Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

ANNUAL REPORT 2021

Brynjar Fredus Svarva, Arild Gustavsen, Ann Kristin Kvellheim, Sunniva Moum Danielsen

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

VISION:

«Sustainable neighbourhoods with zero greenhouse gas emissions»

Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

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Editors: Brynjar Fredus Svarva (NTNU), Ann Kristin Kvellheim (SINTEF), Arild Gustavsen (NTNU), Anne Grete Hestnes (NTNU)
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https://fmezen.no

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THE TRANSITION TO A LOW CARBON SOCIETY

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

In August 2021 the international scientist of the Intergovernmental Panel on Climate Change (IPCC) reported that climate change is widespread, rapid, and intensifying, and the UN Secretary-General António Guterres said the report was a "code red for humanity". The scientists are observing changes in the Earth's climate in every part of the world, and unless rapid reductions in the carbon emissions occur, achieving the goals of the 2015 Paris Agreement will be beyond reach.

In this context the Research Center on Zero Emission Neighborhoods in Smart Cities can take an active and leading role to bring knowledge into action and nudge the necessary societal changes.

The overall objective of the FME centers is to help solving key challenges in the energy sector, generate solutions for the low-emission society and enhance the innovation capacity of the business sector. In 2021 The Research Council of Norway performed its Mid-Term Evaluation, and I'm proud to emphasis that the international evaluation panel found that the FME research centers *"provide a remarkably capable and internationally high-profile national facility to help address the spectrum of energy and emissions reduction transformation challenges required to deal with climate change and the consequent decarbonization agenda".*

The evaluation panel also concluded that: *"Generally, the Evaluation Panel considers that the work of the Centre is of excellent quality and that the productivity is extensive both within research teams as well as in collaboration with the industry and international partners. However, given the breadth of research topics and disciplinary perspectives covered by the Centre, the identification and in-depth study of critical problems for the development of ZEN; the creation of a significant impact on the practical development and implementation of zero-carbon neighborhoods; and the generation of sufficient added value for the participating industry partners will remain a constant challenge and high on the agenda for the final period of Centre activities. "*

Designing and planning a Zero Emission Neighborhood (ZEN) is an interdisciplinary task, and it's done by

> We must create a greater belief that the transition to a low carbon society contributes to the needed climate mitigation.

conveying knowledge and skills within a larger societal and historical context and understanding. It is not only a matter of physical science, energy efficiency, selecting the right low carbon building materials, calculation energy storage capacity, designing energy producing buildings, planning for green mobility and zero waste. We also need to win the hearts and minds of the future citizens of a zero-emission neighborhood, the hearts of minds of the politicians, the decision makers, the developers, the architects, the planners, the engineers, the builders, the farmers, and the generations to come.

We must create a greater belief that the transition to a low carbon society contributes to the needed climate mitigation. Whom more suited to do so than this partnership covering the entire value chain, including perspectives and representatives from municipal and regional governments, property owners, developers, engineers, consultants and architects, ICT companies, contractors, energy companies, manufacturers of materials and products and governmental organizations? The ZEN Research Centre develops solutions for future buildings and neighborhoods with no greenhouse gas emissions and thereby contributes to a low carbon society.

Entering the final years of the FME ZEN center – we will need to speed up and spread the word beyond the pilot projects, beyond the scientific work and reports. Our mission is to move Norway towards a Zero emission society with best practice examples, large scale pilot projects, cases and living labs and together we advocate an excellence in sustainable energy research in Norway.

The Mid-way evaluation panel has given us all 3 key recommendations for the remaining period:

Recommendation 1: "That in the second funding period, the Centre extensively test its various models & tools in the 'real-world' settings that its partners can provide, with an additional focus on reaching the general public."

Recommendation 2: "That the Centre formalize the process used to manage the diversity of topics that come within the purview of zero emissions neighborhoods. While the broad scope of the Centre should be maintained and the development of new topics should be encouraged, transparent and strategically informed decisions need to be taken as to which of these topics should be incorporated into the program, which put aside for associated projects, and which left altogether."

Recommendation 3: "That the Centre increase efforts to improve longevity of the program by expending effort in the last three years on facilitating knowledge transfer from academia and research partners to the industry through researchers spending time in industry and industry partners spending time in the Centre."

The recommendations are a call to action. I can't wait to meet these challenges and nurture the importance and legacy of the ZEN center in the significant final years. We already see results from case studies, the research activities, pilot projects, and living labs. We now need to pivot the testing of the ZEN criteria, tools and KPI's in a broader project portfolio provided by the partners. This way we can scale up the solutions and innovations and cater for an in-depth exchange of knowledge and create an interdisciplinary learning circuit, before finalizing the recommended criteria set and planning tools for our future zero-carbon neighborhoods. Investment in ZEN Cases and intensified collaboration with other FME centers and researchers can be measures to keep focus and better handling the balance of breadth and depth within the Centre's research.

Our research and innovations are unique in a global perspective, and more significant than ever. With the ZEN-definition, criteria, and tools widespread, tested and in place, the ZEN Research Centre with partners will contribute to changing both the industry and the society at large. Together we will implement the knowledge and tools needed for a low carbon society. Welcome to the future!

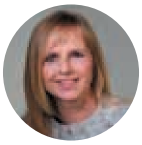
Centre Board

Anders Fylling, Statsbygg
Anna-Thekla Tonjer, Elverum vekst
Jørgen Nordahl, Statkraft
Leif Øie, GK
Marianne Skjulhaug, NTNU
Sigrid Strand-Hanssen, Asplan Viak
Siri Hunnes Blakstad, SINTEF
Tonje Frydenlund, Snøhetta

"A method based on geographical information system (GIS) has been used to analyze spatial conditions essential to carbon emissions in neighbourhoods.

A VERY POSITIVE MIDWAY EVALUATION FOR ZEN

Arild Gustavsen
Centre director
Professor, ZEN, NTNU

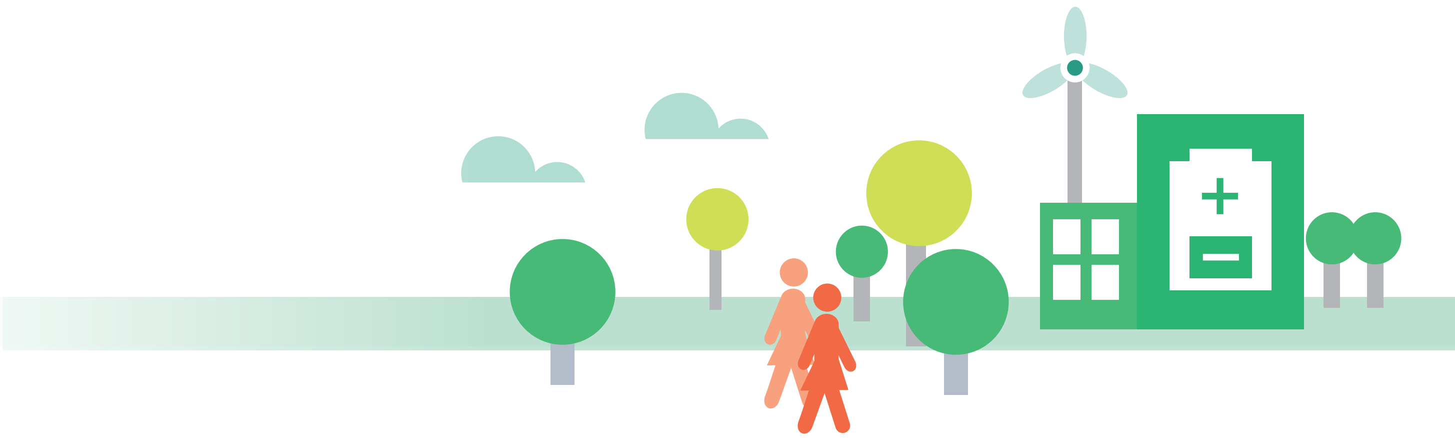


Ann Kristin Kvellheim
ZEN and
SINTEF Community

In 2021, The Research Council of Norway completed its Mid-Term Evaluation report of the Research Centers on Environment-Friendly energy (FMEs). We are willingly quoting from the evaluation report:

> *The quality and outcome of the research carried out in the Centre is impressive at different levels including in terms of its broad scope and the variety of problems and research issues it covers: from more engineering-orientated questions of building design and modelling to questions of integration into the wider energy system; questions of low-carbon transport; and social science issues of stakeholder participation; citizen engagement; and business model development. This broad range of issues could pose a formidable challenge to the organisation and management of research in such a Centre, but at the same time the critical mass achieved in such a research Centre also provides a unique opportunity to deal with such questions in their connectedness and interrelatedness. The Centre does so in an excellent manner and contributes to the forefront of international research on the transition towards low-carbon settlements and societies. Moreover, there is a good mix of industry focused and research-based projects, supported by the ZEN Labs and Pilots.*

However, there is no time to rest on our laurels. The ZEN Centre has entered the final three years of its funding period, and focus will increase on how to implement the knowledge and tools developed in the market and also to make sure that policy makers are aware of ZEN Centre results and that new policies and regulations are adjusted based on the new knowledge.



RESEARCH, DEVELOPMENT, AND INNOVATION ACTIVITIES

FME ZEN has further developed a definition of a zero-emission neighbourhood, which is a group of interconnected buildings with associated infrastructure, located within a confined geographically defined area, aiming at reducing its direct and indirect greenhouse gas (GHG) emissions towards zero. Part of the definition is a set of KPIs that is developed and tested. Life cycle assessment (LCA) is a central methodology in FME ZEN, needed to calculate potential greenhouse gas emissions from a ZEN project. Overall findings indicate that it is challenging to achieve net zero GHG emissions at the neighbourhood level, given how projects are designed today. There is a need for measures to minimize materials embodied emissions, creating surplus generation of renewable energy that can off-set emissions from fossil energy generation or use elsewhere, and ensuring substantially lower emissions from mobility than what is common today.

A suite of models and tools is under development, which enables to study the buildings and neighbourhoods' energy loads and how to modify them. The tool PROFet is being tested by ZEN partners. It provides knowledge on today's typical energy demand profiles from measurements. Another tool, FLEXor, will tackle how to change the demand by implementing demand response in buildings and neighborhoods, thus obtaining flexible energy loads that deviate from the typical ones.

Integrate is a tool used in evaluation of alternative energy system configurations for confined areas. The model minimizes total system costs within a given planning period, subject to hourly energy demands, options for further development, and limitations of the existing energy system. The model includes multiple energy carriers as well as electric and seasonal and diurnal thermal energy storage. The model has been used to assess the importance of district heating and seasonal thermal energy storage in unloading the surrounding power grid, as well as to assess the optimal integration of surplus heat sources in an existing district heating network.

The impact of ZEN and ZEN-solutions on the power system has been explored through further development of a power-system tool (EMPIRE). Some key findings are that reduced use of electricity in Norwegian buildings can increase the contribution from Norwegian hydropower in Europe; and that ZEN can reduce the cost of the transition to a fossil-free energy system.

We need innovative solutions to achieve the ZEN ambition. Sometimes, however, these are in violation of applicable law.

We highlight challenges and opportunities when this is the case, especially in connection with the Planning and Building Act and the Energy Act. Public procurement can be a good tool for achieving the zero-emission ambition. A conceptual model for implementing strategic procurement in complex systems and programs has been developed.

A method based on geographical information system (GIS) is being used to analyse spatial conditions essential to carbon emissions in neighbourhoods. This method was up to now applied to evaluate different proposals for the development of three different pilot areas, Bodø, Sluppen, and Fornebu.

A definition of system boundaries for zero-emission farms has been developed with the pilot Mære. The research is about which factors related to agriculture are to be included in a greenhouse gas calculation for ZEN agricultural areas. Agriculture account for approx. 9% of total direct greenhouse gas emissions in Norway and plays an important role in the transition to a low-emission society.

Several of the activities in the pilot projects are carried out in the form of living laboratories. The pilot Ydalir, Elverum investigated what young and adult residents perceive as the "good life". The living lab collected data through interviews, workshops, and participatory methods. The goal was to understand how the ZEN concept is perceived and how ZEN neighborhoods can contribute to creating attractive places to live.

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

INNOVATION IN THE ZEN RESEARCH CENTRE

Excellence in outcomes arise from excellence in innovation processes which are heightened by innovative mindsets.

For the FME ZEN Research Centre, innovation is the process of developing new knowledge, which is useful for societal actors, and which is in turn utilized by societal actors. In 2021 the Research Centre transitioned into the second half of the FME's lifespan. In this second phase, activities stimulating innovation and the evaluation of key results has become increasing salient when maximizing the impact of the research for the benefit of society and striving to deliver new services, products, and solutions to FME ZEN's partners and to the market.

In 2021 innovation activities have focused on developing a dialogue around the communication, dissemination (how results are shared, with whom and when), and exploitation (utilization) of key exploitable results (KERs) in FME ZEN. The first innovation report published in 2020 laid the foundation for working with partner collaboration and examining the potential for exploiting maturing innovations for both scientific use and commercialization.

Towards the end of 2021, planning was underway for an initial exploitation workshop for selected key exploitable results (KERs) with ZEN's Management Team and key researchers, together with NTNU and SINTEF's Technology Transfer Organizations (TTOs). Dialogue for safeguarding the interests of ZEN partners and ensuring that the results will be used widely in the market shall be highlighted.

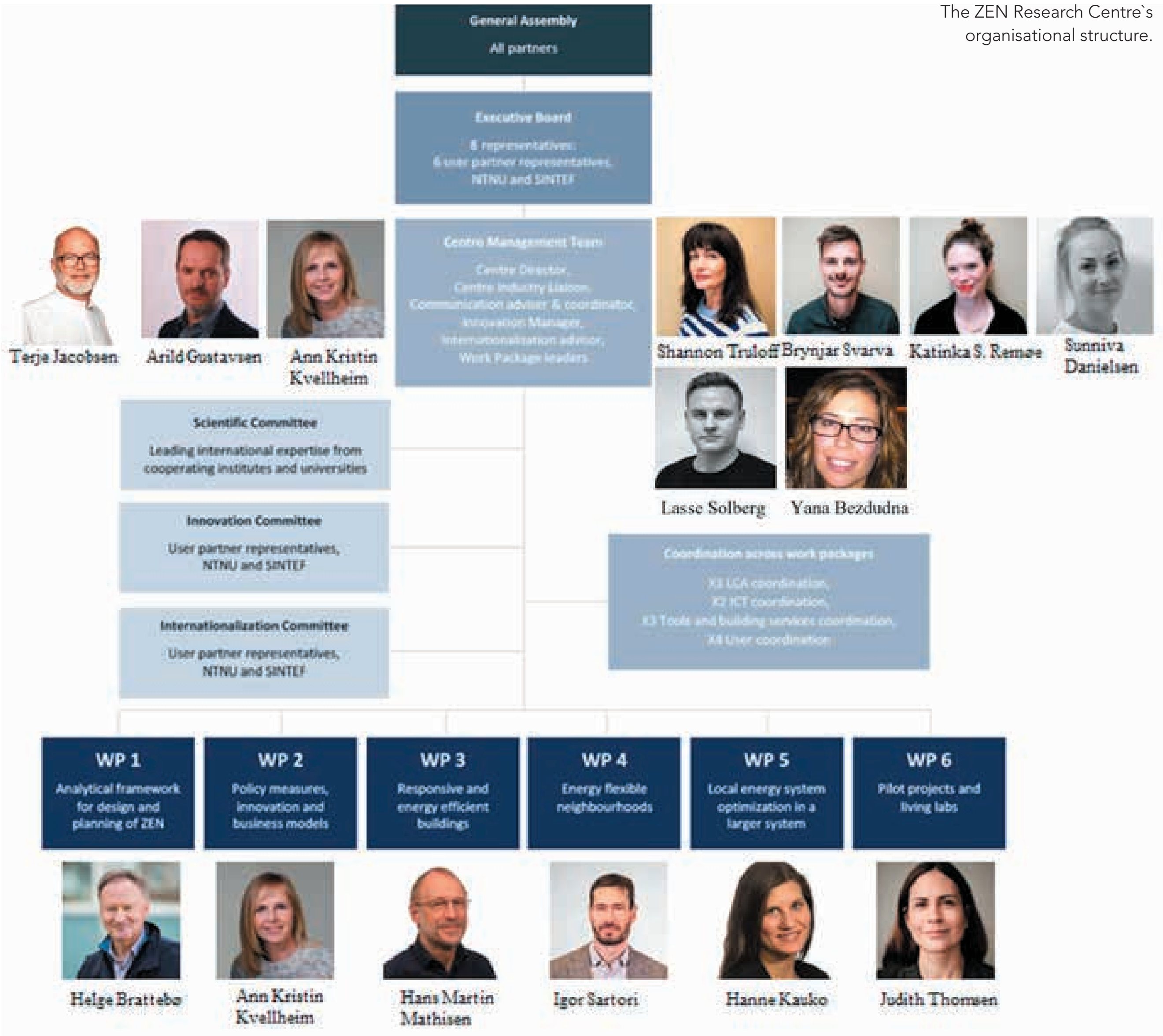
In 2021 the methodology for identifying, registering, and reporting innovations was further developed. Applying a structured, comprehensive, and systematic approach has proved beneficial in capturing and positioning intellectual property (IP) in FME ZEN. Work continues with the IP register which facilitates communication of knowledge. It enables pro-active steering of projects and monitoring of progress and output and has proved to be an effective tool to promote synergies between KERs. As we move forward, the register will be used to identify links to business value and more efficiently make informed decisions. Last but not least, the systematic monitoring of maturing innovations is helping to promote collaborative ability, increased clarity of who brings what into a collaboration and building trust.

In 2021, the ZEN Innovation Committee (see textbox) consisting of representatives from the user partners met three times providing guidance on ZENs innovation processes and acting to ensure the execution of the innovation work plan established for the year.

INNOVATION COMMITTEE MEMBERS:

Name	Organisation
Svein Olav Munkeby (leader until October 2021)	NTE Marked AS
Jørgen Nordahl (new leader from November 2021)	Statkraft AS
Heidi Erikstad (commencing 2022)	Elverum Vekst
Kjell Skjeggerud	Norcem
Zdena Cervenka	Statsbygg
Stein Stoknes	FutureBuilt
Rakel Hunstad (ending 2021)	Bodø municipality
Kai Haakon Kristensen (ending 2021)	Bodø municipality
Shannon Truloff	NTNU
Elsebeth Holmen	NTNU
Ann Kristin Kvellheim	SINTEF Community
Terje Jacobsen	SINTEF Community

ORGANISATION OF THE ZEN RESEARCH CENTRE



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 includes 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.

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 laboratories are being used by our researchers and partners within user cases and the work packages. Examples of lab research activities can be explored 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

Photo: Geir Mogen

Photo: Leikny Havik Skjæseth

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

Photo: Nicola Lolli, SINTEF

ZEB Laboratory

ZEB lab is a laboratory for zero emission buildings (ZEB) – an arena where new and innovative materials and solutions are developed, investigated, tested, and demonstrated in mutual interaction with people.

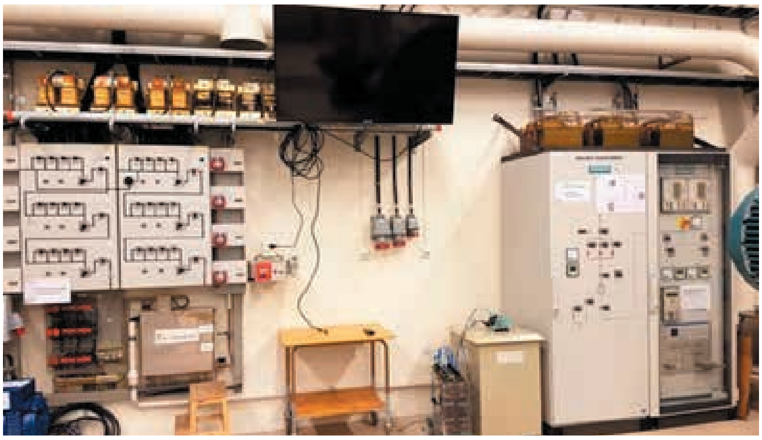
The construction of the laboratory was completed in the fall 2020.

More information: http://zeblab.no/

Smart Grid Laboratory

Distribution network with two departures / radials.

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



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

SNAPSHOTS OF OUR RESEARCH

How heat batteries will reduce both energy costs and carbon footprint in buildings

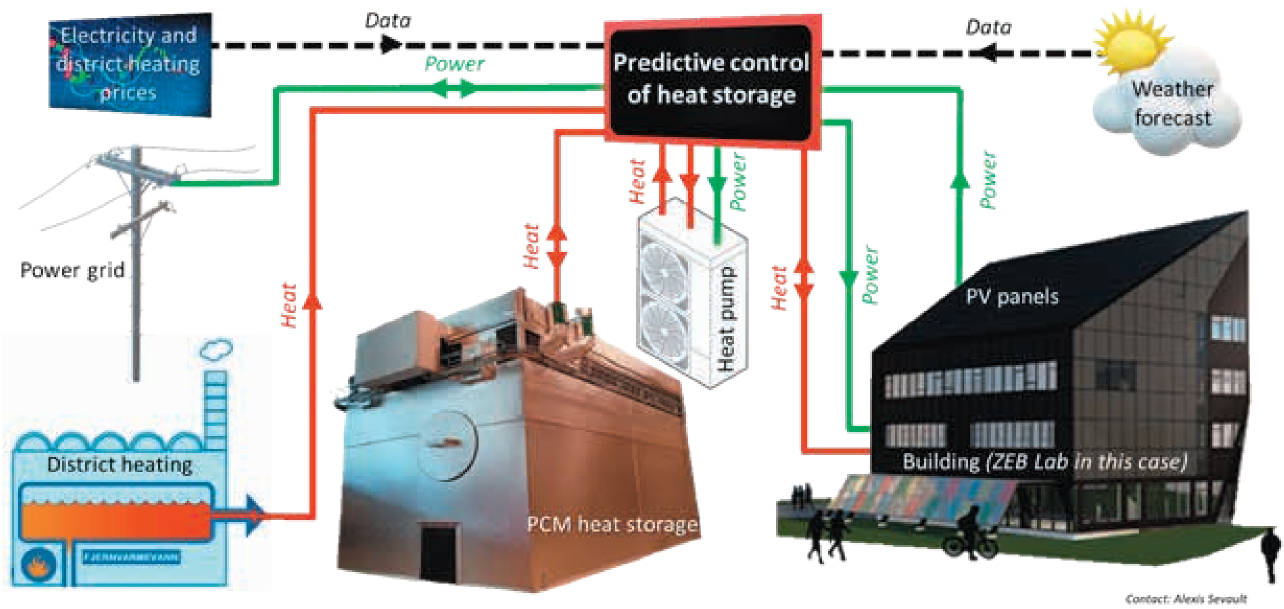
Alexis Sevault
Research leader,
SINTEF Energy

What if you could leave it to a smart system to control your energy consumption for heating and cooling so that you radically reduce both your energy bills and your CO_2-footprint, without a headache? That's the main focus of PRESAV, a spin-off project funded by FME ZEN.

Based on upcoming electricity price, district heating price, weather forecast, and local heat demand in buildings, PRESAV's predictive control system will actively control a heat battery to use it as a heat buffer.

When is it the smartest to use cheaper electricity or district heating to charge the heat battery? Or to charge it using excess electricity from the local PV panels to reduce a building's carbon footprint? SINTEF Energy Research, SINTEF Community, and NTNU gathered some of their best brains to solve these questions into one single predictive energy management system. Every day, the system will make a plan for the next 24 hours to utilize as much of the locally produced solar energy as possible and avoid peak loads on district heating networks and electricity networks during high load times.

The control system will be tested in the ZEB Laboratory in Trondheim, which has both a 200-kWh PCM (Phase Change Materials) heat storage unit and PV panels, in addition to a customizable energy management system. The control system will then be used there.



PIt takes many variables to develop a predictive control system to actively manage heat batteries in buildings

Hvordan varmebatterier skal redusere både energikostnader og karbonfotavtrykk i bygninger

Hva om du kunne la et smart system styre energibruk til oppvarming og kjøling slik at du på en systematisk og enkel måte reduserer både energiregningen og CO_2-fotavtrykket? Dette er hovedmålet til PRESAV, ett spin-off-prosjekt finansiert av FME ZEN.

SINTEF Energi forskere Fride VULLUM-BRUER og Alexis SEVAULT foran det innovative PCM-varmelageret implementert som pilotteknologi i ZEB-laboratoriet (Trondheim). Foto: SINTEF/ Smidesang&Lyng

Basert på strømpris, fjernvarmepris, værmelding og lokalt varmebehov i bygninger, skal PRESAV sitt prediktive styringssystem aktivt styre et varmebatteri som skal utnyttes som en varmebuffer.

Når er det smartest å bruke billigere strøm eller fjernvarme for å lade varmebatteriet? Eller å lade det med overskuddselektrisitet fra de lokale solcellepanelene for å redusere en bygnings karbonavtrykk? SINTEF Energi, SINTEF Community og NTNU har samlet noen av sine beste hjerner for å løse alle disse problemstillingene i et prediktivt energistyringssystem. Systemet vil hver dag legge en plan for de neste 24 timene for å best mulig utnytte den lokalproduserte solenergien og dermed unngå topplaster i fjernvarmenettet og kraftnettet i perioder med høy last.

Styringsstrategiene skal testes i ZEB-laboratoriet i Trondheim som har både et 200-kWh PCM (faseforandringsmaterialer) varmelager og et solcelleanlegg, i tillegg til et programmerbart energistyringssystem. Der skal den beste styringsstrategien brukes fremover.

EV charging in residential buildings: Analysis of charging habits, energy use and flexibility

Åse Lekang Sørensen
PhD-student and researcher, SINTEF Community

Many people want to charge their electric vehicle (EV) at home, and this can create challenges for the local power grid. At the same time, EVs represent a large potential for energy flexibility.

EVs are often connected to the charger longer than the time it actually takes to charge the battery. This available time represents flexibility as charging can be carried out at night when there is less load on the electricity grid. This will reduce the load in the afternoon but still ensure that the car is charged and ready to use the next day. Charging in the afternoon when other energy needs are high.

In FME ZEN, SINTEF has analysed EV charging in apartment buildings, based on charging reports from Risvollan housing cooperative in Trondheim. The housing cooperative installed new charging infrastructure in December 2018, and until January 2020, 97 residents were connected to the system. 58 of these have charge points at their own parking spaces and 24 residents use shared chargers.

We have analysed the times of the day when residents connect their EVs to and from the chargers. From Monday to Friday, a large proportion of the connections take place in the afternoon, and the disconnections in the morning. This agrees well with the typical working days. During weekends, connections and disconnections are more scattered throughout the day. The distribution of times depends on whether the residents have chargers on their own parking spaces or whether they use shared chargers. This also affects the duration of the connections. For users with their own chargers, the average connection time is 12.8 hours, while this is 6.5 hours for the shared chargers at Risvollan.

Often EV charging starts immediately after connection to the charger. This means that the energy used to charge is peaking in the afternoons on workdays, from approx. 16:00 to 24:00. The weekend profile is comparable to the workdays, with a higher charging demand on Sunday evenings than on Saturday evenings.

The analyses show that there is a significant potential for flexibility in the residential EV charging, especially when residents can charge at their own parking spaces.

The number of EVs in Norway is increasing rapidly. Analyses show that there is a significant potential for flexible EV charging in apartment buildings. Photo: SINTEF

Reference

Å.L. Sørensen (2021). Elbillading i borettslag: Ladevaner, energibruk og fleksibilitet (norwegian short version)

Å.L. Sørensen, K.B. Lindberg, I. Sartori, I. Andresen (2021). Analysis of residential EV energy flexibility potential based on real-world charging reports and smart meter data, Energy and Buildings 241, 2021, 110923. https://doi.org/10.1016/j.enbuild.2021.110923.

Å.L. Sørensen, K. Byskov, I. Sartori, I. Andresen (2021). Residential electric vehicle charging datasets from apartment buildings, Data in Brief 36, 2021. https://doi.org/10.1016/j.dib.2021.107105.

Elbillading i borettslag: Analyse av ladevaner, energibruk og fleksibilitet

Elbiler er ofte tilkoblet laderen lenger enn den tiden det tar å lade batteriet. Denne ekstra tiden representerer fleksibilitet ved at ladingen kan styres til natten når det er mindre belastning på nettet. Slik minsker man belastningen på ettermiddagen, men sørger allikevel for at bilen er ladet til den skal brukes dagen etter.

I FME ZEN har SINTEF analysert elbillading i borettslag, basert på laderapporter fra Risvollan borettslag i Trondheim. Borettslaget installerte ny ladeinfrastruktur i desember 2018, og fram til januar 2020 ble 97 beboere tilknyttet systemet. 58 av disse har ladepunkter på egne parkeringsplasser og 24 beboere benytter felles-ladere.

Det er en rask økning i antall elbiler i Norge. Analyser viser et betydelig potensial for fleksibel elbillading i borettslag og sameier. Her fra felleslader i Risvollan Borettslag. Foto: Sunniva Danielsen

Vi har analysert tidspunktene for når beboere kobler elbilene sine til og fra laderne. I ukedagene skjer en stor andel av tilkoblingene på ettermiddagen og frakoblingene på morgenen. Dette stemmer godt overens med typiske arbeidsdager. I helgene er tilkoblinger og frakoblinger mer spredt gjennom dagen. Fordelingen av tidspunkter avhenger av om beboerne benytter ladere på egne parkeringsplasser eller om de benytter felles-ladere. Dette påvirker også varigheten til tilkoblingen. For brukere med egne ladere er gjennomsnittlig tilkoblingstid 12,8 timer, mens dette er 6,5 timer for felles-laderne på Risvollan.

Ofte starter elbillading umiddelbart ved tilkobling. Dette betyr at bruken av energi til lading er størst på ettermiddagene på ukedager, fra ca. klokka 16:00 til klokka 24:00. Helgeprofilen er sammenlignbar med ukedagene, og med et høyere ladebehov søndag kveld enn lørdag kveld.

Analysene viser et betydelig potensial for fleksibel elbillading i borettslag og sameier, særlig når beboere har lademulighet på egne parkeringsplasser.

Referanser

Å.L. Sørensen (2021). Elbillading i borettslag: Ladevaner, energibruk og fleksibilitet (norsk kortversjon)

Å.L. Sørensen, K.B. Lindberg, I. Sartori, I. Andresen (2021). Analysis of residential EV energy flexibility potential based on real-world charging reports and smart meter data, Energy and Buildings 241, 2021, 110923. https://doi.org/10.1016/j.enbuild.2021.110923.

Å.L. Sørensen, K. Byskov, I. Sartori, I. Andresen (2021). Residential electric vehicle charging datasets from apartment buildings, Data in Brief 36, 2021. https://doi.org/10.1016/j.dib.2021.107105.

Grey-box models for the Model Predictive Control (MPC) of space-heating

Xingji Yu
PhD student,
NTNU

Laurent Georges
Associate Professor,
NTNU

How field measurements should be performed?

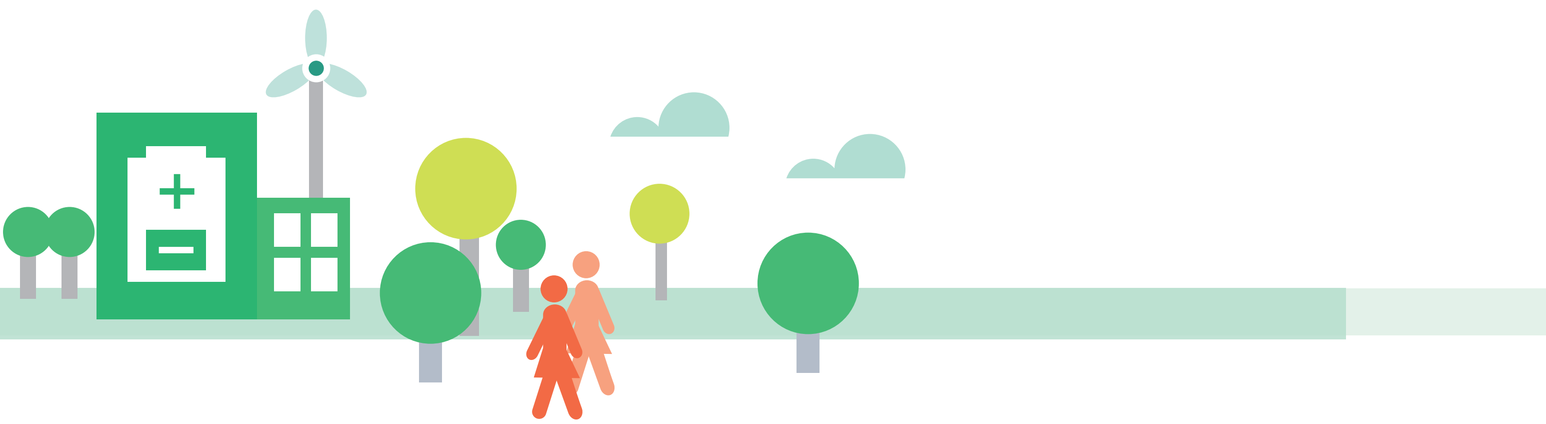
Grey-box models have a structure that is defined by physical laws while their parameters are calibrated using data from field measurements (i.e., data-driven models). Our research provides practical guidelines on the way data should be measured in buildings to create reliable grey-box models.

The thermal behavior of buildings can be modeled using grey-box models. Firstly, the grey-box model can be included in a Model Predictive Control (MPC) of the heating system so that the building fabric is used as thermal storage. This is particularly interesting to activate the building energy flexibility for demand response, like peak-shaving. Secondly, grey-box models can be used to characterize the thermal properties of the building envelope using on-site measurements. For instance, the overall heat transfer coefficient of the building can be evaluated.

Wall-mounted temperature sensors in the ZEB Living Lab

In real life, sensors alter the data before it is used for model identification. For example, a temperature sensor can measure the temperature at a high frequency (like every minute) but only record an averaged value at a longer period of time (like every 15 minutes). In addition, temperature sensors are often integrated in a casing and mounted on a wall so that they do actually measure the exact air temperature of the room.

Our research work investigates these influences of sensors on the performance of grey-box models. The first study [1] is simulation-based but conclusions are confirmed in a second study [2] using the ZEB Living Lab as a case.



Grå-boks modeller for modellprediktiv kontroll (MPC) av romoppvarming

Hvordan skal feltmålinger utføres?

Grå-boks modeller har en struktur som er definert av fysiske lover mens parameterne deres er kalibrert ved hjelp av data fra feltmålinger (dvs. datadrevne modeller). Vår forskning gir praktiske retningslinjer for hvordan data bør måles i bygninger for å lage pålitelige grå-boks modeller.

Den termiske oppførselen til bygninger kan modelleres ved hjelp av grå-boks modeller. For det første kan grå-boks modellen inkluderes i en modellprediktiv kontroll (MPC) av varmesystemet ved at bygningsmaterialene brukes som termisk lagring. Å bruke energifleksibiliteten i bygningen på denne måten, kan bidra til å aktivere etterspørselsrespons, som flytting av effektforbruk (peak-shaving). For det andre kan grå-boks modeller brukes til å karakterisere de termiske egenskapene til bygningsfasaden ved bruk av målinger på stedet. For eksempel kan den totale varmeoverføringskoeffisienten til bygningen evalueres.

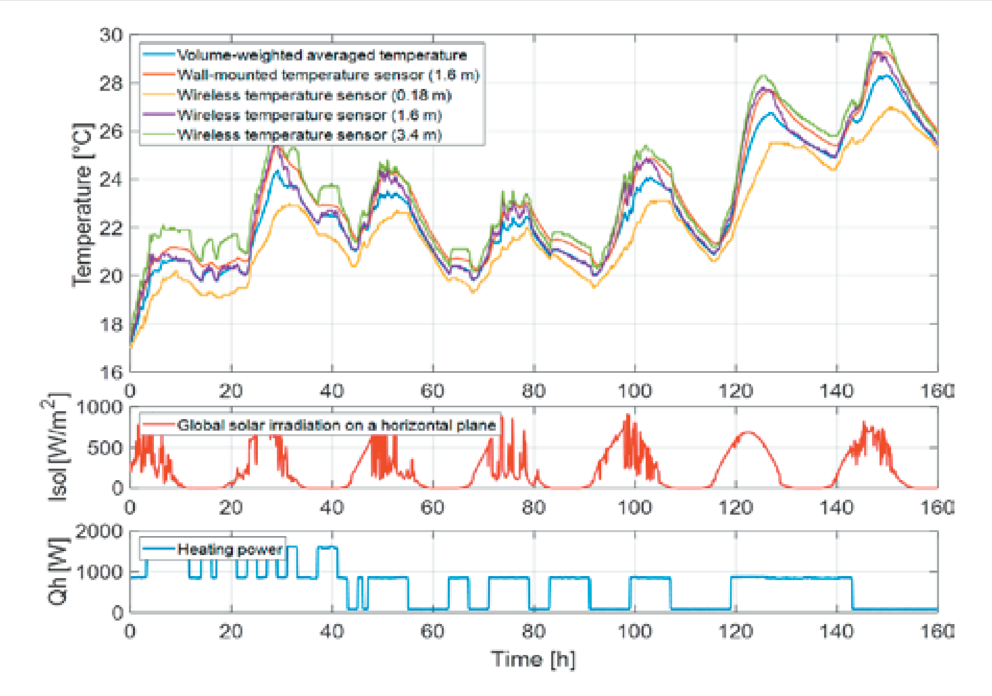
I det virkelige liv endrer sensorer dataene før de brukes til modellidentifikasjon. For eksempel kan en temperatursensor måle temperaturen ved en høy frekvens (som hvert minutt), men bare registrere en gjennomsnittsverdi over en lengre periode (som hvert 15. minutt). I tillegg er temperatursensorer ofte integrert i et kabinett og montert på en vegg slik at de faktisk måler den nøyaktige lufttemperaturen i rommet.

Forskningsarbeidet vårt undersøker hvordan slike sensorer påvirker ytelsen til grå-boks modeller. Den første studien [1] er simuleringsbasert, men konklusjonene bekreftes i en andre studie [2] med ZEB Living Lab som case.

Referanser

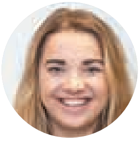
[1] Yu et al., *Data pre-processing and optimization techniques for stochastic and deterministic low-order grey-box models of residential buildings*, Energy and Buildings, 1, February 2021

[2] Yu et al., *Influence of Data Pre-processing and Sensor Dynamics on Grey-box Models for Space-Heating: Analysis using Field Measurements*, Building and Environment, January 2022



Difference in room air temperature measurement depending on the sensor.

Energy and power: Testing of key performance indicators in 6 pilot areas



Synne Krekling Lien
Research Scientist
NTNU

A definition of zero-emission neighbourhoods (ZEN) with related KPIs is under development and will last throughout the program period of FME ZEN.

In 2021, the suggested KPIs in the categories Energy and Power were tested on a selection of pilots. The results show that net energy demand is estimated to be reduced between 8-32%, and the net delivered electricity is expected to be reduced between 66 – 78 % when the ZEN pilots are compared to representative reference projects with electric heating. The testing also shows that the peak load of electricity can be reduced drastically in the ZEN pilots compared to their references.

In the draft of the ZEN definition, the KPIs can be divided into the categories GHG Emissions, Energy, Power, Mobility, Spatial qualities, economy, and innovation. The KPIs for Energy and Power have been tested on six different pilot areas: Ydalir, Oksenøya, Zero Village Bergen, Dolvik, Campus Evenstad, and Mære landbruksskole.

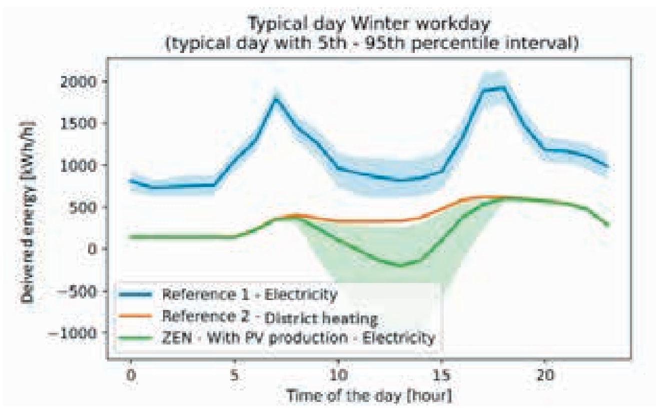
The KPIs seem to provide a way to quantify and grasp the main features of a complex reality where different solutions/technologies might have conflicting effects. The process of working with the KPI calculations shows that there are still challenges linked to calculating the indicators. The study results will be used in further work to establish system boundaries, standard methodologies, and threshold values for evaluating the pilots against the ZEN definition.

The results are published in ZEN report No. 36 – 2021.

Involved ZEN-partners in this study have been SINTEF, Elverum vekst, Elverum kommune, Bærum kommune, ByBo, Bergen kommune, Steinkjer kommune, and Statsbygg.

Involved ZEN-partners in this study have been SINTEF, Elverum vekst, Elverum kommune, Bærum kommune, ByBo, Bergen kommune, Steinkjer kommune and Statsbygg.

Example of results from the report. The presents the typical days for net delivered electricity in three scenarios in Zero Village Bergen (ZVB) on winter workdays between the 5th and 95th percentile. The ZEN-scenario uses district heating for heating and has exports electricity during the middle of the day. The reference scenarios have no export of electricity and use more electricity throughout the day, especially in the reference (Reference 1) with electric heating.



Energi og effekt: Testing av nøkkelindikatorer på 6 pilotområder

En definisjon av nullutslippsnabolag (ZEN) med tilhørende nøkkel-indikatorer er en pågående prosess som vil vare ut forskningssenterets levetid.

I 2021 ble de foreslåtte nøkkelindaktorene fra kategoriene energi og effekt testet på et utvalg av pilotområdene. Testingen viser at netto energibehov er beregnet til å bli redusert med 8-32 % mens netto levert elektrisitet er forventet å bli redusert med hele 66-78 % i pilotområdene når man sammenligner resultatene med representative referanseprosjekter med elektrisk oppvarming. Testingen viser også at topplasten for elektrisitet reduseres drastisk i ZEN-områdene sammenlignet med referansene.

I det gjeldende utkastet av ZEN-definisjonen, kan nøkkelindikatorene deles inn i følgende kategorier: klima-gassutslipp, energi, effekt, mobilitet, stedskvaliteter, økonomi og innovasjon. De foreslåtte indikatorene for energi og effekt har nå blitt testet ut på seks pilotområder: Ydalir, Oksenøya, Zero Village Bergen, Dolvik, Campus Evenstad og Mære landbruksskole.

De foreslåtte nøkkelindikatorene gjør det mulig å kvantifisere og beskrive hovedtrekkene i en kompleks virkelighet der ulike løsninger og teknologier kan ha motstridende effekter. Arbeidet med testing av nøkkelindikatorene har vist at det fortsatt er flere utfordringer knyttet til beregningene. Resultatene fra testingen vil bli benyttet i videre arbeid med å etablere systemgrenser, videreutvikle standardmetoder og bestemme referanseverdier og poenggrenser for å evaluere pilotene opp mot ZEN-definisjonen.

Resultatene fra studien er publisert i ZEN-rapport nummer 36, 2021.

Involverte ZEN-partnere I studien har vært SINTEF, Elverum vekst, Elverum kommune, Bærum kommune, ByBo, Bergen kommune, Steinkjer kommune og Statsbygg.

Nøkkelindikatorene for Energi og Effekt ble testet på 6 pilotomåder. Fra toppen (venstre) til bunn (høyre): Ydalir, ZVB, Mære landbruksskole, Oksenøya, Campus Evenstad og Dolvik.

Thermal comfort enabling thermal flexibility of buildings

Matteo Favero
PhD Candidate
NTNU

Although thermal comfort has been a research topic since the 1960s, some knowledge gaps still affect understanding of the human response to changing thermal environments.

To enhance knowledge in this regard and understand the human response to monotonic thermal variations, an exploratory study has been executed in the ZEB Test Cell Lab [1].

Thirty-eight participants, 29 females and 9 males, worked in an office-like climate chamber and were exposed to dynamic and controlled heating and cooling ramps of the operative temperature with different speeds. Participants could indicate when an uncomfortable event occurred during these temperature ramps by clicking a digital button on a dedicated app. This experience of discomfort was defined in behavioural terms as the decision to "take action to restore a comfort condition".

Survival analysis was used to study participants' reactions to the dynamic thermal stimuli. It showed that two distinct mechanisms caused discomfort events due to overheating and undercooling:

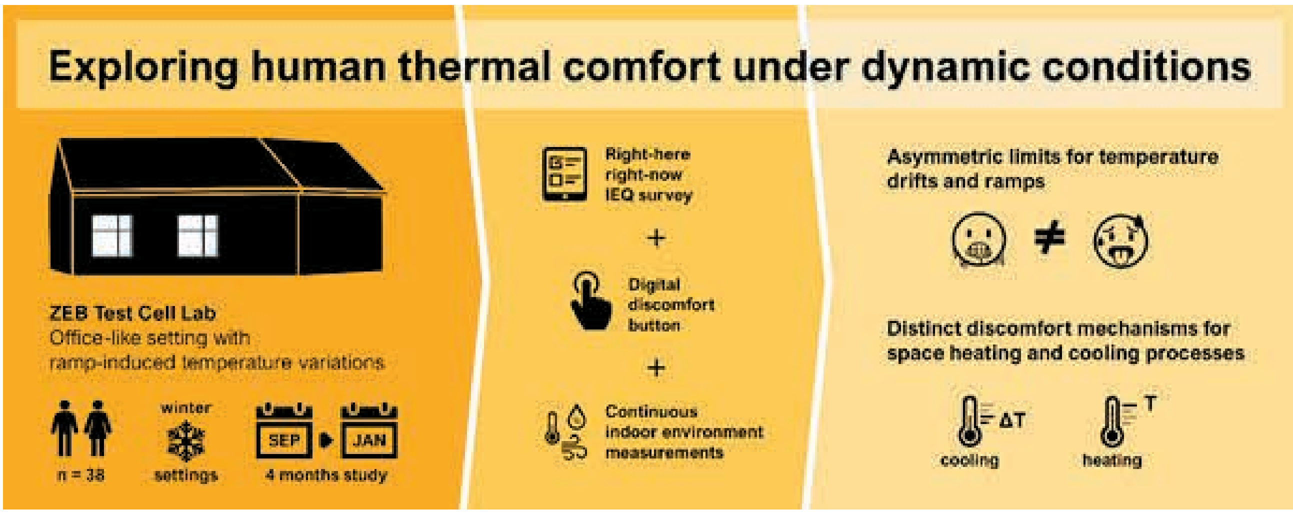
- Warm discomfort is driven by the absolute value of the achieved operative temperature
- Cold discomfort is mainly caused by the relative change in operative temperature

Compared to the current recommendations regarding temperature cycles, drifts and ramps [2], this result shows that current standard recommendations underestimate the risk of thermal discomfort during a cooling process while overestimating it during a heating one.

The new knowledge of human reaction to a dynamic thermal environment can lead to more energy-efficient and satisfactory building control strategies to enable buildings' thermal flexibility. This can for example be done by overheating a building and exploiting its thermal mass to displace the space heating by a certain period, without compromising the occupants' satisfaction.

References:

[1] M. Favero, I. Sartori, S. Carlucci, Human thermal comfort under dynamic conditions: An experimental study, Building and Environment 204 (2021) 108144. doi:10.1016/j.buildenv.2021.108144
[2] ANSI/ASHRAE Standard 55, Thermal environmental conditions for human occupancy, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA, 2020



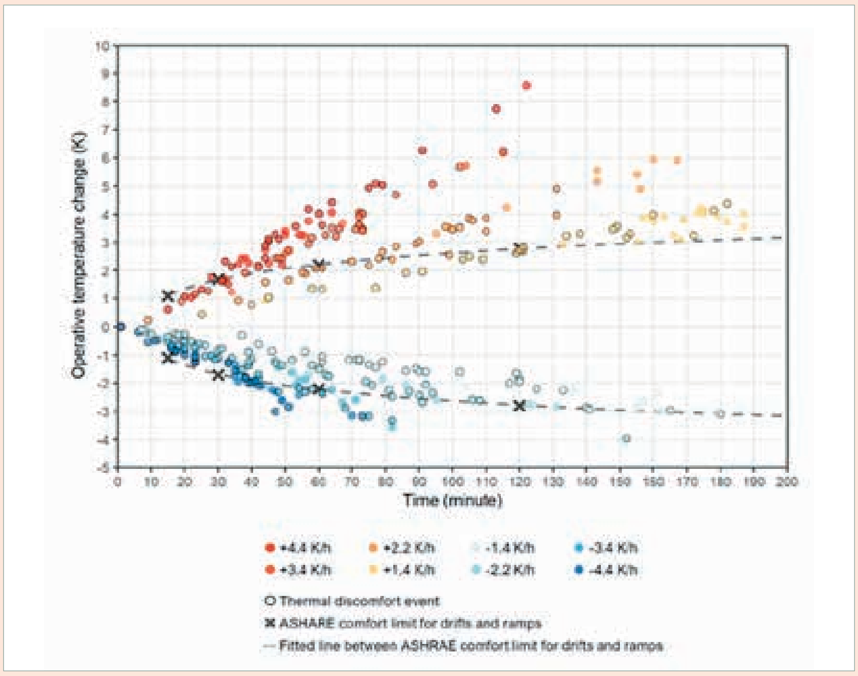
Graphical abstract [1]. Illustration: Matteo Favero.

Termisk komfort som muliggjør termisk fleksibilitet for bygninger

Selv om termisk komfort har vært et forskningstema siden 1960-tallet, er det fremdeles noen kunnskapshull som påvirker forståelsen av hvordan mennesker responderer på skiftende termiske miljøer.

For å øke kunnskapen rundt dette, og forstå den menneskelige responsen på monotone termiske variasjoner, har vi utført en utforskende studie i ZEB Test Cell Lab [1].

I studien jobbet trettiåtte deltakere, 29 kvinner og 9 menn, i et kontorlignende klimakammer. Det ble brukt et dynamisk og kontrollert oppvarmings- og kjøleanlegg som utsatte deltakerne for operativ temperatur med forskjellige hastigheter. Deltakerne kunne indikere når de følte ubehagelig ved disse temperaturrampene. Dette gjorde de ved å klikke på en knapp i en app. Denne opplevelsen av ubehag ble definert som beslutningen om å "iverksette tiltak for å gjenopprette komfort".



Eksperimenter på inneklima i ZEB-testceller: målinger av termisk ubehag ved oppvarming og kjøling med temperaturendring i korte perioder [1].

Overlevelsesanalyse ble brukt til å studere deltakernes reaksjoner på dynamisk termisk stimuli. Analysen viste at to distinkte mekanismer forårsaket ubehag på grunn av overoppheting og underkjøling:

- Varmt ubehag er drevet av absoluttverdien av oppnådd operativ temperatur
- Kaldt ubehag forårsakes av den relative endringen i operativ temperatur

Sammenlignet med gjeldende anbefalinger for temperatursykluser, trekk og kjøleanlegg [2], viser dette resultatet at gjeldende standardanbefalinger undervurderer risikoen for termisk ubehag ved en kjøleprosess, og overvurderer ved oppvarming.

Den nye kunnskapen om menneskelig reaksjon på et dynamisk termisk miljø, kan føre til mer energieffektive og tilfredsstillende kontrollstrategier for å muliggjøre bygningers termiske fleksibilitet. Dette kan skje ved å eksempelvis overopphete en bygning og utnytte dens termiske masse til å forskyve romoppvarmingen for en bestemt periode, uten at det går på bekostning av beboernes opplevelse av komfort.

Referanser:

[1] M. Favero, I. Sartori, S. Carlucci, Human thermal comfort under dynamic conditions: An experimental study, Building and Environment 204 (2021) 108144. doi:10.1016/j.buildenv.2021.108144

[2] ANSI/ASHRAE Standard 55, Thermal environmental conditions for human occupancy, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA, 2020

IAQ+: Long term measurements of Indoor Air Quality in the ZEB-laboratory

Maria Justo Alonso
PhD Candidate
NTNU

Measurement equipment that will be deployed at the ZEB laboratory. Picture: Lars Bang

The ZEB-laboratory is a full-scale office building that was built deploying different ventilation strategies.

The ZEB-lab is built as a ZEB-COM building which means that the building's renewable energy production will compensate for greenhouse gas emissions from the construction, operation, and production of the building materials. Cross-laminated timber, glue-laminated timber, and solid wood were the preferred construction materials to reduce CO_2-emissions.

It is a common assumption that wood positively affects indoor relative humidity, a known challenge during winter in Norwegian offices. However, wood emits volatile organic compounds such as aldehydes, terpenes, and organic acids, which may pose a concern regarding adverse health effects.

By conducting long-term measurements of indoor air quality in the air-tight and well insulated ZEB-laboratory, we will shed light on the effect of using massive wood on:

- Relative humidity
- VOC (Volatile Organic Compounds)
- Formaldehyde
- PM2.5
- CO_2
- Temperature

Only the two last parameters are considered for the control of the different ventilation strategies.

Collecting at least one year of data on the ZEB laboratory with low-cost sensors will give some background to answer the following questions:

- Can we use low-cost sensors for this task?
- What is the evolution of the selected pollutant's concentrations for one year and what are the seasonal effects on the emissions when referring to a wooden building compared to a reference non-wooden building?
- How efficient are the different ventilation strategies in removing these pollutants?
- Does the use of a wooden structure have a positive effect on RH compared to existing measurements in non-wooden offices?

The measurement campaign started in December 2021, with seven sensors installed. Each sensor has a QR-code that accesses a website with updated measurement data.

References:

1 Time, B, et al, 2019: *The design process for achievement of an office living laboratory with a ZEB standard.* 9
2 Thorsell, j. et al, 2019 NERO – *Cost reduction of new Nearly-Zero Energy Wooden buildings in Northern Climate Conditions. D3.4 Report on ZEB cost calculation and analysis*
3 Salthammer, T., & Bahadir, M. (2009). Occurrence, Dynamics and Reactions of Organic Pollutants in the Indoor Environment. CLEAN – Soil, Air, Water, 37(6), 417-435. doi:10.1002/clen.200900015
4 Salthammer, T., Mentese, S., & Marutzky, R. (2010). Formaldehyde in the Indoor Environment. Chemical Reviews, 110(4), 2536-2572. doi:10.1021/cr800399g

IAQ+: Langtidsmålinger av inneluftkvalitet i ZEB-laboratoriet

ZEB-laboratoriet er et fullskala kontorbygg som ble bygget med forskjellige ventilasjonsstrategier.

ZEB-lab er et ZEB-COM bygg som innebærer at bygningens fornybare energiproduksjon skal kompensere for klimagassutslipp fra bygging, drift og produksjon av byggematerialene. For å redusere CO_2-utslipp, ble det brukt krysslaminert tre, limt laminert tømmer og massivtre. Det er en gjengs antagelse at tre har positive effekter på den relative luftfuktigheten innendørs, en kjent utfordring om vinteren i norske kontorer. Imidlertid avgis flyktige organiske forbindelser som aldehyder, terpener, og organiske syrer, og disse kan gi bekymring for mulig ugunstige helseeffekter.

Ved å gjennomføre langtidsmålinger av inneluftkvalitet i det lufttette og godt isolerte ZEB-laboratoriet, vil vi belyse effekten av bruk av massivt tre på:

- Relativ fuktighet
- VOC (flyktige organiske forbindelser)
- Formaldehyd
- PM2.5 (svevestøv)
- CO_2
- Temperatur

Bare de to siste parameterne vurderes for å kontrollere de ulike ventilasjonsstrategiene.

Å samle minst ett år med data på ZEB-laboratoriet med lavprissensorer vil gi grunnlag for å svare på følgende spørsmål:

- Kan vi bruke lavprissensorer til denne oppgaven?
- Hva er utviklingen av de overvåkede forurensningskonsentrasjonene i ett år, og hva er de sesongmessige effektene på utslippene når det refereres til en trebygning sammenlignet med en referansebygning som ikke er av tre?
- Hvor effektive er de ulike ventilasjonsstrategiene for å fjerne disse forurensningene?
- Har bruk av trekonstruksjoner en positiv effekt på relativ fuktighet sammenlignet med eksisterende målinger i kontorer som ikke er av tre?

Målekampanjen startet desember 2021, med syv installerte sensorer. Hver sensor er utstyrt med en QR-kode som gir tilgang til en nettside med oppdaterte måledata.

Referanser:

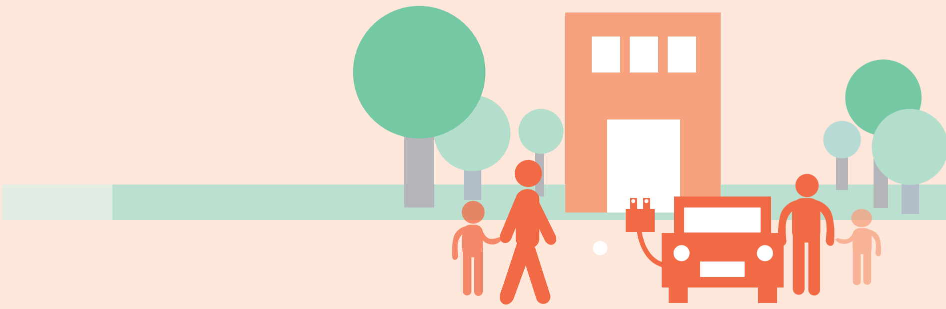
1 Time, B, et al, 2019: *The design process for achievement of an office living laboratory with a ZEB standard.* 9

2 Thorsell, j. et al, 2019 NERO – *Cost reduction of new Nearly-Zero Energy Wooden buildings in Northern Climate Conditions. D3.4 Report on ZEB cost calculation and analysis*

3 Salthammer, T., & Bahadir, M. (2009). Occurrence, Dynamics and Reactions of Organic Pollutants in the Indoor Environment. CLEAN – Soil, Air, Water, 37(6), 417-435. doi:10.1002/clen.200900015

4 Salthammer, T., Mentese, S., & Marutzky, R. (2010). Formaldehyde in the Indoor Environment. Chemical Reviews, 110(4), 2536-2572. doi:10.1021/cr800399g

Skisse av de parameterne som måles i ZEB-Laboratoriet.



Project management – different approaches in ZEN projects

Hasan Hamdan
PhD Candidate
NTNU

ZEN projects are complex and organized differently than traditional housing and construction projects. This has implications for project management processes such as collaboration, procurement, and innovation.

We have studied three different organizing approaches that project managers may consider for complex urban projects such as ZENs (Figure 1).

The first approach, *isolated islands*, illustrates a typical case of disconnected individual infrastructure and buildings. These projects have almost nothing in common. However, a basic form of coordination may exist due to geographic proximity and shared utilities. This approach could work in the future if ZEN goals and KPIs become regulated by law.

ZENs can also be built as *one big island* managed by either one or multiple owners with aligned interests. This approach is common in megaprojects such as large airports. The various infrastructures and buildings are built to serve a well-defined goal, with close interaction and collaboration between the various actors. However, there are some issues that complicate this approach for ZEN including complex land ownership, structure and many stakeholders with different interests and time perspectives.

The last approach represents a middle ground and involves managing ZEN as *weakly connected islands*. Here infrastructures and buildings are built to achieve an overarching goal, with some interaction between the different actors. In other words, they share ZEN related decisions and as little as possible about their individual projects.

This approach can be a preferred way of organizing projects because it provides enough flexibility for stakeholders and provides control for those who want to invest in ZEN.

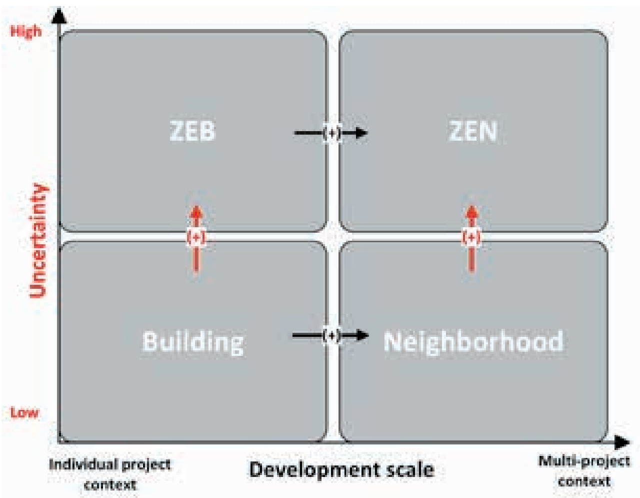


FIGURE 2. GZEN complexity compared to other projects.

References:

Hamdan, H.A.M et al. 2021a. Stakeholder collaboration in sustainable neighborhood projects – A review and research agenda. Sustainable Cities and Society, p. 102776. Available at: https://doi.org/10.1016/j.scs.2021.102776

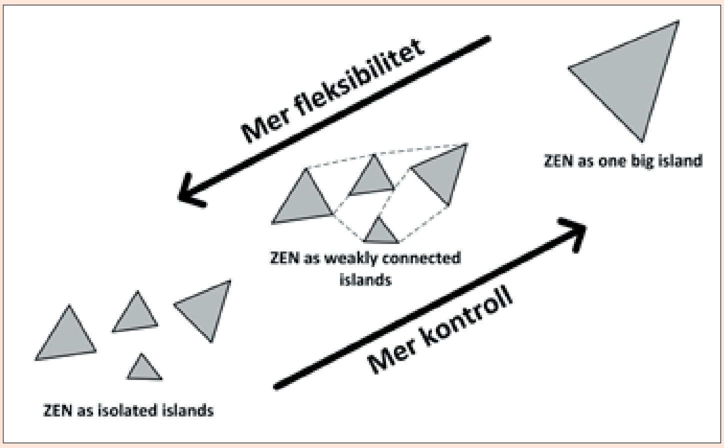
Hamdan, H.A.M. 2021. Strategies promoting innovation in sustainable neighborhood (SN) projects - Lessons from complex and mega projects. Procedia Computer Science 181(2020), pp. 411–418. Available at: https://doi.org/10.1016/j.procs.2021.01.185

Hamdan, H.A.M. et al. 2021b. When green procurement meets complexity: The case of sustainable neighborhood projects. Sustainability 13(4). Available at: https://doi.org/10.3390/su13042116

Prosjektledelse – ulike tilnærminger i ZEN

ZEN-prosjekter er komplekse og organiseres på en annen måte enn vanlige prosjekt. Dette påvirker prosjektledelseprosesser som for eksempel samarbeid, anskaffelse, og innovasjon.

Vi har studert tre ulike tilnærminger som prosjektledere kan ta hensyn til når de organiserer komplekse byprosjekter som ZEN (se Figur 1).



FIGUR 1. Illustrasjon av ulike organiseringsformer for ZEN-prosjekter

Den første, *isolated islands*, illustrerer infrastruktur og bygninger som er frakoblet hvor elementene i nabolaget har lite eller ingenting til felles. En grunnleggende form for koordinering kan imidlertid eksistere på grunn av geografisk nærhet og felles infrastruktur. Denne tilnærmingen kan fungere i fremtiden hvis ZEN mål og KPIer blir regulert i lov og forskrift.

ZEN kan også organiseres som *one big island* styrt av en eller flere eiere med like interesser. Denne tilnærmingen er vanlig i megaprosjekter som for eksempel store flyplasser. Her er infrastrukturer og bygninger utviklet for å nå et veldefinert mål, med tett samspill og samarbeid mellom aktørene. En slik organisering i ZEN kan forhindres av en kompleks eierskapstruktur og aktører med ulike interesser og tidsperspektiv .

Den siste tilnærmingen representerer en mellomting; å utvikle ZEN som *weakly connected islands*. Her bygges de ulike infrastrukturene og byggene for å nå et overordnet mål med noe samspill mellom aktørene. Med andre ord deler de minst mulig om sine ulike delprosjekter, men mer om beslutninger knyttet til ZEN.

Denne tilnærmingen, *weakly connected islands*, kan være en foretrukket måte å organisere prosjekter på fordi den gir nok fleksibilitet for aktører som fortsatt er usikre på sine mål og interesser, men også god kontroll for de som ønsker å investere i ZEN.

Referanser:

Hamdan, H.A.M et al. 2021a. Stakeholder collaboration in sustainable neighborhood projects – A review and research agenda. Sustainable Cities and Society, p. 102776. Available at: https://doi.org/10.1016/j.scs.2021.102776

Hamdan, H.A.M. 2021. Strategies promoting innovation in sustainable neighborhood (SN) projects - Lessons from complex and mega projects. Procedia Computer Science 181(2020), pp. 411–418. Available at: https://doi.org/10.1016/j.procs.2021.01.185

Hamdan, H.A.M. et al. 2021b. When green procurement meets complexity: The case of sustainable neighborhood projects. Sustainability 13(4). Available at: https://doi.org/10.3390/su13042116

Gardermoen – Reduced trip temperature for increased use of surplus heat in an existing district heating system


Hanne Kauko
Senior researcher


Ove Wolfgang
Researcher
SINTEF Energi


Kristin Fjellheim
Researcher


James Kallaos
Researcher
SINTEF Community

Lower temperature in a district heating system reduces loss and makes it more profitable to use a heat pump. This represents both energy efficiency and increased utilization of local energy sources in the analysed area.

Excess heat from data centres and commercial buildings with large cooling systems, is an underestimated and under-utilized resource. Efficient utilization of such low-temperature heat sources is however challenging in existing district heating networks that operate at high temperature levels. Two measures can be used to overcome this:

- Lifting the temperature of excess heat with a heat pump.
- Adapting the heating system to a lower temperature level at the consumer side.

ZEN Case Gardermoen has assessed the problem of finding an optimal supply temperature for an existing district heating network to achieve cost optimality and the highest possible utilization of local surplus heat in combination with a heat pump solution.

The study has used the Integrate -tool1 to examine the socio-economic costs of three different supply temperatures in the district heating network at Gardermoen: 110 ° C (current temperature), 90 ° C and 75 ° C. The analysis shows that today's high temperature level in the district heating network will not be cost-optimal in the future, with the coming development of Oslo Airport City. A reduction from 110 to 90 °C results in a clear reduction in both operating and investment costs. If the temperature is reduced further down to 75 ° C, the result is highly dependent on the investment costs required for measures at the customer. A reduced temperature level additionally provides some clear benefits such as reduced heat losses and increased efficiency for heat pumps.

In addition to the techno-economic analysis, a screening LCA was carried out that can help put the spotlight on the elements that contribute to the highest greenhouse gas emissions over its lifetime. The lowest emissions were achieved with the cases with the lowest temperature due to higher COP for the heat pumps.

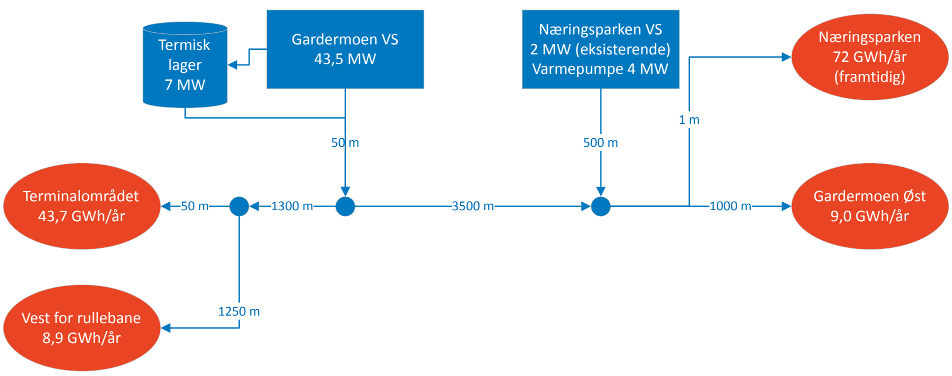


Figure 1. A simplified schematic showing the district heating grid at Gardermoen, and its biggest consumers.

Case Gardermoen – Redusert turtemperatur for økt bruk av overskuddsvarme i et eksisterende fjernvarmesystem

Lavere temperatur i fjernvarmenettet gir redusert tap og gjør det mer lønnsomt å bruke varmepumpe. Dette representerer da både energieffektivisering og økt utnyttelse av lokale energikilder i analyseområdet.

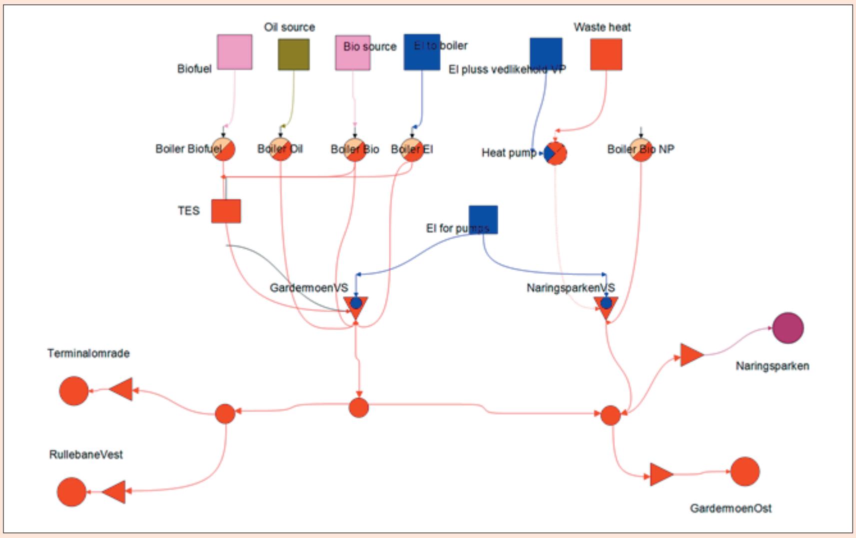
Overskuddsvarme fra datasentre og næringsbygg med store kjølesystem er en undervurdert og lite utnyttet ressurs.

Effektiv utnyttelse av slike lavtemperaturvarmekilder er likevel utfordrende i eksisterende fjernvarmenett som opererer med høye temperaturer. To ulike strategier kan brukes for å overkomme dette:

- Løfting av temperaturnivå ved bruk av varmepumpe
- Tiltak hos kundene for å tilpasse varmesystemet til et lavere temperaturnivå

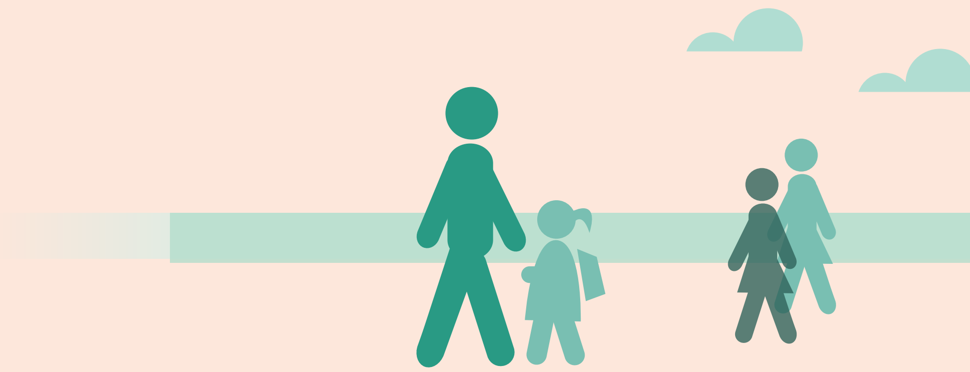
I ZEN Case Gardermoen ble det vurdert hva som er optimal turtemperatur for et eksisterende fjernvarmesystem for å oppnå kostnadsoptimal og høyest mulig utnyttelse av lokal overskuddsvarme i kombinasjon med en varmepumpeløsning.

Studiet har brukt Integrate-verktøyet[1] for å undersøke de samfunnsøkonomiske kostnadene ved tre ulike turtemperaturer i fjernvarmenettet på Gardermoen: 110 °C (dagens temperaturnivå), 90 °C og 75 °C. Analysen viser at dagens høye temperaturnivå i fjernvarmenettet ikke vil være kostnadsoptimalt i fremtiden, med den kommende forbruksveksten i Næringsparken (Oslo Airport City). En reduksjon fra 110 °C til 90 °C gir en tydelig reduksjon både i drifts- og investeringskostnader. Skal en redusere temperaturen videre ned til 75 °C, er resultatet svært avhengig av investeringskostnadene som kreves for tiltak hos kunden. Et redusert temperaturnivå gir i tillegg noen tydelige fordeler som redusert tap og økt effektivitet for varmepumper.



Figur 2. Modell av fjernvarmenettet på Gardermoen i Integrate.

I tillegg til den tekno-økonomiske analysen ble det gjennomført en screening-LCA for å se hvilke elementer i prosjektet som bidrar til høyest klimagassutslipp gjennom levetiden. Laveste utslipp ble oppnådd med casene med lavest turtemperatur grunnet høyere COP for varmepumpene.



Development of ZEN neighbourhoods through social innovation

Daniela Baer
Senior researcher
SINTEF Community

To succeed in developing sustainable ZEN neighbourhoods, which are attractive living spaces, we need to implement technical solutions that increase the quality of life in the community.

This can be achieved by facilitating inclusion, well-being, security, good health, and high housing quality for the inhabitants. Social innovation is often seen from a perspective of empowerment, as a means to realizing development with citizens and other stakeholders as self-reliant actors who take change and development into their own hands, especially under pressing social, economic, and environmental challenges. Focusing on social innovation helps orient technical innovation aspects towards improved quality of life for citizens and civil society.

There are many different participants who are involved in the development of a ZEN in various ways, such as developers, architects, construction workers, neighbours, and those who will live and work in the area. They are all needed in the process to develop a citizen-centred neighbourhood. Their knowledge, needs, and demands must be orchestrated for the result to be liveable. But planning a ZEN is new and do challenge the actors involved.

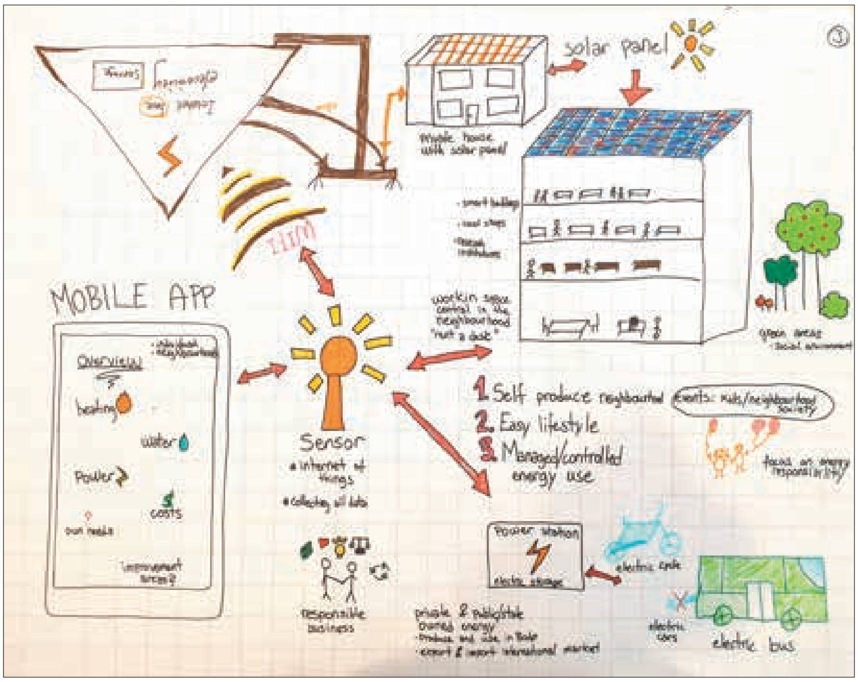
Researchers from SINTEF and NTNU have investigated how those who develop ZEN neighbourhoods and positive energy districts (PEDs) in Norway within the three projects FME ZEN, + CityxChange and syn.ikia do facilitate social innovation. We have identified different approaches to citizen participation, cooperation between actors, and competence building by comparing the projects.

We see three actions as particularly important for the success of developing liveable ZEN neighbourhoods:

- Clarify who is responsible for facilitating social innovation
- Ensure that those who run participation processes have the right competence to facilitate social innovation
- Assess how different actors and stakeholders can contribute to social innovation through collaboration

References:

2021 Baer, D., Loewen, B., Cheng, C., Thomsen, J., Wyckmans, A., Temeljotov-Salaj; A., Ahlers, D. Approaches to social innovation in Positive Energy Districts (PEDs) – A comparison of Norwegian projects. Sustainability, 13(13).



The students of NORD university presents their workshop results to representatives from the municipality, energy, and building sector during the Ny By Festival in June 2021

Utvikling av ZEN-nabolag gjennom sosial innovasjon

For å lykkes med å utvikle bærekraftige ZEN-nabolag, som er attraktive for beboerne, trenger vi å implementere tekniske løsninger som gjør lokalsamfunnet bedre å leve i.

Dette kan vi gjøre gjennom å å legge til rette for inkludering, trivsel, trygghet, god helse- og bokvalitet for innbyggerne. Sosial innovasjon blir sett på som myndiggjøring og som et middel til å gjøre innbyggere og andre interessenter selvhjulpne aktører gjennom å ta endring og utvikling i egne hender, spesielt under presserende sosiale, økonomiske og miljømessige utfordringer. Sosial innovasjon bidrar til å vri det tekniske innovasjonsaspektet mot økt livskvalitet for innbyggere og sivilsamfunn.

Det er mange mennesker som på ulike vis er involvert og har interesser i utviklingen av et nullutslippsområde, som utbyggere, arkitekter, bygningsarbeidere, naboer og de som skal bo i området. Alle disse skal bli invitert til å bidra i prosessen. Kunnskapen de sitter på, og de ulike gruppenes behov, må bli kjent for at resultatet skal gi best bokvalitet. Men å planlegge et område med null utslipp av klimagasser er nytt for de fleste involverte.

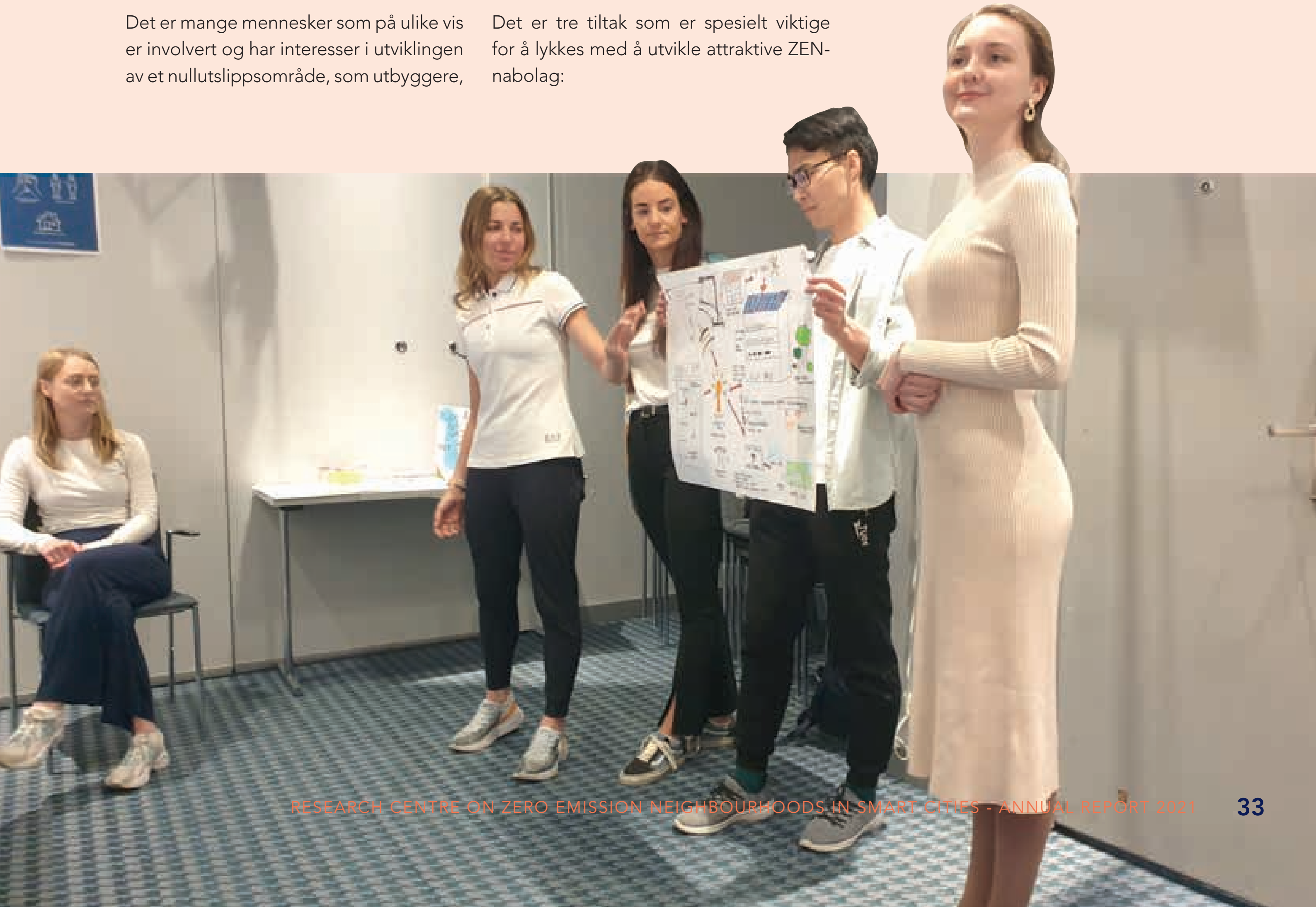
Forskere fra SINTEF og NTNU har undersøkt hvordan de som utvikler nullutslippsområder og plussenergiområder i Norge innenfor de tre prosjektene FME ZEN, +CityxChange og syn.ikia har lagt til rette for sosial innovasjon. Ved å sammenlikne prosjektene, har vi identifisert ulike tilnærminger til innbyggermedvirkning, samarbeid mellom aktører og kompetansebygging.

Det er tre tiltak som er spesielt viktige for å lykkes med å utvikle attraktive ZEN-nabolag:

- Avklare hvem som har ansvaret for å tilrettelegge for sosial innovasjon
- Sørge for at de som driver medvirkningsprosesser har riktig kompetanse til å tilrettelegge for sosial innovasjon
- Vurdere hvordan ulike aktører og interessenter kan bidra til sosial innovasjon gjennom samarbeid

Referanser:

2021 Baer, D., Loewen, B., Cheng, C., Thomsen, J., Wyckmans, A., Temeljotov-Salaj; A., Ahlers, D. Approaches to social innovation in Positive Energy Districts (PEDs) – A comparison of Norwegian projects. Sustainability, 13(13).



How mobility affects and is affected by physical planning

Hampus Karlsson
Master of science

Astrid Bjørgen
Senior researcher

Solveig Meland
Senior researcher
SINTEF Community

Mobility includes both personal travel and transport generated by goods and services. Thus, a ZEN area must be able to change the travel habits of people at the same time as it provides effective solutions for goods and services transport.

In the cases *Zero Village Bergen* and *Montana*, we have tried to examine the effects of various measures such as

- Reduced parking
- Shared mobility
- Distance to various service functions

The work indicates that the most important parameter for whether an area will be able to reduce car use and achieve zero emissions related to private travel is the distance to various service functions. Location should therefore be considered at an early stage and be an important parameter in the choice of project area.

In the case *NTNU unified campus*, we have examined how the new campus is planned and how the need for delivery of goods and services is included in this work. The solution will affect both the vehicle kilometres driven and the spatial qualities of the area. Preliminary studies show that planning of a complex development area is challenging since both different stakeholders and interests must be taken care of in several parallel planning processes.

In order to be able to estimate the effects of coordinated area and transport planning in combination with new transport solutions, more knowledge is needed about the overall effects and how residents use shared mobility. Future ZEN areas must dare to think new and make some decisions on behalf of the residents by reducing the number of parking spaces and move parking spots away from the front door of each apartment.

Hvordan påvirker og påvirkes mobilitet av fysisk planlegging

Mobilitet omfatter både personlige reiser og transport generert av varer og tjenester. Dermed må et nullutslippsområde klare å endre reisevanene til folk samtidig som det legger til rette for effektive løsninger for vare- og tjenestetransport.

I casene *Zero Village Bergen* og *Montana*, har man prøvd å kartlegge effektene av ulike tiltak som

- Redusert parkering
- Etablering av deleløsninger
- Nærhet til ulike servicefunksjoner

Arbeidet indikerer at den viktigste parameteren for å oppnå redusert bilbruk og nullutslipp knyttet til private reiser, er lokaliseringen av ulike servicefunksjoner. Lokalisering bør derfor vurderes i en tidlig fase og være tungtveiende i valg av prosjektområde.

På caset *NTNU Campussamling*, har vi sett på hvordan nytt campus er planlagt for å ivareta behovet for levering av varer og tjenester. Løsningen vil påvirke både transportarbeidet og de stedlige kvalitetene ved området. Foreløpige studier viser at planlegging av komplekse utbyggingsområder er utfordrende da det er mange aktører, ofte med motstridende interesser som skal ivaretas og med parallelle planleggingsprosesser.

For å kunne anslå effekter av samordnet areal- og transportplanlegging, i kombinasjon med nye transportløsninger, trengs det mer kunnskap om de samlede effektene og hvordan beboere benytter seg av delingsmobilitet. Framtidens ZEN-områder må tørre å tenke nytt og ta avgjørelser på beboernes vegne gjennom å redusere antall parkeringsplasser og deres plassering i forhold til selve boligen.

How to facilitate future housing and lifestyle?

Anna-Thekla Tonjer
managing director
Elverum tomteselskap

Ydalir district in Elverum aims to become an environmentally friendly residential area, an example of the future housing and lifestyle. And best of all – an excellent place to live, urban and close to nature. What does this mean?

Home sale in Ydalir is about to start. Should homes in a ZEN neighborhood be more than well-insulated homes with low electricity bills built with materials with low greenhouse gas emissions? How should social sustainability be considered, and challenges related to the "aging wave" and increased loneliness be met? It was natural for us to think that sharing solutions is a significant contribution. But what should be shared, and how should it be organized?

To answer these questions, we created a case together with FutureBuilt, Asplan Viak, SWECO, ByBo, TOBB, SINTEF and NTNU in spring 2021, intending to take a closer look at opportunities and challenges. Then, in the autumn of 2021, we arranged a workshop where we worked with practical solutions for Ydalir. As a result, we came to the conclusion that we should focus on four areas for sharing:

- Mobility
- Spaces
- Equipment
- Community

Some things should be shared only with your closest neighbors, and other sharing solutions should be for the whole neighborhood. Sharing can take place directly between people or be delivered as a service.

The challenge we now face is how sharing solutions should be organized in a district developed over a time frame of 10-15 years by many developers and including around 800 housing units. We believe the answer lies in an overarching organization, such as a welfare association, which can safeguard the ambition and oversee the whole over time.

Photo: Anna-Thekla Tonjer

Hvordan tilrettelegge for fremtidens boform og livsstil?

Ydalir bydel i Elverum har som ambisjon å bli et miljøvennlig boligområde, et eksempel på fremtidens boform og livsstil. Og best av alt – et godt sted å bo, urbant og naturnært. Hva innebærer dette?

Snart starter boligsalget i Ydalir for alvor. Skal boliger i et ZEN-nabolag være noe mer enn godt isolerte hjem med lave strømregninger bygget i materialer med lave klimagassutslipp? Hvordan skal den sosiale bærekraften ivaretas, og utfordringer knyttet til eldrebølgen og økt ensomhet møtes? For oss var det naturlig å tenke at deleløsninger er et viktig bidrag. Men hva skal deles, og hvordan skal det organiseres?

Derfor opprettet vi våren 2021 ett case sammen med FutureBuilt, Asplan Viak, SWECO, ByBo, TOBB, SINTEF og NTNU, for å se nærmere på muligheter og utfordringer. Høsten 2021 arrangerte vi en workshop der vi jobbet med konkrete løsninger for Ydalir. Vi kom frem til at vi bør satse særlig på fire områder for deling:

- Mobilitet
- Arealer
- Utstyr
- Fellesskap

Noe bør deles kun med dine nærmeste naboer, andre deleløsninger bør være for hele bydelen. Deling kan foregå direkte mellom mennesker, eller leveres som en tjeneste.

Utfordringen vi nå står overfor er hvordan deleløsninger bør organiseres i en bydel som skal bygges ut over 10-15 år av et knippe utbyggere og omfatte rundt 800 boenheter. Vi tror svaret ligger i en overordnet organisasjon, eksempelvis en velforening, som kan ivareta ambisjonen og helheten over tid.

Photo: Andreas Kokkvold

Greenhouse gas calculations in ZEN depend on new LCA databases and greenhouse gas tools

Christofer Skaar
Senior researcher
SINTEF Community

Eirik Resch
PhD, Reduzer / NTNU

A new database for life cycle assessments (LCA database) in ZEN will contribute to:

- calculate greenhouse gas emissions from a zero-emission area (ZEN)
- further develop a methodology for life cycle assessments at area level.

By making harmonized LCA data available, it will be easier and faster to calculate greenhouse gas emissions from an area. This applies both to filling data gaps i.e., technical installations and mobility, and generalizing data from calculations. In addition, the database will contribute to further developing methodology, i.e., how to take the time effect of the emissions into account and how to model development over time in infrastructure and scenarios.

Based on his Ph.D. from ZEN, Eirik Resch has developed a tool for building-level assessments, Reduzer (reduzer.com). This tool aims to provide fast and precise decision support at an early stage. Reduzer quantifies the climate account in various alternatives down to building parts and materials, and highlights variation and uncertainty in the calculations. This provides an opportunity to consider important decisions such as the number of floors, size, constructions, and material choices at an early stage. In the long run, it can also be connected to BIM models, further reducing the time spent.

But a complete greenhouse gas calculation for a building should not be an endpoint. That is why back-links from calculations are a crucial action when working with the database. This solution meets a need in today's market, where there is currently a lack of practice to make these calculations available to others who need similar data.

Klimagassberegninger for nullutslipps-områder trenger utvikling av nye LCA-databaser og nye klimagassverktøy

En database for livsløpsvurderinger (LCA-database) i ZEN skal bidra til:

- å beregne klimagassutslippene fra et nullutslippsområde (ZEN)
- videreutvikle metodikk for livsløps-vurderinger på områdenivå

Gjennom å tilgjengeliggjøre harmoniserte LCA-data, vil databasen gjøre det enklere og raskere å regne ut klimagassutslippene fra et område. Dette gjelder både å fylle databehov hvor det i dag er mangler, for eksempel for tekniske installasjoner og for mobilitet, og å generalisere data fra beregninger som gjøres. I tillegg skal databasen bidra til å videreutvikle metodikk, for eksempel hvordan tidseffekten av utslippene skal regnes med og hvordan utvikling over tid i infrastruktur og scenarioer skal modelleres.

Basert på sin PhD fra ZEN har Eirik Resch utviklet et verktøy for vurderinger på bygningsnivå, Reduzer (reduzer.com). Formålet med dette verktøyet er å gi rask og presis beslutningsstøtte allerede i tidligfase. Reduzer tallfester klimaregnskapet i i ulike alternativer ned på bygningsdel og material, i tillegg til å synliggjøre variasjon og usikkerhet i beregningene. Dette gir muligheten til å vurdere viktige beslutninger som antall etasjer, størrelse, konstruksjoner, og materialvalg i en tidlig fase. På sikt vil dette også kobles til BIM-modeller, som kan redusere tidsbruken ytterligere.

Men en ferdig klimagassberegning for en bygning bør ikke være et endepunkt. En sentral aktivitet i database-arbeidet er derfor å sørge for tilbakekoblinger fra beregninger som gjøres. Dette møter et behov i dagens marked, hvor det i dag er mangelfull praksis for å gjøre disse beregningene tilgjengelig for andre som har behov for lignende data.

Building-specific load profiles into an energy system model – connecting Profet and Integrate

Magnus Askeland
Researcher
SINTEF Energy

Dimitri Pinel
Researcher
SINTEF Energy

Igor Sartori
Senior researcher
SINTEF Community

Harald T. Walnum
Senior researcher
SINTEF Community

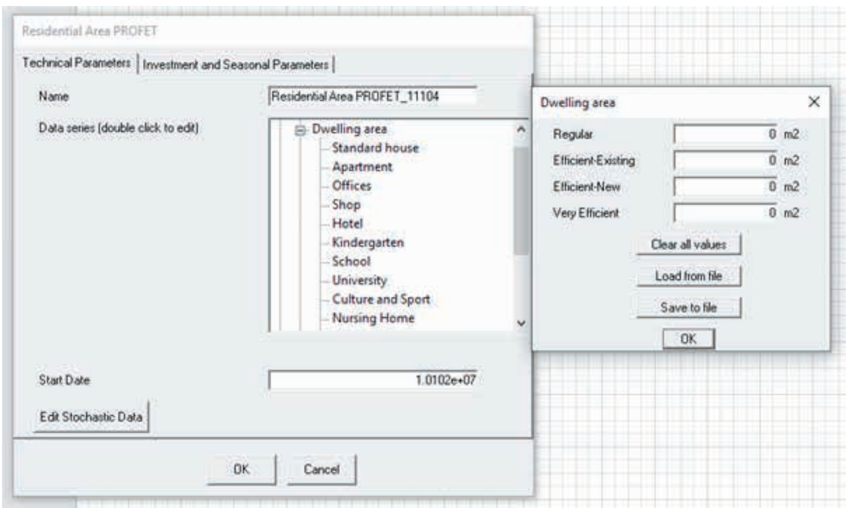
Integrate is a model for optimizing investment strategies in energy systems based on the current situation in an area.

The model describes the expected development in loads, exogenously given prices, and other parameters and describes which investment alternatives are available. Integrate then finds out which investments should be made, when they should be planned, and what kind of system operation it will provide.

The energy need is described by load profiles for different types of energy. These must be defined for the model to know what needs it must meet. In ZEN context, it is most relevant with load profiles for the energy carriers electricity, heat, and tap water, as you can have a separate supply for each of these.

PROFet is a tool that can describe load profiles based on temperature, area, building type, and building standard. These parameters usually have a good overview of an area, and PROFet "translates" this into the need for electricity, space heating, and tap water heating.

In 2021, we connected Integrate and PROFet to generate load profiles efficiently by specifying the needed information from PROFet in a new module in Integrate. Integrate sends this information to PROFet and receives load profiles in return to be stored in the module. This ensures a more efficient and accurate description of the energy needs without the user working with separate tools. The link also means that future development of PROFet will be continuously available from Integrate.



Screenshot of the Integrate module

Bygningsspesifikke lastprofiler inn i en energisystemmodell – kobling mellom Profet og Integrate

Integrate er en modell for å optimere investeringsstrategier i energisystemer.

Man tar utgangspunkt i den nåværende situasjonen i et område og beskriver forventet utvikling i laster, eksogent gitte priser og andre parametre i tillegg til å beskrive hvilke investeringsalternativer man har til rådighet. Deretter finner Integrate ut hvilke investeringer som bør gjøres samt når de bør planlegges, og hvilken systemdrift dette gir.

Behovet for energi beskrives av lastprofiler for ulike energityper. Disse må beskrives for at modellen skal vite hvilket behov den skal oppfylle. I ZEN sammenheng er det mest aktuelt med lastprofiler for energibærerne strøm, varme og tappevann da man kan ha separat forsyning for hver av disse.

PROFet er et verktøy som kan beskrive lastprofiler basert på temperatur, areal, bygningstype og bygningsstandard. Disse parametrene har man som regel god oversikt over i et område, og PROFet "oversetter" dette til hva som trengs av elektrisitet, romoppvarming og tappevannsoppvarming.

Det har i 2021 blitt laget en kobling mellom Integrate og PROFet slik at man effektivt kan generere lastprofiler. Dette fungerer slik at informasjonen PROFet trenger spesifiseres i en ny modul i Integrate. Integrate sender denne informasjonen til PROFet, og mottar lastprofiler tilbake som lagres i modulen. Dette sikrer mer effektiv og nøyaktig beskrivelse av energibehovet, uten at brukeren må jobbe med separate verktøy. Koblingen som er laget gjør også at fremtidig utvikling av PROFet fortløpende vil være tilgjengelig fra Integrate.

Reduced demand for private cars, fact or fiction? Mapping changes in accessibility to grocery stores in Norway

Lillian Rokseth
PhD-candidate
NTNU

There is growing consensus that we need to reduce car use and increase the share of walking and bicycling for various reasons, ranging from improving public health, creating attractive cities, and reducing greenhouse gas emissions, pollution, and noise. To achieve this, planning, design, and construction of cities and neighbourhoods must ensure that people can become less dependent on cars in everyday life.

Travel surveys show that the amount of private driving in Norway has increased significantly since the mid-1980s. Due to the low population density in Norway, the primary mode of transport for retail and service trips has for a long time been private car driving, and grocery shopping represents over 60% of the retail and service travels.

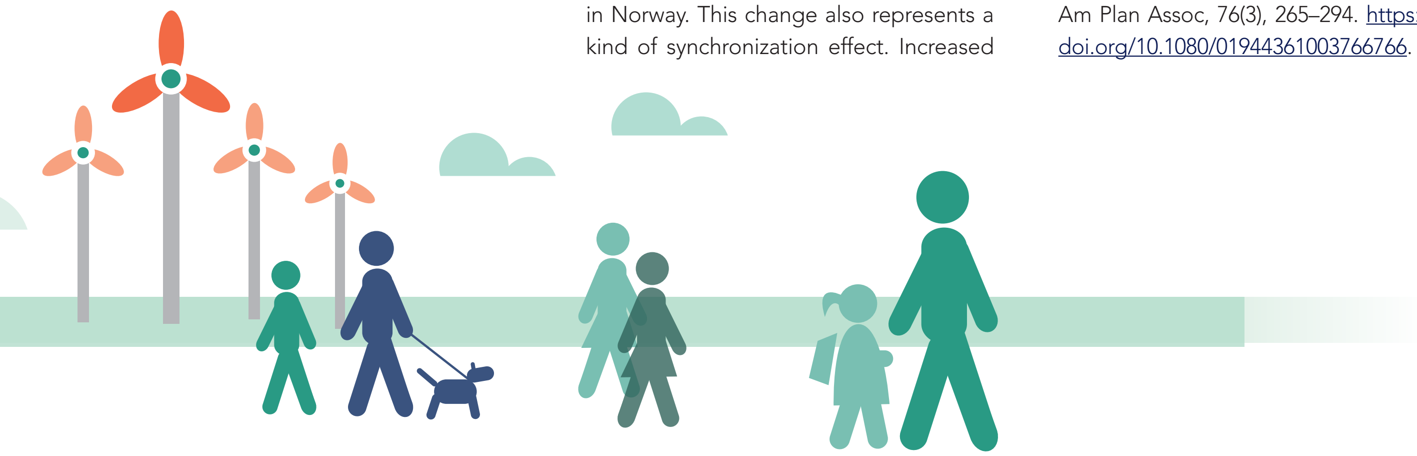
This study aims to investigate changes in accessibility to grocery stores over time and uses the county of Hommelvik and Lørenskog as examples. Distances between homes and nearest grocery stores have been studied based on GIS models consisting of walking and cycling networks, grocery stores, and residential housing. The results from the analysis show significant changes from 1980 to 2019. The share of the population living within 500 m from a grocery store has decreased from 55% to 34% in Lørenskog and from 36% to 19% in Hommelvik.

Due to increased distances to the nearest grocery store, people have become far more dependent on cars for grocery shopping. This increased distance is part of the explanation for the sharp increase in car use for commercial travel in Norway. This change also represents a kind of synchronization effect. Increased distances to daily destinations make shifting from cars to more sustainable transport challenging.

References:

Rokseth, L. S., Heinen, E., Hauglin, E. A., Nordström, T., & Manum, B. (2021). Reducing private car demand, fact or fiction? A study mapping changes in accessibility to grocery stores in Norway. *European Transport Research Review*, 13(1) doi:10.1186/s12544-021-00500-7

1. Hjorthol, R., Engebretsen, Ø., & Uteng, T. (2014). Den nasjonale reisevaneundersøkelsen 2013/14 - nøkkelrapport. https://www.toi.no/getfile.
2. Bhat, C. R., & Eluru, N. (2009). A copula-based approach to accommodate residential self-selection effects in travel behavior modeling. Transp Res B Methodol, 43(7), 749–765. https://doi.org/10.1016/j.trb.2009.02.001.
3. Cervero, R., & Duncan, M. (2006). Which reduces vehicle travel more: Jobshousing balance or retail-housing mixing? J Am Plan Assoc, 72(4), 475–490. https://doi.org/10.1080/01944360608976767.
4. Ewing, R., & Cervero, R. (2010). Travel and the built environment: A metaanalysis. J Am Plan Assoc, 76(3), 265–294. https://doi.org/10.1080/01944361003766766.



Redusert etterspørsel etter privatbiler, fakta eller fiksjon? Utdrag fra en studie som kartlegger endringer i tilgjengelighet til dagligvarebutikker i Norge

Å bytte ut privatbil med økt gange og sykling er ønskelig av en rekke årsaker. Fra å forbedre folkehelsen, skape attraktive byer, redusere klimagassutslipp, forurensning og støy. For å oppnå dette må planlegging, design og bygging av byer og nabolag tilrettelegge for at folk kan bli mindre avhengige av bil i hverdagen.

Reiseundersøkelser viser at mengden privat bilkjøring i Norge har økt betydelig siden midten av 1980-tallet. Privat bilkjøring har i lang tid vært det primære transportmiddelet for handelsreiser, og reiser for å handle dagligvarer utgjør over 60 % av handelsreisene [1].

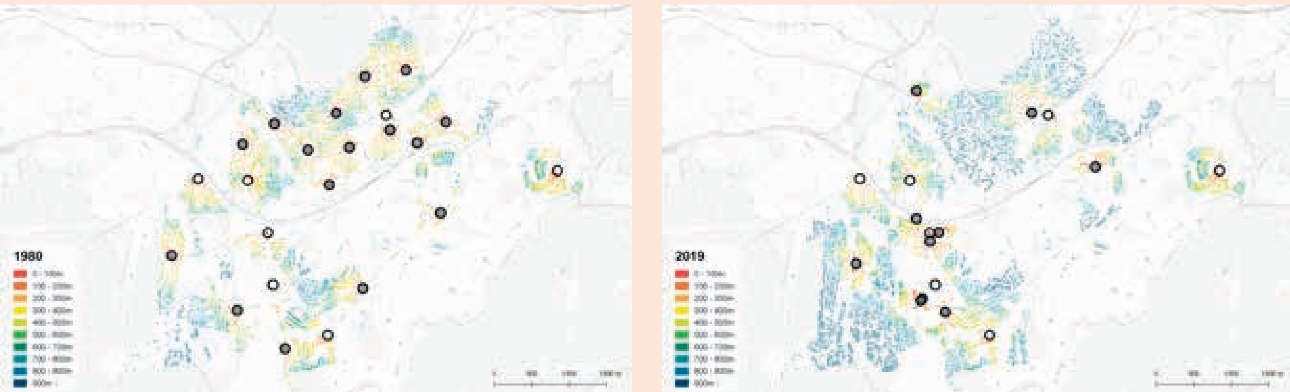
Denne studien tar sikte på å undersøke endringer i tilgjengelighet til dagligvarebutikker over tid og bruker tettstedene Hommelvik og Lørenskog som eksempler. Basert på GIS-modeller bestående av gang- og sykkelnettverk, lokasjoner for dagligvarebutikker og befolkning, er avstander fra bolig til nærmeste dagligvarebutikk undersøkt. Resultatene fra analysene viser betydelige endringer fra 1980 til 2019. Andelen av befolkningen som bor innenfor 500 m fra en dagligvarebutikk har gått ned fra 55 % til 34 % i Lørenskog og fra 36 % til 19 % i Hommelvik.

På grunn av økte avstander til nærmeste dagligvarebutikk har folk blitt langt mer avhengig av bil for dagligvarehandel. Denne økte avstanden er en del av forklaringen på den sterkt økte bilbruken for handelsreiser i Norge. Endringene i avstander representerer også en slags synkroniseringseffekt. Økte avstander til daglige destinasjoner gjør et skifte fra bil til mer bærekraftig transport vanskelig å oppnå [2-4].

Referanser:

Rokseth, L. S., Heinen, E., Hauglin, E. A., Nordström, T., & Manum, B. (2021). Reducing private car demand, fact or fiction? A study mapping changes in accessibility to grocery stores in Norway. *European Transport Research Review*, 13(1) doi:10.1186/s12544-021-00500-7

1. Hjorthol, R., Engebretsen, Ø., & Uteng, T. (2014). Den nasjonale reisevaneundersøkelsen 2013/14 - nøkkelrapport. https://www.toi.no/getfile.
2. Bhat, C. R., & Eluru, N. (2009). A copula-based approach to accommodate residential self-selection effects in travel behavior modeling. Transp Res B Methodol, 43(7), 749–765. https://doi.org/10.1016/j.trb.2009.02.001.
3. Cervero, R., & Duncan, M. (2006). Which reduces vehicle travel more: Jobshousing balance or retail-housing mixing? J Am Plan Assoc, 72(4), 475–490. https://doi.org/10.1080/01944360608976767.
4. Ewing, R., & Cervero, R. (2010). Travel and the built environment: A metaanalysis. J Am Plan Assoc, 76(3), 265–294. https://doi.org/10.1080/01944361003766766.



Gangdistanse til dagligvarebutikk i Lørenskog i 1980 og 2019 hvor dagligvarebutikker er markert med sirkler og fylte sirkler viser endrede butikklokasjoner. / *Walking distances to grocery stores in Lørenskog in 1980 and 2019, where grocery stores are marked with circles and solid circles show changed store locations.*

MEET THE PEOPLE IN THE ZEN-CENTRE

In this new section of the annual report, you get to meet some of the people in the ZEN-centre. We are working every day towards a common goal of an emission free future, focusing on the context of buildings and neighbourhoods. The ZEN-centre has 33 PhDs and 4 postdocs either directly financed by the centre, or associated with the centres work. Here, you get to know some of our PhDs and postdocs, and how they see their contribution to the larger context. The ZEN-centre has 31 user-partners that are vital contributors to the results of the centre. In this report, some of them explain why it is important to be part of a long term, research effort towards a zero emission society. Finally, our researchers and their key competencies are invaluable in order to find the solutions to the challenges we stand up against. We aim to deliver research of world-class quality, and in this section you have the opportunity to get to know some of our key researchers better.

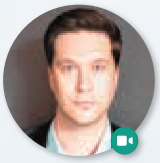
KEY CONTRIBUTIONS TO ZEN FROM OUR PHDS AND POSTDOCS – A CONVERSATION

What do you want to be left with as your most important contribution to ZEN?

Magnus Askeland, PhD WP5:

That I have acquired meaningful cooperation with people outside my daily research environment.

Furthermore, I hope that I have contributed with research that display the importance of regulatory terms and pricing signals, and be a part of realizing solutions that connects players from different sectors



Raymond Stokke, PostDoc:

I believe my most important contribution as a postdoctoral researcher was to help the research centre and its key partners develop new business models and innovation systems for advancing Zero Emission Neighbourhoods. Particularly, my work on developing new business and procurement models for low-carbon cement with CCS has been very rewarding.

Moreover, I hope my research work contributed to both green value creation and green value realization for FME ZEN and its partners

Hanne Marit Henriksen, PhD WP6:

I hope that my research has provided insight into how communicating science from FME ZEN affects the uptake of zero emission neighbourhoods.

Xingiji Yu, PhD WP4:

I hope the most important contribution is the cooperation with other ZEN members.

We work together and use the data form ZEB livingLab to generate several interesting publications on the topic of grey-box modelling of thermal dynamics of the passive house and the MPC control research.

Shabnam Homaie, PhD WP3:

Evaluation of the impact of upcoming changes and uncertainties is going to be important for the future of ZENs.

During my PhD, I have developed metrics and frameworks for evaluation of these impacts and quantification of concepts such as performance robustness and resilience. I hope this can remain as a helpful contribution of mine in ZEN

Kristian Skeie, PhD WP3:

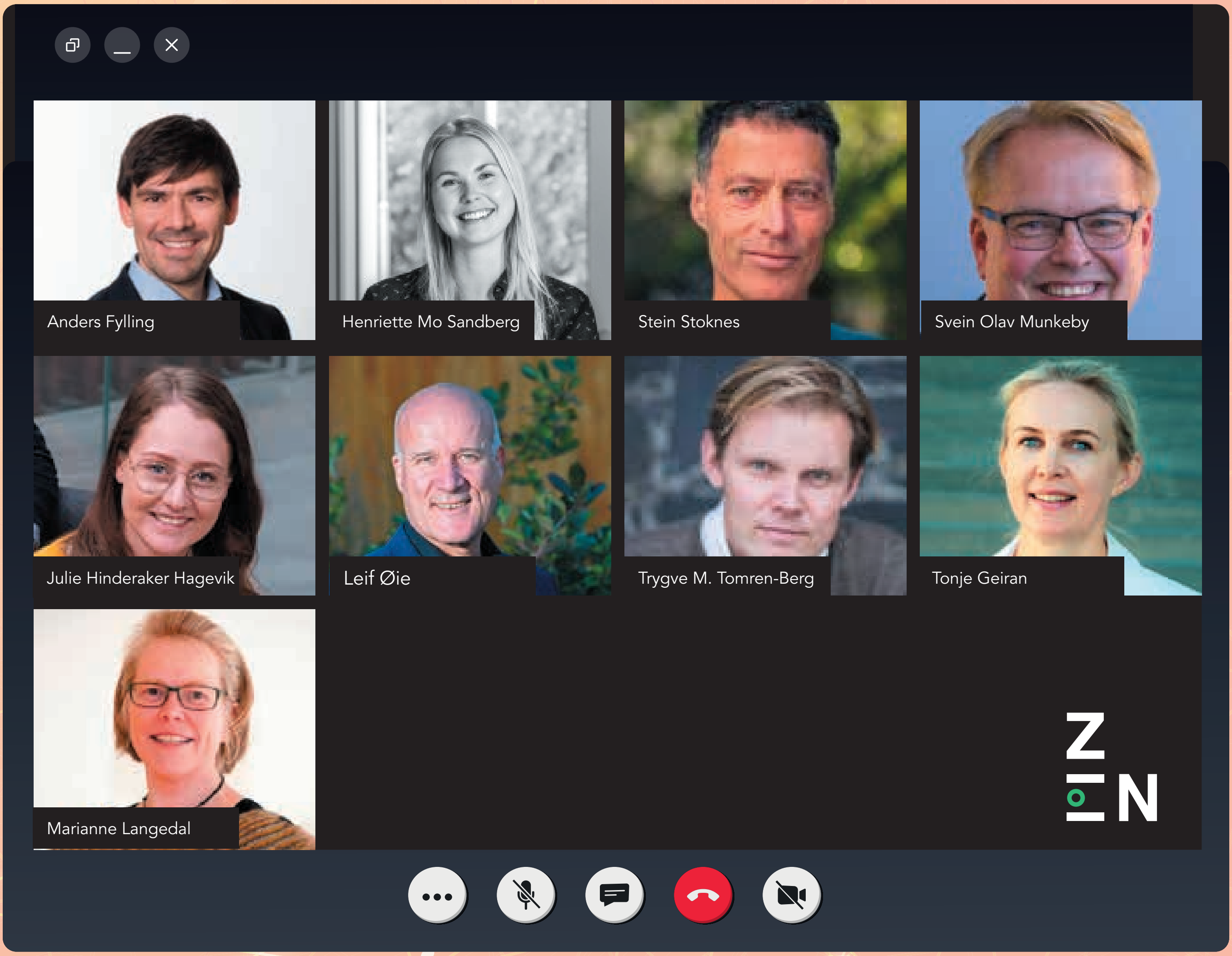
I hope my work will contribute to promoting solar energy application and other low-emission building technologies by simplifying evaluations of the energy performance of buildings and energy supply systems under more realistic operating conditions.

The existing building stock has considerable untapped potential for energy savings, which will not be exploited without stimulus.

Hopefully, by the time ZEN is finished, we will have tools able to assess low emission energy supply options in local climate in a similar way as we calculate building envelope performance during the design phase.

MEET OUR PARTNERS

Get to know some of FME ZENs partners, and why they choose to be a part of the ZEN Research Centre



Anders Fylling, *Statsbygg*

We now have a new strategy for buildings and property in public civil sector. The strategy maintains that climate and environmental effects from public building projects and operation of property have to come down. We need solutions that enable us to plan, build and operate buildings in a future zero-emission community. To us in Statsbygg, Zero Emission Neighbourhoods is an important arena to find and test these solutions. Both for ourselves, and for the construction industry.

Henriette Mo Sandberg, *Asplan Viak*

Asplan Viak is a company that offers innovative services and products in interacting with our customers. Being a partner in ZEN strengthens this. Furthermore, we get the opportunity to cooperate with municipalities, private business, government agencies and researchers achieve a zero-emission community. Partnering in ZEN imbues our services with knowledge and value creation. It involves us in the development and testing of different tools, and the development of methods for greenhouse gas calculations. We use this knowledge in several of our projects and services and contributes positively to what we do.

Stein Stoknes, *FutureBuilt*

FutureBuilt is an innovation program for sustainable architecture and city development. We believe in the power of example and will change the construction industry in accordance with UNs Sustainable Development Goals and the Paris Climate Accords. We will achieve this through realizing no less than a 100 model pilot projects to prove that it is possible. And to do this, we need ZEN. Where FutureBuilt goes broad, FME ZEN works in depth. Whereas we are action-oriented generalists, ZEN are subject-oriented specialists - a perfect combination, and together we will change the world.

Svein Olav Munkeby, *NTE*

NTE is a part of ZEN because we want to learn, and we want the knowledge that we possess about the energy system to contribute to solving the challenges of achieving climate neutral buildings and neighbourhoods. A lot of this knowledge is generated by our customers, so we hope to be able to join them in contributing to a future climate neutral society.

Tonje Geiran, *Norcem*

Norcem er partner i ZEN for å være med og utvikle løsningene for fremtiden. Vi vil bidra til bygninger og infrastruktur med lavest mulige utslipp, og jobber hver dag for å redusere miljøavtrykket fra sementen vår. I Brevik bygger vi nå verdens første karbonfangstanlegg i sementindustrien. I ZEN er kompetansen høy og vi har stor glede og nytte av å diskutere løsninger i ZEN.

Julie Hinderaker Hagevik, *Bodø municipality*

The New City – New Airport-project in Bodø is Norway's biggest city- and community development project. Northerners are famous for their big mouths, and now they need something new, big, and challenging to bite off. What's more appropriate than building a 2900-acre zero emission neighbourhood, the size of New York's Central Park? The New City – New Airport-project and the development of the new district Hernes in Bodø is innovative city and business development at its core and gives us the opportunity to plan and develop city spaces, commercial areas, and new solutions from "scratch". With additional focus on research, development, and innovation we will be a showcase for future zero emission societies. That is why Bodø municipality is a partner and pilot in FME ZEN.

Leif Øie, *GK*

GKs vision is to be a climate role model. We see that there is a need for more research and to broaden the perspective from individual, sustainable buildings, to sustainable neighbourhoods. Therefore, it is natural for GK to join as partner in ZEN. As one of Scandinavia's largest technical entrepreneurs, our participation in ZEN is an important asset in keeping in front and acquiring the latest knowledge. Our entrepreneurship is also well suited to quickly convert the newest knowledge from ZEN into buildings and property – because it is action that really matters.

Trygve Mellvang Tomren-Berg, *Norsk Fjernvarme*

Norsk Fjernvarme is a partner in ZEN because it is a focal point where research in buildings and research in energy systems meet. To properly achieve the green shift, in a cost efficient and good way, these two things must connect. What you do in the buildings, between the buildings, and in the energy system, has to work as parts in a system, and we have to see the value in this system. We at Norsk Fjernvarme find it very exciting to be able to exploit a surplus one place to cover the needs of someplace else, reusing energy and to unload the power grid to make room for more electrification. Because that is what this is all about.

Marianne Langedal, *Trondheim kommune*

Trondheim kommune ble med i ZEN for å bygge kompetanse hos egne medarbeidere. Vi er opptatt av å utvikle null-utslippsområder, og vi er opptatt av å stille byen til rådighet for forskning.
Trondheim kommune har høye ambisjoner om å kutte klimagassutslipp, i det så har vi også ambisjoner om å utvikle null-utslippsområder. Og ZEN skal jo hjelpe oss på veien til det, øke kompetansen og også skaffe oss nettverk, så derfor er ZEN viktig for Trondheim kommune.

RESEARCHER INTERVIEWS

Kristin Fjellheim

Researcher
SINTEF Community

What do you work with in ZEN?
I work with the development of the ZEN definition and ZEN key performance indicators. In this I coordinate all the categories (GHG emissions, energy, power, mobility, spatial qualities, economy, and innovation) so that the definition is coherent and understandable. I also work specifically on the GHG emission part in different ZEN cases on for example life cycle assessment of technical installations, materials, and buildings, and also on the further development and use of calculation methods in ZEN.

What is a highlight from (your work with) ZEN in 2021?
I think that must be the work on further developing the definition for ZEN. This involves so many different fields of study and I have the opportunity to work with a lot of researchers within the different fields and have many interesting and cross-cutting discussions. I also think the work with ZEN cases is very rewarding as you get to know the partners and pilot projects and learn how it is to work with a ZEN area and the ZEN definition in practice and not only on paper.

What do you do every day to contribute to reduced emissions?
I feel like I do the normal things like waste sorting, trying to reduce food waste, use public transport and car sharing (I don't own a car) and at least these days – travel less.

What do you want to look back on as the most important thing you did for ZEN at the end of the centre's time?
I hope we have managed to develop a ZEN definition and key performance indicators which are understandable and usable for ZEN areas in practice, and I hope that this will lead to new ZEN areas being developed after the centers time is over.

Åse Lekang Sørensen

PhD-candidate NTNU
and researcher SINTEF Community

What do you work with in ZEN?
I work with energy flexibility in buildings and neighbourhoods. More specifically I collect and analyse measurements and other data related to EV charging, energy use in buildings and solar energy production.

What is a highlight from (your work with) ZEN in 2021?
Currently I focus on EV charging in residential buildings. I analyse charging reports from apartment buildings, to better understand the energy use and flexibility potential of EVs. I find this very interesting. Norway has a high share of electric vehicles, so our experiences are also useful for other countries with a lower share of EVs.

What do you do every day to contribute to reduced emissions?
I try to not buy too many things and to save energy. It is not always easy to live environmentally friendly – especially when it comes to travelling. Covid has shown us that things can be done differently than before, so I will try remembering this in the future.

What do you want to look back on as the most important thing you did for ZEN at the end of the centre's time?
I try increasing the access to energy data of good quality, since this is important for good analyses, models and understanding in general. It is often a challenge to get access to good data. I also contribute to increase the knowledge of EV charging, and how charging habits influence the available energy flexibility potential.

Sobah Abbas Petersen

Associate Professor,
Dept. of Computer Science, NTNU

What do you work with in ZEN?

I have been working on a few tasks, all related to ICT coordination in ZEN:

i. Within WP1 - the ICT architecture for ZEN, to store and manage the data that is produced and used by ZEN researchers.
ii. In X.2 and X.3 - the cross-cutting tasks on ICT tools in ZEN, to obtain an overview of the different ICT tools that are used in the project. This is relevant to foster synergy across researchers and for prioritising developments.
iii. Data management in ZEN by understanding the needs of the researchers.

What is a highlight from (your work with) ZEN in 2021?

Two Masters theses where the students have explored ideas for web-based applications for the KPI tool and an LCA database of building components, both of which could enhance the accessibility and usability of research that have been done by ZEN researchers.

What do you do every day to contribute to reduced emissions?

Personally – I walk to work. I try to avoid using plastic bags.

I believe in small steps that could lead to a big change. I'm motivated in increasing awareness and knowledge among people, to support them to take small steps. So, I try to design technological solutions to support this. (Other, if relevant: been driving an EV since 2012, space heating at home and a smart system to control heating and EV charging – a lot of upgrading of a house from the 50s to get energy efficiency.)

What do you want to look back on as the most important thing you did for ZEN at the end of the centre's time?

Contributed to increased knowledge and awareness about data, data lifecycle and how best to manage it – this is important for ZEN and ZEN researchers as there is a lot of data!

Contributed to the design and development of an ICT architecture that could support data-intensive multi-disciplinary projects such as ZEN.

Carine Lausselet

Researcher
SINTEF Community

What do you work with in ZEN?

I work with life-cycle assessment (LCA) in WP1. I started my PhD just after the Centre opened and work now as a Research Scientist for SINTEF towards the Centre.

What is a highlight from (your work with) ZEN in 2021?

To finish my PhD – It was a great opportunity to take it as part of the ZEN Centre with such an inspiring mix of competences.

What do you do every day to contribute to reduced emissions?

I live with my husband and three kids in a dwelling of reasonable size for our family size. We heat less in the sleeping rooms than in the common areas. I live close to work and take the chance to walk or bike there. We are not vegetarian but are conscious about our meat consumption and in practice eat little meat.

What do you want to look back on as the most important thing you did for ZEN at the end of the centre's time?

When I started with my PhD in 2017, LCAs performed on a neighborhood scale that would combine buildings, mobility and energy supply were quasi non-existent. To conduct LCA at this scale is a complex task because the subsystems included evolved at very different paces and we assess them over a long period of assessment of 60 years. It was a very exiting challenge and I am happy I could contribute to developing the use of LCA on a neighborhood scale.

Luitzen de Boer

Professor
NTNU

What do you work with in ZEN?

In ZEN I work mainly in WP2 (Policy measures, innovation and business models) and in particular with the question of how public and private actors can work together more effectively towards the aim of creating ZENs, for example through innovative, dialogue -based forms of public procurement.

What is a highlight from (your work with) ZEN in 2021?

I would say a big highlight was the acceptance for publication of the article "Stakeholder collaboration in sustainable neighborhood projects – A review and research agenda" in Sustainable Cities and Society, with co-authors Hasan Hamdan (first author) and Poul Houman Andersen (second author). Hasan is one of ZEN PhD candidates, with me and Poul as his supervisors. I think one of the contributions of the article is proposing how we can conceptualize the continuous "balancing act" going on throughout the different stages of ZEN development: there is a need to both increase collaboration and interaction between stakeholders but also a need to dampen the complexity resulting from this.

What do you do every day to contribute to reduced emissions?

I am sure I should do more! I think my biggest contribution may be that I travel very little (also before Corona) and I am not a fan of streaming movies and series.

What do you want to look back on as the most important thing you did for ZEN at the end of the centre's time?

Hopefully, me and my colleagues in the work package have contributed by providing the ZEN practitioners and policy makers with some insights and tools to deal with the "softer" and less graspable aspects of ZEN development more effectively. How to organize or should we say "steer" collaboration over a long time period with multiple actors, each with their own agenda and time perspective, while facing uncertainty and risk. And more specifically regarding procurement, how can public actors approach a procurement strategy at a "neighborhood" level? This is also a key question in Hasan´s research.

COMMUNICATION AT THE ZEN RESEARCH CENTRE

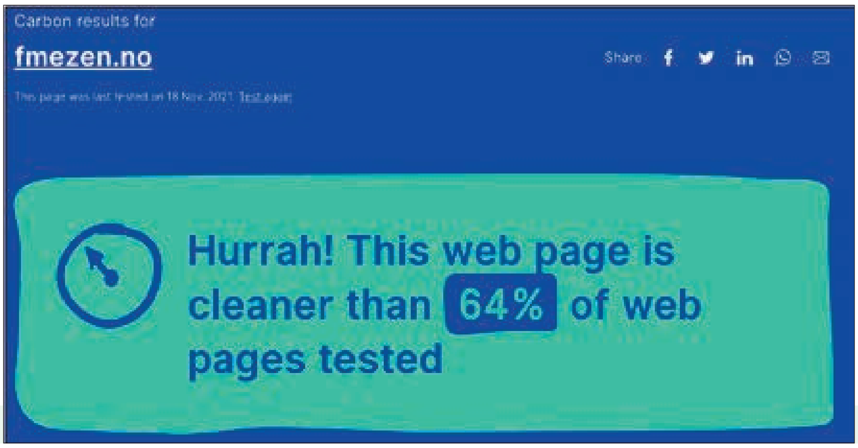
The ZEN Research Centre works continuously with external and internal communication. 2021 has brought an increase in scientific publication activity, as well as a range of important communication activities.

Brynjar Fredus Svarva
Centre coordinator
ZEN, NTNU

In 2020 we had to move much of our academic activity online, which carried over into 2021. Lunch lectures, seminars, PhD defenses, and workshops have all been held digitally on Zoom or Microsoft Teams. Fortunately, a small break in strict infection control guidelines the fall of 2021 gave us the opportunity to host a live conference as well as a partner seminar. Both events were deemed quite successful and generated good discussions between ZEN and our partners, as a well as content for external communication. Recordings from the ZEN Conference will be published in early 2022 to provide the website with more engaging content.

The ZEN Facebook page @fmeZEN and Twitter account @ZENcentre have been updated regularly with recent news, events, and references to publications from the Centre. Our website had 19 000 sessions in 2021, and a Norwegian version of the website was published. It has also undergone changes to make it more modern, accessible, and clean. We have also taken steps to reduce the website's emissions, by cleaning up pictures and graphics, compressing script files, improving search functions and menus, but most importantly, moving the website to a new server host with "green servers".

In sum, this has made our website 64% cleaner than other websites tested. Before we started this clean up, our webpage tested 87% less clean than other websites tested.



The FME ZEN midway evaluation was arranged 2nd of March and provided a key element in further discussions with our partners in one-on-one partner meetings throughout the spring and early fall. The partner meetings are essential for probing needs and wants between the ZEN Centre and its partners. This, along with the midway evaluation, provided an important backdrop for the partner seminar and ZEN conference the 17th and 18th of October respectively.

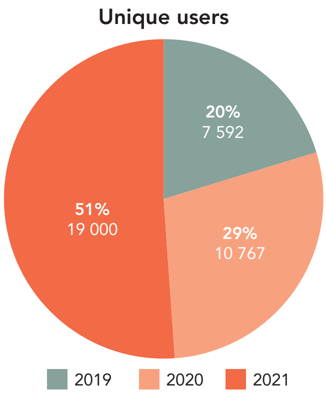
The ZEB laboratory at Gløshaugen Campus was finished in March 2021 and is now the home of ZEN. The building has been operative as a research object since the planning phase, and there is constantly ongoing projects in measuring innovative qualities.

Six PhD candidates finished their doctoral thesis: Stian Backe, Dimitri Pinel, Carine Lausselet,Eirik Resch, Jakub Wladyslaw and Niels Lassen Congratulations from FME ZEN!

Arild Gustavsen was keynote speaker at the closing event for Nordic Innovation House Singapore – Smart & Sustainable Cities Virtual Market Entry Programme, Singapore 2021. The name of the session was Minimizing Carbon Footprint of Buildings and the title of the lecture was Zero Emission Buildings and Neighbourhoods.

COMMUNICATION AT THE ZEN RESEARCH CENTRE

Engaging and knowledgeable keynote speakers at the ZEN conference.
Photos: Sunniva Moum Danielsen



COMMUNICATION ACTIVITIES IN 2021

11
Unique newsletters

Webpage users:
more than
19,000
see pie chart

54
Scientific publications

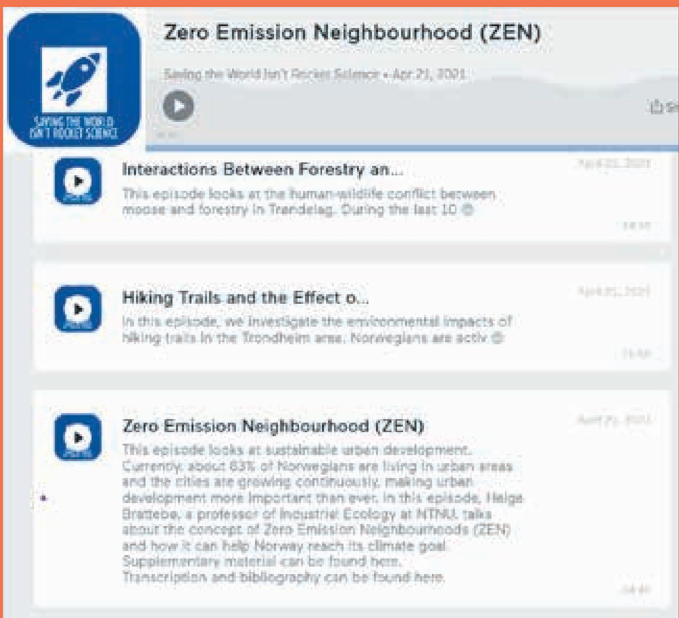
56
Unique popular scientific articles and media features

13
ZEN lunch lectures

25
Partner meetings

4
Partner seminars, conferences and workshops

NEWS FROM ZEN



Zero Emission Neighbourhood (ZEN)

Saving the World Isn't Rocket Science • Apr 21, 2021

Interactions Between Forestry an...

This episode looks at the human-wildlife conflict between moose and forestry in Trøndelag. During the last 10

Hiking Trails and the Effect o...

In this episode, we investigate the environmental impacts of hiking trails in the Trondheim area. Norwegians are activ

Zero Emission Neighbourhood (ZEN)

This episode looks at sustainable urban development. Currently, about 83% of Norwegians are living in urban areas and the cities are growing continuously, making urban development more important than ever. In this episode, Helge Brattebø, a professor of Industrial Ecology at NTNU, talks about the concept of Zero Emission Neighbourhoods (ZEN) and how it can help Norway reach its climate goal.
Supplementary material can be found here.
Transcription and bibliography can be found here.

Zero Emission Buildings: Snart åpner unikt laboratorium i Trondheim

Torsdag 4. mars åpnes ZEB-laboratoriet i Trondheim. I dette skal fremtidens løsninger for bærekraftige bygg og tekniske løsninger testes ut samtidig som forskere jobber der. Norges forskningsråd mener laboratoriet gir Norge en unik posisjon i Europa.

Det nye nullutslippslaboratoriet ligger på Gløshaugen i Trondheim. Foto: Matthias C. Herzog

Grønn byutvikling

Bodø: Ny by – Ny flyplass

På folkets og planetens premisser

ZEB-laboratoriets spesielle krav til ventilasjon og hvordan dette styres

COLLABORATION AMONG OUR PARTNERS

Judith Thomsen
Research manager
SINTEF

The ZEN Centre has several regular activities designed to involve and actively follow up all of the ZEN partners; these include the General Assembly, ZEN partner seminars, lunch lectures, and the biannual conference. In October 2021 the ZEN conference "Zero Emission Neighbourhoods – worth investing in?" was held after being postponed due to the pandemic. The conference was a great opportunity where all the ZEN partners and researchers could finally meet again physically. Both partners and researchers use the pilot projects actively to investigate topics related to planning and developing a ZEN neighbourhood.

SNAPSHOTS FROM ACTIVITIES IN THE ZEN PILOT PROJECTS

One topic of major interest for ZEN is the testing of the ZEN categories and KPI`s in the pilot projects. In 2021 this resulted in a report that analysed the KPI`s for energy and power in six of the pilot projects, in cooperation with the pilot owners.

At Ydalir, a ZEN case was carried out in 2021 on sharing solutions, amongst others, mobility solutions. ZEN partner Asplan Viak has conducted an analysis of the climate effects of sharing solutions based on information from Ydalir. In a workshop at Ydalir, four sub-areas for sharing were identified that will be further worked on in the development of the pilot: spaces, mobility, equipment, and community.

For Evenstad, a memo was completed that presents the energy measurements from Evenstad in the period 2017-2019. Based on the measurements, it provides further recommendations on 1) Optimization, energy management, and visibility, 2) Renewable energy and energy efficiency, 3) Energy flexibility and continued testing of new solutions.

The planned work on optimizing the energy system at Furuset with the software Integrate was completed in 2021. To quantify the benefits of district heating and seasonal storage, three different options for heating were compared with the model: direct electric heating for the whole Furuset neighbourhood, high temperature district heating (for the proportion of the building mass to be supplied with waterborne heat), and low temperature district heating with seasonal storage.

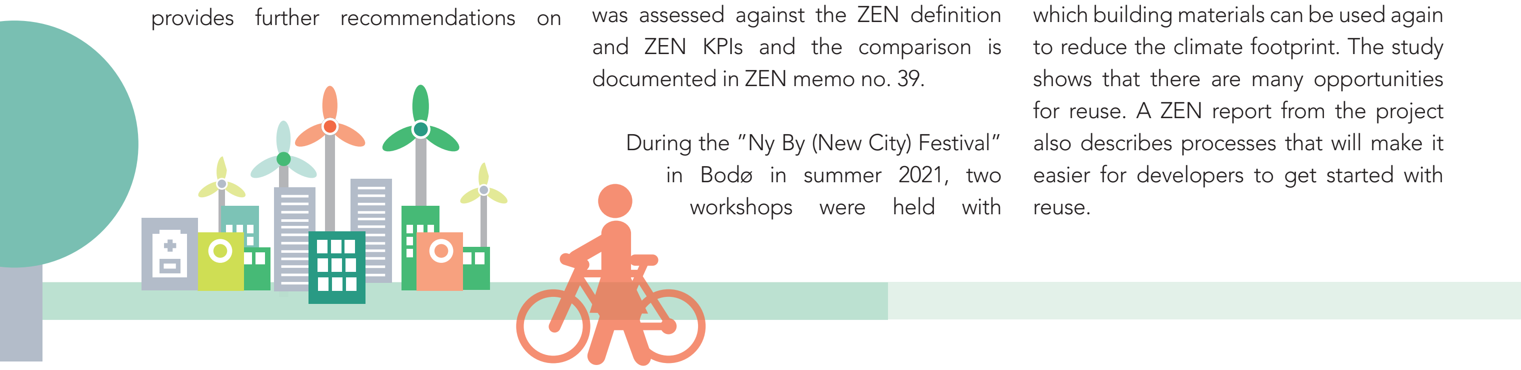
The city planning office in Trondheim municipality has developed a tool "Klimanorm" that will be used in all detailed plans and subsequent construction cases on the ZEN pilot Sluppen, contributing to Sluppen being developed as a zero-emission neighbourhood. The Klimanorm was assessed against the ZEN definition and ZEN KPIs and the comparison is documented in ZEN memo no. 39.

During the "Ny By (New City) Festival" in Bodø in summer 2021, two workshops were held with local actors and students, to identify market preferences and the needs for the development of a zero-emission area.

A ZEN case themed on "Urban logistics in the zero-emission area NTNU Campus". The goal of the study is to shed light on alternative urban logistics solutions for Campus NTNU. The results will give information on how goods and waste logistics should be delt with as a topic in the early stages of planning.

The ZEN pilot Mære agricultural school makes it possible to investigate the role of the farms in a zero-emission area. Here, the interplay between agriculture, building stock, mobility, and energy can be seen in context. A ZEN memo on system boundaries for ZEN agricultural areas has been completed.

When the old air tower at Fornebu, Bærum is to be rebuilt, ZEN researchers Statsbygg and Bærum municipality have mapped which building materials can be used again to reduce the climate footprint. The study shows that there are many opportunities for reuse. A ZEN report from the project also describes processes that will make it easier for developers to get started with reuse.



INTERNATIONAL COOPERATION AT THE ZEN RESEARCH CENTRE

Inger Andresen
Professor
NTNU

Annemie Wyckmans
Professor
NTNU

Niki Gaitani
Associate Professor
NTNU

The ZEN Research Centre aims to create new networks with international partners from research, industry, public authorities, and citizen organisations to gain a leading position in Nordic, European, and global society. The main objectives can be summarized as follows:

- Integrate the ZEN Centre's activities firmly in the EU Cities Mission and New European Bauhaus and the corresponding platforms (EERA Joint Programme Smart Cities, Smart Cities Marketplace etc.) – aiming to create climate-neutral cities that are beautiful, inclusive, and sustainable
- Content-based cooperation with internationally recognized experts
- Creating new and managing existing EU projects and platforms
- Contribute to the internationalization of Norwegian research and business, together with the ZEN innovation manager

ZEN actively cooperates with the following EU projects and initiatives:

The +CityxChange project, a H2020-funded project with 32 partners and demonstration activities on Positive Energy Districts in seven cities across Europe, including Trondheim. The cooperation includes the Sluppen and Brattøra Districts in Trondheim. The SCC Lighthouse projects (of which +CxC is 1 of 18, and the only project led by a university) have close contact with the EU Cities Mission and the New European Bauhaus initiative to help define and shape the target of 100 climate-neutral cities by 2030. This includes writing position papers towards the EU Cities Mission with corresponding meetings with the European Commission. Around eight Norwegian cities have applied to become part of these 100 cities, and they will need knowledge support to implement these plans – at city and regional scale.

The syn.ikia project, a H2020-funded project that involves 13 research and industry partners from six countries and will increase the proportion of sustainable neighbourhoods with surplus of renewable energy in different climates and markets in Europe. Over the course of the project (2021-2024), four real-life plus-energy demo neighbourhood projects tailored to four different climatic zones will be developed, analysed, optimized, and monitored, demonstrating the functionality of the plus-energy neighbourhood concept for the rest of Europe. The project is coordinated by NTNU, and SINTEF is one of the partners.

The ARV project, a H2020-funced project that involves 35 partners from research industry from eight European countries, as part of the European Green Deal. The vision of the ARV project is to contribute to speedy and wide scale implementation of Climate Positive Circular Communities (CPCC) where people can thrive and prosper for generations to come. The overall aim is to demonstrate and validate attractive, resilient, and affordable solutions for CPCC that will significantly speed up the deep energy renovations and the deployment of energy and climate measures in the construction and energy industries. To achieve this, the ARV project will employ a novel concept relying on a combination of three conceptual pillars, six demonstration projects, and nine thematic focus areas. The project is coordinated by NTNU, SINTEF is one of the partners, and the project period is from 2022 to 2025.

NTNU and SINTEF are also part of the newly funded project ***iclimabuilt*** on *Functional and advanced insulating and energy harvesting/storage materials across climate adaptive building envelopes*, where NTNU leads a work package on Living Labs and is part of the project management team.

Recently an additional Horizon Europe project CrAFt (Creating Actionable Futures) was awarded to NTNU that will help us Make our cities and communities be beautiful, inclusive, and sustainable – and yes, climate-neutral. To achieve this, we must use all our expertise - both professional experts, and citizens who are experts in their own everyday lives. In the CrAFt project, we will work closely with residents, architects and planners, municipal administrations and politicians, arts and culture, property developers and tenants, schools and universities, and many more, to make it happen. In this way, we support the European social mission to create at least 100 climate-neutral and socially innovative cities by 2030. NTNU is leading the project.

NTNU and SINTEF have created a Gemini centre to help address the EU Cities Mission and NEB, locally and towards EU (anchored with ZEN through a letter of support)

- Work with Norwegian municipalities, solution providers, academia, citizen organisations etc to build local pilots

- Cross-cutting cooperation and capacity building among staff and students towards this mission

- Joint development of new projects, including mentorship arrangements to include new staff and students into this work

- Advisory Board including Norwegian cities, KS, DOGA, RCN, Innovation Norway, and the Nordic Edge Innovation Cluster

NTNUleads the EERA Joint Programme Smart Cities (European Energy Research Alliance), 2018-2021 and newly elected for 2022-2025. We are now developing the Strategic Research and Innovation Agenda, closely linked to the EU Cities Mission and the NEB initiative. SINTEF is part of the Steering Committee. EERA JPSC and SET-Plan Action 3.2 / Driving Urban Transitions Partnership cooperate to develop a European integrated framework for Positive Energy Districts, together with the SCC Lighthouse projects, the SCALE Secretariat, the Smart Cities Marketplace, the COST Action PED-EU-NET and IEA EBC Annex 83. We also have an ongoing dialogue with the new IEA Technical Cooperation Programme on Decarbonisation of Cities and Communities that will form an important framework for international cooperation on Positive Energy Districts and Climate-Neutral Cities.

Moreover, the ZEN Research Centre is the Norwegian advisor to the SET-Plan Smart Cities and Communities Action 3.2 Funding Agency Working Group (FAWG), which aims to create 100 plus energy areas (PEDs) by 2025. NTNU is the R&I Chair for the European Stakeholder Group, a role that is in addition to the work of developing a research and innovation program coordinated by the joint program Smart Cities within the European Energy Research Alliance (EERA JP Smart Cities). SINTEF and NTNU also participate in the European Construction, built environment and energy efficient building Technology Platform (ECTP) which is a leading membership organisation promoting and influencing the future of the Built Environment.

The ZEN Research Centre has an International Scientific Committee (ISC). The ISC is a selective group of high-level experts and consists of:

- Kristina Mjörnell, Business & Innovation Area Manager for Sustainable Cities and Communities at RISE and Adjunct Prof. in Building Physics at Lund University;
- Eva Heiskanen, Professor at the University of Helsinki at the Consumer Society Research Centre;
- Steve Selkowitz, Senior Advisor for Windows & Envelope Materials Group in Building Technology & Urban Systems Division, at Lawrence Berkeley National Laboratory;
- Lieve Helsen, Professor of Applied Mechanics & Energy Conversion at KU Leuven.

The ZEN Research Centre has hired two international adjunct professors on topics of particular importance:

- Prof. Henrik Madsen from DTU, expert in probabilistic forecasting;
- Assoc. Prof. Eva Heinen from the University of Leeds, with strong competence in urban form, mobility, and GHG emissions.

Researcher Training and Recruitment

Ruth Woods
Research scientist
NTNU

Henrik Madsen
Professor
DTU

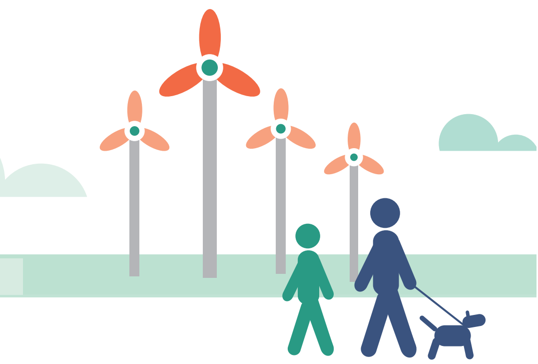
Time Series Analysis – with a focus on modelling and forecasting in energy systems

In August 2021 a summer school 'Time Series Analysis - with a focus on modelling, forecasting and control in energy systems' was arranged. Due to the pandemic the course was arranged as a combined virtual and physical course. About 70 participants from all around the world attended the summer school. The course responsible were Henrik Madsen, professor II at ZEN/NTNU and professor at DTU and Peder Bacher, DTU. Some of the learning outcomes are: Methods and models for short-term forecasting in energy systems, e.g. for heat load in buildings, electrical power from PV and wind systems. The course also included methods for how to identify, formulate and validate grey-box models; including linear and non-linear models. It was shown how to use the formulated models for model predictive control (MPC). A special focus was on providing an understanding of the concepts of the Flexibility Function and Flexibility Index for both single building, clusters of buildings and neighborhoods. The course contained several examples on the use of the methodologies for energy systems, smart buildings and cities. The summer school was held at DTU in Copenhagen in a collaboration with NTNU FME/ZEN and IEA EBC Annexes 81, 82 and 83.

ZEN PhD course

In Spring 2021, the ZEN Centre arranged a PhD course for its PhD candidates, which was also attended by candidates from other programs. Seven candidates participated. The course is intended to convey basic knowledge and skills that every PhD candidate working with ZEN-related topics should have, and it includes knowledge that places their specific projects within a larger societal and historical context. Topics covered by the course also reflect the Centre's interdisciplinary character. A series of five seminars started with an introduction to the ZEN Centre's research activities taking place and was followed up by seminars on the themes of; Energy and CO2: from individual buildings to the European power system, Smart sustainable cities: planning, design and citizen engagement, Ydalir and Elverum: what defines the good life, and finally Responsible research and innovation. COVID 19 caused some disruption to the course, several seminars took place digitally and the site visit to Elverum and Ydalir was replaced by a digital workshop with range of actors from Elverum Municipality.

The candidates have diverse professional backgrounds and different approaches to ZEN (e.g. architecture, civil and mechanical engineering, and science and technology studies). This provides an interesting starting point for interdisciplinary discussions. The main teaching methods are lectures, discussions, a case workshop, and writing a final paper or report that is presented at "ZEN mini conference". The mini conference is open for everyone. More detail about the ZEN PhD course can be found here: https://www.ntnu.no/studier/emner/AA-R8330#tab=omEmnet



APPENDICES

PERSONELL

Management team

Last name	First name	Position	Main research area	Institution
Gustavsen	Arild	Centre director / professor		NTNU
Kvellheim	Ann Kristin	Centre director (jan-july 2021)		SINTEF Community
Jacobsen	Terje	Centre liaison / vice president research		SINTEF Community
Solberg	Lasse Hopstad	Financial officer		NTNU
Bezdudna	Yana	Financial officer		NTNU
Skjevik	Hanne Kristin	Financial officer		SINTEF Community
Sætersdal Remøe	Katinka	Communication adviser		NTNU
Danielsen	Sunniva Moum	Communications adviser and coordinator FME ZEN		NTNU
Svarva	Brynjar Fredus	Centre coordinator		NTNU

Work package leaders

Last name	First name	Position	Work package	Institution
Brattebø	Helge	WP1 leader / LCA coordination / professor	WP 1	NTNU
Kvellheim	Ann Kristin	WP2 leader / research manager	WP 2	SINTEF Community
Mathisen	Hans Martin	WP3 leader / professor	WP 3 & 4	NTNU
Sartori	Igor	WP4 leader / senior research scientist	WP 4	SINTEF Community
Kauko	Hanne	WP6 leader / research scientist	WP 5	SINTEF Energi
Thomsen	Judith	WP6 leader / research manager	WP 6	SINTEF Community

Key researchers

Last name	First name	Position	Work package	Institution
Andresen	Inger	Professor 2	WP 6	NTNU
Baer	Daniela	Researcher	WP 1	SINTEF Community
Backe	Stian	Researcher		SINTEF Energi
Berker	Thomas	Living lab coordination / professor	WP 6	NTNU
Bergsdal	Håvard	Senior researcher	WP 1	SINTEF Community
Boer	Luitzen de	Professor	WP 2	NTNU
Clauss	John	Researcher	WP 3 & 4	SINTEF Community
Farahmand	Hossein	Associate Professor	WP 4 & 5	NTNU
Fjellheim	Kristin	Researcher	WP 1	SINTEF Community
Gaitani	Niki	Associate Professor	Internat. cooperation	NTNU
Georges	Laurent	Building/neighbourhood services coordination / assoc. professor	WP 3 & 4	NTNU
Graabak	Ingeborg	Research scientist	WP 5	SINTEF Energi
Heinen	Eva	Professor II	WP 1 & 6	NTNU
Grynning	Steinar	Research manager	WP 3	SINTEF Community
Hamdy	Mohamed	Assoc. prof.	WP 3 & 4	NTNU
Hrynyszyn	Bozena Dorota	Associate professor	WP 3	NTNU
Lausselet	Carine	Researcher		SINTEF Community
Krogstie	John	Professor	WP 1	NTNU

Lien	Synne Krekling	Master of science	WP 1, 4 & 6	SINTEF Community
Lindberg	Karen B.	Senior researcher	WP 4, 5 & 6	SINTEF Community
Lui	Peng	Researcher	WP 3	SINTEF Community
Neumann	Anne	Professor	WP 2	NTNU
Nordström	Tobias	Researcher	WP 6	NTNU
Manum	Bendik	Professor	WP 1 & 6	NTNU
Resch	Eirik	Researcher		NTNU
Rokseth	Lillian	Researcher		SINTEF Community
Petersen	Sobah Abbas	ICT coordination / assoc. professor	WP 1	NTNU
Pinel	Dimitri	Researcher		SINTEF Energi
Sandberg	Nina Holck	Senior researcher	WP 1	SINTEF Community
Skaar	Christofer	Researcher	WP 3 & 6	SINTEF Community
Tomasgard	Asgeir	Researcher	WP 2	NTNU
Walnum	Harald Taxt	Senior researcher	WP 4 & 6	SINTEF Community
Wiik	Marianne	Senior researcher	WP 1 & 6	SINTEF Community
Wyckmans	Annemie	Internationalisation coordination / professor		NTNU
Hertwich	Edgar	Professor	WP 1	NTNU

Visiting researchers

Last name	First name	Topic	Affiliation
Madsen	Henrik	Energy system modelling	Technical University of Denmark

Postdoctoral researchers with financial support from the Centre budget

Last name	First name	Topic and work package
Stokke	Raymond	Innovation eco-system and green public procurement (WP2)
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	Funding
Korsnes	Marius	The role of prosumers in zero emission buildings and neighbourhoods (WP6)	NTNU Energi
Sandberg	Nina Holck	Dynamic modelling of energy use of building stocks (WP1)	NTNU

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)
Bagle	Marius	Model based control of buildings (WP4)
Backe	Stian	Transition pathways towards zero emission neigh-bourhoods (WP2). Disputas 25th November 2021
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 neigh-bourhoods (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). Disputas 22nd November 2021.
Pinel	Dimitri	Local energy system optimization within a larger system (WP5). Disputas 15th December 2021.
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)
Formolli	Matteo	Solar neighbourhood planning (WP1)
Henriksen	Hanne Marit	Representing zero-emission built environments (WP6)
Rizzardi	Victor	Regulatory challenges and opportunities in zero emission neigh-bourhoods (WP2)
Schön	Peter	Mobilitet

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

Last name	First name	Topic and work package	Funding
Annaqeeb	Masab Khalid	Simulation of energy related occupant behaviour in buildings (WP3)	NTNU
Catto Lucchino	Elena	Double skin facades (WP3)	NTNU
Dziedzic	Jakub Wladyslaw	Modeling and simulating energy-related, occupant behavior in residential buildings (WP3)	NTNU
Henriksen	Hanne Marit	Communication in ZEN pilots (WP 6)	NTNU
Juhasz-Nagy	Eszter	Improving smart energy community planning through collaborative game development (WP1&6)	NTNU
Lassen	Niels	Evaluation of a method for real time user interaction regarding indoor climate in office buildings (WP3)	Skanska Norway
Møgster	Trine Olsen	(WP6)	NTNU
Ness	Maria Coral Albelda-Estelles	Exploring the limits of building bioclimatic design in cold climates (WP6)	NTNU
Valler	Thea Marie	Decarbonization of transport in urban China (WP2&6)	NTNU Energy
Sutcliffe	Thomas	Circular economy (WP6)	NTNU sustainability
Rousseau	Lola	Mitigation of greenhouse gas emissions in urban planning and development (WP 1)	NTNU
Yu	Xingji	Model predictive control to activate the building energy flexibility (WP 4)	NTNU
Yang	Yunbo		
Healey Trulsrud	Tonje	Syn.ikia	
Brudal	Ørjan	ARV	

Other resources associated with the Centre

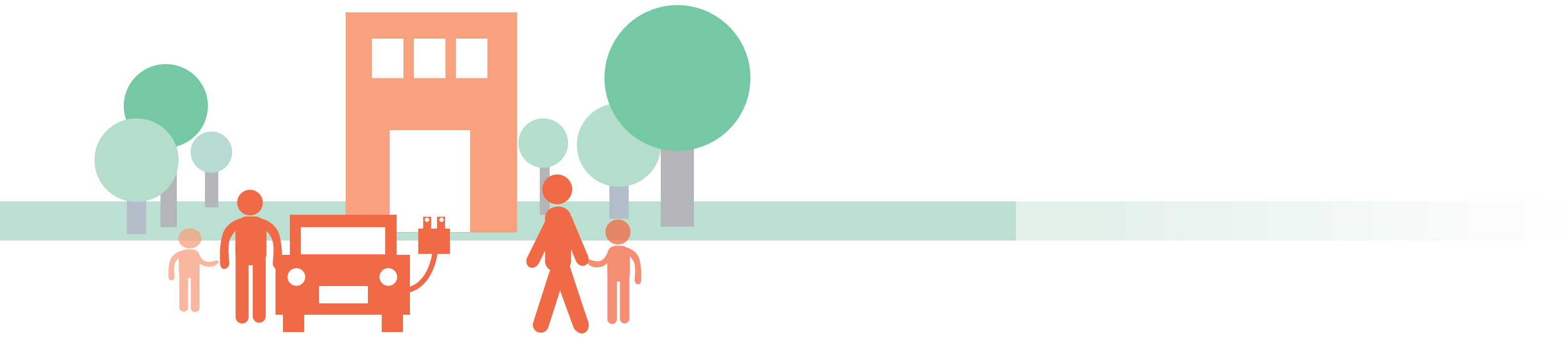
Last name	First name	Institution	Position	Institution	Funding
Andersen	Tuva	NTNU	ZEN stud.ass.		FME ZEN, others
Andresen	Inger	Asplan Viak	Architect		Others
Bergsdal	Håvard	SINTEF Community	Senior researcher	WP 1	NFR, SINTEF
Bø	Lars Arne	SINTEF Community	Senior researcher	WP 1 & 6	NFR, SINTEF
Cao	Guangyu	NTNU	Prof.	WP 3	NTNU
Clauss	John	SINTEF Community	Researcher	WP 3 & 4	FME ZEN, SINTEF
Farahmand	Hossein	NTNU	Assoc. prof.	WP 4 & 5	NTNU
Fufa	Selamawit Mamo	SINTEF Community	Researcher	WP 1 & 6	FME ZEN, others
Goia	Francesco	NTNU	Assoc. prof.	WP 3	NTNU
Gullbrekken	Lars	SINTEF Community	Researcher	WP 3	SINTEF Community
Hestnes	Anne Grete	NTNU	Scientific advisor		NTNU
Holmen	Elsebeth	NTNU	Prof.	WP 2	NTNU
Holøs	Sverre	SINTEF Community	Researcher	WP 3	FME ZEN, others
Korpås	Magnus	NTNU	Prof.	WP 4 & 5	NTNU
Labonnote	Nathalie	SINTEF Community	Researcher	WP 3	FME ZEN, others
Larssæther	Stig A.	NTNU TSO Sustainability	Coordinator	WP 6	Others
Liu	Peng	SINTEF Community	Researcher	WP 3	FME ZEN, SINTEF
Manum	Bendik	NTNU	Prof.	WP 1 & 6	NTNU
Nord	Natasa	NTNU	Assoc. prof.	WP 4	NTNU
Novakovic	Vojislav	NTNU	Prof.	WP 3 & 4	NTNU
Risholt	Birgit	SINTEF Community	Researcher	WP 3	Others
Strømman	Anders	NTNU	Prof.	WP 1	NTNU
Svendsen	Harald	SINTEF Energi	Researcher	WP 5	SINTEF
Sørnes	Kari	SINTEF Community	Researcher	WP 4 & 6	FME ZEN, others
Thunshelle	Kari	SINTEF Community	Researcher	WP 3	FME ZEN, others
Nocente	Alessandro	SINTEF Community	Researcher	WP 3	FME ZEN, others
Andersen	Kamilla Heimar	SINTEF Community	Researcher	WP 4 & 6	FME ZEN, others
Nitter	Kathrine	SINTEF Community	Senior Corporate Communications Officer / Web Manager	WP 7	FME ZEN, others
Oksavik	Andreas Odne	SINTEF Community	Advisor	WP 3	FME ZEN, others
Gaarder	Jørn Emil	SINTEF Community	Researcher	WP 3	FME ZEN, others
Cheng	Caroline Yeng-Ting	SINTEF Community	Researcher	WP 2	FME ZEN, others
Bergheim	Einar	SINTEF Community	Laboratory Manager	WP 3	FME ZEN, others
Fjellheim	Øystein	SINTEF Community	Research Manager	WP 3,4 & 6	FME ZEN, others
Neumann	Anne	NTNU	Prof.	WP 2	FME ZEN, others
Chaudhary	Chamita	NTNU			
Junker	Eivind	NTNU	Researcher	WP 2	FME ZEN, others

ZEN Scientific Advisory Committee

Last name	First name	Institution
Heiskanen	Eva	University of Helsinki, Finland
Helsen	Lieve	KU Leuven, Belgium
Mjörnell	Kristina	RISE, Sweden
Selkowitz	Stephen	Lawrence Berkeley National Laboratory, USA

Master degrees 2021

Last name	First name	Institution
Westad	Maria Claire	A Stochastic Simulation Tool for Generating Hourly Load Profiles for Residential EV Charging, Based on Real-World Charging Reports, NTNU
Beus	Lea	An Investment Model for Energy Systems in Zero Emission Neighborhoods - A Multi-Horizon Stochastic Programming Approach
Eldrup	Caroline	
Hammersbøen	Ingrid	
Verås	Håkon Gjenstad	Analyzing Scenario Generation for Energy Market Modeling
Jørgensen	Thomas Berg	lizing IoT technology for healthy and energy efficient improvement of existing ventilation systems - Case study of indoor air quality in a primary school classroom using Arduino sensors and CONTAM Simulations
Antonsen	Dan Remi	Increased solar energy utilization in Norwegian agriculture - A case study on the milk barn at Mære Agricultural School
Barth-Stenersen	Liv Marie	Analysis and modelling of heat energy use in an office building utilizing monitoring data and building simulations, EPT, NTNU
Hengebøl	Camilla	A study on optimal utilization of electric heating for buildings, IEL, NTNU
Storlien	E.	Characterizing the demand response potential of thermal heat load in buildings EPT, NTNU
Buseth	Emil Risvik	Energisystemet på Svalbard
Kjenstadbakk	Emilie	A Study of How Integration of Solar Photovoltaic Impact a Housing Cooperative in Norway
Robberechts	Jaro	Developing Software Services in Smart Cities based on Edge to cloud Orchestration
Sebastian Gunnestad	Evans	casEV - Modelling smart power grids with V2G charging as complex systems within an urban context



STATEMENT OF ACCOUNTS

FUNDING AND COSTS

Funding	Amount	Total
The research council		20 963 878
The Host institution (NTNU)		12 608 085
Research partners		
SINTEF Energy		634 152
Sintef Community		5 335 793
Enterprise partners		8 472 519
ByBo AS	1 097 100	
AS Civitas	151 200	
Boligbyggelaget TOBB	531 395	
Energi Norge AS	354 760	
ÅF Engineering AS/Gottlieb Paludan Architects	122 000	
Asplan viak	707 650	
GK Norge AS	573 543	
Hunton Fiber AS	358 400	
Moelven industrier ASA	363 850	
Norcem AS	460 750	
Norsk fjernvarme	259 780	
NTE Marked	173 600	
Snøhetta Oslo AS	246 053	
Sweco Norge AS	200 000	
Multiconsult ASA	200 000	
Skanska Norge AS	1 741 750	
Elverum tomteselskap AS	930 688	
Public partners		5 197 540
Bergen kommune	200 000	
Bodø kommune	429 310	
Bærum kommune	738 590	
Direktoratet for byggkvalitet	200 000	
Elverum kommune	255 483	
Norges vassdrag og energidirektorat (NVE)	279 000	
Oslo kommune – Plan og bygningsetaten (futurebuilt)	256 594	
Oslo kommune – klimaetaten	761 500	
Statkraft varme AS	442 300	
Statsbygg	635 600	
Steinkjer kommune	14 400	
Trondheim kommune	367 563	
Trøndelag fylkeskommune	617 200	
Funding transfered to next year		-5 580 000
Total		47 631 967

Cost	Amount	Total
The host institution (NTNU)		21 229 278
Research partners		
SINTEF Energy Research		1 877 200
Sintef Community		16 435 431
Enterprise partners		5 792 519
ByBo AS	947 100	
AS Civitas	101 200	
Boligbyggelaget TOBB	431 395	
Energi Norge AS	204 760	
ÅF Engineering AS/Gottlieb Paludan Architects	22 000	
Asplan viak	507 650	
GK Norge AS	323 543	
Hunton Fiber AS	108 400	
Moelven industrier ASA	113 850	
Norcem AS	210 750	
Norsk fjernvarme	129 780	
NTE Marked	173 600	
Snøhetta Oslo AS	46 053	
Sweco Norge AS		
Multiconsult ASA		
Skanska Norge AS	1 641 750	
Elverum tomteselskap AS	830 688	
Public partners		2 297 540
Bergen kommune		
Bodø kommune	179 310	
Bærum kommune	238 590	
Direktoratet for byggkvalitet		
Elverum kommune	105 483	
Norges vassdrag og energidirektorat (NVE)	79 000	
Oslo Kommune - Plan og bygningsetaten (futurebuilt)	256 594	
Oslo kommune - klimaetaten	511 500	
Statkraft varme AS	192 300	
Statsbygg	235 600	
Steinkjer kommune	14 400	
Trondheim kommune	117 563	
Trøndelag fylkeskommune	367 200	
Total		47 631 967

PUBLICATIONS IN 2021

4 ZEN REPORTS

Sinaeepourfard, Amir; Krogstie, John; Petersen, Sobah Abbas (2021). ZEN DATA MANAGEMENT AND MONITORING. *ZEN report 34*, 3. november 2021.

Kauko, Hanne; Wolfgang, Ove; Pinel, Dimitri (2021) SESONGLAGRING AV VARME FOR LOKALE ENERGISYSTEM Analyse av potensialet på Furuset. *ZEN report 35*, 16. november 2021.

Krekling Lien, Synne; Heimar Andersen, Kamilla; Bottolfsen, Hanne; Lolli, Nicola; Sartori, Igor; Lekang Sørensen, Åse; Clauss, John (2021) ENERGY AND POWER ESSENTIAL KEY PERFORMANCE INDICATORS FOR ZERO EMISSON NEIGHBOURHOODS An analysis of 6 pilot areas. *ZEN report 36*, 16. november 2021.

Kauko, Hanne; Wolfgang, Ove; Kallaos, James; Fjellheim, Kristin (2021). ZEN CASE GARDERMOEN Redusert turtemperatur i et eksisterende fjernvarmesystem for økt utnyttelse av overskuddsvarme. *FME ZEN*, 2021

2 BOOKS:

Ankerstjerne Thilker, Christian; Grønborg Junker, Rune; Bacher, Peder; Bagterp Jørgensen, John; Madsen, Henrik (2021). Model Predictive Control Based on Stochastic Grey-Box Models. *Towards Energy Smart Homes*, 2021.

Woods, Ruth; Berker, Thomas (2021). Navigating the technological logic of sustainable architecture. *Architectural Anthropology*, 2021.

48 JOURNAL ARTICLES:

Backe, Stian; Skar, Christian; Crespo del Granado, Pedro; Turgut, Ozgu; Tomasgard, Asgeir (2021). EMPIRE: An open-source model based on multi-horizon programming for energy transition analyses. *SoftwareX*, 10. desember 2021.

Justo Alonso, Maria; Wolf, Sebastian; Bramming Jørgensen, Rikke; Madsen, Henrik; Mathisen, Hans Martin (2021). A methodology for the selection of pollutants for ensuring good indoor air quality using the de-trended cross-correlation function. *Building and Environment*, 11. desember 2021.

Formolli, Matteo; Lobaccaro, Gabriele; Kanters, Jouri (2021). Solar Energy in the Nordic Built Environment: Challenges, Opportunities and Barriers. *Energies*, 13. desember 2021.

Rahuf, R; Hamdy, M; Homaei, S; Zhang, C; Holzer, P; Attia, S (2021). Simulation-based framework to evaluate resistivity of cooling strategies in buildings against overheating impact of climate change. *Building and Environment*, 19. november 2021.

Baer, Daniela; Loewen, Bradley; Cheng, Caroline; Thomsen, Judith; Wyckmans, Annemie; Temeljotov-Salaj, Alenka; Ahlers, Dirk (2021). Approaches to Social Innovation in Positive Energy Districts (PEDs)—A Comparison of Norwegian Projects. *Sustainability*, 30. juni 2021.

Ankerstjerne Thilker, Christian; Bacher, Peder; Bergsteinsson, Hjörleifur G.; Grønborg Junker, Rune; Cali, Davide; Madsen, Henrik (2021). Non-linear grey-box modelling for heat dynamics of buildings. *Energy and Buildings*, 16. september 2021.

Lausselet, Carine; Brattebø, Helge (2021). Environmental co-benefits and trade-offs of climate mitigation strategies applied to net-zero-emission neighbourhoods. *The International Journal of Life Cycle Assessment*, 23. september 2021.

Favero, Matteo; Sartori, Igor; Garlucci, Salvatore (2021). Human thermal comfort under dynamic conditions: An experimental study. *Building and Environment*, 16. juli 2021.

Backe, Stian; Ahang, Mohammadreza; Tomasgard, Asgeir (2021). Stable stochastic capacity expansion with variable renewables: Comparing moment matching and stratified scenario generation sampling. *Applied Energy*, 18. august, 2021.

Pauliuk, Stefan; Heeren, Niko; Berrill, Peter; Fishman, Tomer; Nistad, Andrea; Tu, Quingshi; Wolfram, Paul; Hertwich, Edgar G. (2021). Global scenarios of resource and emission savings from material efficiency in residential buildings and cars. *Nature Communications*, 24. august 2021.

Bashery Abbass, Mahmoud Abdelkaber; Hamdy, Mohamed (2021). A Generic Pipeline for Machine Learning Users in Energy and Buildings Domain. *Energies*, 31. august.

Sve Rokseth, Lillian; Manum, Bendik (2021). Patterns of Dwelling Types, Location, and Spaciousness of Living in Norway. Critical Remarks on the Practice of Measuring Energy Performance per Floor Area Only. *Buildings*, 4. september 2021.

Lucchino, Elena Catto; Gelesz, Adrienne; Skeie, Kristian; Gennaro, Giovanni; Reith, Andras; Serra, Valentina; Goia, Francesco (2021). Modelling double skin façades (DSFs) in whole-building energy simulation tools: Validation and inter-software comparison of a mechanically ventilated single-story DSF. *Building and Environment*, 23. april 2021.

Knudsen, Michael Dahl; Georges, Laurent; Skeie, Kristian; Petersen, Steffen (2021). Experimental test of a black-box economic model predictive control for residential space heating. *Applied Energy*, 9. juni 2021.

Lassen, Niels; Møller, Jan Kloppenborg; Goia, Francesco (2021). Information match between continuous occupant data streams and one-time manual surveys on indoor climate. *Building and Environment*, 24. juni 2021.

Pisello, A.L.; Piglautile, I.; Andargie, M.; Berger, C.; Bluyssen, P.M.; Carlucci, S.; Chinazzo, G.; Deme Belafi, Z.; Dong, B.; Favero, M.; Ghahramani, A.; Havenith, G.; Heydarian, A.; Kastner, D.; Kong, M.; Licina, D.; Liu, Y.; Luna-Navarro, A.; Wei, S. (2021). Test rooms to study human comfort in buildings: A review of controlled experiments and facilities. *Renewable and Sustainable Energy Reviews*, 30. juni 2021.

Baer, Daniela; Loewen, Bradley; Cheng, Caroline; Thomsen, Judith; Wyckmans, Annemie; Temeljotov-Salaj, Alenka; Ahlers, Dirk (2021). Approaches to Social Innovation in Positive Energy Districts (PEDs)—A Comparison of Norwegian Projects. *Sustainability*, 30. juni 2021.

Rokseth, Lillian Sve; Heinen, Eva; Hauglin, Espen Aukrust; Nordström, Tobias; Manum, Bendik (2021). Reducing private car demand, fact or fiction? A study mapping changes in accessibility to grocery stores in Norway. *European Transport Research Review*, 5. juli 2021.

Favero, Matteo; Sartori, Igor; Carlucci, Salvatore (2021). Human thermal comfort under dynamic conditions: An experimental study. *Building and Environment*, 16. juli 2021.

Brozovsky, Johannes; Simonsen, Are; Gaitani, Niki (2021). Validation of a CFD model for the evaluation of urban microclimate at high latitudes: A case study in Trondheim, Norway. *Building and Environment*, 21. juli 2021.

Jankovic, Aleksandar; Chaudhary, Gaurav; Goia, Fransesco (2021). Designing the design of experiments (DOE) – An investigation on the influence of different factorial designs on the characterization of complex systems. *Energy and Buildings*, 22. juli 2021.

Thorvaldsen, Kasper Emil; Korpås, Magnus; Lindberg, Karen Byskov; Farahmand, Hossein (2021). A stochastic operational planning model for a zero emission building with emission compensation. *Applied Energy*, 12. august 2021.

Annaqeeb, Masab Khalid; Zhang, Yixian; Dziedzic, Jakub Wladyslaw; Xue, Kai; Pedersen, Christoffer; Stenstad, Liv-Inger; Novakovic, Vojislav; Cao, Guangyu (2021). Influence of the surgical team activity on airborne bacterial distribution in the operating room with mixing ventilation system: A case study at St. Olavs Hospital. *Journal of Hospital Infection*, 14. august 2021.

Korsnes, Marius; Throndsen, William (2021). Smart energy prosumers in Norway: Critical reflections on implications for participation and everyday life. *Journal of Cleaner Production*, 25. april 2021.

A. Aganovic; G. Cao; T. Fecer; B. Ljungqvist; B. Lytsy; A. Radtke; B. Reinmüller; R. Traversari (2021). Ventilation design conditions associated with airborne bacteria levels within the wound area during surgical procedures: A systematic review. *Journal of Hospital Infection*, 27. april 2021.

Sadrizadeh, Sasan; Aganovic, Amar; Bogdan, Anna; Wang, Cong; Afshari, Alireza; Hartmann, Anne; Croitoru, Cristiana; Khan, Amirul; Kriegel, Martin; Lind, Merethe; Liu, Zhijian; Melikov, Arsen; Mo, Jinhan; Rotheudt, Hansjörg; Yao, Runming; Zhang, Yixian; Abouali, Omid; Langvatn, Håkon; Sköldenberg, Olof; Cao, Guangyu (2021). A systematic review of operating room ventilation. *Journal of Building Engineering*, 18. mai 2021.

Homaei, Shabnam; Hamdy, Mohamed (2021). Thermal resilient buildings: How to be quantified? A novel benchmarking framework and labelling metric. *Building and Environment*, 2. juni 2021.

Askeland, Magnus; Backe, Stian; Bjarghov, Sigurd; Lindberg, Karen Byskov; Korpås, Magnus (2021). Activating the potential of decentralized flexibility and energy resources to increase the EV hosting capacity: A case study of a multi-stakeholder local electricity system in Norway. *Smart Energy*, 17. juni 2021.

Brozovsky, Johannes; Gustavsen, Arild; Gaitani, Niki (2021). Zero emission neighbourhoods and positive energy districts – A state-of-the-art review. *Sustainable Cities and Society*, 15. mai 2021.

Homai, Shabnam; Hamdy, Mohamed (2021). Quantification of Energy Flexibility and Survivability of All-Electric Buildings with Cost-Effective Battery Size: Methodology and Indexes. Energies, 12. mai 2021.

Brozovsky, Johannes; Corio, Sara; Gaitani, Niki; Gustavsen, Arild (2021). Evaluation of sustainable strategies and design solutions at high-latitude urban settlements to enhance outdoor thermal comfort. *Energy and Buildings*, 22. april 2021.

Sørensen, Åse Lekang; Lindberg, Karen Byskov; Sartori, Igor; Andresen, Inger (2021). Residential electric vehicle charging datasets from apartment buildings. *Data in Brief*, 28. april 2021.

Lassen, Niels; Hegli, Tine; Dokka, Tor Helge; Løvold, Terje; Edwards, Kristian; Goia, Francesco; Andresen, Inger (2021). Enabling holistic design for high energy efficient office buildings through the use of subjective occupant feedback. *Sustainable Cities and Society*, 22. mars 2021.

Lassen, Niels; Goia, Francesco (2021). A theoretical framework for classifying occupant-centric data streams on indoor climate using a physiological and cognitive process hierarchy. *Energy and Buildings*, 19. mars 2021.

Sørensen, Åse Lekang; Lindberg, Karen Byskov; Sartori, Igor; Andresen, Inger (2021). Analysis of residential EV energy flexibility potential based on real-world charging reports and smart meter data. *Energy and Buildings*, 19. mars 2021.

Attia, Shady; Levinson, Ronnen; Ndongo, Eileen; Holzer, Peter; Kazanki, Berk Ongun; Homaei, Shabnam; Zhang, Chen; Olesen, Bjarne W.; Qi, Dahai; Hamdy, Mohamed; Heiselberg, Per (2021). Resilient cooling of buildings to protect against heat waves and power outages: Key concepts and definition. *Energy and Buildings*,

Fan, Minchao; Cao, Guangyu; Pedersen, Christoffer; Lu, Shilei; Stenstad, Liv-Inger; Skogås, Jan Gunnar (2021). Suitability evaluation on laminar airflow and mixing airflow distribution strategies in operating rooms: A case study at St. Olavs Hospital. *Building and Environment*, 12. februar 2021.

Attia, Shady; Levinson, Ronnen; Ndongo, Eileen; Holzer, Peter; Kazanci, Ongun Berk; Homai, Shabnam; Zhan, Cheng; Olesen, Bjarne W.; Qi, Dahai; Hamdy, Mohamed; Heiselberg, Per (2021). Resilient cooling of buildings to protect against heat waves and power outages: Key concepts and definition. *Energy and Buildings*, 6. mars 2021.

Holck Sandberg, Nina; Sandstad Næss, Jan; Brattebø, Helge; Andresen, Inger; Gustavsen, Arild (2021). Large potentials for energy saving and greenhouse gas emission reductions from large-scale deployment of zero emission building technologies in a national building stock. *Energy Policy*, 9. mars 2021.

Mahdavi, Ardeshir; Berger, Christiane; Amin, Hadeer; Ampatzi, Eleni; Korsholm Andersen, Rune; Azar, Elie; Barthelmes, Verena M.; Favero, Matteo; Hahn, Jakob; Khovalyg, Dolaana; Knudsen, Henrik N.; Luna-Navarro, Alessandra; Roetzel, Astrid; Sangogboye, Fisayo C.; Schweiker, Marcel; Taheri, Mahnameh; Teli, Despoina; Touchie, Marianne; Verbruggen, Silke (2021). The Role of Occupants in Buildings' Energy Performance Gap: Myth or Reality? *Sustainability*, 12. mars 2021.

Woods, Ruth; Thomsen, Judith (2021). Unboxing Buildings: Engaging with Occupants during Design, Testing and Use. *Sustainability*, 15. mars 2021.

Hamdan, Hasan A. M (2021). Strategies promoting innovation in sustainable neighborhood (SN) projects – Lessons from complex and mega projects. Procedia Computer Science, 22. februar 2021.

Hamdan, Hasan A. M.; de Boer, Luitzen; Baer, Daniela (2021). When Green Procurement Meets Complexity: The Case of Sustainable Neighborhood Projects. *Sustainability*, 16. februar 2021.

Hamdan, Hasan A. M.; Andersen, Poul Houman; de Boer, Luitzen (2021). Stakeholder collaboration in sustainable neighborhood projects—A review and research agenda. *Sustainable Cities and Society*, 13. februar 2021.

Skeie, Kristian; Gustavsen, Arild (2021). Utilising Open Geospatial Data to Refine Weather Variables for Building Energy Performance Evaluation—Incident Solar Radiation and Wind-Driven Infiltration Modelling. *Energies*, 3. februar 2021.

Yu, Xingji; Georges, Laurent; Imsland, Lars (2021). Data pre-processing and optimization techniques for stochastic and deterministic low-order grey-box models of residential buildings. *Energy and Buildings*, 1. februar 2021.

Nord, Natasa; Shakerin, Mohammad; Tereshchenko, Tymofii; Verda, Vittorio; Borchiellini, Romano (2021). Data informed physical models for district heating grids with distributed heat sources to understand thermal and hydraulic aspects. *Energy*, 28. januar 2021.

Satola, Daniel; Balouktsi, M; Lützkendorf, T; Wiberg, Houlihan A Gustaven, Arild (2021). How to define (net) zero greenhouse gas emissions buildings: The results of an international survey as part of IEA EBC annex 72. *Building and Environment*, 20. januar 2021.

10 CONFERECE PAPERS:

Costardi, Luigi; Chiara Tagliabue, Lavinia; Hamdy, Mohamed; Dotelli. Giovanni (2021). LCA evaluation and Energy performance of a housing building in different technological scenarios. *Journal of Physics: Conference Series*, 2021.

Baer, Daniela; Ekambaram, Anandasivakumar (2021). Integrating User Needs in Sustainable Neighbourhood Transition of the Smart City – Expanding Knowledge and Insight among Professional Stakeholders. *Real Corp 26th International Conference on Urban Planning and Regional Development in the Information Society*, 7. september 2021.

Haase, Mathias; Baer, Daniela (2021). Towards Climate Neutrality through Integrated Energy Planning – a Cross-Country Comparison andCase Study Analysis of Positive Energy District Concepts between Switzerland and Norway. *Real Corp 26th International Conference on Urban Planning and Regional Development in the Information Society*, 6. september 2021.

Woods, Ruth; Berker, Thomas (2021). The good life is in the middle of a Norwegian forest: reflections on a zero emission neighbourhood concept. *Third SIAC National Conference Rome.*

Eide Bagle, Marius; Maree, Philip; Taxt Walnum, Harald; Sartori, Igor (2021). Identifying grey-box models from archetypes of apartment block buildings. *Building Simulation 2021 Conference*, 1. september 2021.

Heimar Andersen, Kamilla; Krekling Lien, Synne; Byskov Lindberg, Karen; Taxt Walnum, Harald; Sartori, Igor (2021). Further development and validation of the "PROFet" energy demand load profiles estimator. *Building Simulation 2021 Conference*, 2. september 2021.

Georges, Laurent; Storlien, Elin; Askeland, Magnus; Lindberg, Karen Byskov (2921). Development of a data-driven model to characterize the heat storage of the building thermal mass in energy planning tools. *Cold Climate HVAC & Energy 2021*, 29. mars 2021.

Justo, Maria Alonso; Jørgensen, Rikke Bramming; Mathisen, Hans Martin (2021). Short term measurements of indoor air quality when using the home office in Norway. *Cold Climate HVAC & Energy 2021*, 29. mars 2021.

Sørensen, Åse Lekang; Walnum, Harald Taxt; Sartori, Igor; Andresen, Inger (2021). Energy flexibility potential of domestic hot water systems in apartment buildings. *Cold Climate HVAC & Energy 2021*, 29. mars 2021.

Haase, Matthias; Baer, Daniela (2021). [Constraints, Stakeholders, and Framing Goals in Energy Master Planning Between Neighborhood and District]. *International conference on Smart and Sustainable Planning for Cities and Regions*, 10. februar 2021.

7 POPULAR SCIENTIFIC PUBLICATIONS:

Woods, Ruth; Henriksen, Hanne Marit; Sutcliffe, Thomas Edward; Berker, Thomas (2021). Gjenbruk til jul. *Adresseavisen*, 16. desember 2021.

Backe, Stian (2021). Utslippsfrie nabolag i Norge kan endre det europeiske kraftmarkedet. *SINTEFblogg*, 15. november 2021.

Baer, Daniela; Tonjer, Anna-Thekla (2021). Det lønner seg å dele: Hvordan kan deleløsninger bidra til å nå nullutslippsambisjonen? *SINTEFblogg*, 23. november 2021.

Dahlberg Hauge, Kristian; Aassved Hansen, Einar; Thomsen, Judith; Askeland, Magnus; Bø, Lars Arne (2021). På med syvmilstøvlene for å nå klimamål i byutvikling. *Adresseavisen*, 26. september 2021.

Dahlberg Hauge, Kristian; Aassved Hansen, Einar; Thomsen, Judith; Askeland, Magnus; Bø, Lars Arne (2021). På med syvmilstøvlene for å nå klimamål i byutvikling. *SINTEF*, 5. oktober 2021.

Andresen, Inger; Dokka, Tor Helge; Petersen, Arnkell Jonas (2021). Byggebransjen er klar for fremtidens lavutslippsbygg – hvorfor henger byggforskriften etter?.*Dagens Næringsliv*, 2. oktober 2021.

Sørensen, Åse Lekang (2021). Elbillading i borettslag: Ladevaner, energibruk og fleksibilitet. *FME ZEN*, 29. april 2021.

29 MEDIA COVERAGE:

Mathisen, Hans Martin (2021). ZEB-laboratoriets spesielle krav til ventilasjon og hvordan dette styres. *ITBAktuelt*, 8. desember 2021.

Asplan Viak (2021). Utvikler fremtidenes nullutslippssamfunn. *NTB kommunikasjon*, 14. desember 2021.

Nitter, Kathrine (2021). Strømmen kan bli billigere ved å bruke lokale energiressurser. *Forskning.no*, 21. desember 2021.

Seehusen, Joachim (2021). Ny programvare skal gjøre klimagass¬beregninger lettere og mer nøyaktige. *Teknisk Ukeblad*, 28. oktober 2021.

Rambæk, Ida (2021). Klimavennlige nabolag må også være menneskevennlige. *forskning.no*, 30. oktober 2021.

Rambæk, Ida (2021). Hvordan kan klimavennlige nabolag bli attraktive nok for folk? *SINTEF*, 16. november 2021.

Norsk Fjernvarme (2021). Eidisiva Bioenergi vinner av innovasjonspris. *NTB*, 19. november 2021.

Grønn byutvikling. *Næringslivnorge (Issuu)*, 17. september 2021.

Arnø, Martine Torstad (2021). Ungdommen skal kommunisere klimabudskap i sommer. KOM24, 29. juni 2021.

Bazilchuk, Nancy (2021). Rapid action can help prevent the worst consequences of global warming. *Norwegian SchiTech News*, 9. august 2021.

Bergheim, Ola (2021). NTNU-professorar trugsmål mot demokratiet? *Firda*, 17. august 2021.

Strand, Sindre Sverdrup (2021). NTNU-ledet EU-prosjekt tester 50 nyvinninger innen rehabilitering. *Byggeindustrien*, 15. juni 2021.

Månedens prosjekt mai 2021: ZEB-laboratoriet. *Grønn Byggallianse*, 27. mai 2021.

Bjørgan, Espen Halvorsen (2021). Fakultet for arkitektur og design har ansatt nye ledere. *Universitetsavisa*, 25. mai 2021.

Ringstad, Ole Marius Skytterholm; Haugan, Idun (2021). NTNU becomes partner to the New European Bauhaus initiative. *Norwegian SchiTech News*, 12. mai 2021.

Javorovic, Benedikt Erikstad (2021). De neste årene skal NTNU ha 15 innovasjonsledere. *Universitetsavisa*, 12. mai 2021.

Tar bærekraft på alvor. *Elmagasinet*, 11. mai 2021.

Høyden, Kathinka Brødreskift (2021). NTNU leder prestisjeprosjekt: 200 millioner EU-kroner til ARV-prosjektet – med SINTEF og Oslobygg som partnere. *NTNU*, 10. mai 2021.

Mathisen, Georg (2021). Data center is the "hot springs" of our time. *Gemini*, April 19, 2021.

Seehusen, Joachim (2021). Kids blame mom for climate change. *Technical Magazine*, April 7, 2021.

Elle, Ingrid (2021). Miljøbølgen har nådd fjellhyttene. *ABC news*, 8. April 2021.

Seehusen, Joachim (2021). The Planning and Building Act prevents the construction of a new environmentally friendly district in Elverum. *Technical Magazine*, 25 March 2021.

Seehusen, Joachim (2021). Vil ha nasjonalt forskningsløft for en sulteforet byggenæring. *Teknisk Ukeblad*, 10. mars 2021.

Nestvold, Veslemøy (2021). Forskningsministeren åpner unikt nullutlipps-laboratorium i Trondheim. *SINTEF*, 24. februar 2021.

Finsmyr, Knut Arne (2021). Bygg er lite rustet for fleksibel strømbruk. *VVSForum*, 24. februar 2021.

Ivarson, Henning (2021). Zero Emission Buildings: Snart åpner unikt laboratorium i Trondheim. *Building Supply*, 25. februar 2021.

Sletvold, Espen (2021). Forskningsministeren åpner unikt nullutslipps-laboratorium i Trondheim. *NTNU*, 1. mars 2021.

Brekkhus, Arve (2021). Åpnet kontor-laboratorium i Trondheim. *Byggeindustrien*, 4. mars 2021.

Krekling Lian, Synne (2021). Det er mye å spare på å spre strømbruken utover døgnet. *SINTEF*, 14. januar 2021.

8 MEMOS:

Skaar, Christofer; Brattebø, Helge (2021) ZEN LCA-WORKSHOP 2020. MEMO - Oppsummering av LCA-workshop 2020-11-27

Gunnarshaug Lien, Anne; Abrahamsen, Rune; Solem Eidsvik, Gunhild (2021) FORTETTING MED PÅBYGG I TRE. Muligheter og begrensninger ved påbygg med tre av nye boliger på eksisterende boligblokker

Petersen, Sobah Abbas (2021) FME-ZEN DATA MANAGEMENT PLAN

Kauko, Hanne (2021) INTEGRATE DISTRICT HEATING MODULE User guide and technical documentation

Manum, Bendik; Nordström, Tobias; Rokseth, Lillian; Schön, Peter (2021) NYE BROER I TRONDHEIM. Analyser av ulike plasseringers effekt på tilgjengelighet

Liland Bottolfsen, Hanne; Lekang Sørensen, Åse; Sartori, Igor (2021) CAMPUS EVENSTAD ENERGIMÅLINGER 2017 - 2019

Meland, Solveig (2021) ZEN MOBILITETSCASE ZVB Sammendrag av utvikling og anvendelse av metodikk for boligprosjekter

Skaar, Christofer; Fjellheim, Kristin; Stråby, Karolina; Myrland Jensen, Tore; Slapø, Fredrik; Liland Bottolfsen, Hanne; Dobnig, Dorina; Hansen, Elin; Mork Kummen, Thea (2021) SIRKULÆRE BYGGEVARER PÅ FORNEBU

ZEN-case om ombruk av byggevarer på Flytårnområdet, Fornebu

1 PODCAST:

Medvirkende: Helge Brattebø (2021). Saving the World isn't Rocket Science.

4 PRESS RELEASES :

ZEN-konferansen 2021: Er det verdt å investere i nullutslippsområder? *SINTEF*, 9. september 2021.

ZEN-konferansen 2021: Er det verdt å investere i nullutslippsområder? *Tekniske Nyheter*, 15. september 2021.

Grønn medlemsvekst i Nord-Norge. *Grønn Byggallianse*, 26. august 2021.

200 millioner til forskning på klimasmart renovering. *Byggmesteren*, 14. mai 2021.

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Editors:
Ann Kristin Kvellheim (SINTEF)
Sunniva Moum Danielsen (NTNU)
Anne Grete Hestnes (NTNU)
Arild Gustavsen (NTNU).

Contributors:
Employees and associated resources of the ZEN Research Centre

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NEIGHBOURHOODS
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NTNU - Gløshaugen campus
Høgskoleringen 13, ZEB-Laboratory
NO-7491 Trondheim, NORWAY

NTNU

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