Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

ANNUAL REPORT 2017

CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH
The Research Council of Norway

VISION:

«Sustainable neighbourhoods with zero greenhouse gas emissions»

Editors: Annika Bremvåg, Arild Gustavsen and Anne Grete Hestnes

TABLE OF CONTENTS

ACTIVE PARTNERS AND RESEARCHERS FROM DAY ONE

Summary of the first year of operation

- By Arild Gustavsen, Centre director and professor

The Research Centre on Zero Emission Neighbourhoods in Smart Cities (ZEN Centre) started its research and development activities during the spring 2017; the contract with the Research Council of Norway was signed in February 2017. The ZEN Centre will enable the transition to a low carbon society by developing sustainable neighbourhoods with zero greenhouse gas emissions and engages in a broad set of activities to explore how to reach this vision.

Some examples of results from the first year include:

- A mapping of seven pilot projects around Norway with focus on challenges and opportunities with respect to achieving ZEN goals. The mapping will be used for identifying focus areas for the ZEN research.

- A sound definition of zero emission neighbourhoods is important when planning and developing the pilot projects of the ZEN Centre. Quite some time has therefore been used on this activity, with input from partners as well as researchers. The goal is to have an operational definition ready by early 2018.

- The software program eTransport has been re-established. eTransport will be a key tool for analyzing the operation and the further development of local energy systems from a socio-economic perspective. Further, a specific plan for a study of the European power market has been developed. This plan will provide a scientific basis for ZEN's assessment of the environmental benefits of local energy solutions.

- Researchers have developed a simple tool able to predict the expected hourly profiles of electric and thermal energy demand in a neighbourhood based on very few inputs: the outdoor temperature, the floor area of different building types, and their level of performance (normal or energy efficient). This tool can be used as input to planning of energy systems in new neighbourhoods.

- Laboratory experiments have been planned together with four ZEN partners. In one experiment the thermal performance of wooden studs with embedded insulation and wood fiber insulation is measured under different moisture conditions, aiming at robust building assemblies with lower embodied emissions. Another experiment will look at heat storage properties of different materials in two comparable rooms (in the ZEB Test Cell Lab). This will be input to the work on responsive buildings.

A core research team was ready from the start; recruitment of additional resources, PhD candidates, and postdocs connected to the Centre has taken some time. A communication advisor and coordinator was hired in September 2017, initiating the work on a communication strategy for the Centre. An EU project developer, an executive officer, and an adjunct professor have also been hired. PhD candidates and postdocs were hired throughout the first period, and at the end of 2017 nine PhD candidates and one post doc were working within the Centre. There was a significant number of applicants for all positions, proving that the Centre deals with relevant and state-of-the-art problems.

Four ZEN Board meetings and sixteen partner workshops have been organized to get input on ongoing and new activities and to allow the partners to get to know each other better. The meetings addressed wide topics, such as the "ZEN definition", as well as more focused topics, such as "Tools for planning of local energy systems". The partners and researchers have shown great enthusiasm in the various events.

Further, innovation and communication committees involving both research and user partner representatives have been established; a communication strategy and an innovation strategy have been developed. Development of an innovation culture and a methodology for the registration and measurement of the Centre's innovations will be important in 2018.

ZEN researchers participate at international conferences and collaborate extensively internationally, e.g. in various EU and IEA projects. The ZEN Centre is already engaged in exchange of researchers (incoming and outgoing) with international partners.

Overall, there is good progress, and a good foundation has been laid for the work to be done in the years to come.

THE START ON A JOURNEY TOWARDS ZERO EMISSION NEIGHBOURHOODS IN SMART CITIES

- By Rune Stene, chairman of the ZEN Research Centre and Director Skanska Technology

One year back we all signed the consortium agreement, committing to the goal of zero emission neighbourhoods in smart cities. The society has put a lot of trust in us – that we are the right companies, research institutions, and municipalities to lead the way towards a smart and carbon free future.

We have spent the first year establishing the centre with administration and PhDs, getting the partners involved and agreeing about the next two years of work. A great number of workshops has been held to investigate the research questions closer, to establish relations, and to better understand each other's competences and potentials.

Our pilots are developing, and the industry partners are starting to position their expertise to future deliveries. In order to increase the motivation and opportunities for each partner to activate their skills and competencies, a number of cases will be introduced as an arena for partner innovation. Results and findings from these cases will be of high importance for the pilots in the years to come. By creating this arena we also expect to lever interaction and collaboration between the partners and to realize impact as we go.

There is a long way to go, with several years of research, problem solving, and decision making, and to reach our common goal we need every partner to engage.

Get involved – get impact!

Centre Board
Tonje Frydenlund, Snøhetta
Partow P. Henriksen, SINTEF
Rakel Hunstad, Bodø municipality
Thomas Løkken, Hunton
Synnøve L. Sandberg, Statsbygg
Fredrik Shetelig, NTNU
Rune Stene, Skanska Norway

OVERALL GOALS AND RESEARCH PLAN

BACKGROUND

In 2010 buildings accounted for 32% of total global final energy use, 19% of energy-related Greenhouse gas (GHG) emissions (including electricity-related), and approximately one-third of black carbon emissions.[1] Improving the energy performance of the building stock is critical[2] and more cost-effective and environment-friendly than extending capacity in the energy supply system[3]. Energy security in the IEA countries is improving with increased energy efficiency, and CO_2-emissions are reduced[4]. Flexibility in buildings' energy use is needed to accommodate the further integration of varying renewable power generation in Europe.

Focusing solely on individual buildings can lead to suboptimal solutions when aiming for a zero emission target due to high power peaks and fast load fluctuations, failing to achieve synergy effects between energy consumption and production. For some buildings it may not even be possible to achieve the zero energy or emissions targets, either because energy demand cannot be reduced sufficiently, such as in building renovation under architectural constraints, or due to a lack of access to renewable energy on-site or near-by. Additionally, to achieve high renewable energy shares in the generation mix, large-scale and centralized resources for generation and storage need to be supported by small-scale and distributed resources.

Energy distribution grids in Norway are designed and dimensioned to supply the bulk of demand. In many areas the grid is rather weak[5] and sensitive to bidirectional power flows (from distributed generation) and large step-changes in consumption (e.g. from fast-charging stations for electric vehicles). This makes development of well-functioning local solutions crucial. For electricity, distributed energy resources (DER) need to be locally optimized within the bottlenecks of the distribution grid. For thermal energy, local, smart thermal energy grids need to be developed concurrently with the renovation and densification of urban settlements[6,7].

OVERALL GOALS

The Research Centre on Zero Emission Neighbourhoods in Smart Cities (ZEN Centre) will enable the transition to a low carbon society by developing sustainable neighbourhoods with zero greenhouse gas emissions. The ZEN Centre will speed up de-carbonization of the building stock (existing and new), use more renewable energy sources, and create positive synergies among the building stock, energy, ICT and mobility systems, and citizens.

The zero emission neighbourhoods and communities should ensure optimal energy use and be good places for people to live and work. This requires continued and increased attention to reduction of GHG emissions, increased production of renewable energy, and energy efficiency and flexibility, while simultaneously developing the quality of the buildings and communities in which people spend their daily lives and empowering citizens and stakeholders by effective ICT services that provide real-time intelligence and understanding of energy, mobility, and people flows.

RESEARCH PLAN

The ZEN Centre delivers benefits for Norwegian and international society through it's new, strategic cooperation between the public partners, the building and energy sectors, and will advance the state of the art in six areas/work packages needed to speed up the transition to a low carbon society (Figure 1). Multidisciplinary collaboration between areas is key to addressing the overall goal.

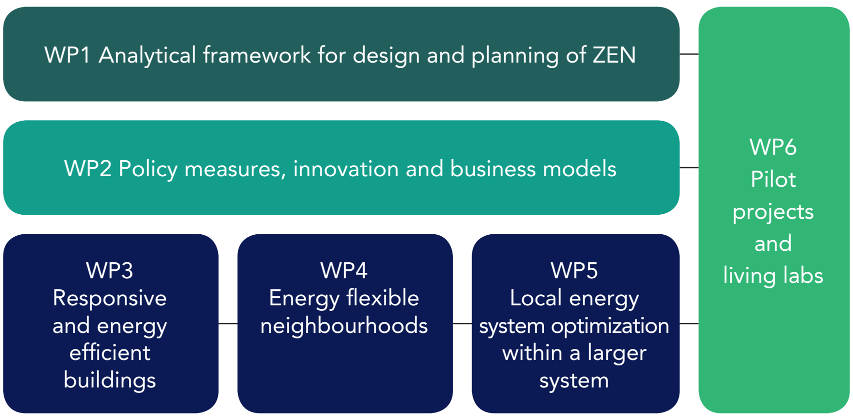


Figure 1: The six work packages of ZEN Centre.

Some of the main tasks carried out in 2017 are listed below.

WORK PACKAGE 1 – ANALYTICAL FRAMEWORK FOR DESIGN AND PLANNING OF ZEN

Goal: Develop neighbourhood design and planning instruments, integrating science-based knowledge on greenhouse gas emissions.

- Establish a set of definitions and key performance indicators (KPI) for ZEN.
- Develop a data management plan to collect, structure, and analyze KPI data.
- Identify, evaluate, and develop modeling principles and methods for consistent use of LCA in ZEN.
- Develop a framework for ZEN scenario analysis with dynamic models linking demand, building stock, and flows of energy and GHG emissions for ZEN concepts to examine aggregated LCA effects when expanding from the building to the neighbourhood scale.
- Analyze which design and planning instruments (analogue, digital, or other) can support design of ZEN Living Labs in the best holistic manner.
- Investigate how 3D visualization can be used as a means to involve stakeholders in the design, planning, and management of ZEN Living Labs.

WORK PACKAGE 2 – POLICY MEASURES, INNOVATION, AND BUSINESS MODELS

Goal: Create new business models, roles, and services that address the lack of flexibility towards markets and catalyze the development of innovations for broader public use; this includes studies of political instruments and market design.

- Study markets, instruments, and other public incentives, including regulation, with an eye to ZEN relevance.
- Study how new markets and business models promote zero emission neighbourhoods and how they can be implemented in models.
- Map state-of-the-art literature on public-private collaboration and identify both successful and less successful cases of public-private cooperation in the area of sustainability and in particular initiatives geared towards zero-emission objectives.
- Map the state-of-the-art literature on possible systems for governance of public-private cooperation at different levels (national, regional, local), including incentive and market systems and sustainable business models (sharing rewards and risks).
- Contribute to the development of an innovation strategy for ZEN.

WORK PACKAGE 3 – RESPONSIVE AND ENERGY EFFICIENT BUILDINGS

Goal: Create cost effective, resource and energy efficient buildings by developing low carbon technologies and construction systems based on lifecycle design strategies.

- To investigate how LCA principles can be used in the design of buildings structures to reduce emissions and enhance flexibility.
- To investigate solutions for heating, ventilation, and cooling of buildings that have lower energy use than existing systems. The solutions should tolerate variations in thermal and/or electric energy supply, have low embodied energy in itself, and secure good indoor environment quality at reasonable costs.
- Analyze the potential of and criteria for use of ventilative heating and cooling in new buildings and for upgrading of existing buildings.
- Mapping and analysis of existing responsive and energy flexible buildings. Develop a definition of the concept "Responsive buildings".

WORK PACKAGE 4 – ENERGY FLEXIBLE NEIGHBOURHOODS

Develop technologies and solutions for design and operation of energy flexible neighbourhoods.

- Survey which pilot projects will develop or use thermal networks (in Norwegian "fjernvarme" or "nærvarme") for heating and cooling distribution, and what technologies are relevant.
- Survey options and costs for introducing hydronic heating (and cooling) in new and renovated buildings.
- Present the state-of-the-art for electric vehicle (EV) smart charging systems, including fast charging stations. Investigate the opportunities for interaction between photovoltaic (PV) and EV charging in buildings and neighbourhoods, including additional stationery batteries.

- Propose a definition of an "energy flexible neighbourhood" that shall be useful for the needs and purposes of the ZEN pilots.
- Collect existing and new data of thermal and electric hourly load profiles for different types of buildings (house, apartment, office, school, etc.), develop a methodology for defining statistically representative load profiles, and define a methodology for aggregation to the neighbourhood scale.

WORK PACKAGE 5 – LOCAL ENERGY SYSTEM OPTIMIZATION WITHIN A LARGER SYSTEM

Goal: Develop a decision-support tool for optimization of local energy systems and their interaction with the larger system.

- Update and make the software tool eTransport fully functional, with a new user-interface, and identify the first steps for further developments in light of needs within ZEN.
- Explore which existing software tools can be used for socio-economic optimal expansion planning of local energy systems.
- Develop a strategy for how to carry out power system analysis and assessment of environmental impacts within ZEN.

WORK PACKAGE 6 – PILOT PROJECTS AND LIVING LABS

Goal: Create and manage a series of neighbourhood-scale pilot projects and living labs which will act as innovation hubs and testing grounds for the solutions developed in the Centre. The pilot projects are Furuset in Oslo, Fornebu in Bærum, Campus NTNU and Sluppen in Trondheim, NRK-site in Steinkjer, Ydalir in Elverum, Campus Evenstad, NyBy Bodø, and Zero Village Bergen. All together, the pilot projects encompass an area of more than 1 million m^2 and more than 30 000 inhabitants.

- Description of ZEN pilot projects with respect to ambition levels, KPIs, definitions, and applied strategies, processes, tools, technologies, and lessons learned.
- Describe what should be the criteria for each of the pilot building projects (in cooperation with Work Package 1 and other WPs).
- Support planning and development of pilot projects. This activity includes participation in the planning, design, and evaluation of pilot building projects, to ensure the relations to the goals and other activities of the ZEN Centre.
- Map, compare, and analyze relevant existing urban living labs.
- Develop ideas for living lab activities that can contribute positively to the pilot projects and identify the most promising ones.
- Describe a realistic experimental design for the first two living labs.

1 IPCC (2014). Climate Change: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmenta Panel on Climate Change.
2 European Union (2010). Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (EPBD).
3 McKinsey & Company (2010). Impact of the financial crisis on carbon economics: Version 2.1 of the global greenhouse gas abatement cost curve.
4 IEA (2015b). IEA energy efficiency market report 2015; Market trends and medium-term prospects.
5 Korpås, M. (2004). Distributed Energy Systems with Wind Power and Energy Storage, PhD thesis, NTNU.
6 Lund et al. (2010). The role of district heating in future renewable energy systems, *Energy*, Vol. 35, pp. 1381-90.
7 Connolly et al (2013). Smart energy systems: holistic and integrated energy systems for the era of 100% renewable energy. Denmark: Aalborg University.

ORGANISATION OF THE ZEN RESEARCH CENTRE

The ZEN Research Centre is a research centre for environmentally friendly energy and was established in 2017 by the Research Council of Norway. It is hosted by the Norwegian University of Science and Technology and organized as a joint NTNU/SINTEF unit.

The ZEN Research Centre has a General Assembly and an Executive Board. The Executive Board (EB) is responsible for the quality and progress of the research activities towards the Research Council of Norway and for the allocation of funds to the various activities. The user partners have majority and the Chair of the EB. The General Assembly (GA) includes a representative from each of the partners. The GA gives guidance to the EB in their decision-making on major project management issues and approval of the semi-annual implementation plans.

The Centre also has a Scientific Committee (SC) with representatives from leading international institutes and universities to ensure international relevance and quality of the work performed. The SC consists of selected representatives from the Centre's international partners, selected to span the research areas of the Centre.

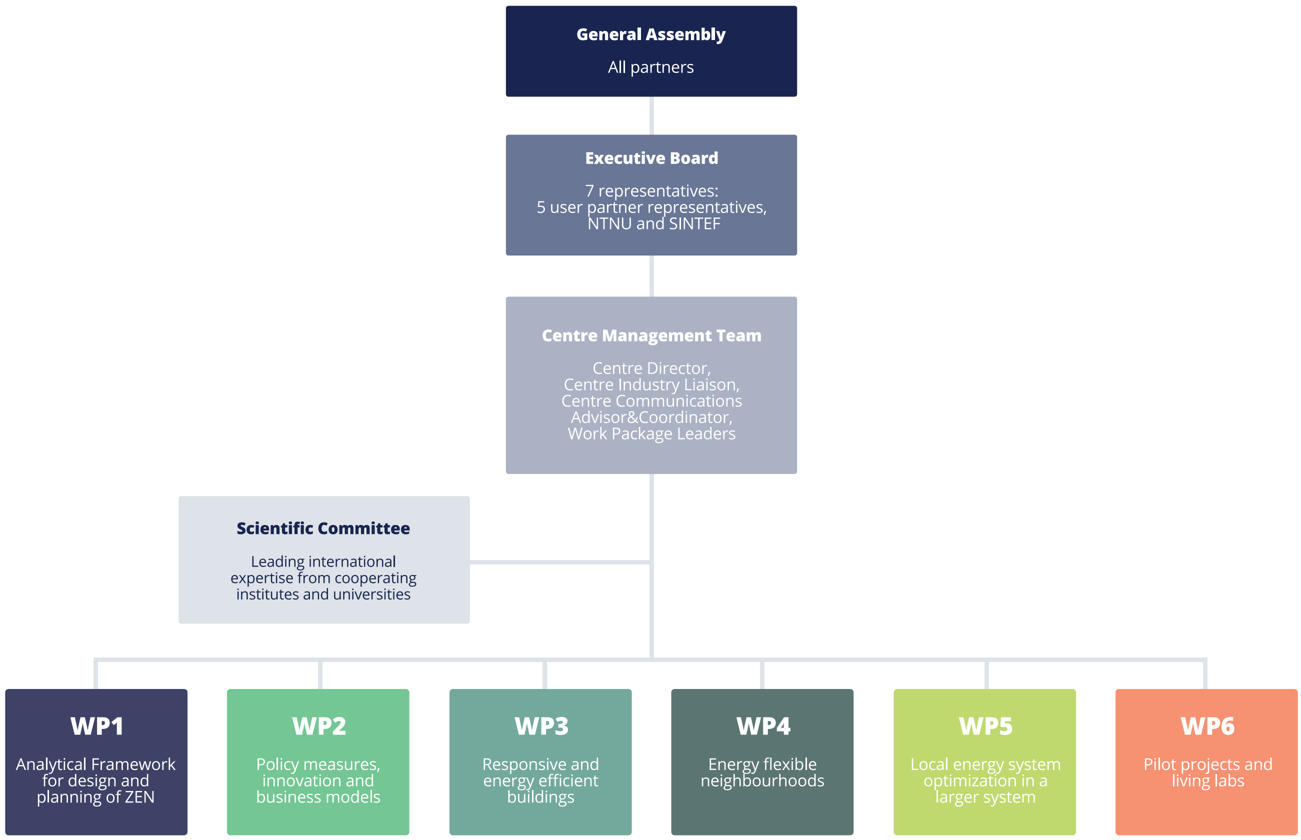


Figure 2: Organisational structure of the ZEN Research Centre.

OUR PARTNERS

The ZEN Research Centre's partners cover the entire value chain and include representatives from municipal and regional governments, property owners, developers, consultants and architects, ICT companies, contractors, energy companies, manufacturers of materials and products and governmental organisations.

The Norwegian University of Science and Technology (NTNU) is the host and leads the Centre together with SINTEF Building and Infrastructure and SINTEF Energy.

PRIVATE SECTOR

PUBLIC SECTOR

RESEARCH AND EDUCATION

Note: Numascale was a partner in the ZEN Research Centre until the end of 2017.
Bærum Municipality and Statkraft Varme joined the ZEN Research Centre in 2018.

SNAPSHOTS OF OUR RESEARCH

Bodø municipality: Stakeholder engagement platform and ZEN planning tool

- By Simon Flack, Chief Digital Officer, City Engineering, Bodø municipality

Bodø municipality has been working with Urbanetic Pte Ltd (Singapore) to develop a modern urban planning tool for designing and managing sustainable green cities.

Urbanetics's Fabric platform is a computational and data management tool for solving real world problems posed by the rapid pace of urbanisation and climate change.

The tool gives urban planners and stakeholders the ability to design for sustainability and significantly improve the understanding of the built environment with the complex and dynamic nature of interrelationships of its components.

Fabric allows high-performance interactive visualization of city or precinct data in 3D. This allows real estate developers, planners, and city councils to make better decisions by simulating scenarios and testing the impact of choices in the present and future.

Following the design concept of "serious play", the software takes away the complexity traditionally associated with computer-aided design software, transparently managing and integrating data from different sources. The user interface focuses on the application of ideas to deliver performance outcomes of design and planning decisions.

The current focus is on the analysis, modelling, and visualisation of land use planning and energy.

Bodø municipality aims at using the platform to create a digital-twin of the city via the integration of Fabric with the city's IoT platform. This will enable access to real-time sensor data and allow Fabrics analysis engine to perform calculations and send alerts or control-signals as events are occurring.

One of the main goals of the project is to incorporate future ZEN metrics and key performance indicators (KPIs) directly into the planning tools. This will give urban planners, architects, and communities the tools needed to design climate neutral neighbourhoods and greener cities.

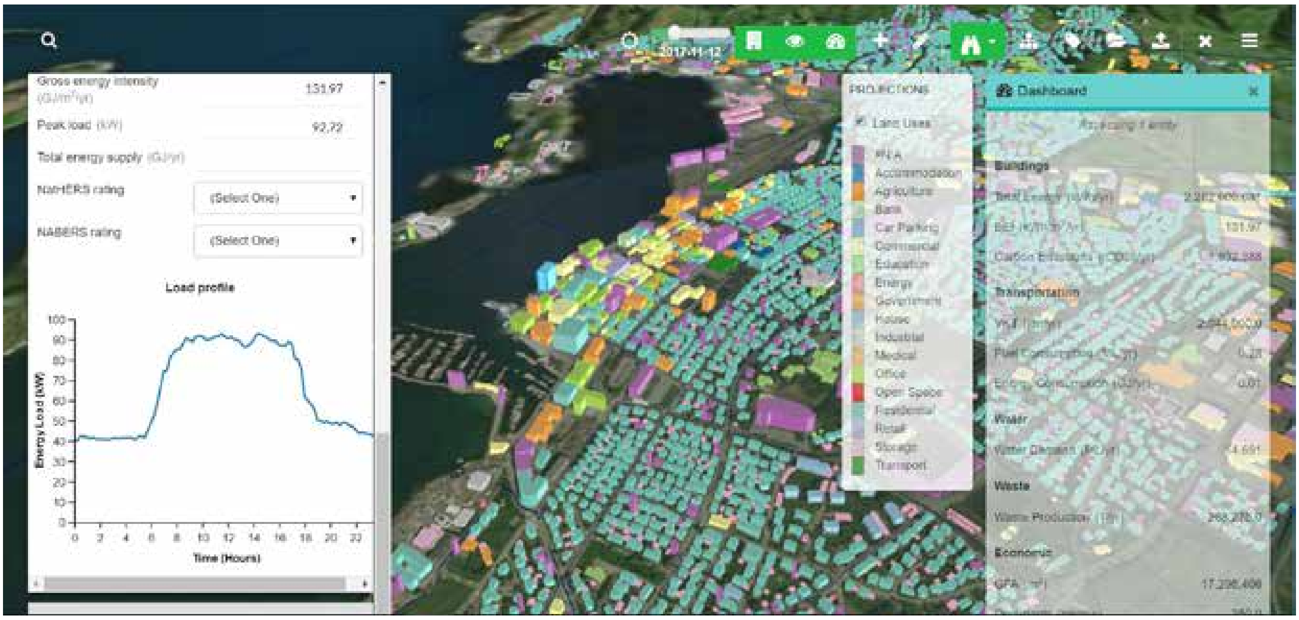


Figure 3: Screenshot of Urbanetic Fabric building and land-use analysis, Bodø municipality.

Low temperature district heating: How low can we go in supplying residential neighbourhoods in Norway?

- By Igor Sartori, leader of work package 4

Supplying the heat demand of Zero Emission Neighbourhoods (ZEN) with 4th generation district heating (4DH) solutions allows for two strategies. One strategy is to connect the buildings with higher temperature requirements to the supply pipe (e.g. for a pre-existing DH system with high temperature) and the most efficient buildings to the return pipe. The other one is to have a low temperature DH system dimensioned to supply the efficient buildings and to use local boosters (at building level), e.g. heat pumps or boilers, in the buildings with higher temperature requirements. Either way, the fundamental constraint is how low the heating supply temperature can be in different building types. In turn, this will determine the minimum DH supply temperature for each building type in the ZEN.

We have performed an analysis of a typical row house from the seventies, considering four levels of energy performance: original, new windows, standard renovation, and ambitious renovation. The building is simulated using the program IDA Indoor Climate and Energy (IDA ICE). The study focuses on how the properties of the thermal envelope and the heat emission system (radiators) affect the indoor comfort and the minimum supply temperature from the district heating.

The results show that lowering the grid temperatures cannot be done without reservation:

- For the non-renovated buildings, a local booster is needed to maintain the comfort in the coldest part of the year;
- For renovated buildings, depending on the extent of the renovation, the comfort may be achieved even for 100% of the time. However, local boosters may still be desirable to avoid overly expensive oversizing of the DH network;
- Finally, for the most ambitious renovation standard, the demands for heating would be very low throughout the year, while the peak demand would still be high in the coldest days of the year.

Reference:

Alonso, M.J. and Sartori, I. (2018) How low can the heating supply temperature in district heating be in networks with non-renovated buildings in Norway? Cold Climate HVAC 2018, 12-15 Mar., Kiruna, SE.

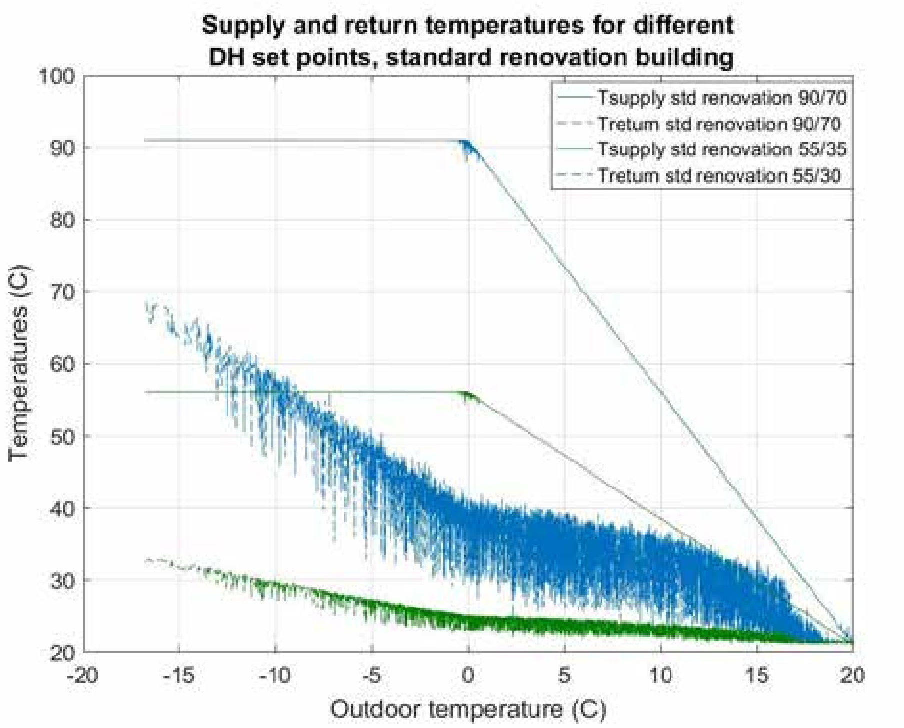


Figure 4: Temperatures in supply and return after the standard renovation.

eTransport: A flexible tool for planning local energy systems

- By Ove Wolfgang, leader of work package 5

"eTransport" is a flexible tool for planning of local energy systems that is developed by SINTEF Energy Research. Through its full-graphical user interface (cf. Figure 5) the tool gives a picture of a geographical confined energy system (e.g. a part of a city) with respect to costs, environment, and utilization of resources. The tool can combine many different technological components and energy types in one integrated analysis. It shows how decisions regarding one energy carrier impact solutions for other energy carriers in the same area, also including the interaction with the surrounding energy supply system.

The main goal for the model is to find the optimal investment strategy in a planning horizon of e.g. 30 years. The model is divided into an operational module and an investment module. In the operational module there are component libraries with sub-modules for all the energy carriers and corresponding technologies. The time-horizon for operational planning is relatively short (1 to 3 days), with a time-step length of 1 hour, for which it calculates the cost-minimization operation.

The full problem is solved by using a combination of linear programming (LP), mixed integer programming (MIP), and dynamic programming (DP) – or stochastic dynamic programming (SDP). These are traditional methods within grid planning. However, there are few similar tools that can calculate an optimal strategy for system development taking into account several energy carriers. A time-resolution of one hour cannot be applied in a planning horizon of 30 years. The investment analysis is thus decoupled from the operation analysis, and the latter is solved many times for different seasons, stochastic realizations, years, and possible energy system designs. Annual operational costs are then forwarded to the investment analysis that calculates the expansion path that minimizes discounted costs in the whole planning period.

Two types of uncertainties are included in the model: within-year uncertainty, and between-years uncertainty.

eTransport is built in a modular structure that makes it easy to add new functionalities. It uses MS Visio (user interface), AMPL (mathematical programming language) CPLEX/COIN (solver), and C++ (investment analysis and administration).

eTransport was originally developed through Research Council projects and bilateral projects with industry. The methodology has become increasingly relevant because of the focus on local energy solutions, smart cities, and a large need for enhancements in the Norwegian distribution grid through increased peak loads. FME ZEN has made it possible to make the model operational again, and in WP5 we will develop it further and apply the model on ZEN pilots and cases.

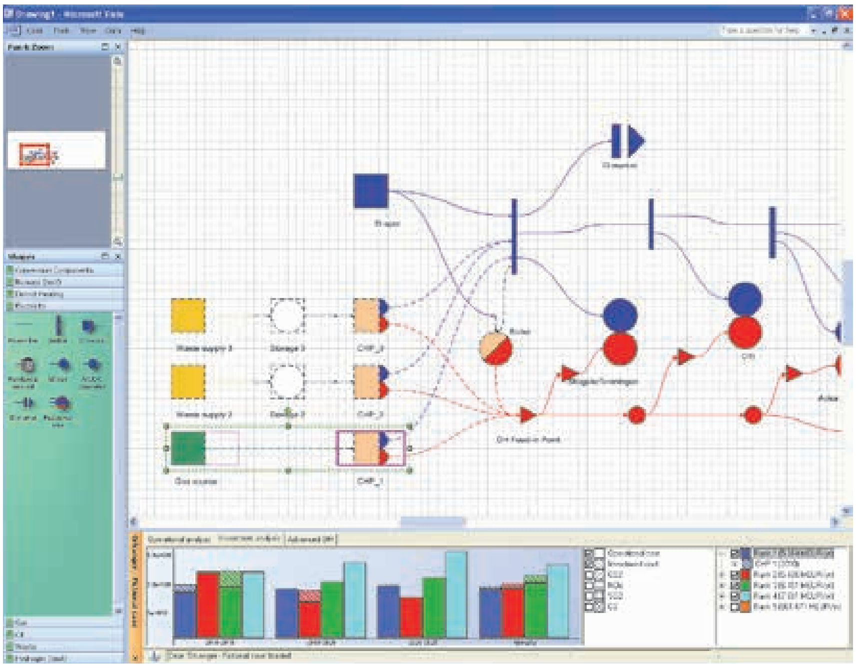


Figure 5: eTransport user interface.

Life-cycle assessment methodology for ZEN projects

- By Carine Lausselet, work package 1

How can life-cycle assessment (LCA) be framed to assess greenhouse gas (GHG) emissions of ZEN projects? How can we benchmark projects towards zero emissions?

The nexus of housing, energy, and mobility associated with human settlements is assessed by widening the scope from a single house to a neighbourhood scale. This task requires detailed expertise on the different neighbourhood elements and services provided, while at the same time having a holistic approach to set the different elements into perspective. By setting the different neighbourhood elements in their context, their individual contribution as well as their relative share to the neighbourhood can be assessed. This task requires good and regular communication with all ZEN partners and actors in order to best understand the environmental performance of ZEN projects.

LCA results give an overview of how various types of environmental impacts accumulate over the different life-cycle stages, providing a basis for identifying environmental bottlenecks of specific systems and for comparing a set of alternative scenarios with respect to environmental impacts. LCA is a methodology that is used extensively in the last decade to evaluate the environmental performance of buildings and that has recently started to be used also on the neighbourhood scale. Previous studies on the neighbourhood scale show the influence of material choices at the construction site, the carbon intensity of the energy mix, the mobility demand, and the influence of inhabitants' behaviour.

We have developed an LCA methodology framework to assess the impacts of buildings, mobility, and open spaces elements in a ZEN project, for different ZEN ambition levels (O, O-EQ, OM), see the table below. This is relevant because

	Buildings	Mobility	Open spaces
	Building type (single family house, terraces house,	Transport mode (train, bus, car, tram, bike etc)	Infrastructure, roads, parks, lighing
O	Operational energy use for heating and cooling	Operation of the cars for daily use	Operational energy use e.g. public lighting
EQ	Domestic hot water, fans and pumps, lighting, electrical appliances		
OM	Embodied emissions from materials production	Embodied emissions from materials production	Embodied emissions from materials production
COM			
COME			
COMPLETE			

Figure 6: Included elements and life cycle stages.

all such elements may be important impact drivers. To test and compare our model with previous studies, we analysed a ZEN project under different scenarios, see indicative results in the figure below. With scenario 1 as reference, scenario 2 shows the influence of different emission intensity assumptions in the operational phase of the building, while scenarios 3 and 4 show the potential positive or negative influence of the inhabitants by their use of energy, numbers of cars, and km driven. For more information and details, please consult a forthcoming report.[1]

Overall, we argue for the use of several performance metrics: On a neighbourhood scale, tons *CO_2-eq/year* will represent the total performance of the neighbourhood. On a scale referring to buildings and their associated infrastructure, *tons CO_2-eq/m²/year* will better depict the efficiency regarding use of energy and materials. On a scale referring to inhabitants and users, *tons CO_2-eq/capita/year* may better depict the characteristics of users, their behaviour and active choices, e.g. in mobility.

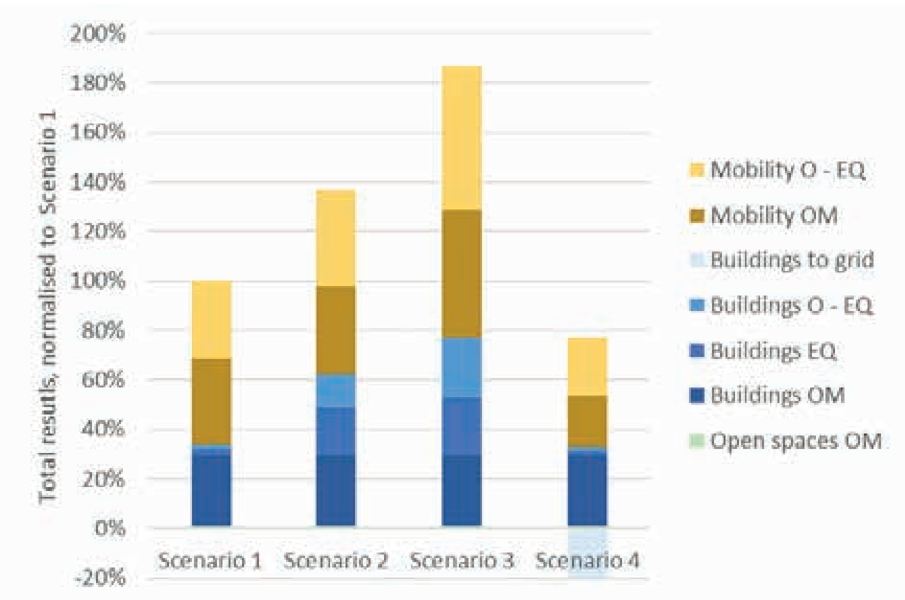


Figure 7: CO_2 emissions relative to Scenario 1.

[1] C. Lausselet et al.: LCA modelling principles and methods for zero emissions neighbourhoods. Forthcoming ZEN report, Deliverable D.1.2.1, 2018.

Parametric LCA for Zero Emission Neighbourhoods

- By Christofer Skaar, work package 3

DESIGN FOR ZERO EMISSIONS

The best time to reduce the environmental impact of a product, a building, or a neighbourhood is before it comes into existence. We have the greatest design freedom in the early design stage, allowing us to make major changes at minor costs. But this is also the stage where uncertainty is at its highest, and we have a nearly limitless number of design options. This makes the early design stage the most challenging for analyzing consequences and calculating the environmental impacts of our design options. Even for buildings, there is a lack of tools for the early design stages, and expanding our perspective to the neighbourhood level multiplies the complexity and brings us further into unchartered territories. This is where parametric approaches for zero emission design come into play.

PARAMETRIC LCA FOR BUILDINGS AND BUILDING COMPONENTS

A parametric life cycle assessment model (parametric LCA model) can contribute to better decision making. But the model must fit the research questions. As the statistician George Box stated: *All models are wrong, but some are useful.* The model must be adapted to the intended use. A tool developed in the Zero Emission Buildings Centre (ZEB) for building assessment provides a basis for developing parametric models that can be adapted to specific purposes. The ZEB tool has been applied to building components, for instance to evaluate carbon footprint consequences from moisture damage in tall timber facades. Here parametric damage scenarios were combined with probabilistic-based design methodology. The ZEB tool has also been used to compare different floor systems, taking into account specific performance requirements and using probability distributions to account for uncertainty of materials' carbon footprint in the design stage. At the building level, the tool has been applied both to new buildings and upgrading of existing buildings. For the upgrading, the tool was adapted to compare upgrading solutions and to identify the stakeholders, the materials, and the building components with the highest impact on the carbon footprint. Instead of developing one complex but generic tool to handle a large degree of variation, these examples instead show how one LCA tool can be adapted to numerous specific contexts. A goal in the ZEN Centre is to also apply this method to the neighbourhood level.

FROM BUILDINGS TO NEIGHBOURHOODS: THE NEED FOR PARAMETRIC DESIGN

In the context of ZEN, there are (at least) three paths for further developing parametric LCA models: i) analyzing

consequences of design choices across system levels, ii) developing parametric models for the manufacturing and building processes, and iii) including parametric models for use stage scenarios. The first provides insight into the consequences across the system levels shown in Figure 8, for example between building component and building and between building and neighbourhood. The second is going deeper into modules A1-A5 in Figure 8, for example mass customization of building components. The third is to use the models to develop scenarios for modules B1-B7 in Figure 8, for example use patterns and replacement patterns.

It is a challenging task to analyze and evaluate available options with this level of complexity. This challenge can be simplified using algorithms. Algorithms applied to parametric LCA models can be used both to generate options and to evaluate options. Parametric design with LCA can for example be used to find the best combination of building shape and material choice. Multi-criteria decision analysis (MCDA) can be used to identify the best solutions under uncertainty. Whichever path we follow, we see that with increased complexity there will also be an increased need for parametric models. These can support design processes and decision making in a life cycle perspective.

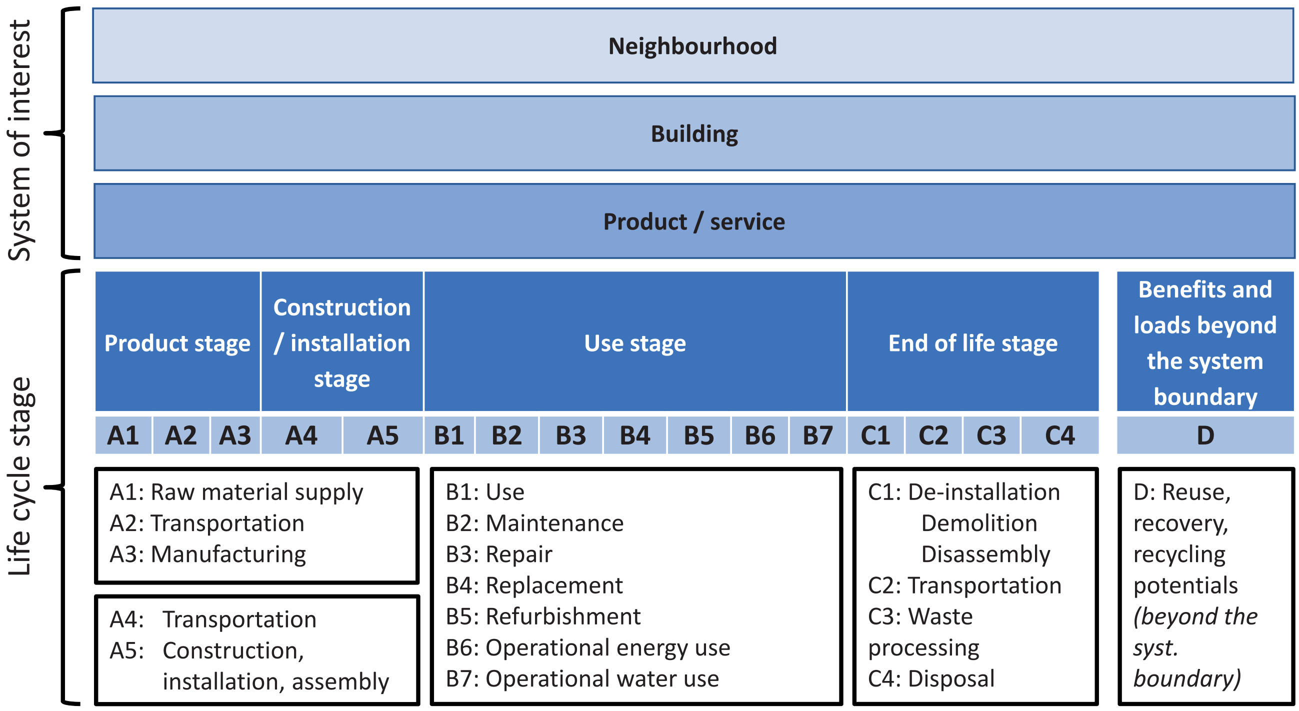


Figure 8: System of interest and life cycle stages (based on the EN 15804 standard)

How do responsive buildings contribute to Zero Emission Neighbourhoods?

- By Steinar Grynning, work package 3

ZERO EMISSION BUILDING DESIGN IN A BUILDING-SCALE PERSPECTIVE

Traditionally, low-, close-to-zero-, or zero-emission building design has focused on improving the energy performance of building envelopes, increasing building equipment efficiency [1], and harvesting renewable energy [2] for one building at a time.

Typically, the measures taken to increase the performance of building envelopes include the use of passive design solutions such as building shape optimization [3], efficient solar gain management, increased insulation levels, improved airtightness, and installing highly insulating windows [4,5]. The combination of these approaches with high-efficiency energy recovery systems and renewable energy harvesting technologies has allowed design teams to reach zero emission building goals [6,7].

However, user comfort and user interaction with the building might be compromised if the sole focus of the optimization is to reach a zero-emission balance. We have seen examples of building designs where energy savings to a large extent have taken precedence over user comfort and demands.

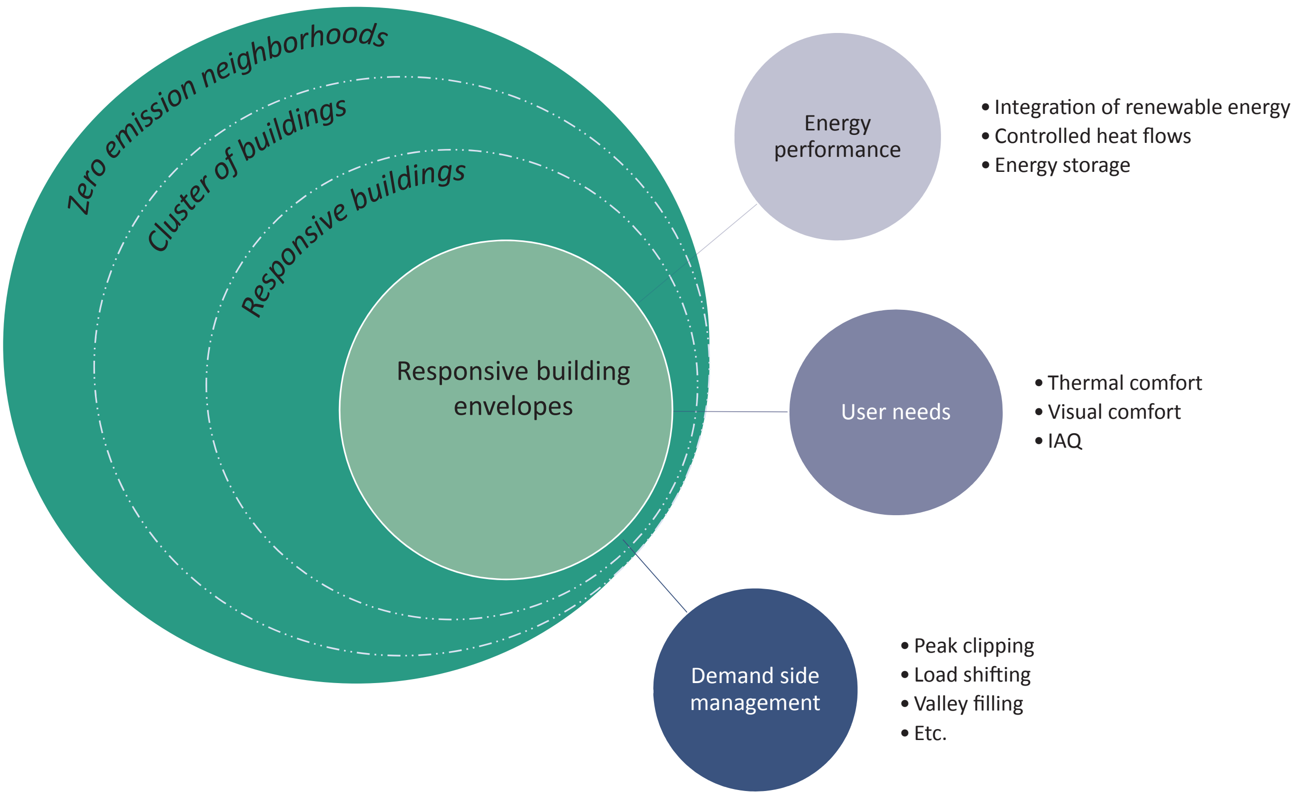


Figure 9: Responsive buildings, from envelopes to neighbourhoods. The blue bubbles give a preliminary indication as to what the goals of the responsiveness could be.

RESPONSIVE BUILDINGS DESIGN

Responsive building design, as a design-concept, is a promising approach which is nested in the idea of creating useful connections between the different functions or components of the building envelope, the various energy flows across it, the resources in the building's direct environment, and the operative goals of the building itself. This approach can yield results two-fold. The first is that it can provide a valuable tool in lowering the energy use and to improve indoor comfort for the occupants in the individual buildings. The second relates to interaction with other buildings in a grid.

THE WHOLE IS GREATER THAN THE SUM OF ITS PARTS

If one looks beyond the single building and starts to think about how this responsiveness can be used in interaction with other buildings, things get even more interesting. There is a saying in Norwegian; "sammen er vi sterke". The English equivalent would be that "The whole is greater than the sum of its parts". How can we apply this to buildings as well?

Different building categories have different use patterns. The differences between building types with their individual use patterns might influence optimization on a neighbourhood scale. When considering how and when an office building and a dwelling are used, this becomes obvious to most. The dwellings can be used as solar powered power-banks for the offices during the day when no one is at home but in the office working. During the afternoons and evenings the tides of power shifts direction, going from the offices to the dwellings. Hence, this way of thinking gives us a larger flexibility in terms of what "zero emission neighbourhood" is or can be. Every building might not need to be a zero-emission building. We can use the benefit of distributing loads over time and having a mosaic of buildings which individually may not have a zero-emission balance, but which reach it as a group. This allows for a larger degree of freedom compared to individual building design. Instead of making one hundred zero-emission buildings we can make one zero-emission neighbourhood.

Beside the technical goals, the esthetic expression of responsive design can even be used as an additional dimension to strengthen architectural concepts.

In order to take this work further, the ZEN Centre is carrying out a study with the aim to establish a common understanding and to establish a vocabulary of what a responsive building is in this context.

References:

[1] M. Justo Alonso, P. Liu, H.M. Mathisen, G. Ge, C. Simonson, "Review of heat/energy recovery exchangers for use in ZEBs in cold climate countries", *Building and Environment,* 84 ,228–237, 2015

[2] P.A. Torcellini, D.B. Crawley, "Understanding zero-energy buildings", *ASHRAE Journal*. 48, 2006.

[3] A. Okeil, "A holistic approach to energy efficient building forms", Energy and Buildings, 42, 1437–1444, 2010.

[4] E. Gratia, A. De Herde, "Design of low energy office buildings", Energy and Buildings, 35, 473–491, 2003.

[5] S.B. Sadineni, S. Madala, R.F. Boehm, "Passive building energy savings: A review of building envelope components", Renewable and Sustainable Energy Review, 15, 3617–3631, 2011.

[6] T.H. Dokka, T., et.al., "A zero emission concept analysis of a single family home", ZEB report 9, 2013.

[7] T.H. Dokka, et.al., "A zero emission concept analysis of an office building", ZEB report 8, 2013.

Stock-flow modelling of Zero Emission Neighbourhoods (ZEN)

- By Helge Brattebø, leader for work package 1 (from 15 March 2018)

How can we use dynamic stock-flow modelling to examine the long-term potentials for low energy use and zero greenhouse gas emissions of a ZEN project?

During recent years we have combined energy balance modelling of building typologies with dynamic stock-flow modelling of the national residential building stock.[1] This model was not tailored to study ZEN projects, where the local level analysis needs a different model structure and a more flexible and detailed data input strategy. Hence, in 2017 we developed a stock-flow model for this purpose and briefly tested it on two case studies; one hypothetical case inspired by Zero Village Bergen and one referring to the campus project at NTNU Gløshaugen that will soon be subject to a large-scale expansion (92 000 m^2) and renovation (45 000 m^2).[2]

Figure 10: Aerial view of Gløshaugen university campus. Photo: Erik Børseth.

[1] N. Sandberg et al., Energy and Buildings, 2016, 132, pp 141-153, and Sandberg et al., Energy and Buildings, 2017, 146, pp 220-232

[2] J. S. Næss et al.; Neighbourhood building stock model for long-term dynamic analysis for energy demand and GHG emissions. ZEN Report No. 1, deliverable D.1.2.2, 2018.

The new model offers a detailed analysis of changes in the neighbourhood building stock and includes hourly energy demand inputs calculated by computer simulations in IDA-ICE. Greenhouse gas (GHG) emissions can be estimated based on monthly or yearly CO_2 intensity profiles for the involved energy carriers, with reductions towards 2070 according to the assumptions one decides to make use of in the specific analysis.

For Gløshaugen as a case, empirical data showed that the energy use in the 46 buildings on campus today depends more on the functionality of the 300 000 m^2 heated floor area than on the age of the buildings. We identified 17 different floor area types, ranging from offices and laboratories to cafeterias and sports halls, and categorized these into seven floor area classes with similar energy characteristics. We added to this plans for new buildings in line with the NTNU Campus project. The main findings of the analysis suggest that the planned *new construction* might reach ZEN targets. However, strong efforts must be taken to compensate for and improve the *existing stock* if the whole neighbourhood is aiming to reach ZEN targets. A few results from the case study are given in Figures 11 and 12; the hourly profile of district heating capacity [W] over the year in 2017 (Figure 11) and the estimated aggregated demand for different energy carriers [10^{10} Wh] towards 2070 (Figure 12).

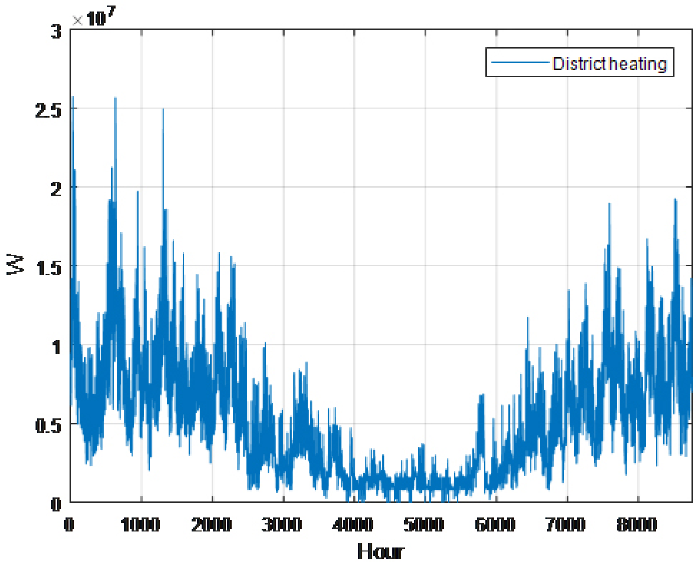


Figure 11: Estimated delivered energy from district heating, Gløshaugen baseline 2017.

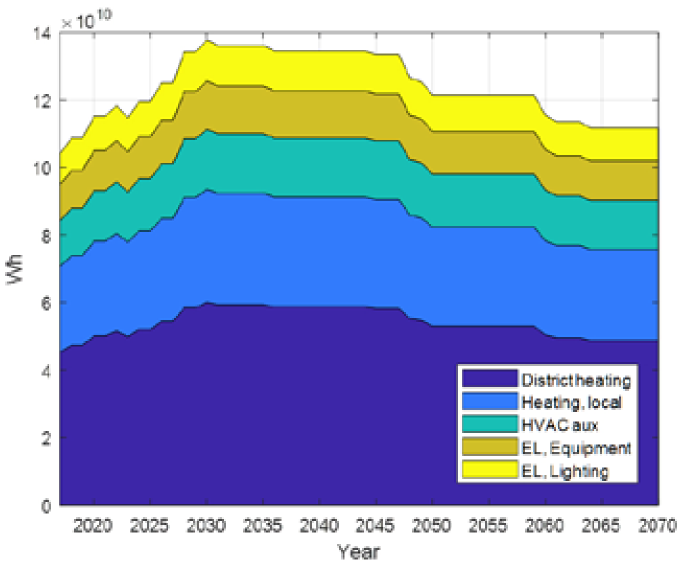


Figure 12: Estimated yearly delivered energy per energy carrier to Gløshaugen.

A small town invests in its zero emission vision

- By Hanne Bjugstad, Elverum Vekst

2017 has been an important year for the Ydalir development. During this year, we moved from the planning process to selling plots and from architectual plans to real estate developers with commercial interests. Buying a plot in Ydalir involves demands and possibilities towards reaching a zero emission neighbourhood. Over the next ten to fifteen years, Ydalir will develop into a new living district in Elverum. However, the idea of transforming the old gravel depot to a living area was already born in 2005.

A BRAND NEW WAY OF THINKING

Ydalir is a ZEN neighbourhood under construction in Elverum, Hedmark. Elverum Tomteselskap, a company owned by Elverum municipality, is responsible for designing and planning the development and for selling plots to real estate developers.

This has been the company's task since 1965, so they should be capable of accomplishing it in Ydalir as well. But, in 2016, Elverum Tomteselskap and Elverum municipality became members of the Research Centre on Zero Emission Neighbourhoods, and Ydalir became a pilot project in the centre. With this came a brand new way of thinking, where they could not lean on experience to the same extent as earlier, and where organization and cooperation became just as important as the physical construction of the area.

THE IMPORTANCE OF ENOVA, AND YDALIR'S MASTERPLAN

In 2016, Elverum Tomteselskap was granted support from ENOVA for a concept study. The goal was to learn how to make Ydalir "ZEN", and six workshops were arranged with participants with different perspectives. Everyone, from architects to the region's CEO of public transport, gave lectures, and several of ZEN's regional partners were invited to participate in the process.

Elverum Tomteselskap comprises 3,3 man-years, and Ydalir is only one of the projects the company runs. This makes it impossible to be constantly updated on everything from the latest development within solar power to driverless transport, and the network created in the ENOVA-supported process has been important in order to make Ydalir a "ZEN" using today's technology. The results from the concept study are summarized in a report to ENOVA and Ydalir's masterplan, where the demands for developers who buy plots in the area are included. These are regulated by a private law agreement following the sale, a solution that makes it possible for Elverum Tomteselskap to lead the development of Ydalir towards the research centre's ambitions.

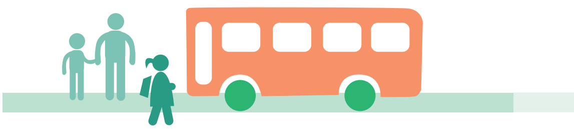
In Ydalir, the municipality is building a new kindergarten, a primary school, and a sports hall. Cooperation between the administration in Elverum municipality and Elverum Tomteselskap is crucial for Ydalir's success, and the fact that these buildings are already under construction is important for the real estate developer's interest in the area.

A SMALL TOWN DARES TO INVEST IN ITS VISION

Maybe the most important aspect of Ydalir is that the zero emission neighbourhood is not being built in the capital or in another big city- it happens in a small town that is comparable to a lot of places in Norway.

Figure 13: Feasibility study of a public space in ZEN pilot project Ydalir. Illustration by tegn_3.

Elverum is trying something with Ydalir that other municipalities and towns of that size do not dare to do– with all the risks and possibilities that follow. The goal is to create a good place to live, while the neighbourhood works as an example on the road to a zero emission society. At the time of writing, three local contractors have bought plots in Ydalir even though the way of building include some elements that are new and maybe unknown for them. But they can and dare to change.



ZEB Living Lab: "Grey-box modelling" to study energy flexibility

- By Igor Sartori, leader of work package 4

Model predictive control (MPC) of heating systems in buildings is a technique that has gained increasing attention over the last years. MPC is seen as a promising tool to deploy the flexibility of the building heat demand because it allows keeping indoor comfort while reducing the peak load and consuming energy at the right time, i.e. when it is cheaper and/or greener. Both the building owners and the energy grids would benefit from this approach.

However, a central aspect and the most demanding tasks in the development of such a control is the identification of a simple and robust model of the building's thermal dynamics; a model suitable to be used in real-time control. Furthermore, stochastic modelling is needed to explicitly account for the uncertainties.

Experiments have been carried out to identify the thermal dynamics of a super-insulated building, the ZEB Living Lab at NTNU Gløshaugen campus in Trondheim. The modelling approach adopted is known as "grey-box modelling", where simplified physical models of the buildings are proposed and their parameters identified from experimental data. The model investigated was a first order model with three parameters to be identified: heat loss to ambient, heat capacity, and solar gain. Two software packages, CTSM-R and the MATLAB System Identification toolbox, were compared. These were found to attain similar performances.

Figure 14: ZEB living lab on Gløshaugen campus. Photo: NTNU.

One week of data metering under pseudo random binary sequences (PRBS) excitation with an electric radiator allowed identifying this single zone model. This model represented the main thermal dynamics of the building-averaged temperature quite well. Further work should investigate more detailed dynamical models, e.g. second or higher order models, and assess their performance when operating the heating system using MPC.

The dataset collected from three experiment periods, with samplings of 15 minutes resolution, is open for research purposes.

Reference:

Vogler-Finck, O.J.C., Clauss, J., Georges, L., Sartori, I. and Wisniewski, R. (2018) Inverse model identification of the thermal dynamics of a Norwegian zero emission house, Cold Climate HVAC 2018, 12-15 Mar., Kiruna, SE.

Don’t forget the total energy system costs!

- By Jon Iver Bakken, Energi Norge

The development of critical infrastructure for electricity and district heating are capital-intensive investments with a long economic life. For high voltage levels there is a very long planning horizon, and one must also consider uncertainty with respect to the future need for capacity. The same considerations are necessary for grid developments at lower voltage levels, but to a lesser extent and with a closer planning horizon. The same applies to district heating.

All investments and developments in such infrastructures for electricity or heat must be dimensioned in such a way that the capacity is higher than the highest possible peak load that can occur in the economic life of the installations, with a considerable safety margin. For such critical infrastructures it is also a requirement that they are very reliable and stable, and there are strong efforts to fulfill this using long experience (good engineering practice) and well-designed regulation.

When considering the flexibility and energy system costs of ZEN pilots that are connected to the electricity grid or a district heating grid, (the surrounding energy system), one needs to consider the full costs of supplying sufficient renewable energy (kWh) and capacity to handle the peak loads (kW) within the pilot. This will be the sum of costs for energy infrastructure operation and investments within the pilot plus the costs in the surrounding energy system (grid and production) that occurs because of the needs of the pilot. A natural goal for the pilot must be to test and demonstrate solutions one believes can give a permanent reduction in the total costs relative to a situation without local energy solutions (business-as-usual solution). Examples of this can be increased end-user flexibility (smart load shifting), local generation/storage, or other, new technologies.

In order for such local solutions to provide a real saving in the total system costs, it is a premise from the energy industry’s perspective that local energy solutions can be trusted 100 % to provide the planned reduction in needed capacity and that they have an economic life of at least 30-60 years. If this is the case, the capacity in the surrounding energy system can be scaled down accordingly. If this is not the case, one can easily, in a socio-economic perspective, end up in a situation where the costs for the surrounding energy system will be as in a business-as-usual situation, and hence result in higher total costs and a correspondingly lower value of the local energy solutions.

The real test for this is the pilot’s need for capacity on the ”coldest day” during the winter – the hours that normally dimension the need for capacity in the electricity grid and the district heating system. This must be a central key performance indicator within the ZEN work as well as a key co-operation topic between the ZEN Centre and the energy industry.

Figure 15: An important aim of local energy solutions in a zero emission neighbourhood should be to reduce the overall energy system costs (included investment costs in the grid and district heating system). Source: 3M, Smart Grid: http://solutions.3m.com/wps/portal/3M/en_EU/SmartGrid/EU-Smart-Grid.

Business models in ZEN: Utilizing energy resources in a neighbourhood

- By Stian Backe, work package 2

To realize the potential in local energy resources in ZEN, new business models and market designs will be an important aspect to consider [1]. The description of a business model mainly answers three questions: (1) What kind of good is traded, (2) how is the good provided and distributed, and (3) how is the value of the good captured. For energy markets, the business model should ensure the reliability, affordability, and sustainability of the energy provided. Ensuring these three aspects is often referred to in the literature as *the energy trilemma* [2]. The energy trilemma has historically been dealt with mainly from the supply side. However, energy consumption has a potential to become more responsive with the integration of new ZEN technologies. To ensure the success of this integration, a modification of the business models that dominate the existing energy system is necessary.

State-of-the-art business models relevant for ZEN can be split into three archetypes [3]: peer-to-peer models (P2P), prosumer-to-grid models (P2G), and organized prosumer group models (OPG).

The least structured group of business model archetypes is the *peer-to-peer models* (P2P) (see Figure 16, left). These models are inspired by the sharing economy, and they can be very similar to platforms such as Airbnb and Uber. The idea is that consumers buy energy directly from independent producers through a decentralized market platform. P2P models are dependent on directly linking buyers and sellers in an easy way. A company inspired by the archetype of P2P models is Vandebron [4], a Dutch energy company established in 2014. They offer a virtual platform where contracts are made between consumers and independent producers of renewable energy systems. The suppliers and consumers are connected to the central grid, which means that the contract only guarantees a balance of input and output through the grid (not real-time matching of supply and demand). The main driver of P2P models is knowing where the energy comes from, as well as lean prices due to direct payment. Barriers include lack of regulations and direction, which can lead to long term failure of P2P models. The design of rules and regulations is therefore very important for P2P models.

Another relevant archetype is the *prosumer-to-grid models* (P2G) (see Figure 16, middle). Prosumers are stakeholders both consuming and producing energy. P2G models are characterized by trading within smaller microgrids. These microgrids can be connected to the central grid or operate in isolation. Supply and demand are continuously matched within the microgrid, and the main goal is to ensure efficient use of all energy units within the system. Inspired by the P2G archetype, The Brooklyn microgrid (BMG) [5] is a pilot project in operation since 2016 in New York, USA. Trading in the BMG is blockchain-based, and the transactions are made in real-time with data from smart meters and customer settings. A driver of P2G models is the long-term efficiency gains that can lead to capital cost reductions. One of the greatest barriers of P2G models is making the complexity of real-time operation easy and affordable to deal with for the market participants.

The third archetype of business models is referred to as *organized prosumer group models* (OPG) (see Figure 16, right). OPG models are characterized by communities pooling prosumers

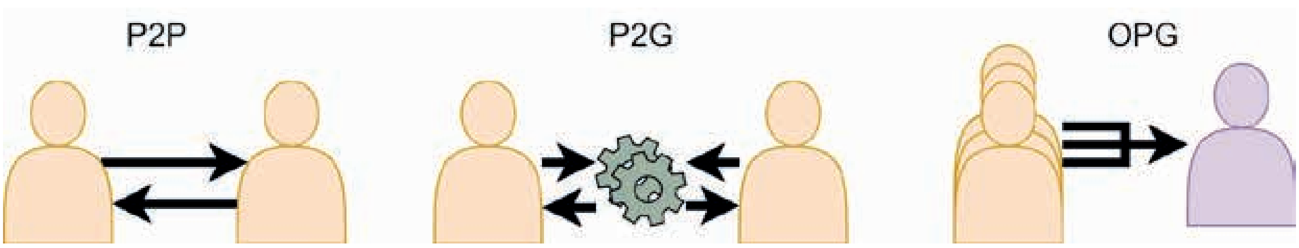


Figure 16: Illustration of three business model archetypes relevant for ZEN.

together, and thereby harvesting benefits through cooperation and synergies. Trading in OPG models happens through an aggregator, an entity that collects energy products and services from prosumers and trades these with external stakeholders. With sufficiently many prosumers, the community can grow into a virtual power plant. The pilot project PowerMatching City [6] in the town of Hoogkerk in the Netherlands belongs to the OPG archetype. A neighbourhood of 42 households is part of a virtual platform, PowerMatcher, where the community's resources are put to best use. The pilot project has demonstrated a large potential for flexibility within the community, and this flexibility can be of significant value to external stakeholders. The OPG models offer shared risk and value allocation for the community, something that is also the natural driver for such models. The question of how to fill the aggregator role remains a barrier.

There are several proposals for business models that are relevant for ZEN, and these are driven by motivations such as energy independence, reducing carbon footprints, community feeling, and lower energy bills. One of the main barriers to local energy trading include the lack of regulatory frameworks, which reflects the lack of knowledge of system consequences in the long run. It is therefore important to investigate how business model designs affect the utilization of energy resources in ZEN, and how local trading of energy resources can support the political goal of creating a sustainable energy system.

References:

H. Chesbrough, "Business model innovation: Opportunities and barriers," Long range planning 43.2, pp. 354-363, 2010.

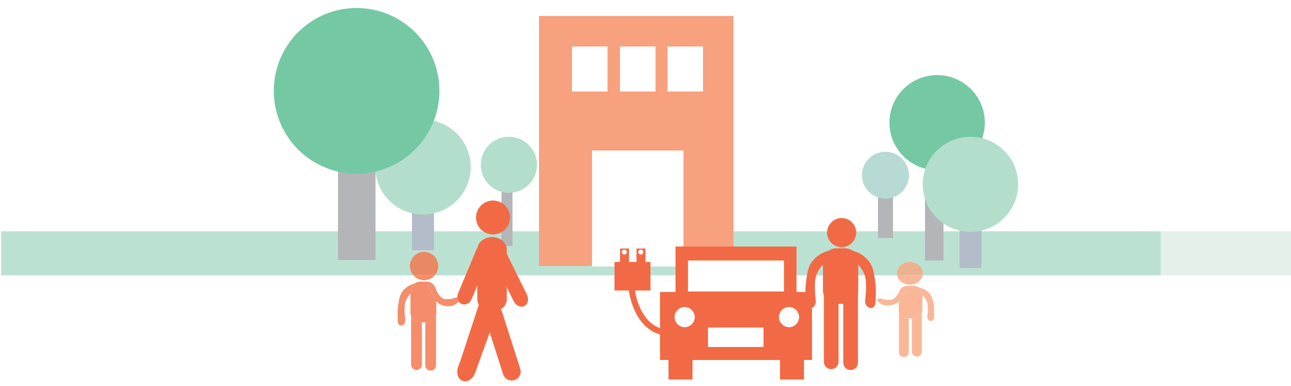
R. J. Heffron, D. McCauley and B. K. Sovacool, "Resolving society's energy trilemma through the Energy Justice Metric," Energy Policy 87, pp. 168-176, 2015.

Y. Parag and B. K. Sovacool, " Electricity market design for the prosumer era," Nature Energy 1, p. 16032, 2016.

Vandebron, [Online]. Available: https://vandebron.nl/. [Accessed March 2018].

E. Mengelkamp, J. Gärttner, K. Rock, S. Kessler, L. Orsini and C. Weinhardt, "Designing microgrid energy markets: A case study: The Brooklyn Microgrid," Applied Energy 210, pp. 870-880, 2018.

R. Kamphuis, B. Roossien, M. Eijgelaar, H. de Heer, J. van de Velde and A. van den Noort, "Real-time trade dispatch of a commercial VPP with residential customers in the powermatching city smartgrid living lab," in 22nd International Conference and Exhibition on Electricity Distribution (CIRED 2013), 2013.



ZEN pilot projects – plans and challenges

- By Inger Andresen, leader for work package 6, and Daniela Baer, work package 1 & 6

In 2017, a mapping of seven Norwegian pilot projects were performed[1] to identify and describe the challenges and opportunities towards becoming Zero Emission Neighbourhoods. The pilot projects include the following ongoing area developments in Norway:

Furuset, an existing semi-urban area in Oslo, built in the 1970s, now conducting a renewal process with emphasis on sustainability. The renewal takes into consideration energy, waste and water, traffic, green landscaping, and social issues, creating 1700-2300 new housing units and 2000-3400 new work places. The development includes the establishment of a thermal micro-grid utilizing excess heat from cooling and ground source storage.

Furuset: Planned central street in ZEN pilot project Furuset. Illustration by the Planning Department of Oslo Municipality.

NyBy Bodø, a planned multifunctional urban area of 3 400 000 m^2. The area is dedicated to expanding the existing city centre and will include residential and business areas, as well as a logistics hub (flights, railway, shipping) close to the airport. The project has high focus on citizen participation, sustainable transport, and the use of IT.

NyBy Bodø: Aerial view of the planned development. Photo by Bodø Municipality.

[1] Baer D. and Andresen I. (2017). Mapping of the pilot projects within the Research Centre for Zero Emission Neighbourhoods in Smart Cities, Memo Version 1, Trondheim, October 2017.

Campus Evenstad, a rural area in Stor-Elvdal municipality, housing the Department of Applied Ecology and Agriculture of the Inland Norway University of Applied Sciences. The campus accounts for 61 000 m^2 of land with 17 buildings with different uses: administration, education, sport, and student housing. The owner, Statsbygg, has already installed state-of-the art technologies for energy supply, including solar thermal, photovoltaics, and a combined heat and power unit based on wood chips. Campus Evenstad will also be a pioneer in testing Vehicle to Grid technology and local battery storage.

Evenstad: ZEN pilot project Campus Evenstad. Photo by Fellesfilm/Statsbygg.

Residential area at Lø, Steinkjer, a small site of about 11 000 m^2 located 1.5 km south-west from the centre of Steinkjer. The site will include a kindergarten and some residential units. Focus areas include re-use of materials and constructions, local energy production and heat recovery, as well as shared spaces and user participation.

Steinkjer:
The site that is to be developed in the Steinkjer pilot project.
Photo by Steinkjer-Avisa.

NTNU Campus, Trondheim, has started a consolidation process that encompasses a spatial demand of 136 000 m^2 of floor area and, after the completion in 2025, 17 000 additional users. The main goal of the campus consolidation project is to develop a campus that provides the best environment for excellent research, education, dissemination, and innovation, and the vision of achieving net zero greenhouse gas emissions by 2060.

NTNU Campus: Illustration for the construction on the west side of the campus. Illustration by Koht Architects.

Zero Village Bergen encompasses the development of a new neighbourhood on the outskirts of Bergen. The planning consists of approximately 720 dwellings (92 000 m^2), in addition to some non-residential purposes such as offices, shops and a kindergarten. The goal of the private developer, ByBo, is to achieve a net zero emission neighbourhood for the residential area.

Zero Village Bergen: Aerial view of the planned development. Illustration by Snøhetta.

The Ydalir project in the town of Elverum in Hedmark aims to develop a new neighbourhood with ambitious goals with respect to energy performance and greenhouse gas emission. The estimated timeframe for completion is 2030. Approximately 800 to 1 000 residential units are planned, along with a school and kindergarten.

Ydalir: Planned neighbourhood in Ydalir. Illustration by tegn_3.

Through interviews with central stakeholders in the development projects, as well as the study of relevant documents, we have identified 10 main challenges in the projects:

1. **Project organization and management**. How to ensure a continuation in process management given the long time frame of the projects. How to ensure commitment to ZEN goals among all participants (different landowners, public and private developers, contractors, end-users, etc.). How to implement new inter-disciplinary ways of working.

2. **Lack of knowledge**. There is limited knowledge about how to plan, develop, construct, and operate a ZEN.

3. **Legislation**. Current codes and regulations are not adapted to the ZEN solutions, in particular with respect to the exchange of energy between buildings.

4. **Goal conflicts**. How to handle conflicting interest of different stakeholders, i.e. developers, municipalities, citizens, etc.

5. **Time and cost pressure**. Even though the development projects have long time frames, the projects are still subject to limited time and resources, which makes it demanding to take into account the added complexity of ZEN projects.

6. **New energy technologies**: How to select, design, and integrate the most suitable energy supply systems with the lowest possible carbon footprint and life cycle costs. Lack of methods, tools, and data.

7. **System boundaries**: What emissions should be included in the calculations, and how. What is the needed level of detail. How to take into account energy plants located outside the development area.

8. **Risks and uncertainties**. How to handle risks given the large uncertainties (long time frame) of the developments. Change in boundary conditions (e.g. regulations and incentives), new technologies developments, etc. Uncertainties about the costs and performance of ZEN solutions.

9. **Flexibility**. How to plan the infrastructure to allow for flexibility and adaptation to future developments in technology, legal frameworks, and use.

10. **Transferability**: How to transfer the knowledge and solutions developed in the pilot project to other neighbourhood developments.

FOCUS ON INNOVATION

- By Ann Kristin Kvellheim (work package 2 & innovation coordination), Svein Olav Munkeby (NTE) and Kjell Skjeggerud (Heidelberg Cement)

The ability to change, adapt, and renew is increasingly important. In our global and ever more digitalized world the average lifetime of a product is shorter than ever. It swiftly becomes replaced, and even a widespread practice of planned obsolescence has been documented; products are supposed to break for us to purchase novel items. In these cases, it is evident that innovation is not an unequivocal good. A counter-reaction to this unsustainable consumption is the circular economy, which stresses the value of re-use, repair, and sharing. Consumption of raw materials, waste, emissions, and energy use should be reduced to a minimum. This way of thinking is also a part of The Research Centre on Zero Emission Neighbourhoods in Smart Cities (ZEN). And society, including public and private organizations, is pointing at the ability to innovate as a central means to climate change mitigation.

ZEN has 32 user partners from public and private enterprises and from different businesses. This is a heterogeneous group which offers the Centre a unique potential. During autumn 2017, a survey was undertaken among the user partners to map what types of innovations they saw as important to develop through ZEN. The survey revealed that even if it is still important to develop and test new products and solutions in the pilot projects, the ZEN partners are more interested in developing new and improved processes, services, and business models as part of a consortium. Two of the user partners explain what they expect from ZEN and why this outcome is important to them:

Heidelberg Cement is, through its subsidiaries, one of the largest suppliers of building materials to the Norwegian building industry. Over many years, the corporation has worked to develop more sustainable products where resources used in the production process and greenhouse gas emissions are significantly reduced. Greenhouse gas emissions from the production of building materials have a significant share of the total emissions from a building complex over its life-cycle. We expect that ZEN will create a platform for additional greenhouse gas reductions from the production of our products through interplay with other actors in the industry. Furthermore, we expect the use of our products to be optimized towards zero emissions over the lifetime of a building, in a broad cooperation within pilot projects and case studies in ZEN. The Centre is an arena for progress and innovation related to technical solutions as well as business models, and our participation in the Centre is strategically important to Heidelberg Cement.

NTE is one of the largest energy corporations in Norway, with activities spanning production, distribution, and sales of renewable energy. The corporation also has a significant Telecom business, where the construction of a fibre-based infrastructure is the main pillar in the corporative emphasis on new and innovative solutions as important input to realize zero emission neighbourhoods in smart cities. ZEN is facilitating a broader arena of collaboration, where NTE is able to work closely with actors in the building industry, the public sector, and researchers towards a common vision of zero emissions. The pilot projects in ZEN will work as living laboratories where customers are involved in an early phase, and we believe strongly that this will inspire many more projects to take on high ambitions within ZEN and beyond. In a digitalized world economy, the energy industry is also exposed to disruptive innovation. Therefore, it is of outermost importance to prioritize business model innovation, as well as innovative processes and services, in the years to come.

ZEN is met by high expectations from participants in the Centre as well as from society at large. The Research Centre is actively facilitating the birth and growth of ideas, inventions, and innovations. To this end, pilot projects and case studies are of foremost importance, but for the future it is vital to establish complementary arenas to exchange experiences and learn about various aspects of the innovation process, from the idea to how to create and capture value from innovations. One such arena could be the establishment of a "ZEN School of Innovation".

Innovation is a critical factor of success to ZEN, and its innovation strategy is a tool to the accomplishment of the overarching objective of ZEN: to design, build, transform, and manage sustainable neighbourhoods. The innovation strategy is built on 3 main pillars:

Main pillars of innovation in ZEN

Open innovation	Testing and demonstration to prepare for market implementation	Visualize and exhibit milestones and success stories

Open innovation means that innovations are developed in interplay with others instead of in closed circuits. This requires confidence among the participants in the Centre. Furthermore, it is important to be able to test and demonstrate innovations within the ZEN Centre in order to ensure a less complicated process towards market implementation. Finally, it is crucial to tell about ZEN projects, milestones, and success stories to the world. There is an immense potential in exhibiting what is possible and get the message out.

Increased focus on innovation from the Research Council and others contributes to more attention and more resources being allocated to innovation, also within ZEN. This is likely to have an effect on the number and quality of innovations that are needed to be able to reach ambitious greenhouse gas reduction targets in the near future.

COLLABORATION AMONG OUR PARTNERS

In 2017, the main focus has been the start-up of the FME Zero Emission Neighbourhoods Centre. This implies getting the partners to learn to know each other, to see what work packages are most relevant for their partnerships, and to learn how the centre's activities are interlinked.

There have been 16 workshops where these topics have been dealt with; see the table below. In addition, the "owners" of the pilot projects have arranged several workshops discussing the content and the topics to be addressed in the different pilots.

The involvement of the partners in the centre takes place in several ways, e.g:

- In the work packages;
- In the creation of an innovation strategy – we have established an innovation committee involving the different partner categories;
- By using the pilot projects as living laboratories;
- By using our laboratory facilities for parametric studies;
- In the arena the industrial partners have created for discussing mutual issues in the centre;
- By participating in the innovation workshop "From ZEB to ZEN", organised by Trondheim municipality.

ZEN PARTNER WORKSHOPS AND SEMINARS IN 2017

Work package (WP)	Topics of the workshop/seminar	Date, place
Joint	ZEN partner seminar about innovation, pilot projects, work plan, knowledge transition from ZEB to ZEN, and the road ahead	21-22 November, Trondheim
Joint	ZEN communications workshop for the communication resources of ZEN partners	22 November, Trondheim
NTNU Evening	NTNU Evening about zero emission buildings and neighbourhoods	2 October, Trondheim
WP1	Principles for life-cycle analysis for zero emission neighbourhoods (ZEN)	23 November, Oslo
WP1	Definition of ZEN: Design and planning, and energy supply	27 April, Trondheim
WP1	Definition of ZEN: Buildings and materials	3 May, Trondheim
WP1	Definition of ZEN: Joint workshops	7 June, Oslo
WP2	ZEN - State of the art. What can we learn from success stories and mistakes? Which barriers and drivers are most important? What do we know about measures that work?	5 December, Trondheim
WP3	Workshop: Introduction to parametric life-cycle analysis. Afterwards meeting with manufacturers (Norcem, Hunton, Moelven) and contractors (Skanska, GK, Caverion) about WP3-activities, especially lab activities, in Trondheim.	13 June, Trondheim
WP3	Definition of responsive and energy efficient buildings, and user-controlled IEQ	13 September, Trondheim
WP4	District heating and local thermal solutions in ZEN	24 August, Oslo
WP4	Flexibility for buildings and neighbourhoods	7 November, Oslo
WP4	Electrical solutions for ZEN (solar power, electric cars and smart charging)	23 October, Oslo
WP5	Data tools for the planning of local energy solutions	23 June
WP5	Design of energy systems analyses for ZEN, How can the building sector and the energy sector improve each other?	22 June, Oslo
WP6	ZEN pilot projects	26 October, Evenstad

ZEN BOARD MEETINGS

Participants	Title	Date, place
Board	ZEN board meeting	8 March, Trondheim
Board	ZEN board meeting	18 May, Oslo and Trondheim
Board and leaders	ZEN combined board and leader group seminar	14-15 September, Oslo
Board	ZEN board meeting	8 December, Trondheim

INTERNATIONAL COLLABORATION

The Research Centre on Zero Emission Neighbourhoods in Smart Cities (ZEN Centre) aims to use its active networks with international partners from research, industry, and public authorities to exchange knowledge and experience, organize secondments and staff exchange among partners, develop joint publications and sharing of laboratory infrastructure, and invest in joint project development and funding. The ultimate goal is to strengthen the international recognition together with the quality and relevance of ZEN Centre R&I activities. The main objectives can be summarized as follows:

I. Build up cooperation with internationally renowned experts
II. Support international recruitment of outstanding academic staff
III. Increase the ZEN Centre's participation in European funding programs, projects, and network organizations

During the first months of the ZEN Centre, an internationalization strategy has been initiated based on existing networks and acknowledging the need for new partnerships. In order to enforce its international collaboration, the centre expanded its team with a project developer in the area of zero emission buildings and neighbourhoods. The main responsibility of this position is to initiate, develop, and write applications for national and international programs together with group members, aiming specifically for the EU Horizon 2020 work program.

As a starting point, a priority plan for new funding applications in H2020, EiT KICs, Joint Programming Initiatives, and other European funding programs has been initiated. During the second semester of 2017 new collaborations for H2020 funded projects have been established and six EU-projects applications have been submitted (two examples are H2020-MSCA-ITN-2018 FAB FACADES and LC-SC3-RES-4-2018 (RIA) EIRB). In addition, a prioritized list of international events and other activities in which ZEN needs to be visible and actively engaged has been developed and will be updated regularly.

The ZEN Centre further engages in several International Energy Agency annexes and Tasks, such as IEA EBC Annex 71 Building energy performance assessment based on in situ measurements, IEA EBC Annex 67 Energy Flexible Buildings, and IEA District Heating and Cooling, TS1 Low Temperature District for Future Energy Systems.

Exchange of personnel is taking place. The ZEN Centre's researchers have stayed at KU Leuven (Laurent Georges) and Lawrence Berkeley National Laboratory (Aoife Wiberg and Steinar Grynning), and researchers from DTU, Xi'an University of Architecture and Technology (XUAT) in China, and the Polytechnic University of Turin (Italy) have visited the ZEN Centre for periods between one week and up to one year.

The ZEN Centre has started to investigate possibilities for extended cooperation towards China. Examples of existing initiatives include, in addition to the exchange of students and PhD researchers, our participation in:

- the Delegation from the Ministry of Education and Research in April 2018;
- the EU H2020 projects URBAN-EU-CHINA and TRANS-URBAN-EU-CHINA on sustainable urbanization including energy, transport, ICT, citizen engagement, living labs, the public and the private sector;
- the International Low Carbon City, Neighbourhood, Building Academic Alliance with the XAUAT Xi'an University of Architecture and Technology;
- the UTFORSK project.

During 2018, the ZEN Centre will discuss whether and how to embed the existing China initiatives more firmly within the Centre's activities.

RECRUITMENT

Figure 17: NTNU students discussing solar panels. Photo: NTNU.

The contract with the Research Council of Norway was signed in February 2017, and shortly after, PhD- and postdoc positions were announced. The number of applicants has been high. However, a relatively high number of applicants do not have the required qualifications or do not have relevant backgrounds. Even so, the number of highly qualified applicants has been high enough to make the selection difficult. Quite a few applicants have therefore been interviewed.

By the end of 2017, seven PhD candidates and two postdocs were working at the ZEN Centre. There is a good mix of gender and nationalities. Another eight PhD candidates and postdocs are associated with the Centre and participate in the Centre's activities, e.g. in the ZEN course and the lunch lectures. This contributes to a good research and learning environment. Another 4-5 PhD candidates and postdocs are expected to be hired during 2018.

An adjunct professor, Henrik Madsen from DTU, was hired to strengthen the Centre's competence in time series analysis, grey box modeling, and probabilistic forecasting. The Centre has also hired an EU project developer, Dr. Niki Gaitani, who will help with increasing the amount of funded projects on topics of interest to the Centre.

In addition to PhD candidates and postdocs, several MSc-students were involved in the work in ZEN in 2017. These include students at NTNU as well as students from the universities ZEN cooperates with abroad.

COMMUNICATION IN THE ZEN RESEARCH CENTRE

Communication is important for the ZEN Research Centre, and much was accomplished in 2017 in this regard.

A communication advisor and coordinator was hired in September 2017. An elaborate communication plan, which addresses internal and external communication as well as communication with and between the Centre's partners, was drafted. The communication plan also encompasses a profile program and a brand strategy for the Centre.

EXTERNAL COMMUNICATION

We published our website, **www.fmezen.no**, and established a Twitter account, **@ZENcentre**. The Centre and its research was covered by mass media 15 times, and an "NTNU Evening" about zero emission buildings and neighbourhoods was arranged on 2 October, featuring some of our researchers. We published 10 scientific reports, 6 scientific journal papers, and 1 conference paper.

WE COMMUNICATE OFTEN AND INTENTIONALLY WITH OUR PARTNERS

As the ZEN Centre still was in its beginning, we focused on establishing contacts, communication platforms, and channels with our partners and among our researchers. 16 partner meetings and 4 board meetings were held, and 95 presentations were given at conferences and in partner seminars. We held a combined board and leader group seminar with 19 participants on 14-15 September in Oslo, where we among other topics mapped expectations for the Centre and moved towards establishing a joint culture. A partner seminar was held 21-22 November in Trondheim, where the main topic was innovation and planning of activities for 2018 and 2019. 10 short newsletters about our research activities were sent out, designed to be relevant and interesting to the Centre's partners. We established a project hotel for our partners and researchers, and this has been actively used for the exchange of mutually useful information, pictures, detailed contact information, and presentations from workshops and seminars.

We have established a network for the communication resources of the ZEN partners ("ZEN kommunikasjonsnett-

Figure 18: Our user partners were all ears when our PhD candidates presented their research to them at the ZEN partner seminar 21-22 November 2017 in Quality hotel Augustin in Trondheim.

verk for partnerne") and held our first workshop on 22 November. At that workshop we planned how we are going to work together to communicate the Centre's and partners' work.

BUILDING A CENTRE IDENTITY AND FACILITATING THE EXCHANGE OF IDEAS AMONG OUR RESEARCHERS

The Centre's leadership meets every other week. On 7 December, we had a seasonal celebration with the Centre's employees and associated researchers. In 2018, we will have lunch lectures for the researchers and partners, where snapshots from the Centre's research will be featured.

COMMUNICATION ACTIVITIES AT THE ZEN RESEARCH CENTRE IN 2017 IN NUMBERS:

Partner workshops and seminars organised: 16

Newsletter «ZEN Partnernytt», sent out: 10

Publications:

- Reports: **10**
- Journal papers: **6**
- Conference paper: **1**
- Presentations by our researchers at conferences and partner seminars: **95**
- Media features: **10**
  (1 of them further featured in 5 media sources)

APPENDICES

PERSONNEL

ZEN management team

Last name	First name	Position	Main research area	Institution
Bremvåg	Annika	Communication adviser & coordinator	x	FME ZEN
Gustavsen	Arild	Centre director / professor	x	NTNU
Jacobsen	Terje	Centre liaison / vice president research	x	SINTEF Byggforsk

Work package leaders

Last name	First name	Position	Main research area	Institution
Andresen	Inger	WP6 Leader / professor	WP6	NTNU
Brattebø	Helge	WP1 Leader from 15 March 2018 / LCA Coordination / professor	WP1	NTNU
Sartori	Igor	WP4 Leader / senior research scientist	WP4	SINTEF Byggforsk
Thomsen	Judith	WP3 Leader / research manager	WP3	SINTEF Byggforsk
Tomasgard	Asgeir	WP2 Leader / professor	WP2	NTNU
Wolfgang	Ove	WP5 Leader / research scientist	WP5	SINTEF Energi
Wyckmans	Annemie	WP1 Leader (until 15 March 2018, then international coordinator) / professor	WP1	NTNU

Key researchers

Last name	First name	Position	Main research area	Institution
Ahlers	Dirk	Research scientist	WP1	NTNU
Baer	Daniela	Research scientist	WP1	SINTEF Byggforsk
Berker	Thomas	Living lab coordination / professor	WP6	NTNU
Boer	Luitzen de	Professor	WP2	NTNU
Grynning	Steinar	Research scientist	WP3	SINTEF Byggforsk
Krogstie	John	ICT coordination / professor	WP1	NTNU
Kvellheim	Ann Kristin	Innovation coordination / senior adviser	WP2 & innovation coordination	SINTEF Byggforsk
Mathisen	Hans Martin	ZEN Services coordination / professor	WP 3&4	NTNU
Mysen	Mads	Chief scientist	WP 3&6	SINTEF Byggforsk
Skaar	Christofer	Senior research scientist	WP3&6	SINTEF Byggforsk
Sørensen	Åse Lekang	Research scientist	WP5	SINTEF Byggforsk
Wiberg	Aoife	Associate professor	WP1	NTNU

STATEMENT OF ACCOUNTS

FUNDING AND COSTS

Funding (1)	Amount	Total
The Research Council		11 214
The Host Institution (NTNU)		1 621
Research partners		
Sintef Byggforsk		7 885
Enterprise partners		9 253
Civitas AS	167	
Elverum Tomteselskap	1 764	
Energi Norge	317	
Hunton	837	
Moelven Industrier ASA	488	
Norcem	386	
TOBB	471	
ByBo	720	
Skanska Norge AS	1 100	
Sweco Norge AS	391	
GK Norge AS	375	
Asplan Viak AS	200	
ÅF Engineering og tegn_3	605	
Caverion Norge AS	139	
Multiconsult ASA	200	
Norsk Fjernvarmeforening	866	
Smart Grid Services Cluster	29	
Snøhetta Oslo AS	200	
Public partners		3 668
Bergen Kommune	323	
Bodø Kommune	298	
Sør-Trøndelag fylkeskommune	638	
Trondheim Kommune	470	
Oslo Kommune Klima og Energiprogrammet	476	
Elverum Kommune	150	
Steinskjer Kommune	200	
DiBK	208	
Statsbygg	905	
Total		33 641

(1) The table shows the funding per partner (all figures in NOK 1000), both cash and in-kind.

Cost [2]	Amount	Total
The Host Institution (NTNU)		7 533
Research partners		
SINTEF Byggforsk		16 196
SINTEF Energi		2 070
Enterprise partners		6 323
Civitas AS	117	
Elverum Tomteselskap	1 664	
Energi Norge	167	
Hunton	587	
Moelven Industrier ASA	238	
Norcem	136	
TOBB	371	
ByBo	570	
Skanska Norge AS	1 000	
Sweco Norge AS	191	
GK Norge AS	125	
ÅF Engineering og tegn_3	355	
Caverion Norge AS	39	
Norsk Fjernvarmeforening	736	
Smart Grid Services Cluster	29	
Public partners		1 518
Bergen Kommune	123	
Bodø Kommune	48	
Sør-Trøndelag fylkeskommune	388	
Trondheim Kommune	220	
Oslo Kommune Klima og Energiprogrammet	226	
DiBK	8	
Statsbygg	505	
Total		33 641

(2) The table shows the cost per partner (all figures in NOK 1000), in-kind.

Activity [3]	2017
WP 1	3 624
WP 2	1 557
WP 3	6 831
WP 4	2 966
WP 5	1 154
WP 6	4 337
WP 10 ADM	583
PhD & postdocs	1 374
The Research Council of Norway	11 214
Total	33 641

(3) The table shows the costs for the different activities (all figures in NOK 1000).

Editors:
Annika Bremvåg
Arild Gustavsen
Anne Grete Hestnes

Contributors:
Employees and associated resources of the ZEN Research Centre

Layout and print:
Fagtrykk Trondheim AS
NO-7038 Trondheim

Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN)

NTNU - Gløshaugen campus
Alfred Getz vei 3, Central Building 1, 8th floor
NO-7491 Trondheim, NORWAY

www.fmezen.no