NEW DESIGN METHODS FOR ENERGY INFRASTRUCTURES IN FUTURE URBAN AREAS

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ABSTRACT

Energy solutions, energy patterns, energy flows, energy systems and their operations will change dramatically in the future urban areas, based on low-energy solutions and with integrated energy generation. The buildings may be energy neutral in average over the year, but they will still need the energy infrastructures to balance their fluctuating energy consumptions and integrated generations over the day and year. The role of the energy networks will change from energy supply to energy distribution.

Nordhavn is a unique example of tomorrow's dense, low-energy urban area – unique in its large size, high density, mix of buildings, smart, low-energy solutions, energy ambitions, development stage, multi energy networks, energy integration, exchange of energy with Copenhagen, and operation on dynamic energy markets.

EnergyLab Nordhavn provides an excellent platform for projects and a unique real live laboratory for smart energy solutions for the future urban areas. The project 'EnergyLab Nordhavn – New urban energy infra-structures' develops new knowledge that will contribute to the development of new tools for optimal design and operation of the energy systems in the future urban areas.

INTRODUCTION

The combination of the rapid developments and changes in the energy conversion technologies, the increased energy efficiencies, the integration of the energy systems and the distributed power generations will all result in dramatically changes of the load profiles in the energy distribution grids in the future – not less in the power distribution grid. This will not happen overnight, but, as the energy infrastructures to be established today will be part of the infrastructures for the next many decades, these should be designed best possible for the future. But we know very little about the future. There are many likely and very different scenarios. In addition, the operation conditions are unique from place to place, and will change over time.

Design and operation of the energy systems are closely linked: the design of energy systems will have huge impacts on the operational options, and the operation strategies will have huge impacts on the requirements to the design of the energy system. Advanced and efficient tools for optimal design and operation of the energy infrastructures and the energy systems have continuously been developed and updated, able to handle multiple and dynamic energy markets, renewable energy sources, and advanced forecasting of loads, generations and prices etc. However, as the actual development of the future energy systems is not fully known, the present design and operation support tools are not developed to optimise the future energy systems.

The first barrier to develop the design and operation support tools is to get more and detailed information about likely scenarios for the future energy systems. Some indications and information can be achieved – relatively cheap and fast – through desk analyses and simulations. Supplementing, and more detailed and reliable indications and information must be achieved through real life demonstrations. The challenge by that is that the future energy systems do not exist as they per definition are not yet implemented.

Nordhavn

A new, large and well-defined area in Copenhagen, Nordhavn, will over the coming decades be gradually developed from scratch to an area with 40 000 new homes and 40 000 new jobs, and entirely with smart and integrated low, zero or plus energy solutions for all energy services [1] – see Table 1 and Table 1Figure 1. Nordhavn shall contribute to Copenhagen's ambitious aim of becoming CO2-neutral by 2025 [2]. The development of Nordhavn has already started, but most of the area is not yet detailed planned. Solutions are already available, new solution are in progress, and the next solutions are to be planned. We therefore now and in the coming years have the possibilities to collect data from the already established solutions, to test and demonstrate new solutions in the areas being developed now, and to impact the solutions to come.

Nordhavn will be served by more energy infrastructures – the electricity grid and various water-based thermal grids with different extents and temperature levels. The grids will be interconnected and integrated through converters (from electricity to heat) and through heat exchangers and heat pumps. Nordhavn's energy systems are parts of the regional, national and international energy systems. Due to the peninsula shape of the Nordhavn area, the energy infrastructures in Nordhavn are connected to the energy infrastructures in Copenhagen in few points only, with clear energy exchanges.

Table 1: Nordhavn @ Copenhagen

Area: 3 km^2
Developed in phases 2010..2060
High desity, low energy
40 000 new homes
40 000 new jobs
Electricity network
Thermal networks

All buildings must fulfil the newest building regulations – from 2015 the Danish BR2020 [3] – and will include advanced energy solutions and integrated energy generations. The construction and the hot tap water solutions will provide short-term energy storage capabilities. And dedicated, associated thermal storages may provide additional long-term energy storage capabilities. The building-integrated energy generations will include heat and light through the windows, solar panels (for heat and electricity generation) and heat pumps. The energy required for heating the hot tap water will become significant.
Nordhavn is unique with respect to the ambitious requirements to all the energy solutions in the area, to the status of the development, to the fact that all solutions in Nordhavn will be highly energy efficient and smart enabled, to its extent, and to its well-defined energy exchanges with Copenhagen.

ENERGYLAB NORDHAVN

The new platform and collaboration EnergyLab Nordhavn will utilise Nordhavn as a live laboratory for developing, testing and demonstration of new energy solutions, optimised for the future, dense urban areas. EnergyLab Nordhavn is a collaboration between the key players, a platform for a series supplementing projects and a real-live energy laboratory in Nordhavn.
The first project 'EnergyLab Nordhavn – New urban energy infrastructures' (2015 – 2018) [4], coordinated by DTU, has focus on the impacts of the operational options on the optimal design of the electricity and thermal infrastructures in Nordhavn. The operational options include the various available energy flexibilities, the available 'fuel-shift' options, and the energy system integration options. The aim of the project is defined as 'to develop new methods and solutions for design and dimensioning of the future cost-effective multi-carrier energy system (electricity, thermal and transport) based on Nordhavn as a highly visible real-life laboratory, including development and experiments with novel business models, smart energy technologies and new intelligent operational solutions'.
The partners in the project include the authorities (Copenhagen Municipality and By & Havn); the utility companies, responsible for the design and operation of the infrastructures (DONG Energy and HOFOR); several suppliers of smart energy solutions (Balslev, ABB,

Figure 1: The new Nordhavn area will be developed in phases 2010..2060.

Danfoss, Metro Therm, CleanCharge Solutions, Glen Dimplex); and the Technical University of Denmark (DTU) – see Table 2. DTU is represented by the three departments: DTU Center for Electric Power and Energy (DTU CEE), DTU Civil Engineering, and DTU Mechanical Engineering. The project is supported by the Danish support scheme EUDP.
The project combines research and demonstration (as indicated by the lists of PhD's and experimental activities below), and contributes to the development of EnergyLab Nordhavn as a unique experimental platform – see Figure 2. The project combines the design and operation of the energy infrastructures, the energy solutions and components, and the energy markets. The project will have influence on the design and operation of selected energy solutions in Nordhavn. The project will have access to selected online system and component controls. And the project will have access to various detailed online energy data from energy systems and solutions in Nordhavn.
The project is somehow a follow-up of the national iPower project [5], with focus on the power system, and a supplement to the national CITIES project [6], a dedicated research project – all with international partners.

Research

The focus of the research in the project is the impact of the availability and management of energy flexibilities on the design and operation of the energy systems. Providing and enabling more distributed energy flexibility through proper design in combination with optimised management of the energy flexibility can at the same time optimise the operation of the individual components and reduce both the peak power flows in the networks and the transport of energy, and thereby reduce the investment costs, the operational costs and the energy losses.
The project will specifically develop, analyse, test and evaluate the following research topics – each associated to a PhD study and to some of the experimental activities

Table 2: EnergyLab Nordhavn partners

DTU – Technical University of Denmark
Copenhagen Municipality
By & Havn
DONG Energy
HOFOR
ABB
Danfoss
Balslev
Metro Therm
CleanCharge Solutions
Glen Dimplex

listed below:

- Design methods for active electrical distribution networks that consider advanced operational solutions such as dynamic network topology, in view of potential interaction with other energy systems. Associated to PhD#7: Advanced design methods for active distribution networks.
- Various adaptive control solutions (both autonomous and coordinated), utilising smart energy components to provide smart energy network services. Associated to PhD#2: Adaptive control solutions for enabling smart network services.
- Smart EV charging solutions for multiple charging spots, adjust their charging or discharging behaviour to provide power and energy services to the local area. Associated to PhD#8: EV smart-grid integration in urban city areas.
- Optimised thermal system designs, including heat exchangers and heat pumps, integrating the various thermal infrastructures, the various heating and cooling services, the various available heat sources and sinks, and the various heat storages options. Associated to PhD#4: Optimal integration of district heating, district cooling, heat sources and heat sinks.
- Methods for modelling and predicting energy flexibility potentials provided by the thermal masses in the building constructions. Associated to PhD#1: Predicting flexibility in thermal mass in buildings for low energy district Nordhavn.
- District heat solutions in the buildings, reducing the return temperature of the district heat water. Associated to PhD#5: Control of return temperature in low-temperature district heating network.
- Heat pump solutions and designs with integrated hot tap water heating, optimised for future low temperature district heating systems. Associated to PhD#3: Heat pump solutions for integration with district heating in a renewable energy system.
- Methods for load profiling, accounting for flexibility characteristics (also for operational forecasting of conditional dynamic elasticity) to be used in in investment, planning and load scenarios studies. Associated to PhD#6: Smart end-user data analysis and pattern recognition.

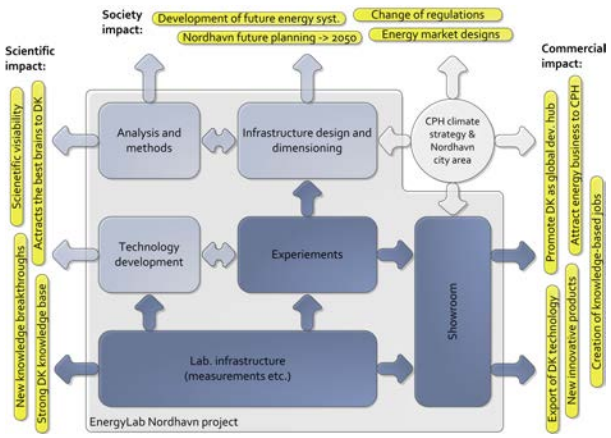

Figure 2: Structure of the EnergyLab Nordhavn project.

- Near future practical solution as well as the gab to fully integrated approaches for multi-carrier energy markets, from the pragmatic coupling of the markets, to the more conceptual approaches, based on energy flows. Associated to PhD#9: Multi-carrier energy market design and analysis.

Experimental activities

The project will include a number of experimental activities, each providing new valuable detailed data and new knowledge about practical challenges and technical values and potentials for smart design and operation of integrated energy systems in dense, low-energy urban areas – see Figure 3. Each experiment provides new knowledge and information about actual technical energy flexibility potentials, and identifies the critical parameters and conditions. The project will specifically execute the 10 pre-defined experimental activities listed below – each associated to the project's research activities.

Experiment #01 and #04 demonstrate how home automation systems and building management systems can be extended and utilised for energy flexibility management in private homes and commercial buildings, respectively. Experiment #02, #05, #08 and #09 demonstrate various solutions to optimise the design and operation of thermal networks in the new dense, low-energy urban areas. Experiment #03 and #06 demonstrate two examples of smart demand controls, while Experiment #07 demonstrates the value of a large-scale battery – all providing power system services. Experiment #10 finally combines it all in a coordinated operation of the integrated energy systems.

- Exp#01 (Balslev): User behaviour and demand response with home management systems. Home management systems in different types of buildings will be used to collect detailed data on user behaviours and energy flows, and will be extended with different types of demand response capabilities. The new knowledge will contribute to the clarification and quantification of the relations between the user behaviours, the energy flows and the demand

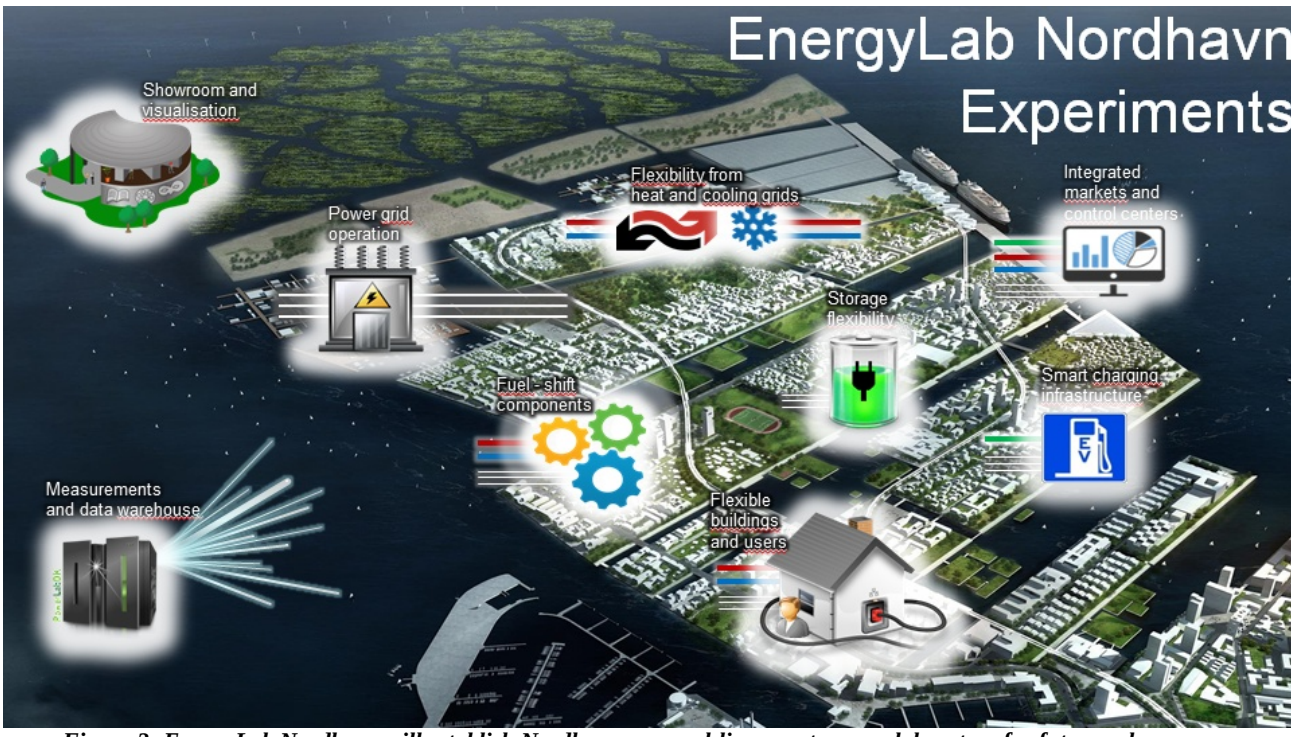

Figure 3: EnergyLab Nordhavn will establish Nordhavn as a real-live smart energy laboratory for future urban areas.

response capacities.

- Exp#02 (Metro Therm): Fuel-shift technology for low temperature district heating. Heating service solutions including either electrical heating elements or heat pumps, and with capabilities to shift smoothly and dynamically between electricity and low temperature district heat sources, will be demonstrated in different specific real applications. The new knowledge will contribute to quantify the actual fuel-shift capacities.
- Exp#04 (Balslev): Smart energy-flexible building management system in commercial buildings. Building management systems (BMS) in commercial buildings will be extended with energy flexibility management, dynamically identifying and activating the actual energy flexibility potentials according to energy system needs and without compromising the primary energy services. This requires the development of a standardised communication of the energy flexibilities available and requested.
- Exp#05 (HOFOR): Controller for optimal operation of large heat pump. Different control strategies and algorithms will be tested and evaluated for a large-scale heat pump installed in the district heating system. The new knowledge will contribute to the development of the tools for optimal design, dimensioning and operation of large-scale heat pumps in the district heating systems.
- Exp#08 (HOFOR): Low-temperature district heating supply solutions. A regulation of the forward temperature in a selected string of the district heating network will be implemented to test and evaluate the impacts and values of low temperature district heating. The new knowledge will contribute to optimise the design, dimensioning and operation of district heating systems in dense, low energy urban areas.
- Exp#09 (HOFOR): Islanding heating system supply. The operation and value of isolated heating systems will be tested and evaluated for a selected building complex. The new knowledge will contribute to the identification of new optimised heating solutions.
- Exp#03 (Glen Dimplex): Grid services by electric water heaters in private homes. Electric water heaters in private homes will be equipped with demand response functionalities for providing grid services in terms of power regulation. The new knowledge will contribute to quantify the actual, aggregated response capacity.
- Exp#06 (CleanCharge): Smart charging EV infrastructure. Multiple charging spots installed at parking areas will be equipped with coordinated demand response functionalities (energy flexibility management) to provide temporary local power regulations according to the power system needs. The new knowledge will contribute to the quantification of the actual, aggregated power regulation capabilities from simultaneously charging (and discharging) of more EVs and to identify the critical parameters and conditions.
- Exp#07 (DONG Energy): Electric battery storage in the grid. The impact on the technical value of different controls of a large-scale electrical battery installed in a low voltage grid with significant PV generation will be tested and evaluated. The new

knowledge will contribute to the technical and economic evaluation of the feasibility of large-scale batteries and to the identification of critical parameters and operation conditions.

- Exp#10 (ABB): Multi-carrier market and control centers. The potentials, challenges and values of advanced and coordinated operation and control of the integrated energy systems will be tested in real, both on existing energy markets and with the introduction of new, appropriate (artificial) energy markets. The new knowledge will contribute to the development of new energy markets, supporting the efficient operation of integrated energy systems.

CONCLUSIONS

Energy solutions, energy patterns, energy flows, energy systems and there operations will change dramatically in the future dense urban areas, solely based on low-energy solutions for all the energy services and with local and integrated energy generation. The future buildings may be energy neutral in average over the year, but they will still need the energy infrastructures to balance their heavily fluctuating energy consumptions and generations over the day and year from their heat pumps, electrical vehicles, windows and solar panels. The role of the energy networks will change from energy supply to energy distribution in all directions.

Smart energy flexibility management can at the same time optimise the operation of the individual components and reduce both the peak power flows in the networks and the transport of energy, and thereby reduce the investment costs, the operational costs and the energy losses.

Nordhavn is a unique example of tomorrow's dense, low-energy urban area – unique in its large size, in its high density, in its mix of buildings with different purposes, in its purely smart, low-energy solutions for all energy services, in its energy ambitions, in its development stage, in its multi energy networks, in its energy integration, in its exchange of energy with the rest of Copenhagen, and in its operation on dynamic energy markets.

EnergyLab Nordhavn provides an excellent platform for execution of supplementing projects and will establish a unique real live laboratory for development, testing, demonstration and evaluation of optimised smart energy solutions for the future dense, low-energy urban areas. The present project 'EnergyLab Nordhavn – New urban energy infrastructures' will develop new knowledge that will contribute to the development of new tools for optimal design and operation of the energy systems in the future dense, low-energy urban areas with integrated, distributed energy generation. We expect a series of coming EnergyLab Nordhavn projects on specific and supplementing topics, that each, in combination and together with the other similar activities Worldwide will contribute to the continuous development of optimised smart energy solutions and support tools.

No cities have identical energy needs and conditions. Complete solutions can therefore not be directly replicated ('copied-and-pasted') from one city to another. However, the individual solutions can inspire others, and concepts and technologies can be adapted and reused. All solutions and technologies should therefore be designed flexible and adaptive in order to fit the different cities' individual needs, conditions and solutions.

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