ZEN

Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

ANNUAL REPORT 2019

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

VISION:

«Sustainable neighbourhoods with zero greenhouse gas emissions»

ZEN REPORT No. 21 – 2020

Editors: Annika Bremvåg, Anne Grete Hestnes and Arild Gustavsen.

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CAN YOU IMAGINE LIVING IN A ZERO EMISSION NEIGHBORHOOD?

A message from the Chair of the Board

Tonje Frydenlund
Chair of the Board
at the ZEN Resarch Centre,
Snøhetta

Three years into the Research Centre activities we already see results from case studies, the work package research activities, pilot projects, and living labs. We have established a solid set-up and framework for the Centre, with the best expertise on board, and we are starting implementation in full scale neighborhood pilots. We will continue working for encouraging more active involvement from the industry partners, municipalities, and public partners, to increase the Centre's total volume of research and dissemination of expertise.

Entering the next decade, we need to broaden the perspective on what the future zero emission neighborhoods will be. In the 2-year workplan for 2020-2021, we have in addition to the already established research perspectives, strengthened the focus on circular economy and re-use of materials, innovation and cross disciplinary collaboration, user involvement, and mobility.

Our research and innovations are unique in a global perspective, especially when it comes to the holistic approach and enabling the transition to a low carbon society. With the ZEN-definition, criteria, and tools in place, the ZEN Research Centre with partners will contribute to changing both the industry and the society at large. Our mission is to share insight, inspire, and support the necessary actions to ensure optimal energy use, zero emission building, sustainable neighborhoods, and smart cities.

In order to succeed we still need to expand and test actual solutions. Here more case studies and living labs will play the major role, with the initiative and ownership anchored in the public and industry partners, supported by the researchers' in-depth knowledge and analytical approach. To enhance more partner initiatives the Board has further increased the budget for case studies, innovation, and coordination activities as connectors. We are moving ahead with a closer focus on the collaboration and interaction between work packages and with partner involvement in case studies, living labs, and pilot activities. You are all invited to participate in the on-going lunch lectures, seminars, dialogue meetings, and the biannual ZEN conference.

The ZEN Centre has nine pilot projects spread across Norway, with an area of more than 1 million m^2, creating homes for over 30 000 inhabitants in total. Together we will develop solutions for the future buildings and sustainable neighborhoods with no greenhouse gas emissions, creating the future low carbon society.

Centre Board
Tonje Frydenlund, Snøhetta
Partow P. Henriksen, SINTEF
Rakel Hunstad, Bodø Municipality
Svein Olav Munkeby, NTE
Thomas Løkken, Hunton
Anders Fylling, Statsbygg
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Jo Mortensen, Skanska Norway

CHALLENGING BUT NECESSARY AMBITIONS!

Summary of our research in 2019

Arild Gustavsen
Centre director and
professor, ZEN, NTNU

The vision of the Research Centre on Zero Emission Neighbourhoods in Smart Cities (ZEN Centre) is Sustainable neighbourhoods with zero greenhouse gas emissions. Results from the ZEN Centre demonstration and research projects start to show how challenging this ambition is, while at the same time showing that substantial environmental performance improvements are possible. The research and development activities address greenhouse gas emission across several sectors and across their life cycle. A holistic approach is needed to find the most optimal solutions for the society, not arriving at suboptimal solutions. At the same time a changing climate shows that high and challenging ambitions are more important than ever.

STRONG PARTNER INVOLVEMENT IN ZEN DEMONSTRATION PROJECTS AND ZEN CASES

In 2019 the interaction between researchers and public and industry partners increased substantially. A lot of this is connected to the activities in the in the nine ZEN Centre demonstration projects around Norway: Nyby Bodø, Mære in Steinkjer, NTNU Campus and Sluppen in Trondheim, Campus Evenstad in Hedmark, Ydalir in Elverum, Zero Village Bergen, Furuset in Oslo, and Fornebu in Bærum. The projects are in different stages of development, with different sizes, functions, and contexts. The ZEN researchers work with municipalities and other stakeholders to define goals and key performance indicators (KPIs). They give advice, test and analyze solutions, and document the KPIs.

Further, the ZEN Centre Board initiated ZEN Cases, which resulted in more partner engagement. The ZEN Cases are initiated by the user partners and carried out with collaboration between researchers and public and industry partners. Topics studied include: business models for low-carbon concrete, policy barriers related to zero emission neighbourhoods, and analysis of the energy system improvements for a building cooperative in Trondheim consisting of about 1000 units. The ZEN Cases allow partner-initiated projects to be started during the ongoing work plan period.

KNOWLEDGE AND TECHNOLOGY FOR A BETTER WORLD

International collaboration is an important part of a research centre for environmental-friendly energy. Participation in collaboration projects under the International Energy Agency has been important from the start. In 2019, we in addition saw that our strategic internationalization work pays off, being awarded an EU H2020 project on Sustainable Plus Energy Neighbourhoods, named Syn.ikia. Researchers

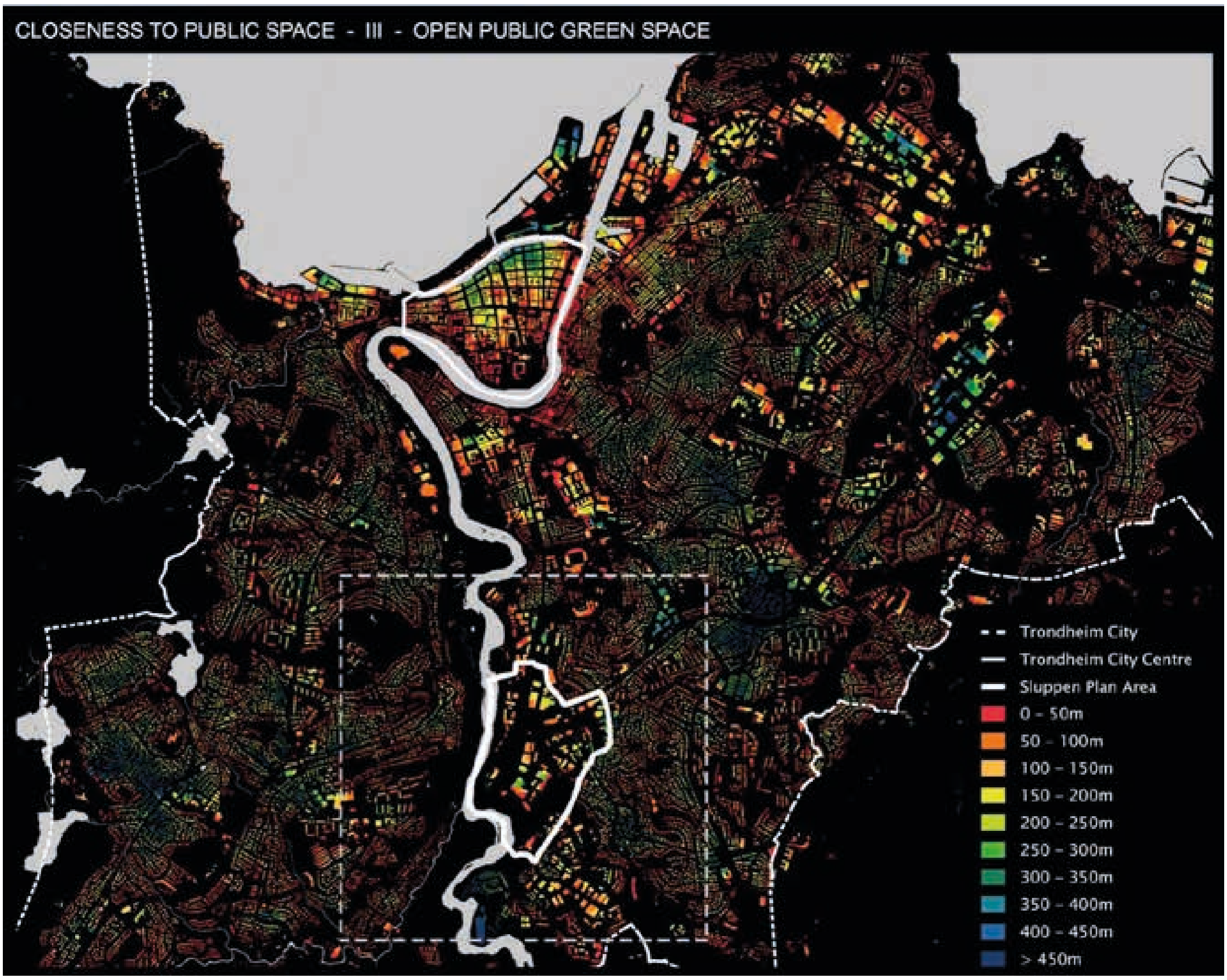
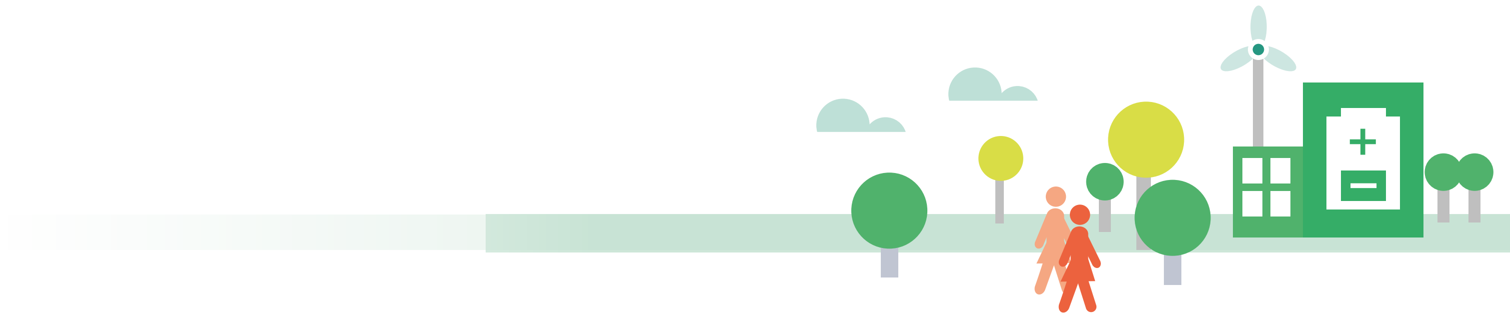


Figure 1. Spatial qualities: Closeness to public space, from a study performed by Tobias Nordström, Lillian Rokseth, Sylvia Green, Bendik Manum.

from the ZEN Centre were also invited to participate in several new H2020 project initiatives, to be decided on in the near future. At the end of 2019 the ZEN Centre was awarded a new research project towards China, jointly funded by the Research Council of Norway and the Ministry of Science and Technology of China. In addition, several of our PhD candidates are staying periods at our international partners, and we also have several incoming candidates.

RESEARCH, DEVELOPMENT, AND COMMUNICATION ACTIVITIES

The various research and development activities are progressing nicely, and the zero emission neighbourhood definition stands at the center of this, connecting most of the activities carried out. A zero emission neighbourhood is defined as a group of interconnected buildings with associated infrastructure, located within a confined geographical area, aiming at reducing its direct and indirect greenhouse gas (GHG) emissions towards zero. Energy efficiency, new local renewable energy production, energy flexibility, sustainable transport solutions, economic sustainability, spatial qualities, sustainable behavior, and innovative solutions are the criteria considered, in addition to greenhouse gas emissions. The definition is being tested in several pilot and research projects and made applicable in practice using a set



of indicators and a tool for multi-criteria analysis for ZEN projects.

An innovation registration system has been established to actively follow up the innovation work and to ensure that ideas are implemented. For each idea we register the name, description, the partners involved, the technology readiness level (TRL), the market potential, and the potential impact. At the end of 2019 there were 67 registered ideas in ZEN. This registration system is updated regularly, and goals are set related to the further development of the ideas and possible commercialization.

So far, our ZEN Centre has published close to 150 scientific reports and articles, 20 popular science publications, 125 media publications (in newspapers, radio, or TV), and 250 reports, memoranda, articles, and presentations held at meetings or conferences for project target groups. The ZEN Centre researchers get frequent requests to present ongoing work, as well as to contribute to new development projects with high environmental performance ambitions.

Snapshots of our research, development, and innovation activities are presented in the following chapters. Enjoy reading!

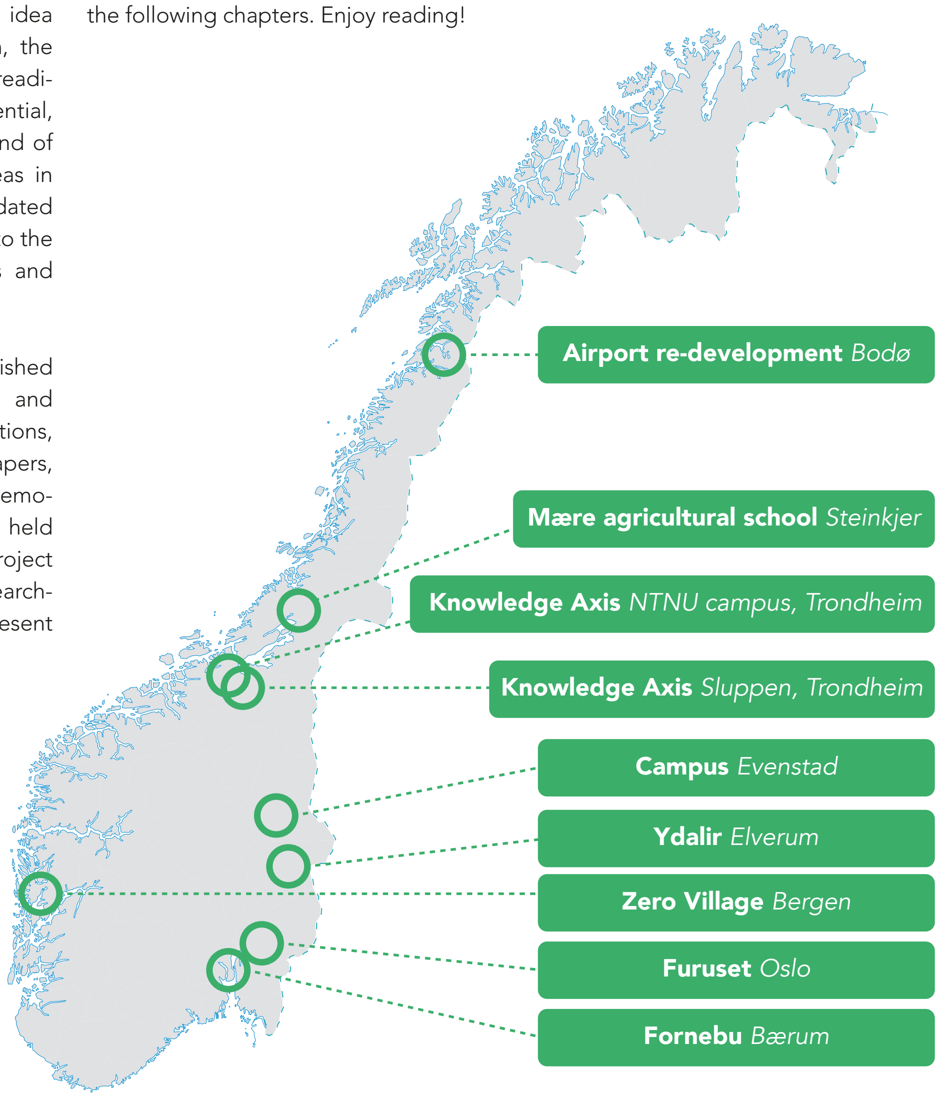


Figure 2. Location of the ZEN Centre demonstration neighbourhoods.

OVERALL GOALS AND RESEARCH PLAN

BACKGROUND

The buildings and construction sectors combined, account for 36% of total global final energy use and nearly 40% of total direct and indirect CO_2 emissions[1]. Improving the energy performance of the building stock is critical[2] and is 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 bi-directional 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

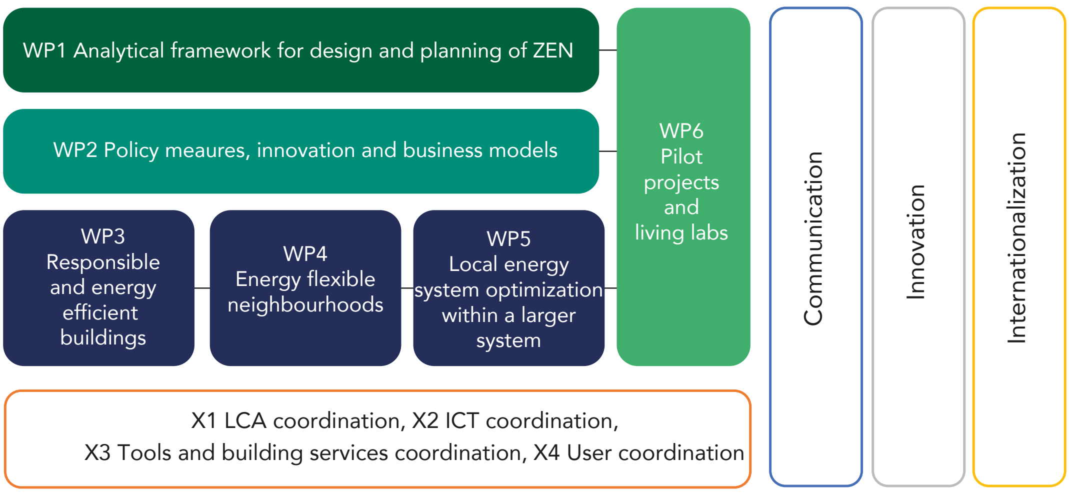


Figure 3. The ZEN Centre's six work packages.

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 3). Multidisciplinary collaboration between areas is key to addressing the overall goal.

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 building 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

Goal: 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 IEA (2019). Energy Efficiency: Buildings, The global exchange for energy efficiency policies, data and analysis. https://www.iea.org/topics/energyefficiency/buildings/.
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.

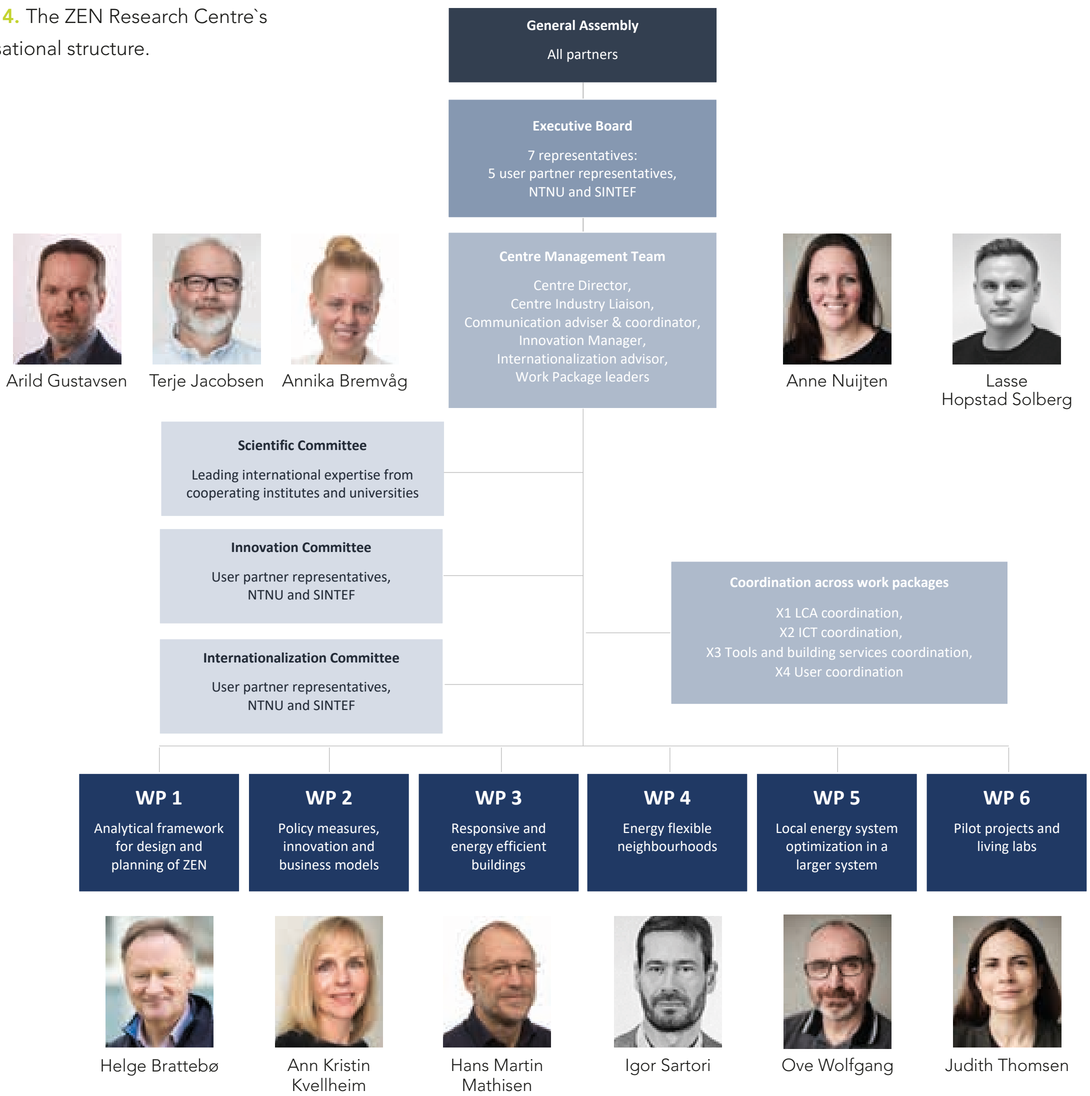
ORGANISATION OF THE ZEN RESEARCH CENTRE

The ZEN Research Centre is a Centre for Environment-friendly Energy Research (FME) and was established in 2017 by the Research Council of Norway. The Centre is hosted by the Norwegian University of Science and Technology, and jointly organised by NTNU/ SINTEF.

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 and for the allocation of funds to support the various activities. The user partners have the 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, who have been selected because their competence is relevant for the Centre's research activities.

Figure 4. The ZEN Research Centre`s organisational structure.



OUR PARTNERS

The partners in the ZEN Research Centre hold central roles within the design and development of neighbourhoods and the energy system. This 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 Community and SINTEF Energy Research.

PRIVATE SECTOR

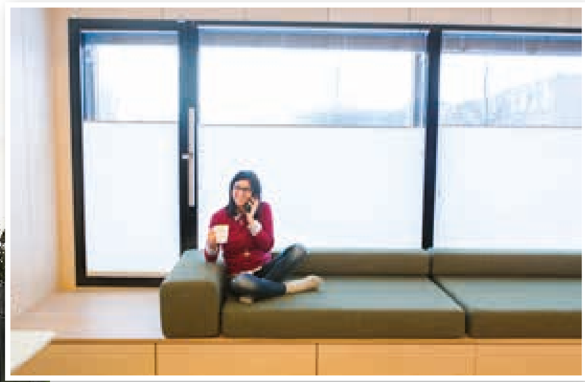
PUBLIC SECTOR

RESEARCH AND EDUCATION

OUR LABORATORIES

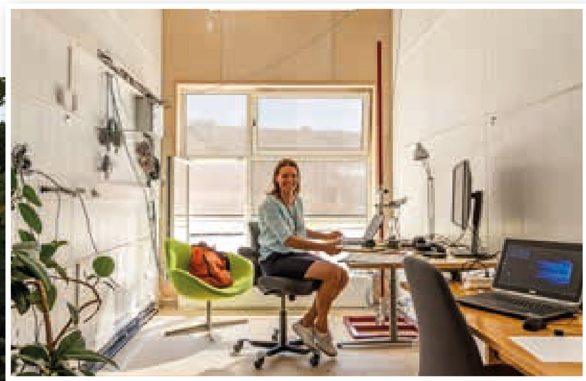
We have systematically developed our laboratories through the FME Zero Emission Buildings and several other projects, and we continue to do so in the ZEN Research Centre. Our labs are being used by our researchers and partners within user cases and the work packages. Find examples of our lab research activities in the snapshots-chapters in this annual report. In addition to the labs below, several of our pilot projects function as living labs.

ZEB Living Lab



More information:
http://zeb.no/index.php/en/living-lab-trondheim

ZEB Test Cell



More information:
http://zeb.no/index.php/en/test-cell-laboratory

ZEB Laboratory

More information: http://zeblab.no/

Smart Grid Laboratory

More information: https://www.ntnu.edu/smartgrid

SNAPSHOTS OF OUR RESEARCH

Further development of the ZEN definition and the ZEN KPI tool

Marianne Kjendseth Wiik
Researcher,
SINTEF

Helge Brattebø
Professor,
NTNU

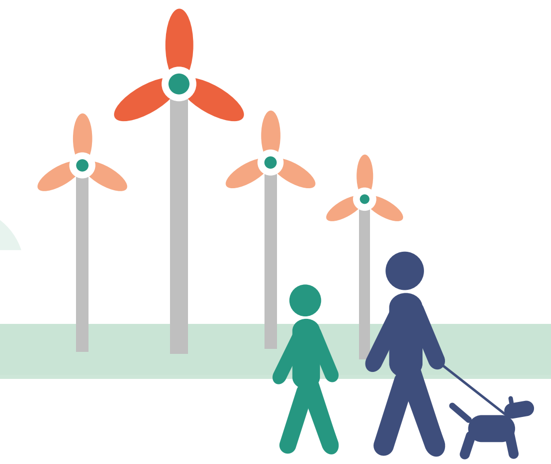
The ZEN Research Centre has defined a zero emission neighbourhood as an area that reduces its direct and indirect GHG emissions towards zero during its life cycle, with focus on seven categories:

- **GHG emissions**
- **Energy**
- **Power**
- **Mobility**
- **Economy**
- **Spatial qualities**
- **Innovation**

Each category shall have its own set of qualitative and quantitative key performance indicators (KPI). In 2019, there has been a main focus on developing a framework for the ZEN definition in a ZEN KPI tool since the pilot projects require KPIs, methods, and tools to be able to plan, implement, measure, and follow up projects. It is thought that KPI shall be used in all project phases and involve various actors. The scope can include buildings, infrastructure, or both. The necessary tools required by ZEN partners to complete a ZEN assessment shall be collected in a ZEN toolbox. The results generated by tools in the ZEN Toolbox can then be fed into the ZEN KPI tool in order to evaluate the performance of the pilot area at the category and neighbourhood level. Here, reference values, threshold values, benchmark values, and weightings will be developed for each KPI.

We have also developed a point scoring system that shows how well a pilot area is performing. Partners can set their own ambition level for each category. The points are weighted once all categories have been measured. The weightings are based on a survey completed by ZEN partners and experts, whereby they answered how relevant, potential, and serious they think each category is. After the weighting process has been carried out, the pilot area is awarded a result for the whole area and for each category. It is possible to achieve a category rating (dark green, green, or light green) and neighbourhood rating (bronze, silver, or gold). Achieving a neighbourhood rating is deemed very ambitious. It may not be possible for a pilot area to achieve the neighbourhood rating immediately, but they can begin by focusing on a couple of category ratings.

Figure 5. ZEN neighbourhood ratings bronze, silver, and gold are very ambitious.



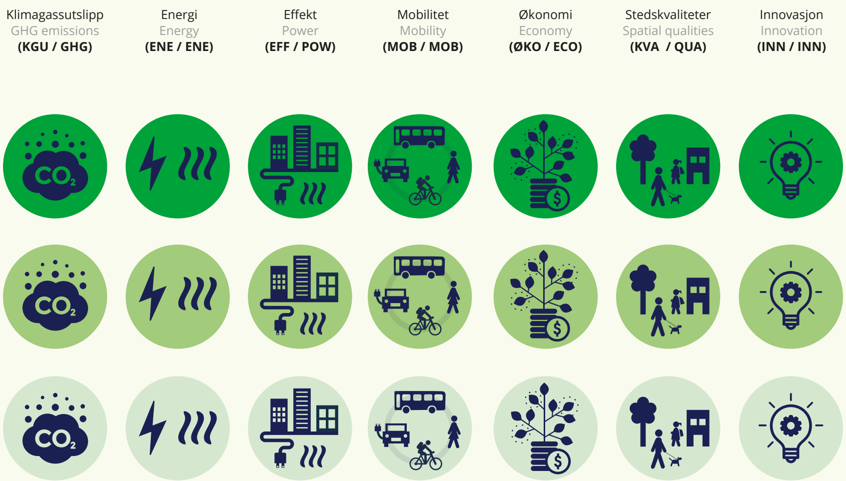
Videreutvikling av ZEN definisjon og ZEN KPI verktøy

FME ZEN har definert et nullutslippsområde som et område som jobber mot å redusere sine direkte og indirekte klimagassutslipp mot null innenfor sin livssyklus, med søkelyset på syv kategorier:

- **klimagassutslipp**
- **energi**
- **effekt**
- **mobilitet**
- **økonomi**
- **stedskvaliteter**
- **innovasjon**

Hver kategori skal ha et sett av kvalitative og kvantitative nøkkelindikatorer (KPI). I 2019 har det vært stort fokus på å utvikle rammeverket for ZEN definisjonen i et ZEN KPI verktøy siden pilotprosjektene trenger nøkkelindikatorer, samt metoder og verktøy som gjør dem i stand til å planlegge, prosjektere, måle og følge opp prosjekter. Det er tenkt at KPI skal brukes i alle prosjektfaser og involvere ulike aktører. Omfanget kan inkludere bygninger, infrastruktur eller begge deler. Nødvendige verktøy som setter ZEN partnere i stand til å gjennomføre en ZEN vurdering av nabolaget sitt samles i et ZEN verktøykasse. Resultatene kan derfra mates inn i ZEN KPI verktøyet for å vurdere området på både kategori og område nivå. Her skal vi utvikle referanseverdier, terskelverdier, referansemålinger og vekting for hvert KPI.

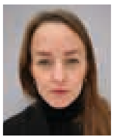
Vi har også utviklet en poengscore som skal vise hvor nært man er målet om å bli et nullutslippsområde. Partnerne velger selv ambisjonsnivå for hver kategori. Når alle kategorier er målt skal poengene vektes. Vektingen baseres på en spørreundersøkelse fylt ut av ZEN partnere og eksperter, hvor de fortalte hvor relevant, hvor stort potensiale og hvor alvorlig de mente hver kategori var. Etter vektingen får man et sluttresultat for hele området og på alle syv kategorier. Da er det mulig å oppnå kategorimerke (i mørkegrønn, grønn eller lysegrønn) og områdemerke (i bronse, sølv eller gull). Det å få et områdemerke er meget ambisiøst. Det er ikke sikkert pilotene oppnår områdemerking med det samme, men at de heller kan sette seg et mål om å få et par kategorimerker.



Figur 6. Kategorimerke i ZEN. Mørkegrønn er utmerket, grønn – meget god og lysegrønn – god.

Opportunities for establishing finite GHG emission allowances for material use in buildings

Marianne Kjendseth Wiik
SINTEF



Mie Fuglseth
Adviser,
Asplan Viak

Helge Brattebø
Professor,
NTNU

Greenhouse gas (GHG) emission targets for material use in buildings have so far been expressed as percentage reductions relative to socalled reference buildings. The advantage of this approach is that it has been possible to quantify targets despite lacking sufficient empirical knowledge on average emission levels for different building typologies.

However, this approach is challenging since projects are evaluated relative to a reference which is customised for each project. This way, calculated emission reductions can intentionally or unintentionally reflect an adapted reference instead of the actual mitigation measures taken.

The aim of this project is to establish scientifically robust benchmark values for different Norwegian building typologies that can be used by the Research Centre for Zero Emission Neighbourhoods (ZEN) in Smart Cities, by Futurebuilt, and in Norwegian building codes to help form recommendations for national GHG emission requirements.

Empirical life cycle GHG emission data have been collected from Norwegian building case studies in the reference, design, and as built project phases and for the production (A1-A3) and replacement (B4) phases of material use in buildings. They are sampled from Norwegian programmes and research centres such as Futurebuilt, Framtidens Byer, the Research Centre on Zero Emission Buildings (ZEB), and ZEN. Altogether, over 120 Norwegian building case studies have been gathered from 2009-2019, covering over one million m^2 of heated floor area and over 47 000 users.

The results show an interquartile range of 232-474 kgCO_{2eq}/m^2 or 3.9-7.9 kgCO_{2eq}/m^2/yr and a median of 300 kgCO_{2eq}/m^2 or 5 kgCO_{2eq}/m^2/yr for all building typologies in the as built phase.

The results show a decrease in emissions from 2012-13, when EN 15804 and EN 15978 were introduced, as well as klimagassregnskap.no version 4 with an improved emission factor database and the introduction of the ZEB tool. This result is thought to be because of the introduction of more standardised data sources from for example environmental product declarations (EPDs) and the Ecoinvent database. It will be interesting to see what developments the introduction of NS 3720 and the wide-spread use of OneClick LCA in 2018 will have on future life cycle GHG emission calculations and results in Norway.

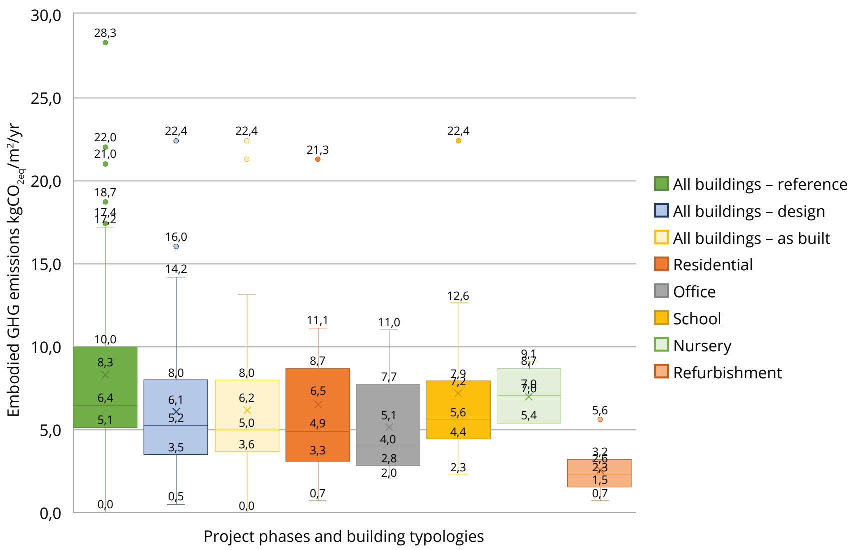


Figure 7. Boxplot of embodied GHG emissions across different project phases and building typologies (A1-A3, B4).

Muligheten for å etablere absolutte klimagassutslippskrav til materialer i bygninger

Målsetting om klimagassutslippsreduksjoner fra materialbruk i bygg har fram til i dag vært knyttet til prosentvis reduksjon sammenlignet med referansebygg. Fordelen ved denne tilnærmingen er at det har vært mulig å sette mål, på tross av manglende statistikkgrunnlag og kunnskap om utslippsnivå for ulike typer bygninger.

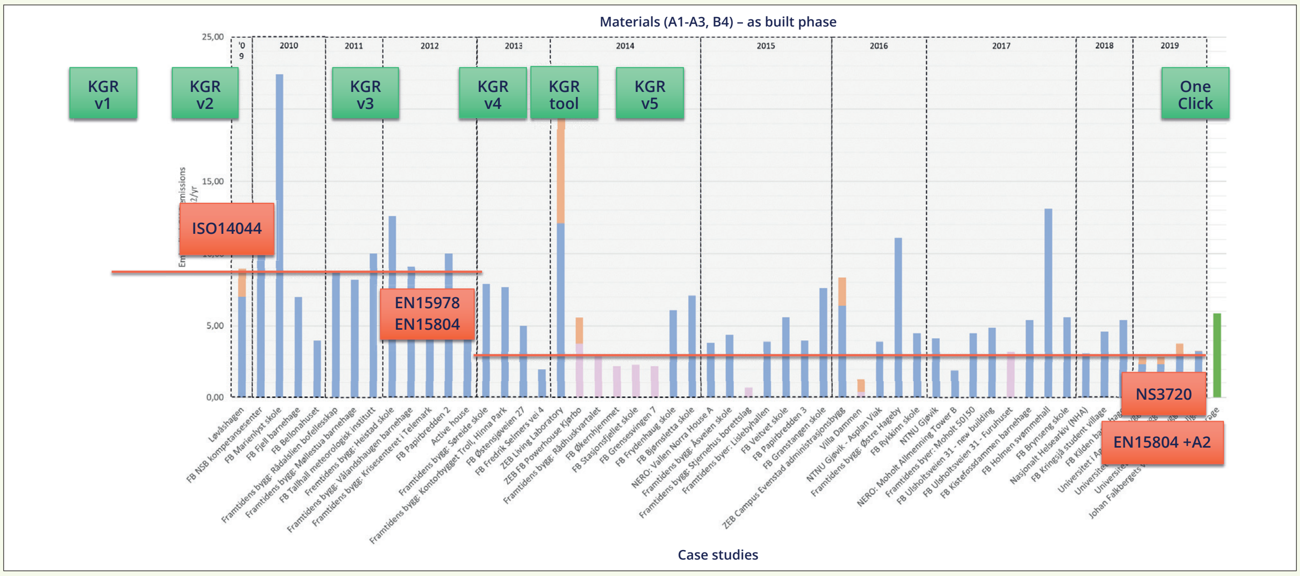
Utfordringen ved bruk av denne typen relative mål er imidlertid at prosjektene forholder seg til beregninger av referansen som utføres i hvert enkelt prosjekt. Dette åpner for at beregnede utslippsreduksjoner tilsiktet eller utilsiktet kan gjenspeile en tilpasset referanse i stedet for tiltak i prosjektet.

Målet for prosjektet er å etablere vitenskapelig forankrede referanseverdier for utslippsnivå for materialbruk i bygninger med ulike funksjoner. Slike absolutte utslippsnivåer kan benyttes av ZEN og FutureBuilt og kan danne grunnlag for myndighetskrav til utslipp i byggteknisk forskrift (TEK).

Data fra livsløpsbaserte klimagassberegninger for norske bygninger har blitt samlet inn, med fokus på produksjonsfasen (A1-A3) og utskiftninger av materialer i bruksfasen (B4), og fra ordninger som FutureBuilt, Farmtidens Byer, ZEB, og ZEN, samt andre case. Totalt er det samlet inn data for over 120 prosjekter fra perioden 2009-2019. Disse dekker til sammen over 1 million m² oppvarmet bruksareal og over 47.000 brukere.

Resultatene av sammenstillingen viser en kvartilbredde på 232-474 $kgCO_{2eq}/m^2$, eller 3.9-7.9 $kgCO_{2eq}/m^2$/år, og en median på 300 $kgCO_{2eq}/m^2$ eller 5 $kgCO_{2eq}/m^2$/år for alle bygningstypene som bygget.

Resultatene viser en nedgang i beregnede utslipp fra 2012/13, på tidspunktet der både EN 15804 og EN 15978 ble introdusert, i tillegg til versjon 4 av klimagassregnskap.no med en forbedret utslippsdatabase, og ZEB-verktøyet. Dette funnet er antatt å skyldes at introduksjonen av mer standardiserte datakilder fra for eksempel miljødeklarasjoner (EPD) og Ecoinvent-databasen. Det vil bli interessant å følge hvilken betydning NS 3720 og bred bruk av OneClick LCA vil ha på fremtidige klimagassberegninger og -resultater for bygninger i Norge.



Figur 8. Søylediagram av klimagassutslipp fra livssyklusmodulene A1-A3 (blå) og B4 (oransje) i som bygget fasen i kronologisk rekkefølge. Alle bygninger fra Futurebuilt har aggregert klimagassutslipp fra materialbruk (A1-A3 og B4) I ett (blå). Renoveringsprosjekter vises i rosa.

Strategies and business models for low-carbon concrete with CCS

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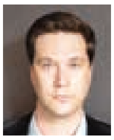

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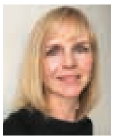

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Concrete is one of the most widely used materials in the world and accounts for approximately 7-8% of the climate gas emissions worldwide.[1] Except from infrastructure, buildings are the main consumer of concrete. The cement in the concrete stands for around 90% of the climate gas emissions, and therefore it is undertaken considerable efforts to reduce the emissions from the production of cement is undertaken. In ZEN we are working on the reduction of climate gas emissions from materials, and apart from that, a ZEN case is exploring strategies and business models for low-carbon concrete with carbon capture and storage (CCS).

Norcem is preparing a CCS facility at Brevik outside of Porsgrunn. This will become the first full-scale CCS-facility connected to the production of cement in the world. The degree of innovation is high and the potential for diversification likewise. From earlier experience and calculations undertaken we are relatively confident that the cost of CCS will decrease when the first facilities have been built. The technology is already developed, but the financing seems to be the biggest issue. The share of concrete in a building structure is relatively small. Estimates show that the impact of low Carbone Concrete will be a price increase of 1-3 % for the building project. [2]

In the ZEN-case on strategies and business models for low-carbon concrete with CCS, scenarios are developed and the impact of alternative measures are calculated. This can be market based measures or different types of public incentives or regulations. How much the end-user is willing to pay is one of the questions we have asked ourselves. A small survey conducted by ZEN indicates that there will be a market demand for materials with low emissions. 75% of the respondents in the survey were willing to pay more for materials with a lower climate footprint. A new approach to measures to promote environmental qualities and innovative business models is necessary. Public procurement and ecolabelling are measures that the industry itself can influence. The conclusions of the ZEN case will be published in the first part of 2020.

Figure 9. The cement production site at Brevik, where CCS is planned. Photo: Norcem.

Strategi og forretningsmodeller for lavkarbonbetong med CCS

Betong er et av verdens mest anvendte materialer og regnes for å bidra til 7-8% av klimagassutslippene på verdensbasis. [1] Bortsett fra infrastruktur er bygg den største forbrukeren av betong. Sementen i betongen står for rundt 90% av utslippene, derfor gjøres det en betydelig innsats for å redusere utslippene fra sementproduksjon. I FME ZEN arbeider vi blant annet med å redusere klimafotavtrykket fra materialer og har dessuten et ZEN case som undersøker strategier og forretningsmodeller for lavkarbonbetong med karbonfangst- og lagring (CCS).

Figur 10. Beregnet reduserte utslipp ved realisering av CCS anlegg på Brevik. Foto: Norcem.

Norcem legger nå til rette for et CCS anlegg på Brevik utenfor Porsgrunn. Dette vil bli det første fullskala CCS-anlegget tilknyttet sementproduksjon i verden. Innovasjonsgraden er svært høy, og det er også spredningspotensialet. Og fra tidligere erfaringer og beregninger som er gjort er vi rimelig sikre på at kostnaden ved CCS vil synke etter at de første anleggene er oppført. Teknologien finnes, det er finansieringsløsningene som er den største utfordringen. Andelen betong i en bygning er relativt liten, og prisøkningen for byggeprosjekt som baseres på lavkarbonbetong med CCS er estimert til 1-3%. [2]

I et ZEN case om strategier og forretningsmodeller for lavkarbonbetong med CCS utarbeider vi scenarier og beregner effekten av alternative tiltak. Dette kan være markedsbaserte tiltak eller ulike typer offentlige incentiver eller reguleringer. Hvor mye sluttbrukeren er villig til å betale av regningen er et av spørsmålene vi har stilt oss. En undersøkelse gjennomført av ZEN indikerer at markedet vil etterspørre materialer med lave utslipp, og 75 % av de spurte i undersøkelsen svarer at de er villige til å betale mer for materialer med lavere klimafotavtrykk. Det er behov for å tenke nytt med hensyn til miljøkvaliteter hvor innovative forretningsmodeller, innkjøp og miljømerking er virkemidler som bransjen selv kan utforme eller påvirke. Konklusjonene fra arbeidet blir publisert i første del av 2020.

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Circular buildings are about to take off in the market. What does that mean?

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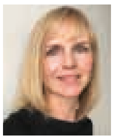

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In 2019 and 2020 the ZEN Research Centre is cooperating with ZEN-partner FutureBuilt, Norwegian Green Building Council, and Enova to conduct a series of innovation workshops. The themes are different for each workshop, but a common denominator is a goal to illuminate possibilities and the innovation front, as well as issues for the built environment in a sustainability- and climate perspective. One of these workshops was about circular buildings, which is also a central theme in the next project period of FutureBuilt. The interest to attend the workshop was overwhelming and discussions many and engaged. But what does the concept of circular buildings mean to the market and what does it mean to ZEN?

A large amount of resources are lost each year due to building materials and building components being thrown away, destroyed, burned, or deposited. This happens due to incorrect orders and/or deliveries and, excess materials and parts during construction, as well as fully usable building materials and building components being destroyed during demolition. In order to reduce the strain on climate and environment it is important to exploit the possibilities for a better utilization of resources. The potential is great and possibilities many, but there are also some challenges along the way. One of the challenges is how to ensure that reused building materials and -components are of adequate quality to be reused. There is a strict regulation of product documentation [1] which is difficult to comply with when reusing materials and components. Trading goods that do not have product documentation is illegal, and there is a lack of systematic testing and quality control of such goods as of today. There is also a lack of a well-functioning marketplace for legally traded goods, even if some businesses have been established over the last few years. The building industry must prepare for dismantling of buildings instead of demolition in the future. This has consequences for how buildings and building parts are designed, put together, and erected.

There is no doubt that many market actors find circular buildings appealing, and several best practice projects are about to be completed in line with the FutureBuilt criteria for circular buildings [2]. Authorities and academia have an important role in controlling and substantiating a safe, efficient, and sustainable development through research-based knowledge. ZEN has an important role to play by including circular issues in the research and as far as possible illuminating areas of importance.

Figure 11. Workshop on circular buildings. Photo: FutureBuilt.

Sirkulære bygg er på vei inn i markedet, hva innebærer det?

I 2019 og 2020 samarbeider forskningssenteret ZEN med ZEN-partner FutureBuilt, Grønn Byggallianse og Enova om å gjennomføre en serie med innovasjonsworkshops. Tema er ulike for hver workshop, men alle har som fellesnevner et mål om å belyse muligheter, innovasjonsfront og problemstillinger av betydning for det bygde miljø i et bærekrafts- og klimaperspektiv. En av disse workshopene tok opp temaet sirkulære bygg som også er et sentralt tema i FutureBuilt sin neste prosjektperiode. Interessen for workshopen var overveldende stor og diskusjonene mange og engasjerte. Men hva innebærer sirkulære bygg for markedet, og hva innebærer det for ZEN?

Det er store ressurser som går tapt hvert år ved at byggematerialer og bygningskomponenter blir kastet, destruert, brent og deponert. Dette skjer ved feilleveranser/-bestillinger, materialer og deler som blir "til overs" under bygging, samt fullt brukbare byggematerialer og bygningskomponenter som blir destruert ved rivning av bygg. For at vi skal redusere klima- og miljøbelastningen er det viktig at vi utnytter mulighetene for å få til en bedre ressursutnyttelse. Potensialet er stort og mulighetene mange, men det er også noen skjær i sjøen. En av utfordringene er hvordan vi sikrer oss at brukte materialer og komponenter er av tilfredsstillende kvalitet for ombruk. Det stilles krav til produktdokumentasjon [1] som er vanskelig å overholde ved ombruk av materialer og komponenter. Omsetning av varer uten dokumentasjon er ulovlig, og det finnes ingen systematikk for testing og kvalitetssikring av slike varer per i dag. Det mangler også velfungerende markedsplasser for lovlig omsatte varer, selv om flere slike er forsøkt etablert de siste årene. Byggebransjen må også forberede seg på at bygg i fremtiden skal demonteres og ikke rives. Det har konsekvenser for hvordan bygg og bygningsdeler designes, oppføres og settes sammen.

Det er ingen tvil om at mange markedsaktører synes at dette er et interessant og viktig område, og flere forbildeprosjekter er i ferd med å bli gjennomført, i tråd med FutureBuilt sine kriterier for sirkulære bygg [2]. Myndigheter og forskningsinstitusjoner har en viktig rolle i å styre og underbygge en god utvikling gjennom forskningsbasert kunnskap. Her vil ZEN kunne spille en viktig rolle ved å inkludere sirkulære problemstillinger i forskningen og så langt mulig bidra til at området blir belyst.

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Figur 12. Utstillingen Wasteland – fra avfall til arkitektur. Foto: Ann Kristin Kvellheim.

Improving the knowledge of environmental performance of ventilation systems

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The environmental footprint of buildings can be roughly divided in two; emissions related to operational energy use during the use phase and embodied emissions in material use for construction, renovation, and maintenance. The current decades' efforts to improve energy efficiency have been successful in significantly reducing the operational energy use. However, there has been a cost in terms of increased material use to minimize heat losses and more technical installations to control the building performance. The environmental impacts from use of materials and energy have been widely studied, but the embodied emissions in technical systems are generally insufficiently addressed. This is also the case for ventilation systems, which contains e.g. ducts, bends, fans and air handling units, inlet air valves, variable flow dampers, etc.

Life Cycle Assessment (LCA) is commonly used when assessing the full environmental impacts of buildings. In these studies, ventilation systems are generally represented by highly generic proxy components (limited selection of dimensions and component types), by an estimated emissions penalty, or by simply omitting the component from the study. In this work we provide a detailed library for the main components in common ventilation systems. The library covers a wide range of dimensions, providing inventory descriptions and environmental assessment of more than 270 individual components, ranging from small dimensions for private homes to large commercial buildings. Improved information on individual components will contribute to a better understanding of the impacts from ventilation systems and can be tailored to represent ventilation system designs for specific variants or specific buildings instead of being omitted or represented by proxies.

Having a library of building blocks for ventilation design also offers additional possibilities for further and more advanced use. The library can for example be used by an evolutionary/genetic algorithm to find optimal design solutions taking into account operational fan energy use and material use in order to minimize the total life cycle impacts of ventilation systems, thereby addressing the trade-off between operational energy and material use. For instance, for ventilation systems with low specific fan power (SFP), the energy use for the fan is reduced, while material use is increased (larger physical dimensions).

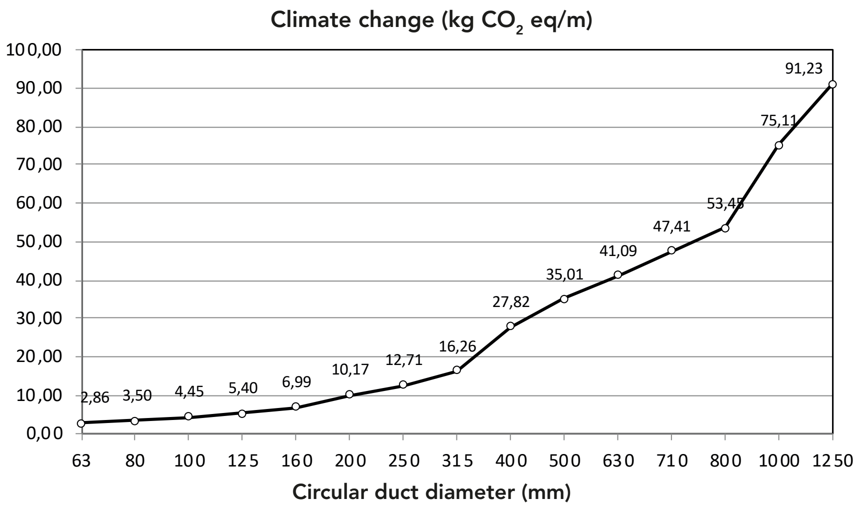

Figure 13. Climate emissions per 1 m of different cross-sections for circular ducts.

Økt kunnskap om ventilasjonssystemers miljøprestasjon

Miljøpåvirkningen fra bygg kan grovt sett deles i to hovedkategorier; utslipp fra energiproduksjon i bruksfasen og utslipp fra materialproduksjon knyttet til bygging, vedlikehold og renovering. Gjennom arbeid med energieffektivisering har man i de siste tiårene oppnådd betydelig reduksjon i energibruk i driftsfasen, men dette har hatt en kostnad i form av økt materialbruk for å redusere varmetap og mer omfattende bruk av tekniske installasjoner for å oppnå ønsket prestasjon. Miljøpåvirkning fra både materialer og energi har vært tema for mange studier og er velkjent, men utslipp forbundet med tekniske installasjoner er generelt sett ikke tilstrekkelig beskrevet. Dette er også tilfelle for ventilasjonssystemer og -komponenter, som kanaler, bend, vifter og aggregater, inntaksventiler, VAV-spjeld etc.

Livsløpsvurderinger (LCA) er en vanlig metode for helhetlig miljøvurdering av bygninger. I disse studiene er ventilasjonssystemer vanligvis representert ved et svært begrenset utvalg av standardkomponenter og -størrelser, ved et generelt utslippspåslag eller de er rett og slett utelatt. I dette arbeidet har vi utarbeidet et detaljert bibliotek for de viktigste komponentene i vanlige ventilasjonssystemer. Biblioteket inneholder et bredt utvalg av dimensjoner med en detaljert beskrivelse og tilhørende miljøvurdering for over 270 enkeltkomponenter; fra mindre dimensjoner til bruk i privathjem til store næringsbygg. Økt detaljeringsnivå for ulike komponenter vil bidra til en bedre forståelse av miljøbelastning og utslipp knyttet valg av ventilasjonsløsninger og kan også brukes til å designe og vurdere ulike spesifikke alternativer.

Et komponentbibliotek med material- og miljøinformasjon gir også muligheter for mer avansert bruk. Eksempelvis kan et slikt bibliotek være utgangspunkt for bruk i en genetisk algoritme for å finne designløsninger som tar hensyn til både energi til viftedrift og materialbruk for å finne optimale løsninger med lavest mulig miljøfotavtrykk gjennom et byggs levetid. For ventilasjonssystemer med lav vifteeffekt (SFP) er energibruk til viften redusert mens materialbruken er økt (større dimensjoner). Et godt komponentbibliotek koblet med en optimaliseringsalgoritme kan belyse avveiningen mellom energi- og materialbruk.

Figur 14. Utsnitt av ventilasjonssystem med ventilasjonsaggregat. Foto: Jens Tønnesen.

An energy resilience framework for zero emission buildings at the neighborhood scale

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Buildings performance can be affected by uncertainties and unforeseen events related to changing environments (e.g. extreme weather conditions and changes in occupant behavior) or changing requirements (e.g. applying new technologies and regulations). Thus, buildings should be able to react to these events in order to last their performance. It is recommended that building designers and decision-makers consider such changes and uncertainties in the design or renovation phase and that they implement mechanisms to protect the building performance against adverse events in the future. One of these mechanisms is a resilient building design. A resilient building can *prepare* and *plan for*, *absorb*, *recover from*, and more successfully *adapt* to adverse events in the operation phase. These stages are known as resilience abilities [1] (Figure 15).

Taking resilience into account assures designers, decision-makers, and homeowners that the buildings will perform well and on the expected level against future changes, through either maintaining its performance and functionality or recovering quickly in the case of failing its functionality.

Literature shows that in order to achieve resilient design, different principles, such as redundancy, robustness, efficiency, adaptability, flexibility, etc., should be considered. [1] This confirms that resilience demands more than robustness, flexibility, etc.

My PhD project aims to develop a framework for energy resilience evaluation of buildings at a neighborhood scale. So far, we have focused on robustness assessment under uncertain climate and occupant-behavior scenarios. The results of this work are presented in a paper submitted to the Journal of Applied Energy.

In this work, robustness is defined as the ability of a building to perform effectively and remain within acceptable margins under changing environments. Also, we introduced a new approach which is called T-robust, a multi-target robustness-based decision-making approach which gives the following opportunities to designers and decision-makers:

- Selecting a robust and high-performance building design from energy and comfort perspectives under different uncertainties.
- Reducing the performance gap between estimated and actual performance of buildings.
- Comparing the performance of designs not only to each other but also to the target value (desired value by designers, homeowner, etc.)
- Introducing a transparent and easy to understand approach which can settle the performance targets automatically in the procedure of robustness assessment and reduce the computational time and cost in comparison with other approaches.

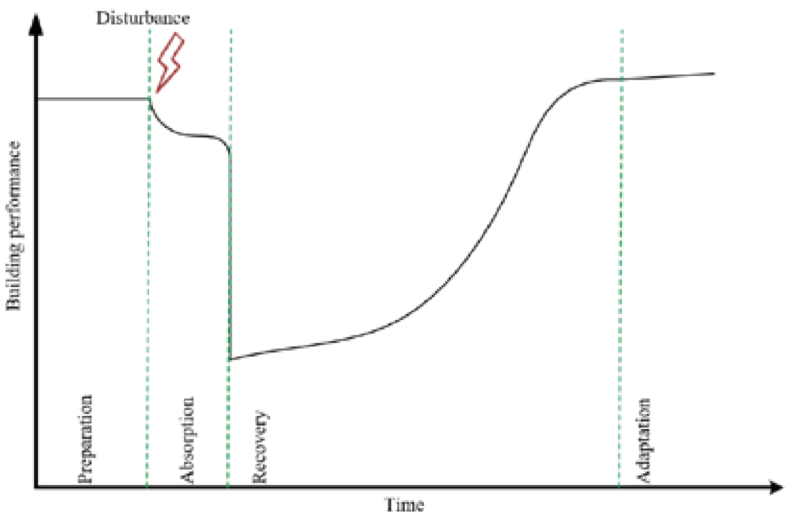
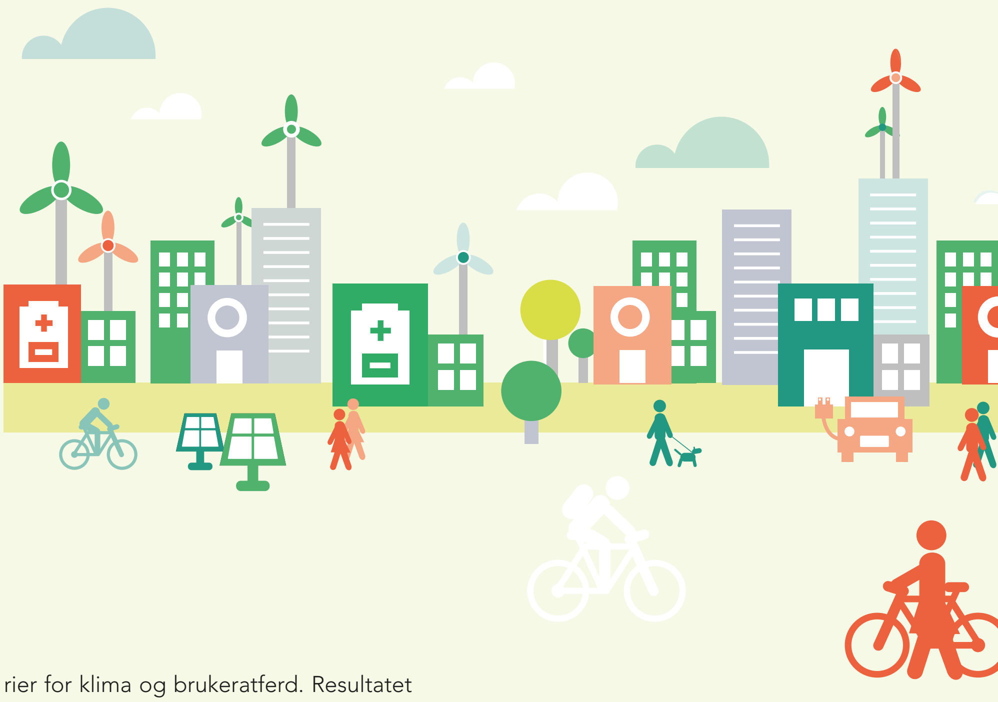


Figure 15. The four abilities of a resilient system.

Et rammeverk for energiresiliense for nullutslippsbygg i nabolagsskala

Ytelsen til en bygning kan påvirkes av uforutsette hendelser på grunn av miljøendringer (f.eks. ekstremvær eller endret brukeradferd) eller nye krav (f.eks. ny teknologi eller endrede forskrift-er). Bygninger bør være i stand til å reagere på slike hendelser sånn at de beholder sine ytelser og gode egenskaper. Designere og beslutningstakere bør å ta i betraktning slike mulige hendels-er og usikkerheter i design- eller renoveringsfasen og implementere mekanismer som beskytter bygningens ytelse mot uønskede hendelser i fremtiden. En av disse mekanismene er en resili-ent bygningsdesign. En resilient bygning kan forberede seg på, absorbere, komme seg fra og tilpasse seg uønskede hendelser på en vellykket måte i driftsfasen. Disse stadiene kalles resiliensmuligheter [1] (Figur 15).



Ved å ta hensyn til resiliens kan designere, beslutningstakere og huseiere forsikre seg om at bygningene vil fungere godt og på forventet nivå ved at den motstår eller svarer på fremtidige endringer ved å opprettholde ytelsen og funksjonaliteten eller raskt kommer seg tilbake til normal tilstand.

Litteraturen viser at for å oppnå resiliens så bør forskjellige prinsipper som redundans, robust-het, virkningsgrad, tilpasningsevne, fleksibilitet, etc. vurderes, [1] men at resiliens krever mer enn robusthet og fleksibilitet.

Doktorgradsprosjektet mitt har som mål å utvikle et rammeverk for evaluering av energiresiliens av bygninger på områdenivå. Så langt har vi fokusert på robusthetsvurdering under usikre scenarier for klima og brukeratferd. Resultatet av dette arbeidet er innsendt til journalen Applied Energy. I dette arbeidet er robusthet definert som en bygnings evne til å yte effektivt og forbli innenfor akseptable marginer under varierende miljøbelastninger. Vi introduserte også en ny tilnærming som kalles T-robust, en flermåls robusthetsbasert beslutningstilnærming som gir følgende muligheter til designere og beslutningstakere:

- Velge et robust bygningsdesign med høy ytelse ut i fra et energi- og komfortperspektiv under usikkerhet.
- Redusere ytelsesgapet mellom estimert og faktisk ytelse for bygninger.
- Sammenligne ytelsen til ulike design ikke bare med hverandre, men også med målverdien (ønsket verdi av designere, huseier, etc.)
- Introdusere en gjennomsiktig og lettforståelig tilnærming som automatisk kan fastsette resultatmålene i forbindelse med vurderingen av robusthet samt redusere beregningstiden og kostnadene sammenlignet med andre tilnærminger.

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Energy flexibility of buildings: Understanding how – and how much – thermal comfort by occupants can enable demand-response strategies

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Current research in building science aims at implementing strategies to exploit the energy flexibility of buildings. This consists in shifting energy use for different energy services in order to adapt the hour-by-hour energy consumption to what is optimal for the energy system. One of the most cost-effective solutions consists in utilising buildings' thermal mass as heat storage. Energy uses for space heating and cooling are important terms of a building's energy balance and can be displaced by some hours, utilising the building's thermal mass, without significantly affecting the thermal comfort of the occupants. However, this is an assumption that needs to be verified. One of the main purposes of a building is to provide an environment that is comfortable and that fosters health and performance of its occupants. So, to what extent it is possible to utilize the energy flexibility of buildings without compromising thermal comfort experienced by their occupants remains an open research question.

In this research, we aim at understanding occupant's thermal acceptability in dynamic indoor conditions – that is conditions where the indoor temperature varies +/- some degrees within a short time (three hours in these experiments) – and how it compares with the standard ASHRAE 55-2017 [1] limits on temperature cycles, ramps, and drifts. To do so, we designed a dedicated experiment executed in the ZEB Test Cell Lab from August to December 2019, where 40 people participated. Participants were asked to spend full or half days in the facility, furnished like a typical cellular office, and to evaluate the indoor environment through questionnaires while carrying out their everyday work activity. During the experiment, the air temperature was modified according to predefined thermal ramps while other environmental parameters, such as air velocity, relative humidity, CO_2 concentration, and illuminance on the work surface were also recorded. Furthermore, the participants were asked to press a button as soon as they felt uncomfortable, where uncomfortable was defined as "take an action to restore a comfort condition" (e.g., if too warm environment, then regulate the thermostat or open the window). In this way, it will be possible, after the analysis of collected data, to understand the limits of the human thermal acceptability under different temperature variations, before voluntary adaptation mechanisms or actions are undertaken.

Figure 16. Experiment in the test cell. From the left: Matteo Favero, Alla Marchenko, and Victor Rizzardi. Photo: ZEN.

Energifleksibilitet i bygninger: Å forstå hvordan – og hvor mye – termisk komfort kan muliggjøre "demand-response" strategier

Nåværende forskning innen bygningsvitenskap har som mål å iverksette strategier for å utnytte energifleksibiliteten til bygninger. Energifleksibilitet består av å kunne muliggjøre forflytninger i energibruket til et bygg, time for time, til det som er gunstig for energisystemets etterspørsel. En av de mest kostnadseffektive løsningene består av å utnytte bygningers termiske masse som varmelager. Siden alle bygninger har termisk masse innebygd i sine konstruksjoner, er det mulig å lagre en viss mengde indre energi her. Energibruk til oppvarming og kjøling av rom er viktige parametere for bygningens energibalanse, men disse parameterne kan utsettes noen timer ved å bruke bygningens termiske masse, uten å påvirke beboernes termiske komfort betydelig. Et av hovedformålene med en bygning å bidra til et behagelig innemiljø, som ikke skader beboernes helse eller produktivitet. I hvor stor grad det er mulig å utnytte bygningers energifleksibilitet uten at det går ut over termisk komfort, er imidlertid en antagelse som må bekreftes.

I denne studien ønsket vi å oppnå en bedre forståelse av beboerens "thermal acceptability" under dynamiske innendørsforhold – det vil at innetemperaturen varierte +/- noen grader i løpet av tre timer – og sammenlignet med standarden ASHRAE 55-2017 [1] grenser for forskjellige temperatursykluser, grensesnitt og drivere. Vi utførte et eksperiment i ZEB Test Cell Lab fra august til desember 2019, hvor 40 personer deltok.

Deltakerne ble bedt om å tilbringe hele eller en halv dag på anlegget, innredet som et typisk kontor. I løpet av oppholdstiden ble deltagerne bedt om å evaluere innemiljøet med bruk av spørreskjemaer. Over tid ble lufttemperaturen endret i henhold til forhåndsdefinerte måleparametere. Disse måleparametere var lufthastighet, relativ luftfuktighet, CO_2-konsentrasjon og belysning. Videre ble deltakerne bedt om å trykke på en knapp så snart de følte seg ukomfortable, der ubehag ble definert som "iverksette tiltak for å gjenopprette en komforttilstand" (f.eks. for varme omgivelser: må regulere termostaten eller åpne vinduet). På denne måten var det mulig å forstå grensene for "thermal acceptability" under forskjellige temperaturvariasjoner, før frivillige tilpasningsmekanismer og handlinger ble utført.

Referanser
[1] ASHRAE: American Society of Heating, Refrigeration and Air-conditioning Engineers. The ASHRAE standard 55 standard "Thermal Environmental Conditions for Human Occupancy" specifies some limits on short term variations of the indoor temperature.

Establishing a database and a model of building load profiles from measurements in buildings representing over 2.5 mill m² floor area across Norway

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Planning and design of the energy systems on different scales, from neighborhoods to city and to regional and national levels, relies upon estimating the aggregated load profiles of a given building stock. Aggregated load profiles illustrate the hourly energy demand, separated into heating demand and electric specific demand, for the sum of all buildings in the given area and climate. This information is the starting point for designing for example a local heat pump system or for planning the expansion of a district heating system.

A database of energy measurements has been established, gathering data from several sources, including ZEN pilot buildings and previous ZEB pilot buildings that are in operation. The database consists of ca. 340 independent entries representing more than 2.5 million m² of floor area, from several locations in Norway. The database contains 11 building categories, where more than 90% of the represented building mass is from non-residential buildings, such as offices, shops, and schools. Approximately 5% of the measurements come from very energy efficient buildings. All entries consist of hourly measurements for a continuous period of observation between 1 and 4 years. The measurements are split in electric specific load and heating load, given that all data are collected from buildings served by district heating.

A statistical model of a building's load profiles has been developed from the database, as presented in a previous publication [1]. However, since the database has been significantly expanded, work is in progress to update the model, and its accuracy is expected to improve. Furthermore, the modelled load profiles will be compared with out-of-sample data, i.e. with measurements that are not part of the database, for validation purposes.

For new buildings and buildings to be renovated with an energy efficiency upgrade, measurements cannot be directly used, thus the need for an estimation. Often such estimations rely on simulations although there is a well-known gap between simulated and real performance. The load profile model allows to overcome this barrier.

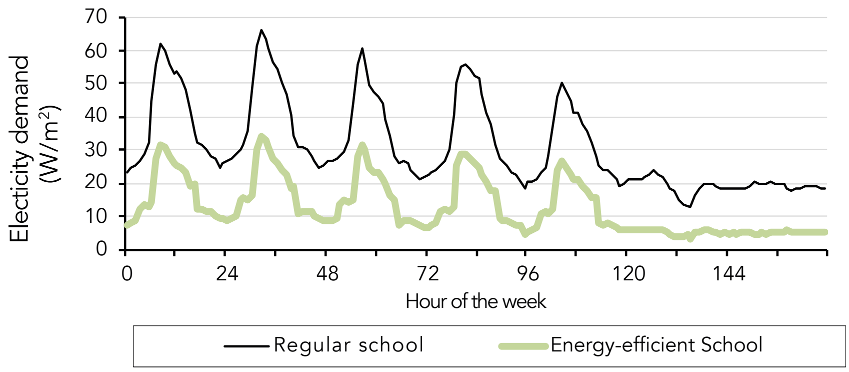


Figure 17. Hourly electricity load in a cold week in winter. Comparing a regular building to an energy-efficient building, if both are heated by electric radiators [2].

Etablering av en database og en modell for å lage lasteprofiler fra målinger for 2,5 millioner m² gulvareal fra hele Norge

Planlegging og utforming av energisystemene på forskjellige skalaer, fra nabolag til by, regionalt og nasjonalt nivå, er avhengig av å estimere de samlede aggregerte lastprofilene til gitte bygninger. Aggregerte lastprofiler betyr at energibehovet per time er atskilt fra varmebehov og elektrisk spesifikt behov og er summen av dataene for alle bygninger i et gitt område og klima. Denne informasjonen er utgangspunktet når man for eksempel skal utforme et lokalt varmepumpesystem eller ved planlegging av utvidelse av et fjernvarmeanlegg.

Det har blitt opprettet en database med energimålinger som samler inn data fra flere bygg, inkludert ZEN-pilotprosjekter samt ZEB-pilotbygg som er i drift. Databasen består av ca. 340 uavhengige data innganger som representerer mer enn 2,5 millioner m2 gulvareal fra flere steder i Norge. Databasen inneholder også 11 bygningskategorier, der mer enn 90% av den representerte bygningsmassen kommer fra kontorer, butikker og skoler. Omtrent 5% av målingene kommer fra svært energieffektive bygninger. Alle målingene er timesbaserte for en kontinuerlig observasjonsperiode mellom 1 og 4 år og er delt i elektrisk spesifikk belastning og varmelast, gitt at alle data er samlet inn fra bygninger som betjenes av fjernvarme.

En statistisk modell av bygningens lastprofiler er utviklet fra databasen, og denne statistiske modellen er presentert i en publikasjon [1]. Siden databasen har blitt betydelig utvidet, pågår det imidlertid arbeid med å oppdatere modellen, hvor nøyaktigheten forventes å bli forbedret. Videre vil de modellerte lastprofilene sammenlignes med andre data, dvs. med målinger som ikke er en del av databasen for valideringsformål.

For at nybygg og bygninger skal renoveres med energieffektivitetsoppgradering, kan ikke målinger brukes direkte, og dermed er det behov for en estimering. Ofte er slike estimater avhengige av simuleringer, selv om det er kjent avvik mellom simulert og reell bygningsytelse. Lastprofilmodellen gjør det mulig å overvinne denne barrieren.

Referanser

[1] K.B. Lindberg, S.J. Bakker and I. Sartori (2019) Modelling electric and heat load profiles of non-residential buildings for use in long-term aggregate load forecasts, Utilities Policy (58) 63-88.

[2] K.B.Lindberg, P.Seljom, H.Madsen, D. Fischer and M.Korpås (2019) Long-term electricity load forecasting: Current and future trends, Utilities Policy (58) 102-119.

Are Norwegian ZENs contributing to reduced greenhouse gas emissions in Europe?

Ingeborg Graabak
Researcher,
SINTEF Energy Research

Calculations of greenhouse gas (GHG) emissions for energy use in buildings are a debated topic. How will e.g. reduced power consumption, self-generated electricity with solar cells, and increased flexibility affect GHG? This is an important issue within the ZEN Research Centre.

SINTEF Energy Research and SINTEF Community have studied how ZENs in Norway contribute to reduced emissions in Europe. A main purpose of the analysis has been to show that different approaches can give different answers, and still be correct. Scenarios for Europe in 2030 have been analysed using the EMPS model (Samkjøringsmodellen). All capacities are set according to scenarios that correspond to political goals for 2030. A reference case without ZENs in Norway is compared with a case with 25% ZENs. 25% ZENs is modelled as reduced heating demand, changed consumption profile, and significant PV production. The different approaches were (text in brackets refers to columns in Figure 19):

1) Calculation of average emissions in Europe (REF, ZEN)
2) Calculation of marginal change in emissions between reference case and
   a. ZEN case (ZEN-REF)
   b. ZEN case taking into account the quota market and assuming that the number of quotas is kept unchanged (ZENKvot-REF)
   c. ZEN case taking into account the quota market and assuming that half the number of allowances released due to ZEN is revoked (ZEN-Pol-REF)
3) Calculation of marginal change in emissions, taking into account that ZEN affects prices and thus profitability for new investments in both transmission capacity, new wind power, and new gas power and whether it is profitable to maintain existing thermal power generation capacity (ZENInv- REFInv).

In this analysis, 25% ZENs led to Norway exporting 16.4 TWh more electricity per year. This reduced emissions in European power generation by just over 1%. Emissions were reduced across Europe, but most in Norway's neighbouring countries. In the case of keeping the number of allowances unchanged, emissions remained the same per construction. They decreased if any released allowances were withdrawn. The highest change in emissions was in Approache 3. Solar power makes it profitable with more cables to other countries and thus also increases the profitability of new wind power in Norway. This is because wind power produces at other times than solar power and because prices are somewhat higher in Norway with more cables.

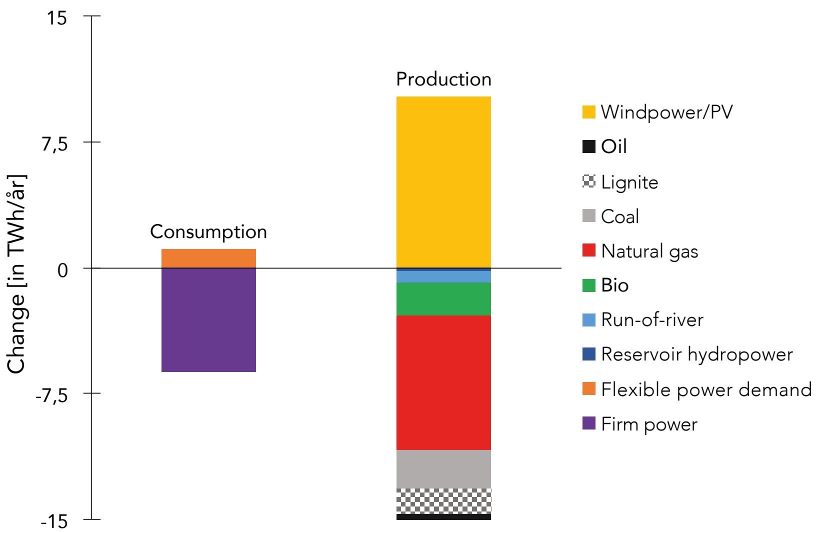


Figure 18. Marginal changes in electricity consumption and production as a result of the introduction of 25% ZEN in Norway (Approach 2b).

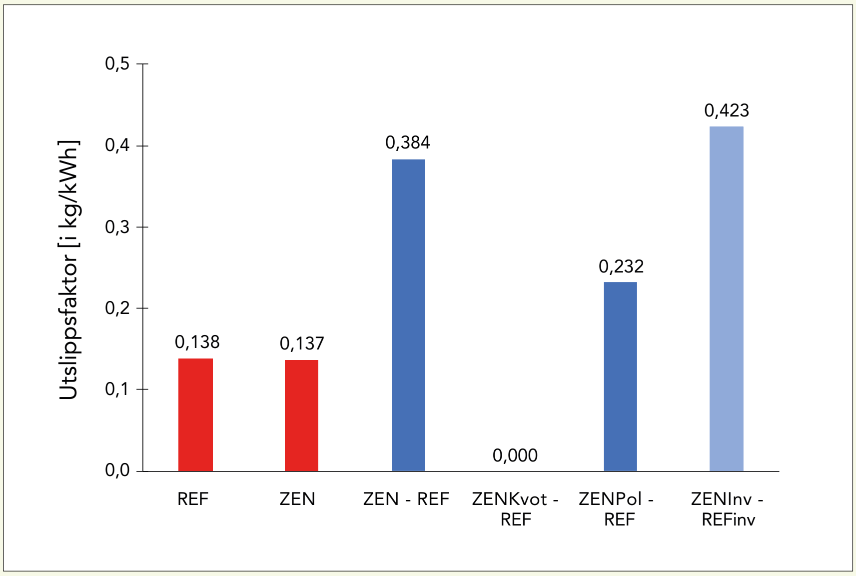
Bidrar norske nullutslippsområder til reduserte klimagassutslipp i Europa?

Klimagassberegninger for energibruken i bygg er et omdiskutert tema. Hvordan vil f.eks. redusert strømforbruk, egenproduksjon av strøm med solceller, og økt fleksibilitet påvirke klimagassutslippene? Dette er et viktig spørsmål innenfor forskningssenteret FME ZEN, som omhandler nullutslippsområder.

SINTEF Energi og SINTEF Community har analysert hvordan ZEN i Norge bidrar til redusert utslipp i Europa. En hovedhensikt med analysen har vært å vise at ulike tilnærminger kan gi ulike svar, men likevel være riktige. Europa i 2030 er analysert ved hjelp av Samkjøringsmodellen. Alle kapasiteter er satt i henhold til scenarier som samsvarer med politiske målsettinger for 2030. Et referansecase uten ZEN i Norge er sammenlignet med et case med 25% ZEN. 25% ZEN er modellert som redusert oppvarmingsbehov, endret forbruksprofil sammen med en vesentlig kraftproduksjon fra PV. De ulike tilnærmingene var (tekst i parentes viser til kolonner i figur 19):

1) Beregning av gjennomsnittutslipp i Europa (REF, ZEN)

2) Beregning av marginal endring i utslipp mellom referansecase og
   a. ZEN case (ZEN-REF)
   b. ZEN case hensyntatt kvotemarked og forutsatt at antall kvoter holdes uendret (ZENKvot-REF)
   c. ZEN case hensyntatt kvotemarked og forutsatt at halvparten av antall frigjorte kvoter pga. ZEN blir inndratt (ZENPol-REF)

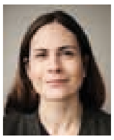


Figur 19. Gjennomsnittlige (røde) og marginale (blå) utslipp for alle tilnærminger.

3) Beregning av marginal endring i utslipp når en også hensyntar at ZEN påvirker priser og dermed lønnsomhet for nye investeringer i både transmisjonskapasitet, ny vindkraft, og ny gasskraft samt om det er lønnsomt å vedlikeholde eksisterende kapasitet for termisk kraftproduksjon (ZENInv-REFInv).

I denne analysen førte 25% ZEN til at Norge eksporterte 16.4 TWh mer strøm pr år. Dette reduserte utslippene i europeisk kraftproduksjon med i overkant av 1%. Utslippene ble redusert over hele Europa, men mest i Norges naboland. I caset med uendret antall kvoter ble utslippene uforandret per konstruksjon, mens de gikk ned hvis noen frigjorte kvoter ble inndratt. Den høyeste endringen av utslipp var i tilnærming 3. Solkraft gjør det lønnsomt med flere utenlandskabler og dermed øker også lønnsomheten for ny vindkraft i Norge. Dette fordi vindkraften produserer på andre tidspunkter enn solkraft og fordi prisene blir noe høyere i Norge med flere kabler.

Mære – a zero emission farm as a living laboratory



Judith Thomsen
Research manager,
SINTEF Community

Torger Mjønes
Project manager,
Trøndelag county

John Clauss
Researcher,
SINTEF Community

The agricultural school in Steinkjer municipality is the latest project among the ZEN pilot areas. The area is one of two ZEN pilots that have been completed and are in use. The agricultural school is owned by Trøndelag County Council. The school has 70 employees and educates about 200 pupils and adults in agriculture, forestry, local food production, and climate/energy measures in agriculture. Mære has a total building area of approximately 20,000 m2, which includes operational buildings, a greenhouse, an apartment building, and administration and educational buildings. In recent years, Mære has got a new cowshed, a shed with a roof-integrated solar cell system and a building with passive house standard and solar cells. In addition, a new stable is being built as a zero emission building (ZEB-O). The greenhouse is used for cultivation of tomatoes and flowers and contains a hall for gardening business.

As early as in 2015, the county council established the "Agriculture's Climate and Energy Center" at Mære as an arena for R&D, where the development of the Center has been done in close cooperation with agricultural organizations. A dedicated R&D team has been established to work on research initiatives.

MÆRE'S AMBITION IS TO BECOME A LIGHTHOUSE EXAMPLE FOR AGRICULTURAL AREAS

ZEN will help to work towards this ambition, especially from the building-point-of-view. Various technologies and processes related to buildings and the energy system have already been established. Among other things, a local heating grid has been established between most of the buildings. This provides a good basis for further optimization of control and thermal energy exchange between the buildings. The energy system is monitored continuously. Based on these measurements, ZEN will in 2020 map and investigate how the energy system at Mære currently performs and look at opportunities to improve operational strategies. This also includes considering thermal energy storage and improving the use on-site generated electricity from photovoltaic panels.

The energy system is not ZEN's only focus here. A life cycle analysis will also be done to look at greenhouse gas emissions from different parts of a farm. Among other things, work will be done on defining system boundaries for a zero emission farm from a ZEN perspective and even beyond. There are many partners involved in this process, so further topics may come up in the course of 2020.

Figure 20. Impressions from Mære agricultural school in Steinkjer municipality.
Photo 1 and 2: ZEN Research Centre, photo 3: Zeiner Media.

Mære – En nullutslippsgård som et levende laboratorium

Mære landbruksskole i Steinkjer kommune er det siste tilskuddet blant pilotområdene i ZEN. Området er et av to ZEN piloter som er ferdig bygd og i bruk. Landbruksskolen er eid av Trøndelag fylkeskommune. Skolen har 70 ansatte, og det utdannes om lag 200 elever og voksne innen jordbruk, skogbruk, lokal matproduksjon og klima/energitiltak i landbruket. Mære har et samlet byggeareal på om lag 20 000 m^2 og omfatter driftsbygninger, et veksthus, hybelhus, administrasjonsbygg og undervisningsbygg. I de senere år har Mære fått et nytt melkefjøs, et ammekufjøs med takintegrert solcelleanlegg og et hybelbygg med passivhusstandard og solceller. I tillegg bygges en ny stall som nullutslippsbygg (ZEB-O). I veksthuset er det produksjon av tomat, blomster og en hall for anleggsgartner-virksomhet. På skolen er det også en frukt- og bærhage.

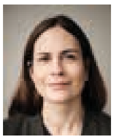
Fylkeskommunen etablerte allerede i 2015 «Landbrukets klima og energisenter» på Mære som arena for FoU. Utviklingen av Landbrukets klima og energisenter har skjedd i nært samarbeid med landbrukets organisasjoner. Det er etablert et eget FoU-team som jobber med forskningsinitiativene.

MÆRE HAR SOM AMBISJON Å BLI ET FYRTÅRNSEKSEMPEL FOR LANDBRUKSOMRÅDER

ZEN skal bidra til å nå dette ambisjonsnivået på bygningsnivå. Ulike teknologier og prosesser relatert til bygninger og til energisystemet er allerede etablert. Blant annet er det etablert et nærvarmeanlegg mellom de fleste byggene, noe som danner et godt grunnlag for videre optimalisering av styring og termisk energiutveksling mellom byggene. Strømbruk i de fleste komponentene måles fortløpende. Basert på disse målingene skal ZEN i 2020 kartlegge og forske på hvordan energibruken og energisystemet på Mære yter per i dag og se på muligheter for å forbedre driftsstrategier, behov for energilagring og hvordan området kan bruke mest mulig egenprodusert strøm. Det er ikke bare energisystemet som står i fokus i ZEN. Det skal også gjøres en livssyklusanalyse for å se på klimagassutslipp fra ulike deler av en gård. Det skal jobbes blant annet med å definere systemgrenser for en nullutslippsgård ut ifra ZEN sitt perspektiv og som del av et større perspektiv. Her er det mange involverte, der ulike tema vil bli drøftet i 2020.

Rethinking process and stakeholder involvement to achieve zero emission neighbourhoods (ZEN)

Daniela Baer
Research scientist,
SINTEF Community



Judith Thomsen
WP 6 leader,
SINTEF Community

Since the ZEN Research Centre started in 2017, researchers from several work packages followed the development of the ZEN pilot projects. What we have learned so far is that there is no one single way leading to zero emission neighbourhoods. The pilot projects` approaches to ZEN vary depending on the size of the project, its characteristics, and the phase of development. Depending on the approach, we involve different stakeholders and see their roles changing over time. Especially the involvement of citizens and users and their impact on the development is pointed out as crucial for creating a zero emission and livable neighbourhood. As long as ZEN is not a regulatory obligation, the realization is dependent on a well-functioning collaboration within a multi-stakeholder environment, where stakeholders voluntarily agree on the same ambitious goals of ZEN. When interviewed about the main challenges to realize a ZEN in 2017/2018, partners pointed to collaboration. Technical solutions to build ZENs are perceived as available, but these are challenging to implement within a multi-stakeholder environment characterized by diverse interests. Multiple sectors, from energy, building materials, and construction to mobility, must have a joint approach to realize a ZEN. Our interviews showed how the disagreement between single stakeholders, such as e.g. the citizens and the regional councilman [fylkesmann], can challenge the ZEN development or put it on hold.

On the other hand, new approaches for a collaborative planning process applied in the pilot projects, such as the masterplan development in Ydalir, the Forum Sluppen (a consultation forum for landowners during the planning phase) or a broad citizen engagement process with the Bodø CityLab, showed how commitment, a joint vision, and collaboration can be achieved through new ways of stakeholder involvement.

What we learned so far is that we need innovation not only in technical solutions or business models, but simultaneously in processes to plan, design, and operate ZENs. A successful process for a ZEN needs to incorporate different stakeholders and thematic sectors over the ZEN lifetime. This is the pathway to the successful implementation of new technical alongside societal solutions in a holistic and collaborative manner. Such processes also demand ambitious leadership and management.

Figure 21. Workshop "Re-framing Citizen Participation" within the Bodø CityLab. Photo: Daniela Baer.

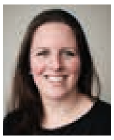
Nytt blikk på prosesser og samarbeid for å oppnå nullslippsområder (ZEN)

Figure 22. Prosessen av masterplan utvikling i Ydalir er preget av sterkt samarbeid.
Foto: Anna-Thekla Tonjer (Elverum Vekst).

Siden FME ZEN startet i 2017 fulgte forskere fra flere WP-er utviklingen av ZEN-pilotprosjektene. Det vi har lært så langt, er at det ikke er kun én vei som fører til nullutslippsnabolag. Prosjektenes tilnærminger til ZEN varierer; avhengig av størrelse, egenhet eller fase i utviklingen. Det individuelle veikartet til ZEN vil bestemme hvilke aktører som er involvert, og rollene deres endres også ofte over tid. Spesielt involvering av innbyggere og brukere og deres innvirkning på utviklingen peker seg ut som avgjørende for å skape et attraktivt nullutslipps nabolag. Så lenge ZEN ikke er en lovpålagt forpliktelse, er veien til ZEN avhengig av et velfungerende samarbeid mellom aktørene, som enes om den samme ambisiøse målsettingen av å nå ZEN. ZEN partnerne ble intervjuet i 2017/2018 om de viktigste utfordringene for å realisere ZEN. Partnere pekte sterkt på samarbeidsprosess. Tekniske løsninger for å bygge ZEN områder oppleves som tilgjengelige, men disse er utfordrende å implementere i et miljø der forskjellige aktører er berørt. Flere sektorer, fra energi, byggematerialer, og konstruksjon til mobilitet, må forenes under en felles tilnærming for å realisere ZEN. Intervjuene viste hvordan uenighet mellom enkeltstående interessenter, som innbyggerne og fylkesmann, kan utfordre ZEN-utviklingen eller sette den på vent.

I flere av ZEN sine pilotprosjekter testes nye former for samarbeidsprosesser, for eksempel masterplanutviklingen i Ydalir, "Forum Sluppen" (et høringsforum for grunneiere i planleggingsfasen) eller det ble tilrettelagt for bred innbyggerinnvolvering gjennom Bodø ByLab. Disse eksemplene viser hvordan engasjement, en felles visjon og samarbeid kan oppnås gjennom nye måter å involvere aktørene og innbyggere på. Det vi har lært så langt er at vi trenger innovasjon ikke bare i form av teknologiske løsninger eller forretningsmodeller, men også i form av prosesser for å planlegge, designe og drifte ZEN områder. En vellykket prosess mot ZEN må involvere forskjellige aktører og sektorer fra tidligfase og over hele nabolagets levetid. Dette muliggjør en vellykket implementering av nye tekniske løsninger side om side med samfunnsløsninger. Slike prosesser krever også ambisiøs drift og ledelse.

INNOVATION
IN THE ZEN RESEARCH CENTRE



Anne Nuijten
Innovation manager,
ZEN, NTNU

In 2019 we have developed an innovation registration system to actively follow up the innovation work and to ensure that ideas are implemented. For each idea we register the name, the partners involved, a description of the idea, the TRL (2017-2024), the market potential, and the potential impact. At the end of 2019 there were 67 registered ideas in ZEN. This registration system is updated regularly, and goals are set related to the further development of the ideas and possible commercialization. Starting in 2020, those ideas will be reported in an annual innovation report.

It is important for ZEN to increase collaboration and innovation activities in clusters and centers where ZEN participates. Where ZEN has the same interests and goals as other centers or groups, we aim to work more closely together to implement the research results and increase the impact of innovation. In 2018 an analysis into the effect of energy research was done together with the other FMEs. For a number of different innovations, the impact was described, and where possible, quantified.

In 2019 the 'FME Innovasjonslederforum' was established to follow up on this work. The FMEs involved are: ZEN, NTRANS, HydroCen, Bio4fuels, CINELDI, HighEFF, MoZEES, NCCS, and SUSOLTECH. ZEN has led the forum in 2019. Last year we have presented and discussed how we work with innovation and have continued to work on how the impact of innovation can be measured and presented. A report from the 'FME Innovasjonslederforum' will be finished in March 2020, describing how the different FMEs work with innovation.

In 2019 the innovation committee of ZEN has written a new innovation plan for the period 2020-2021, as part of ZEN's work plan. We aim to translate more of the knowledge and research results at the Research Centre into benefits for society, including the private and public sector. We will continue to focus on increasing innovation and knowledge transfer to and in collaboration with the public and private sector in order to increase the impact of innovation, identifying ideas with the potential to become new innovations, further developing an innovation culture, and to increase collaboration in clusters and centers where ZEN participates.

Innovation Committee
Morten Dybesland, Statsbygg
Zdena Cervenka, Statsbygg
Elsebeth Holmen, NTNU
Rakel Hunstad, Bodø kommune
Terje Jacobsen, SINTEF Community
Kai Haakon Kristensen, Bodø kommune
Ann Kristin Kvellheim, SINTEF Community
Svein Olav Munkeby, NTE Marked AS (Chair of the committee)

COMMUNICATION AT THE ZEN RESEARCH CENTRE

Annika Bremvåg
Communication adviser and coordinator, ZEN, NTNU

The ZEN Research Centre has worked continuously with external and internal communication throughout 2019. There has been substantial scientific and popular scientific publication activity at ZEN, as the numbers below show. Also, **@fmeZEN** on Facebook and **@ZENcentre** on Twitter have been updated regularly with recent news, events, and publications. Our website now has more than 12.500 users.

After a questionnaire among our partners, we changed our newsletter format to a more traditional monthly newsletter.

ZEN researchers and PhDs had 16 ZEN lunch lectures in the ZEN lunchroom and on Skype. 18 partner workshops/seminars were held, and partners, researchers, PhDs, and postdocs laid plans for 2020-2021 at our 3rd partner seminar in Trondheim 15-16 October. Furthermore, partners visited the ZEN Research Centre, among others Asplan Viak and the NTNU campus project, as well as external entities like the Norwegian Ministry of Petroleum and Energy.

16-19 June, the FUTURUM-exhibition took place in Trondheim where the ZEN Research Centre was represented with its own stand, as well as at the opening of Powerhouse Brattøra on 30 August. ZEN researchers were likewise heavily involved in the 1st Nordic conference on zero emission and plus energy buildings that took place in Trondheim 6-7 November.

In addition, ZEN personnel attended a writing workshop and a chronicle course.

Figure 23. Child entering the VR simulation at the ZEN stand at the Futurum-exhibition in June.

Figure 24. ZEN Board and leaders visit the newly built Ydalir school in August.

COMMUNICATION ACTIVITIES IN 2019

8
ZEN newsletters

More than
12,500
users on fmezen.no

102
Scientific publications

82
Presentations

87
Unique popular scientific articles and media features

16
ZEN lunch lectures

18
partner workshops/seminars

2
communication courses for ZEN personnel

OUR FIRST PHD CANDIDATES HAVE GRADUATED!

Our first ZEN PhDs graduated in August 2019:

- **Amin Moazami**: "Climate Robust Buildings: Towards Buildings with a Robust Energy Performance Under Climate Change»
- **John Clauss**: "Energy flexibility of Norwegian residential buildings using demand response of electricity-based heating systems"

AWARDS

Our PhD candidates **Kristian Stenerud Skeie** and **Elena Catto Lucchino** won this year's Climathon in Trondheim with their solar energy sharing model Nabosol. Congratulations!

Congratulations to **Igor Sartori** and **Anne Grete Hestnes** who won the award «Best review paper 1998-2007» in Energy and Buildings for their article «Energy use in the life cycle of conventional and low-energy buildings: A review article».

OUR MEETING PLACES

Type of activity	What	Date
Lectures	ZEN lunch lectures in Trondheim and on Skype	16x in 2019
Meetings	Work package meetings	Regularly, 1-2/month
Meetings	ZEN Board meetings	5x in 2019: 27.3., 17.6., 28.8., 8.10., 6.12.
Gathering	PhD gathering	15 January
Course	ZEN PhD course with mini conference	25-26 February, 27-28 March, 30 April & 29 May
Workshop & seminar	Leaderhip gathering	5-6 March
General Assembly	General Assembly	27 March
Communication course	Shut up & write workshop in the ZEB living lab	23 April
Communication course	Kronikk-kurs for ZEN arbeidspakkelederne ved forskning.no	24 April
Meeting	Meeting of the ZEN International Advisory Comittee	5-6 May
Seminar	Partnerseminar: Pilotprosjektene i ZEN – status og utfordringer	20 May
Conference	Urban Future global conference	22-24 May
Gathering	ZEN summer party	5 June
Exhibition	FUTURUM – An exhibition about the future	16-19 June
Guest lecture	Guest lecture on ecoanxiety and regenerative buildings	20 June
Seminar	The FUTURUM seminar series: «Participatory methods during urban transformations»	20 June
Summer school	Summer school: Time series analysis – with a focus on modelling and forecasting in energy systems	26-30 August
Seminar & workshop	ZEN Board and leadership gathering	27-28 August
Workshop	Workshop on ZEN-case about greenhouse gas requirements in TEK	28 August
Course	The good, the bad and the ugly om Ventilasjonskjøling	29 August
PhD defense	PhD defense by John Clauss: "Energy flexibility of Norwegian residential buildings using demand response of electricity-based heating systems"	29 August
Exhibition	Opening of Powerhouse Brattøra	30 August
PhD defense	PhD defense by Amin Moazami: "Climate Robust Buildings: Towards Buildings with a Robust Energy Performance Under Climate Change»	30 August
Workshop	Workshop on ZEN KPI tool development	16 September
Workshop	Workshop on ZEN-case about greenhouse gas requirements in TEK	2 October
Seminar	ZEN Partnerseminar	15-16 October
Seminar	Frokostseminar: Hvorfor er det viktig at vi sikter mot 1.5 og ikke 2 grader?	17 October
Seminar	IBPSA Nordic Seminar om praktisk bruk av simuleringsverktøy	23 October
Workshop	Energisystemet i Risvollan borettslag: renovere nær-/fjernvarme eller gå for helelektrisk?	24 October
Workshop	Workshop om ZEN-case: Lovverket og hvordan sikre ZEN-kvalitetene ved utvikling av et ZEN-område	28 October
Workshop	Workshop om forretningsmodeller og strategier for reduksjon av klimagassutslipp fra betong	29 October
Meeting	Delegation of about 30 people from Asplan Viak visit ZEN	29 October
Workshop & seminar	Information and Communication Technology (ICT) in smart cities	30 October
Conference	1st Nordic conference on zero emission and plus energy buildings	6-7 November
Meeting	NTNU campus project visits ZEN	8 November
Meeting	Frokostmøte: Erfaringer med sirkulære bygg	21 November
Gathering	ZEN Christmas celebration	4 December
Seminar	Byutviklingsseminar ZEN -Trondheim kommune	6 December

COLLABORATION AMONG OUR PARTNERS

Terje Jacobsen
Vice president research,
SINTEF Community

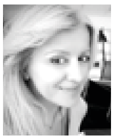
The ZEN Centre has a number of regular activities designed to involve and actively follow up all of the ZEN partners; these include the General Assembly, ZEN partner seminar, lunch lectures, and the biannual conference. In addition, in 2019, the ZEN Centre has organised 18 workshops/seminars with partners and welcomed several partners for a visit, e.g. Asplan Viak on 29 October and the NTNU campus project on 8 November.

There were meetings with almost all partners on the leadership level during winter and spring 2019. The purpose of the meetings was to gain a better foothold at the leadership level of the partners, present mutual expectations and relevant activities and carry out an internal evaluation of the work in the Centre. The meetings and follow up actions have been very useful to the collaboration and the development of ZEN workplan 2020-2021.

Figure 25. Planning future research activities at our partner seminar 15-16 October in Trondheim.

INTERNATIONALIZATION AT THE ZEN RESEARCH CENTRE

Annemie Wyckmans
Professor,
NTNU



Niki Gaitani
Senior researcher &
project manager,
NTNU

2019 was a very productive year for internationalization at the ZEN Research Centre, in particular towards EU and China.

The ZEN Centre was awarded its first H2020-coordinated project, syn.ikia, with Niki Gaitani as Project Coordinator. The syn.ikia innovation project involves 13 partners from six countries and aims at increasing the proportion of sustainable neighbourhoods with surplus renewable energy in different contexts, climates, and markets in Europe. Syn.ikia's concept relies on the interplay between novel technologies at the neighbourhood scale, energy efficiency of the buildings, energy flexibility, good architectural and spatial qualities, sustainable behaviour, and citizen engagement. Four real-life plus-energy demo projects (in Norway, Spain, Hungary, and the Netherlands) tailored to four different climatic zones, will be developed, optimized, and monitored within the duration of the project.

Based on syn.ikia, ZEN successfully applied for Supplementary Funding for Norwegian Participants in Horizon 2020 Projects at the Research Council of Norway (RCN), to strengthen the participation of Norwegian stakeholders in EU projects. ZEN also contributed to the successful application for RCN funding for the "Horizon Europe Norwegian Urban Partnership" project, to accelerate Norwegian impact within Horizon Europe.

In autumn 2019, the ZEN Centre led the Norwegian team for the research project ChiNoZEN that was submitted at RCN/ Chinese-Norwegian collaboration project on Energy. ChiNoZEN has recently been awarded funding by the Ministry of Science and Technology (MOST) in China and by RCN.

On 6-7 November, ZEN organized its first Nordic Conference on Zero Emission and Plus Energy Buildings, "Nordic-Towards Carbon Neutral Built Environments", with more than 100 presentations and 330 participants from 29 countries. Inger Andresen was the Nordic ZEB+ Conference Chair.

As Director of ZEN, Arild Gustavsen continued to participate in the SET-Plan Smart Cities and Communities Action 3.2 (aiming to create 100 Positive Energy Districts by 2025) Steering Group. In addition, as Coordinator of the EERA Joint Programme on Smart Cities, Annemie Wyckmans became Research & Innovation Chair of the SET-Plan Action 3.2 Stakeholder Group, aligning the R&I efforts of European stakeholder networks. Annemie was also invited to become part of the Assembly to the Mission Board for Climate Neutral and Smart Cities.

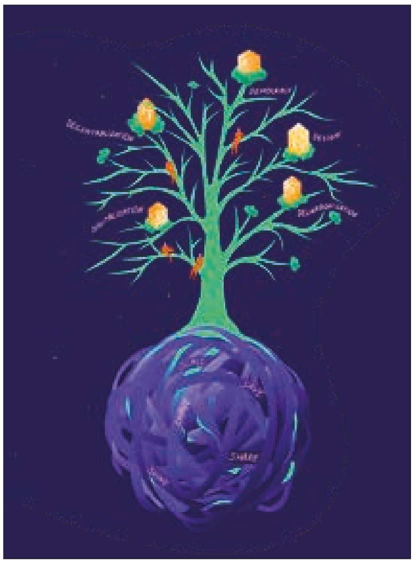


Figure 26. syn.ikia's 5D Focus areas: Design-Digitalization-Decentralisation-Democracy-Decarbonisation & 5S Strategies: Save-Shave-Share-Shine-Scale.

syn.ikia | Sustainable plus energy neighbourhoods

RESEARCHER TRAINING AND RECRUITMENT

Tommy Kleiven
Professor,
NTNU

Henrik Madsen
Professor,
NTNU and Technical University of Denmark (DTU)

During 2019 15 PhDs and 4 postdocs were part of the ZEN Centre, these are candidates funded directly or by in-kind from the research partners. In addition, 10 PhD candidates were doing ZEN related research, with funding from other sources.

The ZEN Centre organized two PhD courses in 2019. The ZEN PhD course (AAR8330) is open for everyone with a masters degree interested in Zero Emission Neighbourhoods. It is obligatory for ZEN PhD fellows, and ZEN researchers and postdocs are welcome to join. Creating Zero Emission Neighbourhoods is an interdisciplinary task. The course reflects this by conveying basic knowledge and skills that every PhD student working with ZEN-related topics should have, but we also include knowledge which helps the students relate their specific projects to a larger societal and historical context. In this sense the course is advanced not by going into depth in selected topics but rather because it provides a broad overview of relevant topics. The students have diverse professional backgrounds and different approaches to ZEN (e.g. anthropology, psychology, architecture, civil engineering, mechanical engineering, and economy). This provides a fruitful and interesting basis for cross-disciplinary discussions in the course, broadening the students' knowledge-horizon. The main teaching methods are lectures, discussions, a case workshop, and writing a final paper or report that is presented at the "ZEN mini conference" that is open for everyone. Professor Tommy Kleiven was responsible for the course.

In August 2019 a summer school course in time series analysis, with a focus on modelling and forecasting in energy systems, was arranged. There were 42 participants. Henrik Madsen, adjunct professor at ZEN/NTNU and professor at DTU, was responsible for the course together with Peder Bacher, DTU. Some of the learning outcomes are: To formulate and apply models for short-term forecasting in energy systems, e.g. for heat load in buildings, electrical power from PV and wind systems, to formulate and apply grey-box models – model identification - tests for model order and model validation, and advanced non-linear models, to achieve understanding of model predictive control (MPC) – via applied examples on energy systems, and to achieve an understanding of flexibility functions and indices. The summer school was held at DTU in Copenhagen in a collaboration with NTNU and IEA EBC Annexes 67 and 71.

In 2019 14 MSc theses were carried out within the ZEN Centre. Three examples are *The challenges and opportunities to shift from Net Zero Energy Building to Net Zero Emission Building in a hot tropical climate in Singapore* by Jingjing Zhou, *Scenario Analysis in LCA on the Zero Emission Neighbourhood Ydalir: A Norwegian Case Study* by Kristi Marie Lund, and *Energy performance of a university campus in Norway* by Martina Bianchi, an exchange student from The University of Genoa. A complete list can be found on the ZEN Centre webpage.

Figure 27. ZEN PhDs and postdocs at one of their gatherings in 2019.

APPENDICES

PERSONELL

ZEN management team

Last name	First name	Position	Main research area	Institution
Bremvåg	Annika	Communication adviser & coordinator for ZEN		NTNU
Ersfjord	Eva	Journalist for ZEN		NTNU
Gustavsen	Arild	Centre director / professor		NTNU
Jacobsen	Terje	Centre liaison / vice president research		SINTEF Community
Nuijten	Anne	Innovation manager		NTNU
Remøe	Katinka Sætersdal	Communications adviser for ZEN (temporary until May 2019)		NTNU
Solberg	Lasse Hopstad	Financial officer		NTNU
Skjevik	Hanne Kristin	Financial officer		SINTEF Community
Iversen	Hege Island	Financial officer		SINTEF Energy Research
Woods	Ruth	Coordinator for ZEN (temporary until May 2019)		NTNU

Work package leaders

Last name	First name	Position	Work package	Institution
Brattebø	Helge	WP1 leader / LCA coordination / professor	1	NTNU
Kvellheim	Ann Kristin	WP2 leader / senior adviser	WP2 & innovation coordination	SINTEF Community
Mathisen	Hans Martin	WP3 leader / professor	WP3&4	NTNU
Sartori	Igor	WP4 leader / senior research scientist	4	SINTEF Community
Thomsen	Judith	WP6 leader / research manager	6	SINTEF Community
Wolfgang	Ove	WP5 seader / research scientist	5	SINTEF Energy Research

Key researchers

Last name	First name	Position	Work package	Institution
Baer	Daniela	Research scientist	WP1	SINTEF Community
Bergsdal	Håvard	Senior researcher	WP1	SINTEF Community
Berker	Thomas	Living lab coordination / professor	WP6	NTNU
Boer	Luitzen de	Professor	WP2	NTNU
Clauss	John	Researcher	WP3&4	SINTEF Community
Farahmand	Hossein	Assoc. professor	WP4&5	NTNU
Gaitani	Niki	EU project developer	x	NTNU
Georges	Laurent	Building/neighbourhood services coordination / assoc. professor	WP3&4	NTNU
Graabak	Ingeborg	Research scientist	WP5	SINTEF Energy Research
Grynning	Steinar	Research scientist	WP3	SINTEF Community
Hestnes	Anne Grethe	Senior scientific adviser/ professor	x	NTNU
Kauko	Hanne Laura Pauliina	Research scientist	WP5	SINTEF Energy Research
Krogstie	John	Professor	WP1	NTNU
Lindberg	Karen B.	Senior research scientist	WP4&5&6	SINTEF Community
Liu	Peng	Researcher	WP3	SINTEF Community
Manum	Bendik	Professor	WP1&6	NTNU

Nordström	Tobias	Researcher	WP6	NTNU
Petersen	Sobah Abbas	ICT coordination / assoc. professor	WP1	NTNU
Skaar	Christofer	Researcher	WP3&6	SINTEF Community
Tomasgard	Asgeir	Professor	2	NTNU
Venås	Christoffer	Researcher	6	SINTEF Community
Walnum	Harald Taxt	Researcher	WP4&6	SINTEF Community
Wiik	Marianne	Researcher	1 & 6	SINTEF Community
Wyckmans	Annemie	Internationalisation coordination / professor	x	NTNU

Visiting researchers

Last name	First name	Topic	Affiliation
Madsen	Henrik	Energy system modelling	Technical University of Denmark
Wang	Nan	Energy efficiency and carbon reduction of railway stations	Tianjin University

Postdoctoral researchers with financial support from the Centre budget

Last name	First name	Topic and work package
Sinaeepourfard	Amir	Information management of big data to achieve ZEN (WP1)
Stokke	Raymond	Innovation eco-system and green public procurement (WP2)
Tereshchenko	Tymofii	Interaction between zero emission neighbourhoods and district heating systems (WP4)
Woods	Ruth	ZEN living labs (WP6)

Postdoctoral researchers working on projects in the centre with financial support from other sources

Last name	First name	Topic and work package
Korsnes	Marius	The role of prosumers in zero emission buildings and neighbourhoods (WP6)
Nielsen	Brita	Planning tools for smart energy communities (WP1&6)
Sandberg	Nina Holck	Dynamic modelling of energy use of building stocks (WP1)

Graduated PhD candidates in 2019

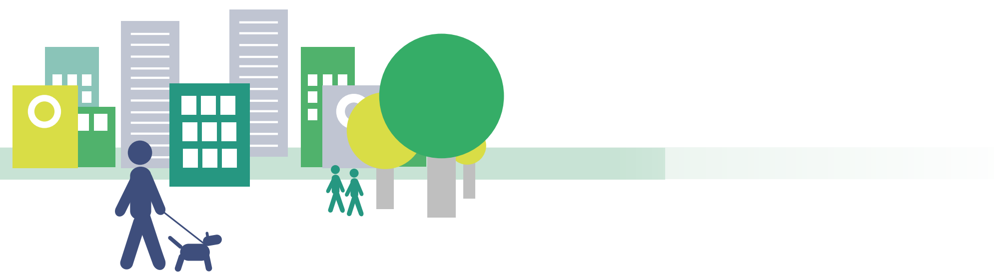
Last name	First name	Topic and work package
Clauss	John	Design and control of heat pump systems in energy flexible residential buildings in cold climate (WP4)
Moazami	Amin	Energy flexible neighbourhourhoods (WP4)

PhD candidates with financial support from the Centre budget

Last name	First name	Topic and work package
Askeland	Magnus	Regulatory and economical aspects related to ZEN within a larger energy system (WP5)
Backe	Stian	Transition pathways towards zero emission neighbourhoods (WP2)
Brozovsky	Johannes	The climate dimension and the physical principles of zero emission neighborhoods in Norway (WP1&6)
Favero	Matteo	Thermal comfort enabling thermal flexibility of buildings (WP4)
Hamdan	Hasan Ahmed	Public private collaboration (WP2)
Homaie	Shabnam	Optimal integrated building designs for resilient zero emission neighbourhoods (WP3)
Justo Alonso	Maria	Optimal combination of demand controlled ventilation and heat recovery for ZEB (WP3)
Lausselet	Carine	LCA methods for zero emission neighbourhood concepts (WP1)
Pinel	Dimitri	Local energy system optimization within a larger system (WP5)
Rokseth	Lillian	CO_2 emission and correlation to building form and spatial morphology at neighbour-hood scale (WP6)
Satoła	Daniel	Off-grid zero emission building concepts for warm climates (WP3)
Skeie	Kristian	Building energy performance assessment through in-situ measurement (WP3)
Sørensen	Åse Lekang	Smart strategies for energy and power management in neighbourhoods (WP6)
Thorvaldsen	Kasper	The value of buildings energy flexibility in power markets (WP4)
Yu	Xingji	Model predictive control to activate the building energy flexibility (WP4)

PhD candidates working on projects in the centre with financial support from other sources

Last name	First name	Topic and work package
Annaqeeb	Masab Khalid	Simulation of energy related occupant behaviour in buildings (WP3)
Catto Lucchino	Elena	Double skin facades (WP3)
Dziedzic	Jakub Wladyslaw	Modeling and simulating energy-related, occupant behavior in residential buildings (WP3)
Juhasz-Nagy	Eszter	Improving smart energy community planning through collaborative game development (WP1&6)
Lassen	Niels	Evaluation of a method for real time user interaction regarding indoor climate in office buildings (WP3)
Ness	Maria Coral Albelda-Estelles	Exploring the limits of building bioclimatic design in cold climates (WP6)
Resch	Eirik	A framework for analysis of embodied emissions in zero emission neighborhoods (WP1&6)
Valler	Thea Marie	Decarbonization of transport in urban China (WP2&6)
Sutcliffe	Thomas	Circular economy (WP6)



STATEMENT OF ACCOUNTS

FUNDING AND COSTS

Funding	Amount	Total
The research council		25 160
The host institution (NTNU)		15 327
Research partners		
SINTEF Energy Research		975
Sintef Community		7 140
Enterprise partners		7 528
ByBo AS	350	
AS Civitas	50	
Boligbyggelaget TOBB	522	
Caverion Norge AS	100	
Energi Norge AS	234	
ÅF Engineering AS/Gottlieb Paludan Architects	250	
Asplan Viak	325	
GK Norge AS	501	
Hunton Fiber AS	756	
Moelven industrier ASA	461	
Norcem AS	550	
Norsk fjernvarme	487	
Snøhetta Oslo AS	433	
Sweco Norge AS	200	
Multiconsult ASA	-	
Skanska Norge AS	874	
Elverum tomteselskap AS	1 435	
Public partners		6 089
Bergen kommune	200	
Bodø kommune	862	
Bærum kommune	864	
Direktoratet for byggkvalitet	208	
Elverum kommune	150	
NTE Marked	331	
Norges vassdrag og energidirektorat (NVE)	200	
Oslo kommune - Plan og bygningsetaten (FutureBuilt)	425	
Oslo kommune - klimaetaten	250	
Statkraft varme AS	689	
Statsbygg	709	
Trondheim kommune	449	
Trøndelag fylkeskommune	752	
Funding transfered to next year		-5 793
Total		56 427

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

Cost	**Amount**	**Total**
The host institution (NTNU)		24 214
Research partners		
SINTEF Energy Research		3 560
Sintef Community		20 829
Enterprise partners		4 798
ByBo AS	200	
AS Civitas	-	
Boligbyggelaget TOBB	422	
Caverion Norge AS	-	
Energi Norge AS	84	
ÅF Engineering AS/ Gottlieb Paludan Architects	-	
Asplan Viak	125	
GK Norge AS	251	
Hunton Fiber AS	506	
Moelven industrier ASA	211	
Norcem AS	300	
Norsk fjernvarme	357	
Snøhetta Oslo AS	233	
Sweco Norge AS	-	
Multiconsult ASA	-	
Skanska Norge AS	774	
Elverum tomteselskap AS	1 335	
Public partners		3 026
Bergen kommune	-	
Bodø kommune	612	
Bærum kommune	201	
Direktoratet for byggkvalitet	8	
Elverum kommune	-	
NTE Marked	331	
Norges vassdrag og energidirektorat (NVE)	-	
Oslo kommune - Plan og bygningsetaten (FutureBuilt)	425	
Oslo kommune - klimaetaten	-	
Statkraft varme AS	439	
Statsbygg	309	
Trondheim kommune	199	
Trøndelag fylkeskommune	502	
Total		56 427

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

PUBLICATIONS IN 2019

BOOKS AND BOOK CHAPTERS

Gustavsen, A., Jacobsen, T. & Andresen, I. (2019) **Klimanøytrale bygg og nabolag**. Det Nye Digitale Norge (book), chapter 6, pages 73-80

Korsnes, Marius (2019) **Wind and Solar Energy Transition in China** New York: Routledge

JOURNAL ARTICLES

Askeland, M., Jaehnert, S. & Korpås, M. (2019) **Equilibrium assessment of storage technologies in a power market with capacity remuneration** Sustainable Energy Technologies and Assessments, volume 31, pages 228-235

Clauß, J., Stinner, S., Sartori, I. & Georges, L. (2019) **Predictive rule-based control to activate the energy flexibility of Norwegian residential buildings: Case of an air-source heat pump and direct electric heating** Applied Energy, volume 237, pages 500-518

Clauß, J., Stinner, S., Solli, C. Lindberg, K. B., Madsen, H. & Georges, L. (2019) **Evaluation method for the hourly average CO2eq. Intensity of the electricity mix and its application to the demand response of residential heating** Energies, volume 12, issue 7

Clauß, John; Georges, Laurent. (2019) **Model complexity of heat pump systems to investigate the building energy flexibility and guidelines for model implementation** Applied Energy, Vol. 255

Dziedzic, J.W., Yan, D. & Novakovic, V. (2019) **Indoor occupant behaviour monitoring with the use of a depth registration camera** Building and Environment, volume 148, pages 44-54

Dziedzic, Jakub Wladyslaw; Yan, Da; Novakovic, Vojislav (2019) **Framework for a transient energy-related occupant behaviour agent-based model** REHVA European HVAC Journal, Vol. 10, Issue 3

Gullbrekken, L., Grynning, S. & Gaarder, J. E. (2019) **Thermal performance of insulated constructions – experimental studies** Buildings, volume 9, issue 2

Hamdy, M. & Mauro, G. M. (2019) **Optimizing hybrid ventilation control strategies toward zero-cooling energy building** Frontiers in Built Environment, volume 5, issue 97

Johnsen, T., Taksdal, K. Clauß, J., Yu, X. & Georges, L. (2019) **Influence of thermal zoning and electric radiator control on the energy flexibility potential of Norwegian detached houses** E3S Web of Conferences, volume 111

Lausselet, C., Borgnes, V. S., & Brattebø, H. (2019) **LCA modelling for Zero Emission Neighbourhoods in early stage planning**. Building and Environment, volume 149, pages 379-389

Lausselet, C., Ellingsen, L.A.W., Strømman, A.H. & Brattebø, H. (2019) **A life-cycle assessment model for zero emission neighborhoods** Journal of Industrial Ecology, online

Lindberg, K.B., Bakker, S.J. & Sartori, I. (2019) **Modelling electric and heat load profiles of non-residential buildings for use in long-term aggregate load forecasts** Utilities Policy, volume 58, pages 63-88

Lindberg, K.B., Seljom, P., Madsen, H., Fischer., D. & Korpås, M. (2019) **Long-term electricity load forecasting: Current and future trends** Utilities Policy, volume 58, pages 102-119

Moazami, A., Carluccia, S.Nik, V.M. & Geving, S. (2019) **Towards climate robust buildings: An innovative method for designing buildings with robust energy performance under climate change** Energy and Buildings, volume 202

Moazami, A., Nik, V.M., Carluccia, S. & Geving, S. (2019) **Impacts of future weather data typology on building energy performance – Investigating long-term patterns of climate change and extreme weather conditions** Applied Energy, volume 238, pages 696-720

Moschetti, R., Brattebø, H. & Sparrevik, M. (2019) **Exploring the pathway from zero-energy to zero-emission building solutions: A case study of a Norwegian office building** Energy and Buildings, volumes 188-189, pages 84-97

Nielsen, B. F., Woods, R. & Lerme, W. (2019) **Aesthetic Preference as Starting Point for Citizen Dialogues on Urban Design: Stories from Hammarkullen, Gothenburg** Urban Planning, volume 4

Nielsen, B.F., Baer, D. & Lindkvist, C. (2019) **Identifying and supporting exploratory and exploitative models of innovation in municipal urban planning; key challenges from seven Norwegian energy ambitious neighborhood pilots** Technological Forecasting & Social Change, volume 142, pages 142-153

Resch, E., Lausselet, C., Brattebø, H. & Andresen, I. (2019) **An analytical method for evaluating and visualizing embodied carbon emissions of buildings** Building and Environment, volume 168

Rønneseth, Ø., Sandberg, N. H. & Sartori, I. (2019) **Is It Possible to Supply Norwegian Apartment Blocks with 4th Generation District Heating?** Energies, volume 12, issue 5

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Schönfeldt Karlsen S., Hamdy M. & Attia S. (2019) **Methodology to asses business models of dynamic pricing tariffs in all-electric houses** Energy and Buildings, Accepted 04.11.2019, In press

Sørensen, Åse Lekang; Sartori, Igor; Lindberg, Karen Byskov; Andresen, Inger (2019) **Electricity analysis for energy management in neighbourhoods: Case study of a large housing cooperative in Norway** Journal of Physics: Conference Series, Vol. 1343

Wolf, S., Calí Davide, Krogstie, J., & Madsen, H. (2019) **Carbon dioxide-based occupancy estimation using stochastic differential equations** Applied Energy, volume 236, pages 32-41

Wolf, S., Møller, J. K., Bitsch, M. A., Krogstie, J., & Madsen, H. (2019) **A Markov-Switching model for building occupant activity estimatio**n Energy and Buildings, vol.183, pages 672-683

Wolf, Sebastian; Cali, Davide; Alonso, Maria Justo; Li, Rongling; Korsholm Andersen, Rune; Krogstie, John; Madsen, Henrik (2019) **Room-level occupancy simulation model for private households** Journal of Physics: Conference Series, Vol. 1343

Šuklje, Tomaž; Hamdy, Mohamed; Arkar, Ciril; Hensen, Jan L.M.; Medved, Sašo (2019) **An inverse modeling approach for the thermal response modeling of green façades** Applied Energy, Vol. 235, pp. 1447-1456

CONFERENCE PAPERS

Alonso, M. J., Stuart Dols, W. & Mathisen, H. M. (2019) **Using co-simulation between EnergyPlus and CONTAM to develop IAQ and energy-centric demand-controlled ventilation systems** Conference Proceedings, AIVC Conference 2019

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