

RECOMMENDATIONS AND MAIN RESULTS

ENERGYLAB NORDHAVN



Terminology

Energy flexibility: Energy flexibility can be in time, place, or form—displacement of the energy flow in time, energy flow transfer to another location, or the switch between using different energy carriers for the same energy service.

Energy sectors: Sectors are electricity, heat, and gas supply as well as consumption in buildings, industry, and transportation.

Energy services: Energy-based services that the customer needs—not energy, but the services that the energy provides, e.g. comfort (rather than heating/cooling).

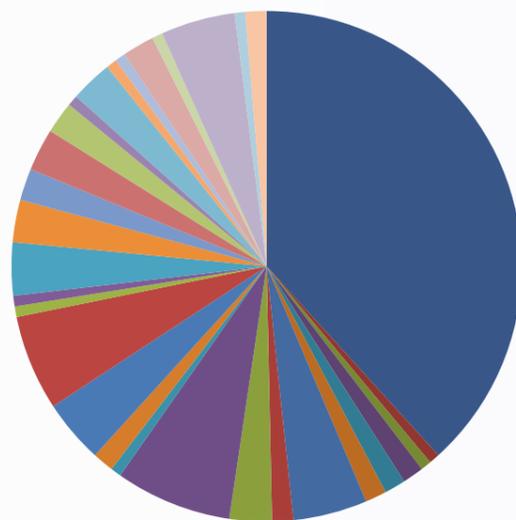
Fuel shift: Provision of the same energy service with a shift between energy carriers. This could be the production of domestic hot water based on either district heating or electric power.

Integration: Integration of the energy system includes 1) conversion between sectors 2) more energy sources for the same service and 3) market integration.

Interoperability: Characteristic of a product or system, whose interfaces are completely understood, to work with other products or systems, at present or in the future, in either implementation or access, without any restrictions.

Low-temperature district heating: District heating at a temperature level where the hot water can be produced through a direct heat exchange (flow temperature around 55°C).

Peak shaving: Controlled consumption reduction when other consumption in the area is maximized, e.g. around the cooking peak between 17:00 and 20:00, but also for district heating peak loads, which are traditionally handled by increasing production.



Smart energy: A cost-effective, sustainable, and secure energy system integrating and coordinating renewable energy production, infrastructures, and consumption through energy services, active players, and new technologies.

Stable and robust system: The energy system operation should be stable in any anticipated operating situation as well as be robust in unforeseen incidents and development over time (e.g. technology, prices, conditions).

Ultra-low temperature district heating: District heating at a temperature where boosting (temperature increase) is necessary to produce hot water (flow temperature around 45°C).



OUR EFFORTS ARE BASED ON OUR DEDICATION TO OUR TASK AND TO REALIZING OUR AMBITION:

"The project will result in substantial commercial impact by leading the way for new innovative products, attract new energy businesses to Denmark and create knowledge based jobs, societal impact by developing a future energy system, guide new rules and regulations, emerge new market designs and scientific impact by new knowledge breakthroughs and expansion of the Danish knowledge-base."

In this report, we are presenting a number of key messages that have emerged as part of the project and which are aimed at municipalities, utilities, authorities, building consultants, and technology suppliers. In several of the recommendations we refer to the project's technical explanations, scientific articles, theses etc.

We hope you enjoy the report.

The EnergyLab Nordhavn team

This report was prepared with contributions from the project participants of the EnergyLab Nordhavn partnership. Attitudes, recommendations, and conclusions are based on the collaboration project, and some of these may not be fully aligned with all project partners' established policies, assessments, statutory mandates, etc.



Introduction

Denmark's largest and most ambitious smart energy project, EnergyLab Nordhavn, is now ready to present the main results and a number of recommendations for how to promote smart solutions that work across the energy sector and thereby accelerate an effective green transition. It is the result of four and a half years of work developing new methods and solutions for designing and operating the flexible and integrated energy system of tomorrow, based on Copenhagen's Nordhavn as a living metropolitan laboratory.

THE PROJECT RESULTS WILL BE FURTHER DESCRIBED AND ANALYSED IN THE FINAL PROJECT REPORT. BELOW, YOU WILL FIND A SUMMARY OF THE RESULTS:

- ▶ We have shown how the varying energy needs of buildings can be exploited and coordinated by a district heating company, enabling energy efficiency improvements and a reduction in the use of peak load boilers, thus helping to realize a district heating system based on 100% renewables and to realize the Copenhagen 2025 climate plan for district heating. The solution is being rolled out in 7000 Copenhagen homes.¹
- ▶ With Flexheat, we have demonstrated possibly the smartest large ammonia-based (800 kJ/s) heat pump in the world.²
- ▶ We have demonstrated how district heating at ultra-low temperatures combined with a booster heat pump can supply housing blocks (buildings) with hot water as well as ensure a low return temperature.
- ▶ Our grid-connected battery has demonstrated how batteries can be integrated in a city and has demonstrated a combination of frequency regulation and local peak shaving.
- ▶ Through a coordinated operation of battery and heat pump, we have shown a unique control concept that goes across companies using a shared data platform.³
- ▶ We have created an energy data warehouse that supports secure real-time data sharing between the players, thus supporting the realization of a smart energy system encompassing electricity, heat, buildings, transport, and residents.
- ▶ Along with our other partners, we have created EnergyHub, a groundbreaking new concept in the form of an innovation hub that combines communication, player dialogue, international marketing, incubation, and innovation under one roof. This platform has enabled us to spread awareness of Danish energy technology to several national and international delegations.

Regulators and authorities

1. ENERGY TAXES MUST BE REFORMED SO THAT THEY REFLECT THE CLIMATE IMPACT AND CAN THUS ALSO BE DYNAMIC

If taxation becomes more uniform across the different energy types and also internalizes the climate impact, obvious unintended effects of charges will be eliminated.

An example of this is the electricity tax on a grid-connected battery which is charged based on the (gross) consumption read from the electricity meter, while taxes are not lifted for electricity distributed on the grid. This means that batteries are taxed unfairly—many times higher than the actual consumption dictates—and this prevents battery owners from supporting the energy system in a financially viable way.

During certain periods, e.g. periods of very high wind power generation, fuel shifts (switching between district heating and electricity) can be financially beneficial to the customer and to society. However, the gain is now so low that necessary investments in such solutions for consumers are not worthwhile, unless the necessary equipment can also be used for other valuable services.

As the climate impact of energy production and consumption varies, open data can establish time-dependent/dynamic energy taxes that are transparent and follow common cost allocation principles.

2. DISTRICT HEATING COMPANIES CAN APPLY A PRICE DIFFERENCE BETWEEN NORMAL DISTRICT HEATING AND LOW-VALUE DISTRICT HEATING TO INCREASE THE INTEGRATION OF SURPLUS HEAT

The basis for utilizing low-value heat (surplus heat at low temperatures) in the district heating grid can be the design and expansion of ultra-low temperature district heating clusters connected to existing grids. This will also enable the use of return water from existing district heating for ultra-low temperature clusters, which will result in lower heat losses from the pipes and better operating finances on the plants.⁴

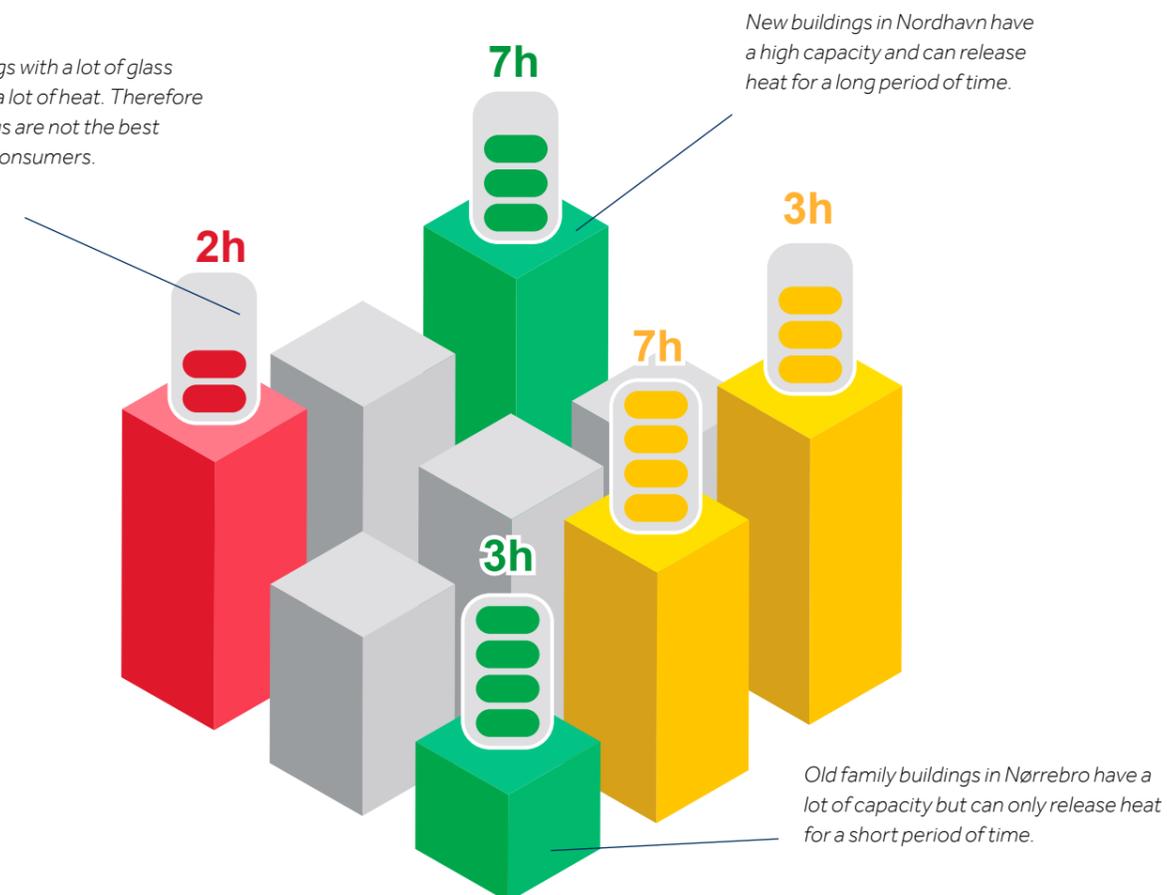
3. MARKET RULES ON CONSUMPTION AND DISTRIBUTION SYSTEMS SHOULD BE ADJUSTED

Based on the tests conducted at the FlexHeat Nordhavn plant, a significant potential has been identified by changing market rules, so that they allow for offering different services in each direction (asynchronous services). The result will be a quicker integration of the heat pumps.⁵

4. THE ENERGY FRAMEWORK CALCULATION PROGRAMMES, I.E. THE BE PROGRAMMES (CURRENTLY BE18) OF THE SBI (DANISH BUILDING RESEARCH INSTITUTE) MUST BE ADJUSTED

The current rules are poorly suited for hybrid solutions, which prevents the implementation of some of the smart energy solutions such as a combined use of district heating and electricity for the production of hot water. The calculations only take into account the grounds until the boundary line, which means that the benefit of a lower heat loss from the distribution of heating to homes with low-temperatures or ultra-low temperatures is not included.⁶

Office buildings with a lot of glass cannot store a lot of heat. Therefore these buildings are not the best flexible heat consumers.



New buildings in Nordhavn have a high capacity and can release heat for a long period of time.

Old family buildings in Nørrebro have a lot of capacity but can only release heat for a short period of time.

5. CURRENT BUILDING ENERGY LABELS SHOULD BE UPDATED

The current labels for building energy consumption assume that the behaviour of the residents is rational and, not least, that the construction is perfect, and that the technical installations are designed and aligned with each other. This does not provide a true and fair view of the energy consumption in buildings and we therefore recommend supplementing the current labels with a measured and realized energy label which is in line with reality. We have shown how home automation systems can detect heating and ventilation systems that are poorly aligned with each other early. They thus provide a database that makes it meaningful and reasonable to provide clients, developers, and consulting engineers the responsibility of documenting and verifying that the building actually delivers as promised over a number of years.⁷

6. THE 1988 BAN ON ELECTRIC HEATING SHOULD BE RECONSIDERED

With the increasing supply of fossil-free electricity and the phaseout of natural gas, a modification of the restrictions on the use of electric heating should be considered. Especially for homes with low heating requirements and homes with solar cells as well as for solutions that can combine electric heating with dynamic storage.

Cities and players responsible for concrete urban development

7. CITIES CAN SPEARHEAD THE GREEN TRANSFORMATION BY ROLLING OUT THE NEW SOLUTIONS WITHIN THEIR OWN FACILITIES

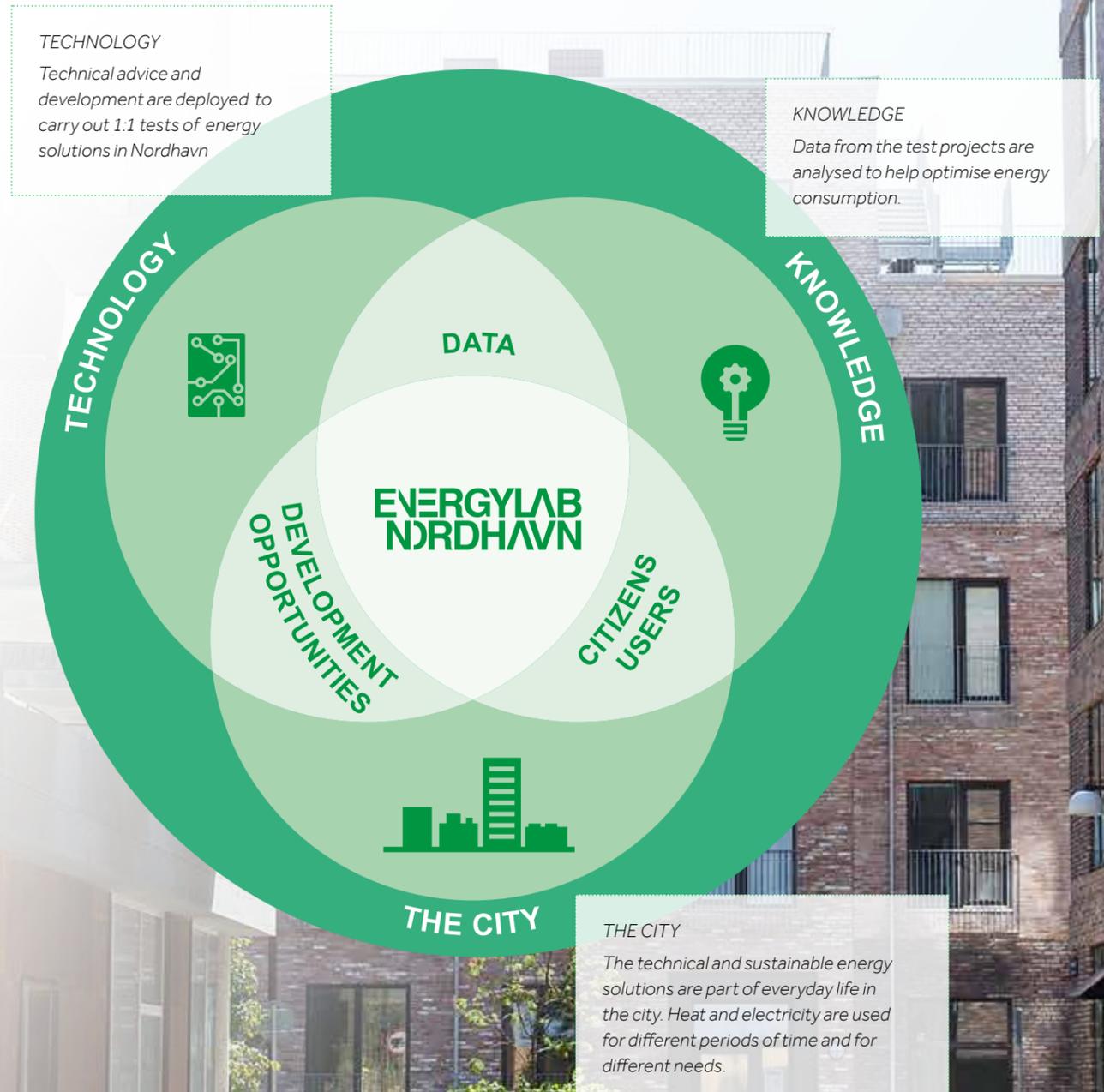
Climate change typically results in high costs for major cities, which means that political backing for rolling out the new smart energy solutions should be readily available. Major cities typically have a number of facilities, buildings, etc. that can serve as examples to other players.

8. MUNICIPALITIES SHOULD BE PROACTIVE IN PROVIDING ACCESS TO DATA

Data exchange is vital for the development of sustainable cities, as intelligent energy systems are based on data from buildings and infrastructures, among other things. The project has taken the first steps in that direction and proved that establishing a safe free data exchange can be both a technical and legal challenge. Municipalities must contribute by assisting in obtaining permits and commitments for data use and establishing trust between the organizations⁸, and data platform alliances with the universities would be useful.

9. ENERGY SAVINGS SHOULD BE SUPPORTED BY SMART BUILDINGS WHICH SHOULD BE INCLUDED IN THE EARLY URBAN DEVELOPMENT PLANNING STAGE

DGNB and other certification systems are prepared for the use of smart building management, as it is deemed to help reduce energy savings. The latest edition of EU's EPBD (Energy Performance of Buildings Directive of 2018) now also includes requirements for building automation and control systems, but so far only for large commercial buildings (with heating systems with an output of at least 290 kW). Similar requirements should also be made for housing construction and small-scale buildings integrated into city energy systems. The opportunities in smart buildings, energy, and solutions in connection with urban development require all relevant partners to be involved early in the process. In some cases, the project has played a facilitating role that municipal administrations and urban development companies can play in some cases by making explicit demands for contractors to establish these functions in the buildings, including housing construction.



Utility or energy companies

10. THE MAIN FOCUS SHOULD BE ON ENERGY CONSUMERS THROUGH NEW SERVICES AND MARKETS

Many energy consumers want to contribute to the green transition. They can be included by combining the advanced energy management^{ix} with the user's preferences and other needs. This creates a high-value product that is handled in new ways, e.g. by combining with other comfort services that can use the same data such as alarms, leak controls, indoor climate systems, etc.

11. BETTER POSSIBILITIES FOR ACTIVATING HEAT FLEXIBILITY SHOULD BE INTRODUCED SO THAT FLEXIBILITY CAN CONTRIBUTE MORE TO THE INTEGRATION OF THE ELECTRICITY AND HEATING SYSTEMS

The need for energy flexibility is expected to increase in future energy systems. The need for flexibility arises due to fluctuations in energy production from renewable energy and, in part, the energy consumption of new technologies, as production and consumption must be balanced and bottleneck issues handled. Here, sector coupling is key, and more flexibility solutions and products that can increase the integration of renewable energy into the system in the best and cheapest way need to be arranged. There is already an emerging market for electricity flexibility services. An increased market for heat flexibility, where it can be quantified, demanded and supplied under market conditions, will provide a diversity of solutions and stimulate innovation in solutions, especially in relation to the connection between electricity and heat. This could also include dynamic heating tariffs.⁹

12. STATIONARY BATTERIES SHOULD BE INCORPORATED INTO THE ELECTRICITY GRID FOR FREQUENCY STABILIZATION AND LOCAL PEAK SHAVING

The project has shown that grid-connected batteries are a technically effective tool for evening out the load and stabilizing the grid voltage. However, it is not possible, now or in the near future, to get a positive business case out of a battery investment if it is used only for DSO purposes, which is why they should be considered where they can also provide frequency stabilization and other services.

13. HEAT PUMPS IN DISTRICT HEATING SYSTEMS SHOULD BE IMPLEMENTED FROM AN OVERALL SYSTEM PERSPECTIVE

In a densely populated city with new buildings equipped with large heat pumps, the lowest heat price for customers is achieved at low-temperature district heating, compared to an alternative with ultra-low temperature district heating or individual heat pumps. When it comes to heat sources, bigger is not always better. One analysis indicates that systems relying on multiple plants with multiple heat sources, preferably combined with district cooling, provide the best financial result.¹⁰





District heating is on and the building is heating up

District heating is reduced with up to 5°C for a few hours and the building's thermal mass provides the heat

14. THE VALUE OF HEAT PUMPS IN THE DISTRICT HEATING GRID CAN BE INCREASED IF THE HEAT PUMPS CONTRIBUTE TO BOTH THE ELECTRICITY AND HEATING SYSTEMS IN A FLEXIBLE WAY

The development of heat pumps fits well into a diversification of district heating; they contribute to the phaseout of fossil fuels, they are a supplement to sustainable biomass, and they enable the combination of the electricity and heat sectors in a future with increased electrification for additional benefits.

In case of the latter, it is essential that the electricity consumption units are flexible and can thus integrate increased fluctuating energy sources. Therefore, the operation of the heat pumps must be adapted to the requirements for participation in the system performance markets and, where appropriate, in such a way that they can solve bottleneck issues in the distribution grid, thereby supporting electrification.¹¹

15. ELECTRIC HEATING FOR HOT WATER PRODUCTION IS ALSO PART OF THE SOLUTION.

Like with stationary batteries, fuel-shift (temporary electricity instead of district heating) can be incorporated into the electricity grid for frequency stabilization and local peak shaving.

16. DISTRICT HEATING OPERATIONAL PLANNING CAN BENEFIT FROM BEING BASED ON STOCHASTIC MODELS OF THE ELECTRICITY MARKETS

In Copenhagen as well as in many other cities with large district heating grids, heat production and delivery is based on a cost minimization of the heat production units, which takes into account a forecast of expected developments in electricity prices. One of the project's PhD theses shows how this method can be improved by analysing several possible scenarios using a stochastic model.¹² From the analysis it is concluded that up to 10% of total energy costs can be saved using this approach.¹³ This is just one of the approaches that the EnergyLab

Nordhavn project has investigated, some of which rethink not only the order and models of market clearing and heat pricing (e.g. alternatives such as dynamic prices), but also energy communities that re-use waste heat and coordinate prosumers. The possibilities offered by an integrated approach will only materialize by rethinking a market-based operation of the systems that highlights and rewards different types of flexibility on the interfaces between the electricity and heating systems.

17. FOR ELECTRICITY GRID PLANNING, NEW ADAPTIVE METHODS FOR THE CATEGORIZATION OF CONSUMERS SHOULD BE APPLIED

New methods of adaptive categorization of electricity consumers may be beneficial and enable determination of the power grid load without knowledge of the specific consumption types¹⁴. The method can quickly detect patterns in new types of electricity consumers, such as heat pumps and electric cars, which can be directly applied in a more efficient and precise extension and reinforcement plan for the grid.

18. UTILITIES SHOULD SHARE THEIR METER DATA WITH EACH OTHER AND OPEN UP ACCESS TO THESE

Access to meter data is important, e.g. to stimulate innovation.^{viii} Access typically involves difficult considerations of possible future community gains and specific customer/supplier relationships or personal data, as well as non-negligible work efforts. At EnergyLab Nordhavn, we have solved this by allowing a neutral operator—in our case a university—to agree with the data providers to establish such a shared access in the individual cases. The fact that it is typically regulated monopolies, and thus not companies with interests in a narrower commercial exploitation, that obtain energy data should also be exploited to ensure a more open data access.

Architects and consulting engineers

19. SMART BUILDING MANAGEMENT MUST BE INCORPORATED INTO NEW CONSTRUCTION WORKS

Smart home technology can be incorporated into both new construction work and renovation work, and home automation must be integrated into the design. It provides a range of comfort benefits while allowing energy consumption to be coordinated with energy supply, e.g. so that the peak load in total district heat consumption can be levelled and thus contribute to reducing the use of fossil fuels for peak-load plants.¹⁵ EU's Energy Performance of Building Directive (EPBD) already includes increased requirements for automation and control systems in commercial construction. Based on the project work, we propose to include housing construction, more benchmarks¹⁶, and performance guarantees in the legislation. We also propose that more players be involved in the preparation of the legislation.

20. MEASUREMENT AND CONTROL SYSTEMS SHOULD BE DESIGNED FOR INTEROPERABILITY

IoT, like with energy meters, has an infrastructure where you can become tied to certain supply chains. By making demands for interoperability, the state of the energy system can more easily be made available to several players, and it is possible to present a project to the contractor with a reduced risk of being tied to a particular supplier during the operational phase. In the project, we have learned how difficult it can be for third party players to offer solutions and services based on data streams that are beyond their control.

21. IT WOULD BE BENEFICIAL IF SOLUTIONS WERE BASED ON DATA STREAMS FROM UNIVERSITIES¹⁷

Data collected through a university's data platforms are primarily used for research, but many data streams are neither sensitive personal information nor commercially protected. Using university data sources will allow for a better data basis from which to carry out analyses and models and develop early commercial solutions. If, for example, a data processing agreement is entered into with DTU, it is possible to work with data that is closer to the citizens, as this allows them to extract/filter/anonymize datasets.

22. CONTRIBUTION TO THE SPECIFICATION OF THE NEW REGULATORY TESTING ZONES

There is a political focus on the creation of these test zones, and using our experience from Nordhavn to qualify the work with these would be an obvious next step. Here, advisers have an opportunity and a key role in bringing knowledge of the barriers of technological distribution into play, along with university recognition. Furthermore, it would be an obvious choice to designate Nordhavn as the regulatory test zone based on investments made, total players involved, and experience accumulated. A complementary option is using the existing free municipality scheme.

Technology providers

23. NEW PRODUCTS THAT PROVIDE FLEXIBILITY FOR THE ENERGY SYSTEM FOR BOTH ELECTRICITY AND HEATING SHOULD BE DEVELOPED

For example, this can be done by combining a heat pump with storage, which can be a combination of a battery and thermal heat storage and/or buildings, so that the heat pump mainly runs when the electricity is green and inexpensive. Increased wind power integration requires that the electrification contributes with flexible electricity consumption units that can balance the electricity grid. Here, it is an advantage to work with the design of the heat pump, so it can change the performance quickly enough to be able to offer system services to the electricity grid. Such system services can improve the heat pump business case and help integrate more green power, reducing CO₂ emissions.ⁱⁱ

24. BATTERIES SHOULD OFFER A COMBINATION OF STORAGE SERVICES, FREQUENCY STABILIZATION, AND LOCAL PEAK SHAVING

Batteries can currently only provide a (approximate) positive business case if it delivers more services. This requires careful consideration of the battery function and power/energy ratio. In the project, we have developed algorithms for the battery's delivery of peak shaving and system market services, and this complicated control system can probably be further optimized¹⁸. It is essential that the physical systems are combined with appropriate algorithms in relation to the markets and services that the batteries will be aimed for.

25. INCREASED VALUE IS AVAILABLE FOR PLAYERS WHO CAN TRANSLATE KNOWLEDGE OF CONSUMPTION PATTERNS INTO SYSTEM SERVICES

If you know your customers well and have a high diversity, you as an aggregator can make sure that, e.g., the storage solutions are pushing consumption at times when power is greenest, and at the same time offer services to energy companies such as frequency stabilization, voltage quality stabilization, or peak shaving.

26. TAKE ADVANTAGE OF THE UPCOMING REGULATORY TEST ZONES

Denmark holds a strong position within energy technology. When our technology companies are to develop new solutions, there is a need for demonstration areas, where both large-scale and real-life laboratory testing can be conducted. The upcoming regulatory test zones will improve the possibilities, and it can be investigated already now, which of our technologies can be scaled up within the framework of the test zones..

Contractors and building operation managers

27. CONTRACTORS SHOULD SET DEMANDS FOR INTELLIGENT BUILDING MANAGEMENT AND FOR SUBSYSTEMS SUCH AS HEATING AND VENTILATION TO SUPPORT EACH OTHER

Intelligent building management ensures a higher comfort and the building's energy flexibility can be made available to both the district heating company and the electricity supplier¹⁹, possibly through an ESCO supplier.

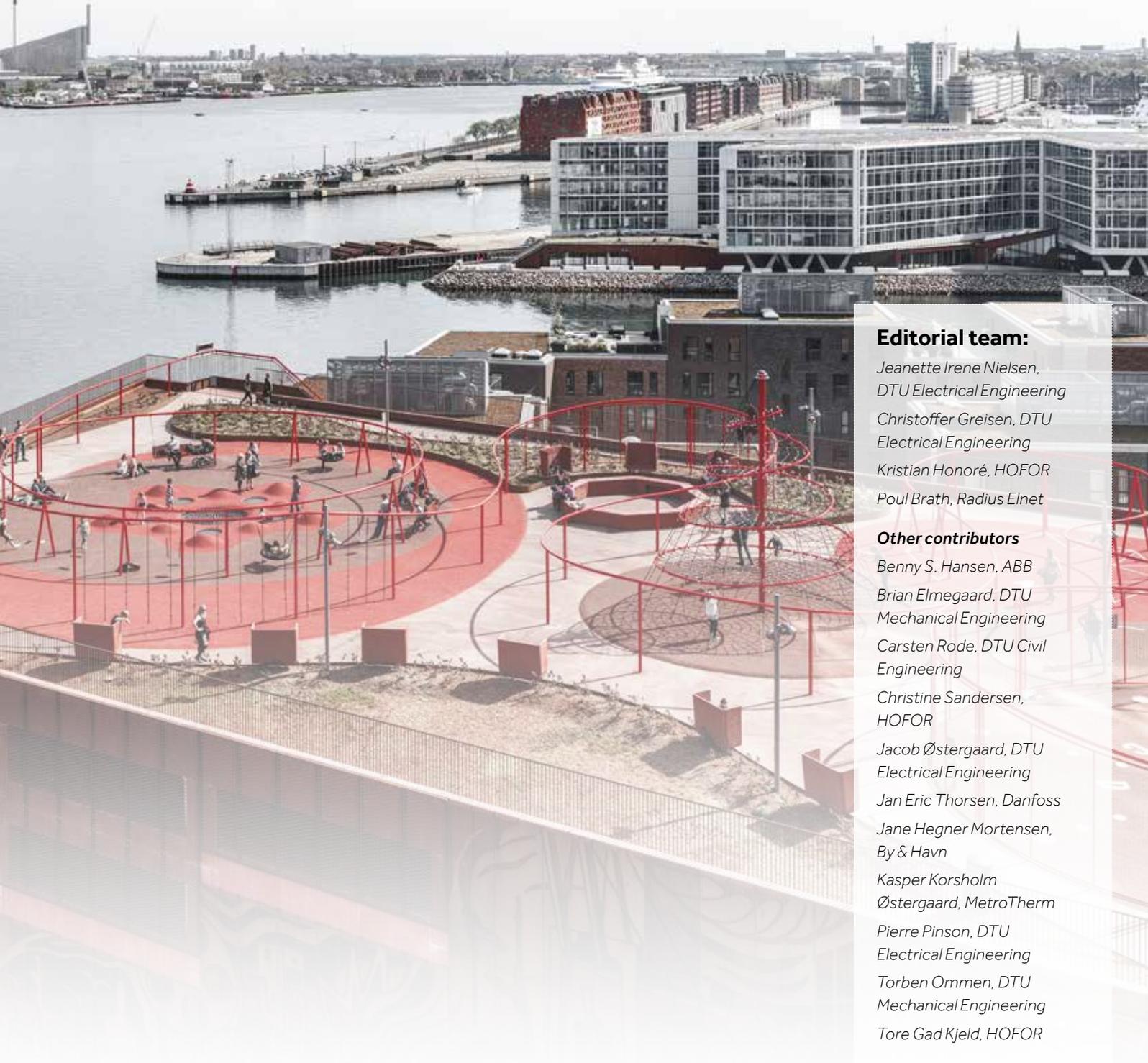
If, in connection with the construction itself, the data collection and control systems that we have worked with in EnergyLab Nordhavn are installed, the investment will in many cases be returned through the commissioning and optimization of the building operation, not least because digitization opens the possibility for a professionalization of this. For example, in some of the buildings we have worked with, we have seen that ventilation and heating systems are not designed for coordinated operation. However, this also points to an additional need for the qualification of the construction consultants and suppliers in understanding and managing the integrated function of the products and services they deliver—both within the individual buildings and in interaction with the surrounding city and neighbourhood.

28. THE DEVELOPMENT AND OPERATION OF THE SMART BUILDINGS CAN INVOLVE CUSTOMERS AND END-USERS MUCH MORE

Many energy consumers want to take the lead in the green transition and to participate and contribute actively to making the city carbon neutral. Therefore, the energy consumers we have worked with have rarely had problems sharing their data and participating in new management concepts, even if this has sometimes caused temporary inconveniences. It is important to study further how energy consumers and building management staff engage in the operation of smart cities and building systems, as well as studying how these techniques can provide better comfort and function for consumers. This will support energy consumers' understanding and continued confidence in the systems around them.

Endnotes

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