Final report

1.1 Project details

Project title	Bygninger som energilager i smart-grid Buildings as energy storage in a smart-grid
Project identification (program abbrev. and file)	Systemintegration EUDP17-I: (12548) - J.nr. 64017-0039
Name of the programme which has funded the project	Energiteknologisk Udviklings- og Demonstrations Program (EUDP)
Project managing company/institution (name and address)	Aalborg University A.C. Meyers Vænge 15 2450 Copenhagen SV
Project partners	Danish Building Research Institute, Aalborg University DTU Compute
CVR (central business register)	29102384
Date for submission	29/11/2019

1.2 Short description of project objective and results

Based on existing measurements of night set-back experiments in single-family houses at Middelfart, it has been possible to analyse time-constants ($\tau = R \times C$) and to some extend the heat transfer coefficient (1/R) for these houses. The time-constant and the heat transfer coefficient give an indication of the houses ability to act as thermal storage (C) in a renewable energy based future smart-grid where flexibility is key.

A set of archetype models of Danish single family-houses have been set up in a dynamic simulation tool, BSim. This have indicated time-constants similar to those found by measurements.

Further simulation analyses have revealed that a house can avoid taking energy for space heating between 1 and 4 hours without compromising the indoor thermal comfort. This period can be extended by further 1-4 hours, if the house is preheated in advance of the shutdown period.

1.3 Executive summary

The purpose of the project was, based on existing data from detailed measurements, to investigate typical Danish detached single-family houses ability to act as energy storage in a future smart-grid. Introduction of an increasing share of renewable energy in the energy system will call upon flexibility. Danish houses are traditionally constructed of heavy materials (high heat storage capacity) and most of them have a reasonable good insulation level. Theoretically, this opens for the use of discontinued heating, without loss of thermal indoor comfort to create flexibility in the grid. Statistical analyses of existing data on buildings heating and cooling performance will reveal the Danish housing stocks capability to postpone or accelerate the uptake of electricity, if using heat pumps, to heat the houses providing flexibility to the grid. The statistical analyses was supplemented by dynamic simulations of archetype houses to analyse the full national potential for increasing the flexibility offered by Danish single family houses. Additionally, the dynamic simulations was used to investigate possible improvements of the existing houses in order to increase the flexibility potential.

Form the measurements, time constants for the houses has been identified, and in most cases two time-constants. The first, short, time-constant (τ_1) represents the indoor air and lightweight furniture in the house, while the second, long, time-constant (τ_2) represents the building constructions. The long time-constant give an indication of how long time a house can refrain from taking energy from the grid for space heating. Long time-constants identified in the measurements ranges between 30 and 60 hours. The expression time constant are given in seconds and characterises a system's response over time – in this case a house. In practice, the time constant is the time it takes a house to drop the temperature by 1/e, where e is the cardinal number of the natural logarithm (e ≈ 2.7183). A drop in temperature of 1/e equals a drop equal to 36.8%. Accordingly, the time constant expresses the time it takes the indoor temperature to increase by 1-1/e or 63.2%.

		τ_1 [h]	$\bar{\tau}_1^k$ [h]	sd(τ_1^k) [h]	τ_2 [h]	$\bar{\tau}_2^k$ [h]	sd(τ_2^k) [h]
39000	A	0.14	0.13	0.33	72.9	74.6	12.8
	B	0.13	0.13	0.04	57.3	55.4	8.5
	C	0.05	0.08	0.02	55.5	58.0	11.4
35710	A	0.30	0.71	0.27	30.7	32.9	4.2
	B	0.72	0.68	0.26	29.3	29.4	4.8
	C	0.17	0.23	0.23	28.2	28.1	7.0
40165	A	0.33	0.5	0.24	43.3	46.4	4.5
	B	0.43	0.48	0.23	39.3	38.5	7.8
	C	0.1	0.15	0.09	38.1	39.1	13.7

Table 2: Comparison between different statistics from the different models. All units in hours.

Models have been set up for simulations of the same archetype houses as identified in previous project (e.g. Danish Building Typologies and Building Stock Analyses. SBi 2016:18). These simulations are used to quantify the amount of energy that can be stored in Danish single family houses outside district heating networks, if they all were all heated by heat pumps.

A second step of this project is an expected future collaboration between the partners on developing a module for the dynamic simulation tool BSim, to make it possible to implement model predictive control of heat supply in buildings. With this module, building designers can predict the buildings' flexibility and utility companies will be able to utilize this via aggregators. There is a need for aggregators between the utilities and the buildings as the individual building's energy flexibility is too limited to be of interest for a utility company by itself.

1.4 Project objectives

The project was challenged by workload of key persons involved in the project, and was for the same reason extended by one year.

When analysing data from the houses at Middelfart it proved that the quality and content of data was not as expected for all measured houses. In some houses, data for energy use was not a frequent at data for the indoor temperature. Additionally, data for energy use was a mixture of energy for space heating and for domestic hot water in some houses. Therefore, it was not possible to estimate the heat transfer coefficient for all houses in the sample. Other, simpler, methods was thus used to identify the characteristics of the houses. This information was supplemented by simulated data from archetype buildings and provided the necessary information to carry out the analyses.

Besides this, the project did not experience any unexpected problems.

1.5 Project results and dissemination of results

There are no commercial results from the project to be used directly. However, the project have proven a need for extending the existing dynamic simulation tool with the capability of simulating a demand response control in buildings. It is planned to continue the collaboration between Aalborg University and DTU Compute to achieve this goal.

Results from the project are:

- A technical report SBi 2020:14 – Buildings as energy storage in a smart grid (In Danish: *Bygninger som energilager i et smart-grid*)
- A scientific article *Scalable strategies for characterizing flexibility potential in residential buildings* submitted to international journal of Energy and Buildings.
- A conference article *Analyses of energy flexibility in single-family houses* submitted to BuildSim-Nordic, 14-15 October 2020, Oslo, Norway.

1.6 Utilization of project results

It is not possible to commercialise the project results before finalising the above-mentioned development of the dynamic building simulation tool BSim. When this is accomplished, building designers can simulate buildings potential flexibility. Utility companies will be able to quantify the flexibility potential in the grid and utilize this via aggregators.

1.7 Project conclusion and perspective

It is possible to utilize the energy flexibility in Danish single-family houses to shift energy uptake from the grid by several hours. If multiple houses can be controlled centrally, this can potentially lead to a better utilization of renewable energy sources when it is available. Single-family houses is only a small share of the total building stock in Denmark. A large share of the remaining building stock is connected to district heating networks. This is however, not a reason for not considering the need for energy flexibility provided by buildings. District heating networks do also suffer from peak demand problems and it becomes increasingly necessary to deal with it in a future where the heat may come from large heat pumps. So, utilization of energy flexibility in buildings can play a central role in the future to move demands from periods with low capacity in the grids to periods with high capacity.

Annex

Relevant links

(the guidelines should be deleted – they should NOT be included in the final report)

GUIDELINES FOR FINAL REPORT

General
Depending of project type, project size and project complexity the **number of pages** in the final report may vary. For smaller **demonstration** projects the final report normally should not be more than 20 pages plus possible relevant appendices. For **research and development** projects the final report should not be more tha 50 pages.

The final report will be used for dissemination purposes and the information given in the final report should be suitable for dissemination, cf. point 1.4.

1.2 Short description of project objective and results
The short description should be in two versions:
- an *English version* and
- a *Danish version.*

Each version should be brief, not more than 600 to 800 characters.

1.3 Executive summary
Brief summary of the project and its results and expected utilisation of project results.

1.4 Project objectives
Description of the project objectives and the implementation of the project. How did the project evolve? Describe the risks associated with the project. Did the project implementation develop as foreseen and according to milestones agreed upon? Did the project experience problems not expected?)

1.5 Project results and dissemination of results

Description of main activities and technical results in the project as well as description of commercial results and expectations of the project.

Did the project succeed in realising its objectives? If not, why? Did the project give answer to the problem stated in the project proposal which the funding has been based on. Did the project produce results not expected?

Did the project so far result in increased turnover, exports, employment? Do the project partners expect that the project result in increased turnover, exports, employment?

How has project results been disseminated?

1.6 Utilization of project results
How do the project participants expect to utilize the results obtained in the project? Do any of the project participants expect to utilize the project results - commercially or otherwise? Which commercial activities and marketing results do you plan for? Has your business plan been updated? Or a new business plan produced? What future context is the end results expected to be part of, e.g. as part of another prod-

uct, as the main product or as part of further development and demonstration? What is the market potential? Competition?

Do project participants expect to take out patents?

How do project results contribute to realize energy policy objectives?

Have results been transferred to other institutions after project completion? If Ph.D.s have been part of the project, it must be described how the results from the project are used in teaching and other dissemination activities

1.7 Project conclusion and perspective

State the conclusions made in the project. Try to put into perspective how the project results may influence future development.

Annex

Add links to relevant documents, publications, home pages etc.