong, Jiawei Wang, Jakub Krzysztof Rodek, Chuhao Jiang and Morten Herget Christensen, et.al., “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”, submitted to *10th International Conference* on Applied Energy (ICAE2018), 22-25 August 2018, Hong Kong, China.

Rongling Li, Andong Wang, Carsten Rode and Shi You. “Energy Flexibility of Building Cluster – Part I: Occupancy Modelling”. *IBPC2018 Conference*, September 2018, USA. under review

Student theses

Christine Emilie Pettersen Sandersen. Thermal Flexibility in Different Buildings in a District Heating Network, MSc-thesis, 2017, Technical University of Denmark, Kgs. Lyngby, Denmark

Athanasia Keli. Energy flexibility potential of large scale buildings. Special course, 2017, Technical University of Denmark, Kgs. Lyngby, Denmark

Athanasia Keli. Analysis of the thermal energy use in apartments of a low-energy building in Nordhavn for achieving flexibility. Special course, 2017, Technical University of Denmark, Kgs. Lyngby, Denmark

Ann-Britt Vejlgaard and Julie Lindgaard Hald. Simulation of building energy consumption on an urban scale. BSc-thesis, 2018, Technical University of Denmark, Kgs. Lyngby, Denmark

Yann Randrianarison. Investigation of building designs with active technologies and impact on building energy performance and indoor climate: a short literature review and investigation. Special course, 2017, Technical University of Denmark, Kgs. Lyngby, Denmark

Audrey Ryan. Real-life studies of user acceptance of smart home energy technologies. Report, Technical University of Denmark, 2017, Kgs. Lyngby, Denmark

Next steps

- Structuring (metadata) of data in collaboration with WP2.
- Collaboration with WP8 about integration of intelligent building flexibility.
- Second round of residents' meetings and interviews
- Planning and carrying out of tests and measurements in Frihavnstårnet, Sundmolehusene, TerraNova and CIS
- Publication of due deliverable reports
- Further studies based on the data of 2017-2018 heating season
- Completion of PhD projects on “Models for flexible operation of buildings in district energy system Nordhavn” (Sept. 2018) and “Implementation of flexible operational schemes for buildings in a district with smart energy systems" (Oct. 2018)

Quality Assurance

Status of deliverable		
Action	By	Date
Sent for review	Palle Holdt	2018-06-08
Reviewed	Carsten Rode	2018-06-10
Approved		

Author	Reviewer	Approver
Palle Holt	Carsten Rode	

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.