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ZEB

FME CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

The Research Centre on Zero Emission Buildings

ANNUAL REPORT 2012

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Contents

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FME
The scheme of the Centres for Environment-friendly Energy Research (FME) seeks to develop expertise and promote innovation through focus on long-term research in selected areas of environment-friendly energy, transport and CO_2 management in close cooperation between prominent research communities and users.

Partners:

NTNU, Faculty of Architecture and Fine Art, Dept. of Architectural Design, History and Technology

SINTEF Building and Infrastructure, Energy and Architecture

SINTEF Energy Research

BNL – Federation of construction industries

Brødrene Dahl

ByBo

DiBK – Norwegian Building Authority

DuPont

Enova SF

Entra

Forsvarsbygg

Glava

Husbanken

Hydro Aluminium

Isola

Multiconsult

NorDan

Norsk Teknologi

Protan

Skanska

Snøhetta

Statsbygg

VELUX

Weber

Caverion Norge AS

Front and back page picture: *Kjørbo in Sandvika, Powerhouse 2. (Illustration: Snøhetta/MIR)*

Summary

The vision of The Research Centre on Zero Emission Buildings is to eliminate the greenhouse gas emissions caused by buildings. The main objective is to develop competitive products and solutions for existing and new buildings that will lead to market penetration of buildings that have zero emissions of greenhouse gases related to their production, operation and demolition. The ZEB Centre encompasses both residential and commercial buildings, as well as public buildings.

The Research Centre is organized as a joint NTNU/SINTEF unit, hosted by The Norwegian University of Science and Technology (NTNU). The Centre encompasses the whole value chain of market players within the Norwegian construction business. The companies represent more than 100 000 employees and have a yearly turnover of more than 200 million NOK.

The activities for the ZEB Centre are divided in five work packages, these are:

WP-1: Advanced materials technologies

WP-2: Climate-adapted low-energy envelope technologies

WP-3: Energy supply systems and services

WP-4: Energy efficient use and operation

WP-5: Concepts and strategies for zero emission buildings

In addition The ZEB Centre is working on upgrading and expanded existing laboratories and building new laboratory facilities for development, research and testing of zero emission building technologies.

Important results in 2012 include continuation of the development of new nano insulation materials (NIMs), a new glass material with reduced thermal conductivity and weight, and aerogel incorporated concrete. The new nano insulation material has a thermal conductivity of about 0.020 W/(mK). A new wall building system with encapsulated vacuum insulation panels has also been developed, and an advanced Phase Change Material (PCM) window has been investigated in the new climate simulator. Further, energy supply solutions for zero emission buildings are being investigated, and a new type of cross flow energy exchanger using membrane technology is under development. Energy efficiency and thermal comfort for simple heating systems in super-insulated envelopes has also been investigated.

Evaluations of (near) ZEBs in use have shown that user interfaces still need a lot of work to support users in their daily use of these buildings. The current use of information and communication technologies (ICTs) in building operation has been evaluated, and improvements have been proposed. Non-technical and non-economic factors supporting or slowing down implementation of ZEBs have been identified.

The Centre is involved in seven pilot building projects with ambitions ranging from close to zero emission in operation to the final ZEB-ambitions of zero emission during the whole life cycle of the building. Several of the projects have planned construction start in 2013, e.g. Skarpnes in Arendal (40 dwellings) and the office renovation project Powerhouse Kjørbo in Sandvika. Results from concept studies (and pilots) indicate that more focus should be put on the embodied energy of the loadbearing structure and the building envelope. So far it seems like more than 60 % of the CO_2 emissions from a zero emission building in its life cycle come from the materials used in the building. A revised ZEB definition has also been proposed.

The laboratory facilities have been further expanded and the turnable hot box and climate simulator is now in full operation. Detailed planning of two test buildings, the ZEB Test Cell and ZEB Living laboratory, has been performed. The buildings will be realized in 2013.

Furthermore, in 2012 13 PhD candidates are partly/directly funded by the centre, with an additional 8 being associated with the centre. About 25 researchers have conducted research within the centre (of which several have been working part time).

Vision and goal

The vision of The Research Centre on Zero Emission Buildings, ZEB, is to eliminate the greenhouse gas emissions caused by buildings. This national research centre will place Norway in the forefront with respect to research, innovation and implementation within the field of energy efficient zero-emission buildings.

The main objective of ZEB is to develop competitive products and solutions for existing and new buildings that will lead to market penetration of buildings that have zero emissions of greenhouse gases related to their production, operation and demolition. The Centre will encompass both residential and commercial buildings, as well as public buildings.

In addition to being highly energy-efficient and carbon-neutral, the buildings and related solutions also have to fulfil a range of other criteria in order to be competitive. They need to provide a healthy and comfortable indoor environment and be flexible and adaptable to changing user vdemands and needs. They need to be cost-effective, i.e. give economic benefits to producers, users and the society. They need to be architecturally attractive and easy to construct, use, operate and maintain. Finally, they need to have minimum environmental impacts during production, use and demolition, and be robust with respect to varying climate exposure and future climate changes.

Research Questions

The following research questions are being examined:

- Which material properties are important in order to achieve optimal envelopes for zero emission buildings and how can such materials be developed?
- How should the buildings be built in order achieve optimal energy efficient, climate adapted, and renewable energy harvesting envelopes?
- How should the building services systems be designed in order to optimize for energy efficient use and operation of zero emission buildings?
- Which combinations of building envelope and building services technologies are preferable in zero emission buildings?
- How should the implementation, use, maintenance, and operation be organized in

The ZEB Pilotbuilding PowerHouse 1, Trondheim (Illustration: Snøhetta/MIR).

order to realize the technical potentials of zero emission buildings?

- Which measures are needed for zero emission buildings to become the default building standard?
- Which building concepts are optimal with regard to achieving cost optimal zero emission buildings?

Organization

Organizational Structure

The Research Centre is organized as a joint NTNU/ SINTEF unit, hosted by The Norwegian University of Science and Technology (NTNU). The Centre leadership is thus shared between the two organizations.

Centre Director: Professor, PhD Arild Gustavsen, NTNU, Faculty of Architecture and Fine Art, Dept. of Architectural Design, History and Technology. *Centre Director until September 2012 was Professor Anne Grete Hestnes.*

Centre Manager: Senior researcher, PhD Anne Gunnarshaug Lien, SINTEF Building and Infrastructure, Energy and Architecture.

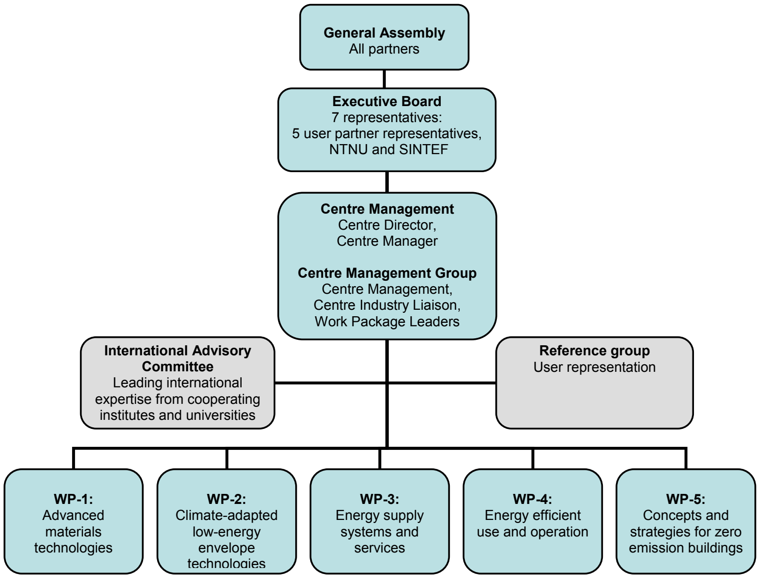
Senior Scientific Advisor: Professor Anne Grete Hestnes, NTNU, Faculty of Architecture and Fine Art, Dept. of Architectural Design, History and Technology.

Centre Industry Liaison: Vice President Terje Jacobsen, SINTEF Building and Infrastructure.

European Research Contacts: Professor Øyvind Aschehoug and Associate Professor Annemie Wyckmans, NTNU, Faculty of Architecture and Fine Art, Dept. of Architectural Design, History and Technology.

The Centre has a General Assembly and an Executive Board. The General Assembly includes all partners. The General Assembly gives guidance to the Board in their decision-making on major project management issues and
wapproval of the semi-annual implementation plans. The Board is responsible for the quality and progress of the research activities towards the Research Council of Norway and for the allocation of funds to the various activities. The Board is comprised of the Centre management and partner representatives. The user partners have majority on the Board and are selected from different groups of user partners.

The International Advisory Committee has representatives from leading international institutes and universities and will ensure international relevance and quality of the work performed. The Reference Group consists of representatives from end user groups and relevant organizations and is used both as a forum for testing the relevance of the work and to help



disseminate the results to appropriate Norwegian audiences.

The main participating NTNU departments are Dept. of Architectural Design, History and Technology (host institution), Dept. of Civil and Transport Engineering, Dept. of Interdisciplinary Studies of Culture, and Dept. of Energy and Process Engineering. The main SINTEF units participating in the Centre are SINTEF Building and Infrastructure, SINTEF Materials and Chemistry, and SINTEF Energy Research. In addition, cooperation is established with other relevant FMEs. SINTEF has status as research partner in the Centre.

The Work Package (WP) leaders coordinate the research tasks within the WPs, and report to the Centre management.

The leaders of the Work Packages are:

WP-1: Professor, PhD Bjørn Petter Jelle, Department of Civil and Transport Engineering, NTNU, Senior researcher, SINTEF Buildings and Infrastructure. *Professor, PhD Arild Gustavsen until August 2012*

WP-2: Research Manager, PhD Berit Time, SINTEF Buildings and Infrastructure

WP-3: Professor, PhD Vojislav Novakovic, Dept. of Energy and Process Engineering, NTNU

WP-4: Professor, PhD Thomas Berker, Dept. of Interdisciplinary Studies of Culture, NTNU

WP-5: Senior researcher, PhD Tor Helge Dokka, SINTEF Buildings and Infrastructure. (until June 1th 2013).

Activities

WP 1: Advanced Material Technologies

Goal: Development of new and innovative materials and solutions, as well as improvements of the current state of the art technologies.

In 2012 the main research activities have been on:

- Theoretical studies of heat transfer in and development of nano insulation materials (NIMs).
- Investigations of transparent pigments for application on aluminum surfaces, with Hydro Aluminium.
- Development of new glass materials and coatings.
- New formulations for phase change materials (PCMs).

The main activities and results from the nano insulation and glass materials developments are further described in the next chapter.

WP 2: Climate Adapted, Low Energy Envelope Technologies

Goal: Development of climate adapted, verified, and cost effective solutions for new and existing building envelopes (roofs, walls and floors) that will give the least possible heat loss and at the same time a reduced need for cooling.

The main activities in WP 2 in 2012 have been:

- Development and testing of a new sandwich masonry building block with vacuum insulation panel (VIP), with Weber.
- Planning and construction of a masonry wall insulated with VIP on the inside, with Chalmers Technical University. Hygrothermal conditions will be experimentally investigated in 2013.
- Studies of renovation options for a dwelling from the 1980s towards zero emission buildings.

- Numerical and laboratory investigations of building integrated photo-voltaics to investigate cooling by natural convection and rain tightness.
- Studies of improved window and facade solutions (e.g. window rating procedures, optimal window to wall ratios, shading solutions and PCM windows).
- Embodied energy in building components.

The sandwich masonry building block design and dwelling renovation activity is further described in the results chapter.

WP 3: Energy Supply Systems and Services

Goal: Development of new solutions for energy supply systems and building services systems with reasonable energy and indoor environment performance appropriate for zero emission buildings.

Some of the main activities in WP 3 in 2012 have been:

- Investigations of renewable energy supply options for zero emission buildings (e.g. studies of an air-to-water heat pump coupled to solar thermal panels for a ZEB residential building).
- Numerical studies of interaction between user needs, energy supply and building services (e.g. thermal comfort and energy efficiency has been investigated for a Norwegian passive house with air heating, and looking at the effect of realistic occupational patters on energy supply efficiencies).
- Post occupancy evaluation (POE) and monitoring of passive residential buildings with regard to energy performance, indoor air quality, thermal comfort and user behavior.
- Development and testing of a new energy recovery system based on membrane technology.
- Development of new concepts for wood fired furnaces.

Simplified distribution for space-heating of Norwegian passive houses and the new membrane based energy recovery system is further presented in the next chapter.

WP 4: Use, Operation, and Implementation

Goal: Development of knowledge and tools which assure usability and acceptance, maintainability and efficiency, and implementation of ZEBs.

In 2012, the some of the main activities in WP 4 in have been:

- Research on roles and potential impact of end-users' practices on energy use in high performance buildings.
- Development of knowledge and tools for efficient maintenance, operation and administration of zero emission buildings.

- Exploration of opportunities and barriers regarding feed-in tariffs in Norway.
- Observation and analysis of some of the ZEB Centre pilot building projects.

Some lessons learned in two of the activities are further presented in the next chapter.

WP 5: Concepts and Strategies for ZEBs

Goal: Development of concrete concepts for zero emission buildings which can be translated into realized pilot buildings within the time frame of the Centre.

The main activities in WP 5 in 2012 have been:

- Development of a revised zero emission building (ZEB) definition.
- Development of two ZEB concept buildings (on residential and one office building) for analysis of energy use and CO2 emissions.
- Participation in development of zero emission pilot buildings (seven building projects are being developed, where construction start is expected in 2013 for some of them).
- Participation standardization work for implementation of methodology on export/import of near zero, zero energy and plus energy buildings.

One of the pilot projects and the concept buildings are further described in the results chapter.

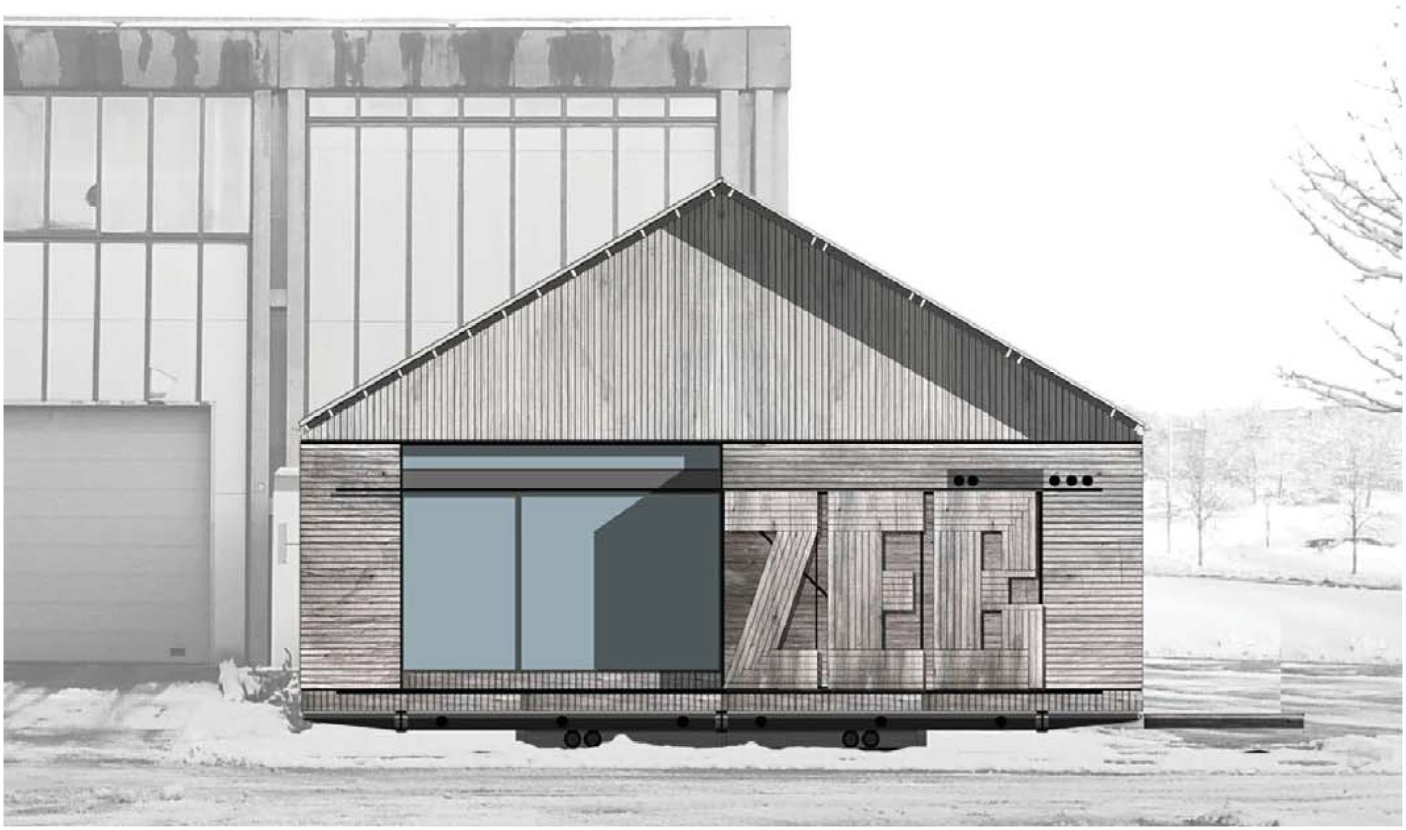
Laboratories and Infrastructure

The six laboratories in which the ZEB researchers are performing research have been further developed:

1. Advanced Material Technologies Laboratory
2. Climate and Building Technologies Laboratory
3. Energy and Environmental Laboratory
4. Full Scale Test Cell Laboratory
5. Living Laboratory
6. Pilot Building Measurement In Situ Laboratory

Several experiments have been and are being carried out in these facilities, both within The ZEB Centre and within other projects. The newly installed climate simulator have been in continues operation since it was ready for use. The turnable hot box has been used in several experiments. Both apparatus demonstrate good flexibility and give valuable results. The experiments give excellent learning on how to operate and to make important adjustments to the equipment. New tests are waiting in line.

Detailed planning of two test buildings, the ZEB Test Cell and ZEB Living laboratory, has been performed. The buildings will be realized in 2013 and used for studies of user-technology interaction and research on interconnected zero emission building technologies. An application has also been submitted to the Research Council of Norway on establishment on a new large scale “Norwegian



The projected ZEB Test Cell (Illustration: Luca Finocchiaro).

Zero Emission Building Laboratory”. The main objectives of the laboratory developments are to develop, investigate, test and demonstrate new and innovative building technologies. The laboratory facilities will be an arena for risk reduction in implementation of zero emission building technologies, needed in buildings becoming the default standard in 5-20 years, i.e. buildings with improved performance levels both with regard to energy use and climate robustness.

REBO

REBO (Sustainable Renovation of Multi-Storey Housing) is an interdisciplinary research project financed by the Norwegian State Housing Bank. The project is part of the ZEB-program and its overall objective is to contribute to increased knowledge as well as actual changes in praxis in achieving sustainable renovation of existing buildings. In a first part of the research project seven case studies were carried out. The cases with ambitious goals for universal design, reduced energy demand, increased use of renewable energy sources and/or user participation were studied. The results are presented in four reports; REBO: User participation and decision making processes, REBO: Ambitions in energy efficiency and universal design, REBO: Presentation of case studies and REBO: Interdisciplinary analysis of case studies. In the project, researchers from different disciplines, i.e. architects, engineers and social scientists, have cooperated in collecting and analyzing the data and have recommended strategies to achieve sustainable renovations.

Four pilot building projects are followed in 2012. Energy strategies and strategies for universal design have been developed. The projects are either cooperative multifamily housing or owned by the municipality with long decision processes. Whether the strategies developed through REBO will be followed is not jet decided.

The project started in 2008 and is to be finalized in December 2012 a closing seminar is held during the spring of 2013.

Results

Ten short articles that present some of the results from ZEB in 2012

NANO Insulation Materials (NIMs) for Buildings

Background and Objective

Currently, research is being conducted to accomplish the leap from today's traditional and state-of-the-art thermal insulation materials to the future solutions. Increasingly more energy-efficient buildings are being constructed, thus leading to larger wall thicknesses. In order to achieve passive house standard, zero energy and zero emission buildings, the wall thicknesses may become 40-50 cm by application of traditional thermal insulation materials like e.g. mineral wool and polystyrene products (EPS og XPS) with thermal conductivities between 30 to 40 mW/(mK). Hence, there will be several challenges with respect to economy, floor area, transport volumes, architectural restrictions and other limitations, material usage, existing building techniques and building physical principles and issues. Polyurethane (PUR) has thermal conductivity values between 20 to 30 mW/(mK), but during a fire PUR will when burning release hydrogen cyanide (HCN) and isocyanates, which are very poisonous. So-called state-of-the-art thermal insulation materials like e.g. vacuum insulation panels (VIP) and aerogels do also exist.

VIP and Aerogel

Vacuum insulation panels (VIP) consist of an open porous core of fumed silica enveloped of several metalized polymer laminate layers. VIPs represent a state of the art thermal insulation solution with thermal conductivities ranging from typical 4 mW/(mK) in fresh non-aged condition to typically 8 mW/(mK) after 25 years ageing due to water vapour and air diffusion through the VIP envelope and into the VIP core material which has an open pore structure. Depending on the type of VIP envelope, the aged thermal conductivity after 50 and 100 years will be somewhat or substantially higher than this value. This inevitable increase of thermal conductivity represents a major drawback of all VIPs. Puncturing the VIP envelope, which might be caused by nails and similar, causes an increase in the thermal conductivity to about 20 mW/(mK). As a result, VIPs cannot be cut for adjustment at the building site or perforated without losing a large part of their thermal insulation performance. This represents another major disadvantage of VIPs. Aerogels represent another state of the art thermal insulation solution with thermal conductivities between 12 to 20 mW/(mK) at ambient pressure.

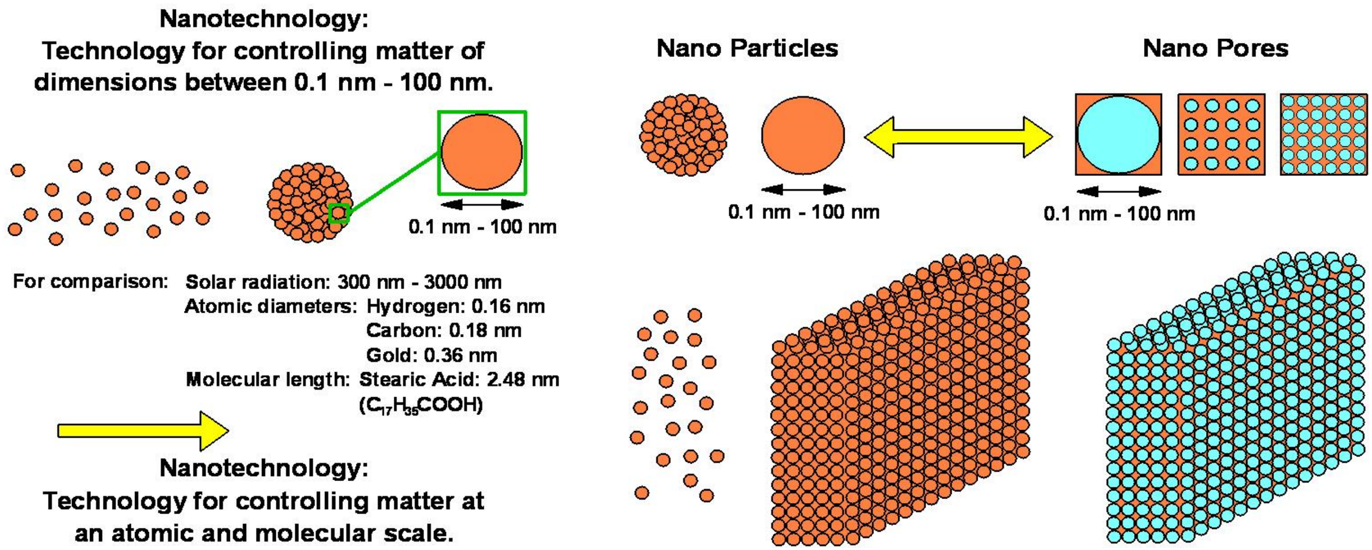


Figure 1 *Nanotechnology and its application on high performance thermal insulation materials.*

The production costs of aerogels are still very high. Aerogels have a relatively high compression strength, but is very fragile due to its very low tensile strength. A very interesting aspect with aerogels is that they can be produced as either opaque, translucent or transparent materials, thus enabling a wide range of possible building applications. For aerogels to become a widespread thermal insulation material for opaque applications, the costs have to be lowered substantially.

The Path to NIM

During experiments with developing a thermal insulation material surpassing both the traditional and state-of-the-art thermal insulation materials regarding robustness and overall performance, the idea with nano insulation materials (NIM) was conceived. The theoretical models and calculations resulted in the concept material NIM. This involved among others the Knudsen effect to reduce the gas thermal conductivity in nano porous materials (Fig.1). Hence, initial experiments to manufacture NIMs based on hollow silica (SiO2) nanospheres were carried out (Fig.3). Thermal conductivity values down to 20 mW/(mK) have been measured for these hollow silica nanospheres as a bulk powder before optimization has been performed with respect to e.g. inner sphere diameter and shell thickness.

ADVANCED Glass and Coating Materials and Solutions for Buildings

Background and Objective

Glass and various coating materials constitute an important part of buildings with windows and miscellaneous glass structures, both for existing buildings and for the ones to be built in the coming years. These transparent glass configurations provide daylight and heating by the solar radiation throughput. However, in general, windows have a larger heat loss due to a larger thermal transmittance (U-value) than the rest of the building envelope. Furthermore, buildings may also be overheated by the solar radiation. Thus, the aim is to make advanced glass and coating materials and solutions for the best optimization and dynamic control of solar radiation and thermal radiation throughput in windows, hence reducing the need for heating and cooling in buildings.

A New Glass Material

A new glass material has been fabricated in the laboratory (Fig.1). Glass represents an important and widely used material in buildings, and crucial aspects to be addressed include heat loss through windows and glass structures, solar radiation and visible light transmittance, and weight and total thickness issues for windows with many glass panes in order to obtain as low U-values as possible. Hence, we have currently developed a new and innovative glass material with reduced mass density (weight) by almost a factor 2 for building applications, i.e. 1.6 kg/dm^3 (new glass) versus 2.8 kg/dm^3 (normal glass). Added benefits are reduced thermal conductivity, currently by a factor 2, i.e. 0.45 W/(mK) (new glass) versus 0.9 W/(mK) (normal glass), and increased solar and visible transmittance (Fig.1), the latter one being important with respect to reduced solar and visible transmittance due to several glass pane layers in order to obtain as low thermal transmittance (U-value) as possible.

Advanced Coating Materials for Windows and other Glass Configurations

Transparent, and partly translucent, materials and solutions represent an important part of the building envelope, and crucial aspects to be addressed include heat loss, solar radiation and visible light transmittance, and weight and total thickness issues, when attempting to obtain as low

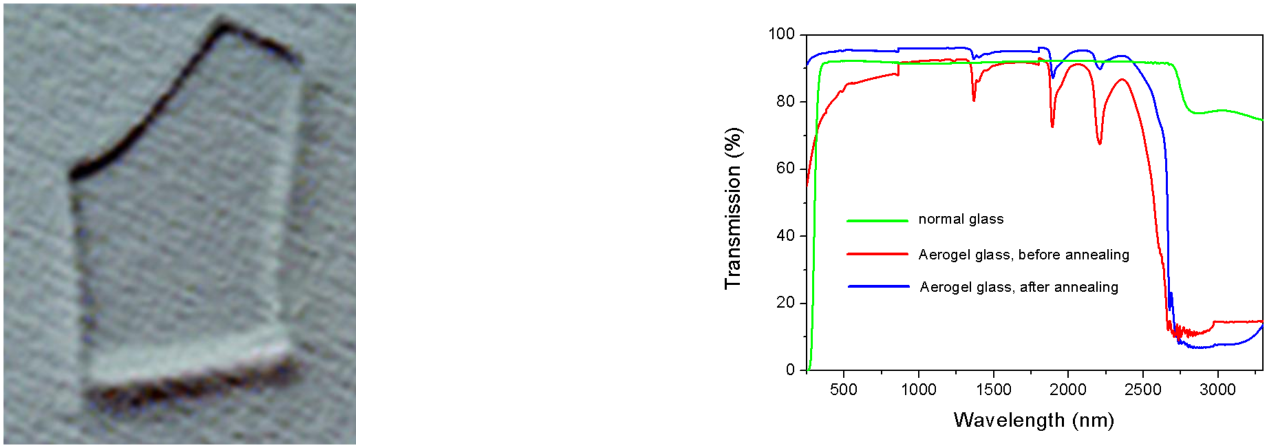


Figure 1 Photo (left) of a new developed glass material with reduced mass density (weight), reduced thermal conductivity and increased solar transmittance (right).

U-values as possible. Thus, investigations are being carried out in order to determine what transparent materials and solutions may be applied in future buildings. Parts of this work investigate and fabricate advanced coatings like e.g. low emissivity, anti-reflection, solar selective and smart coatings for windows, which will have a large impact on the buildings with respect to solar radiation aspects, energy-efficiency and comfort. Electrochromic windows, which are one type of smart windows, are able to dynamically control the solar radiation through windows, thus enabling a large potential for application areas and energy savings. To tailor-make anti-reflection coatings and solar selective coatings (Fig.2) by applying nanotechnology represent two other pathways for various application areas within solar radiation control.

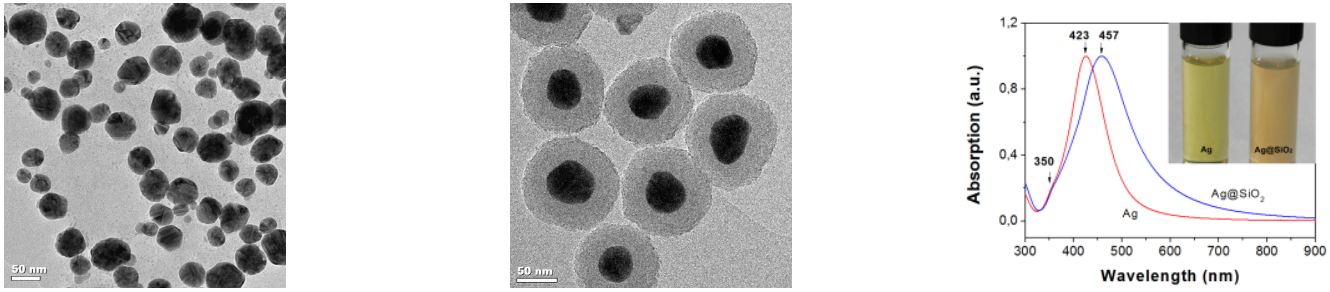


Figure 2 *Developing core-shell-typed Ag@SiO2 nanoparticles as a solar selective coating material. Transmission electron microscope (TEM) images of the as-prepared Ag nanoparticles (left) and Ag@SiO2 nanoparticles (middle), and selective absorption spectra and photos (right) of the solutions for the Ag and Ag@SiO2 nanoparticles.*

The researchers look at the 80-CENTURY house

Upgrading the 80-century house to a zero energy home is the topic of the PhD-study performed by Birgit Risholt at NTNU/ SINTEF.

Technical potential

Objective for the thesis is to examine whether it is possible to upgrade houses built in the 80's to become a zero energy house. The focus is on finding upgrading measures that are optimal with respect to the economy and where the solution is also attractive to home owners with respect to indoor air quality, functionality and maintenance. The solutions should therefore be tailored both to the house and the residents.

The first step was to look at the technical potential for energy efficiency of the building and installations. 80th century houses have 20-25 cm insulation in the roof. This is somewhat less than what we use today. But the biggest difference is found in floors, facade and installations. The floors and basement walls are poorly insulated, exterior walls have only 10-15 cm of insulation, windows let through twice as much heat as those sold today and the ventilation is only exhaust ventilation. Air tightness for many of these villas is also far worse than today's buildings.

Lack of progress

The most effective improvement measures for these homes is by insulating outer walls, installing windows with triple glazing and installing balanced ventilation system with heat recovery.

For that to be cost effective the measures should be carried out when the landlord decide to do renovation anyhow, for reasons other than energy. Status reports for 91 houses have been investigated. Results show that 60% of the houses have defects and damage in plumbing (Fig.1). The interesting thing is that 46 houses had renovated the bathroom, still 22 of these were poorly performed and damages had occurred. It is also worrying to see the high proportion of houses that have moisture problems in the basement. Only 3 of the 91 houses that were included in the study had improved the drainage. When homeowners are replacing drainage and have to dig up around the house, it's a great opportunity to add heat insulation.

Special care is needed

Fig.1 also shows that many of the houses need refurbishment of windows, exterior walls and roof. Also for wood walls and ceiling, adding 20 cm insulation is recommended if it is possible to achieve. But beware of built- in- moisture during the construction phase; thick walls must be protected from rain. And make sure that the vapour barrier is sealed and that the wind barrier provides sufficient air tightness. Further, special attention should be put on the ventilation system when improving the air tightness of the house, if good ventilation is not ensured. All new homes are built with balanced ventilation where the supply air is preheated by the air drawn out. This is also a good solution for the 80-century houses.

Renewable energy production

To get down to zero energy for daily use of the property, renewable energy production should be installed, like solar collector, PV, heat pump or a biofuel boiler. Which solution is the best depends on who is living in the house and where the house is located. If you have access to cheap firewood, wood-fired boiler can be profitable. If you have teenagers in the house and a large consumption of water a solar thermal collector can be a solution to get 50% of the hot water for free. Air-water heat pumps can both meet the needs for hot water and space heating.

Photo: Birgit Risholt.

If the house owner does not wish to insulate the house as much as described, one may also choose to install renewable heat production to compensate for heat loss, although this is a less robust solution. In the current situation of relatively low energy prices and high expenses related to upgrading, that can also be a cost effective solution.

The profitability of energy efficiency depends on the individual household use of energy throughout the year and between different house models.

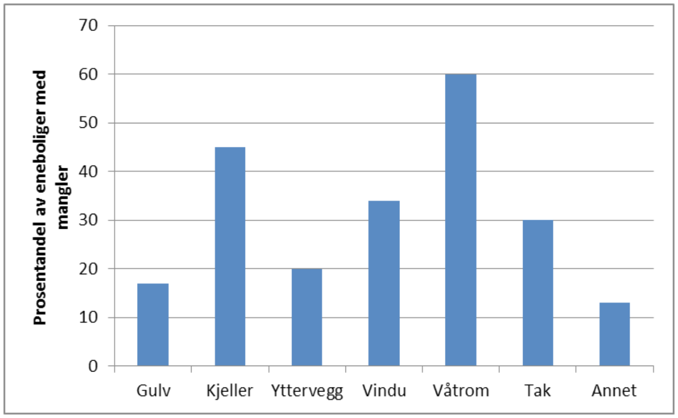


Figure 1 *Percentage share of the investigated dwellings with defect in floor – basement – exterior wall – windows – bathroom – roof - or other.*

Energy DESIGN of Sandwich Masonry Blocks

Sandwich elements are widely used in the building envelope, in walls and foundations in particular. The thickness of sandwich elements is increasing as the demand for reduced heat loss from the building envelope is required. The building industry is searching for means and alternative materials to reduce the volume of the building envelope, but at the same time obtain the same thermal performance.

Sandwich element constructions might be especially suitable for highly effective insulation materials as VIPs (Vacuum Insulation Panels) and aerogels. Some commercial products are available on the market today others exist as prototypes.

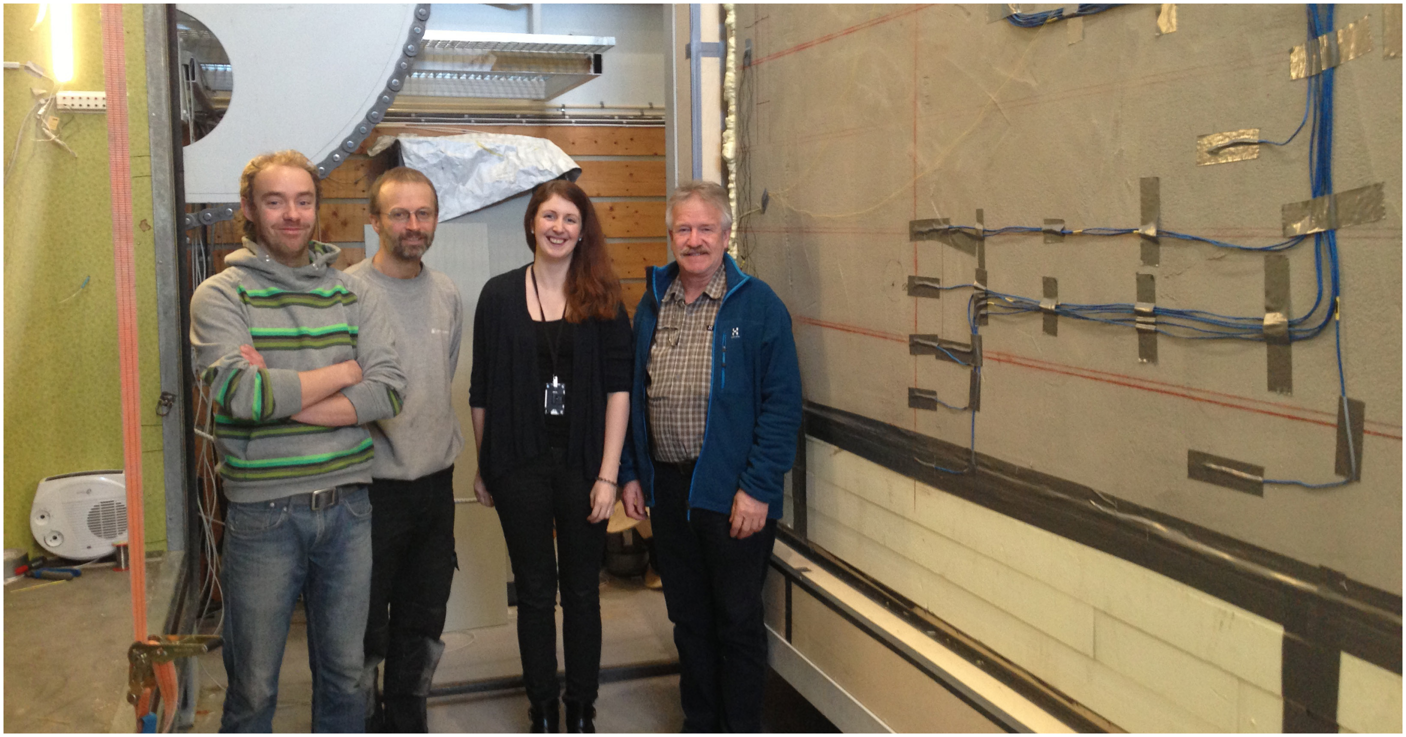
A new masonry block design

The aim of this work has been to investigate the possibilities of optimizing the thermal performance of a sandwich masonry block system as a case study.

The possibilities of maintaining the thermal performance and the structural properties and at the same time decreasing the thickness of the sandwich construction block systems have been the aim of the producer. A block system with VIPs has been developed and a prototype has been made.

An integrated working process

The design of the masonry block system has been performed in close cooperation between researchers in the ZEB Centre and the producer of the block system. The motivation for the researchers was twofold: 1) to gain and spread new knowledge about optimal energy design of sandwich elements in general and with VIPs in particular, and 2) to participate in the development and to verify a prototype of a sandwich element block system. The motivation for the producer has been to further develop a well known and successful product towards the future energy regimes in the building sector. The producer (Saint-Gobain Byggevarer) is offering several versions of sandwich masonry block systems today. The sandwich blocks, known as Isoblocks, consists of two light-weight aggregate block leaves and a highly insulating core of polyurethane (PUR). The most used products today having a PUR thickness of 100 or 150 mm. To meet future operational



Testing of developed sandwich masonry block system in the hot box in the ZEB/NTNU/SINTEF laboratory.

energy requirements in buildings the producer has even delivered products with 300mm PUR thickness (Leca® Rex 50, total wall thickness 500mm).Their experience in building with such block thicknesses is that it is not always practical.

Workshops have been arranged in order to discuss the theoretical approach performed by the researchers and the possibilities and limitations in production. The producer has filed for a patent for the product and process of incorporating the VIP in the PUR core.

A step forward

Sandwich elements can be a robust way of using VIPs in building components like wall elements. This work shows how to reduce thickness and volume in order to optimize the thermal performance of a sandwich element. Comparative studies with simplified and advanced numerical simulation models and large scale laboratory tests have been performed for verifications of performance and studies of air transport within the wall. For the time being durability studies are being performed and a survey among potential users of ZEB technology is going to take place.

Membrane based ENERGY exchanger

In order to minimize the energy use for heating, passive houses are constructed using well insulated building assemblies. In addition they have minimal air leakages and no vents in exterior walls for direct supply of fresh air. Therefore mechanical ventilation systems are a mandatory requirement in these buildings.

With the aim of achieving further energy use reduction, the effort must be set on efficient energy recovery from used air. In residential buildings with several living units, centralized air handling units are regarded as the most energy efficient system. However, to prevent odours to transfer between flats it is important to avoid carryover leakages of pollutants between the exhaust air and the supply air inside the heat exchanger.

Rotary heat exchangers (heat wheels) are very energy efficient (85%), but have the drawback of transferring odours from exhaust air to fresh supply air. To avoid transfer of odours in apartment buildings, flat plate heat exchangers are commonly used instead. Unfortunately the state-of-the-art flat plate heat exchangers have problems concerning water vapour condensation and frost formation at low supply inlet temperatures. To avoid this problem the efficiency must be reduced on cold days, causing a decrease of the annual efficiency (70%) and a consequent increase in yearly energy use for air heating.

An alternative to the flat plate heat exchanger are the so called quasi-counter flow membrane-based heat and mass recovery exchangers. In a membrane based exchanger, moisture is transferred from the humid exhaust air to the dry supply air. In this way condensation and frosting should be avoided at the exhaust air side. Experiments have been performed to compare a membrane energy exchanger to a heat exchanger using thin non vapour permeable plastic foil as heat transfer surface. The study focused on verifying condensation and freezing problems and how the membrane energy exchanger performs.

To compare the different plate materials a test rig has been built in the laboratory. The experiments proved that non permeable heat exchangers had problems with condensation and freezing during the tested conditions. For the same conditions the membrane based exchanger did not experience the same problems. However, additional problems with swallowing of the membrane in high humidity conditions showed that the tested membrane type had drawbacks and needs further development to become commercially applicable.

In addition a mathematical model was derived to predict the heat and moisture transfer effectiveness in a membrane based energy exchanger. The model was validated against measurements and showed very good correlation with the experimental results and results from literature. The derived method and the developed calculation tool may then be used to investigate alternative membranes heat and moisture transfer effectiveness. The calculations indicate that membrane based exchangers might reach values comparable to the best rotary wheels and preliminary tests has proven efficiencies of 85%.

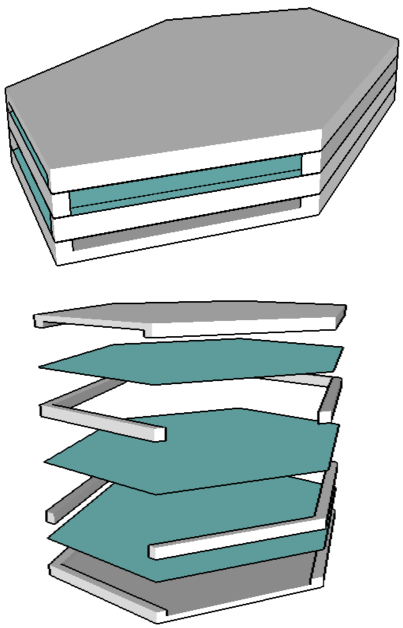


Figure 1 *The flat plate heat exchanger is composed of several layers of heat transfer surfaces.*

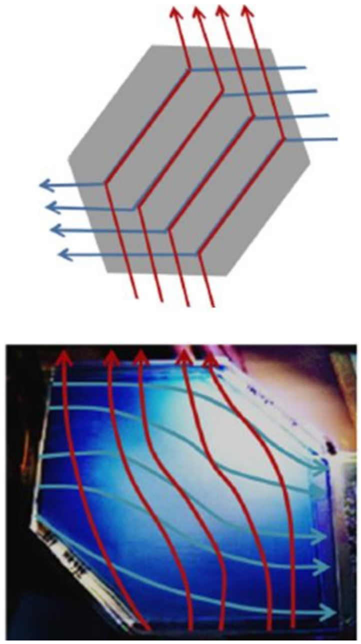


Figure 2 *The air flow in counterflow directions at each side of the heat transfer surfaces. Ideal flow pattern at the top and real at the bottom.*

Simplified distribution for SPACE-HEATING in Norwegian passive houses

The passive house standard is often associated with the idea that the heat distribution system can be simplified. This opportunity is connected to the well-insulated building envelope. For example, radiators are not required anymore below each window. In passive houses, these windows are equipped with a well-insulated frame and triple glazing. Three different strategies can be followed for the simplification of heating systems: distribution using the ventilation air (the so-called air heating), a reduced number of low-temperature radiators and the use of wood stoves. Our research proposes to analyse these techniques using modern simulation tools. For the time being, standard equipment already present on the market is analysed. The overall objective is to give guidelines to the building industry for the proper integration of space heating systems in passive houses as well as to pave the way for the development of new solutions, by highlighting the limitations of current technologies.

- Wood stoves are often said not to be adapted to passive houses. Passive houses are indeed airtight and equipped with balanced mechanical ventilation, so that the combustion air induced by the stove draft may interfere or pollutants may even be emitted inside the building. Fortunately, the stove industry is now proposing airtight stoves with an independent air supply and flue gas exhaust, solving the aforementioned problem. The second argument against the integration of wood stoves is that the power of current models is well oversized compared to the needs of a passive house (e.g. a passive house in the Oslo climate typically need 3kW while the lowest stove power is about 6kW). This may lead to severe overheating. With lowest stove powers available, our simulations have shown that the overheating risk can be controlled by current pellet stoves if they are equipped with a large power modulation (i.e. 30%), while the integration of log stoves is still critical (but possible under certain conditions). Results also prove that special skills and knowledge are required for the correct stove selection. This choice is thus less subjective than before. This work is done in collaboration with the StableWood project from SINTEF Energy Research.

- Air heating is the simplification that is most often associated with the passive house concept. Nevertheless, unlike the German definition of the passive house standard, the Norwegian one is not directly related to the air-heating concept. A specific analysis was thus required to investigate the air heating potential under Norwegian conditions. Simulation results showed that this potential strongly depend on the building location in Norway. For example, air-heating temperatures remain moderate for the mild climate of Bergen while prohibitive temperatures can be found for the extreme case of Karasjok. Considering a detached passive house, it was also shown that the current air-heating solutions do not offer a sufficient flexibility for the user to adapt the temperature locally in a given room (e.g. it is common to have a lower temperature in bedrooms in Norway). Again, a specific knowledge is built in order to better understand the conditions that lead to a correct air-heating integration and design.

The passive house standard is often considered as the future minimal performance requirement for new building envelopes in Norway. Due to their high-level of insulation, these envelopes respond thermally to their environment in a different way compared to past buildings. As a consequence, the low-term goal of the research is to build a fundamental knowledge about the main heat transfer processes inside these buildings.

Figure 1 *Picture illustrating the reduced power needs of the house with increased insulation level (from StableWood project).*

Marienlyst School:
Learning from Norway's first PASSIVE house school

Houses with balanced ventilation systems are received with some scepticism in Norway. Can a building that does not "breath naturally" be a good building at all? We have conducted one of the most comprehensive evaluations of a passive house school building so far and the conclusions are clear: both teachers and students are generally satisfied with their new school, but there is still room for learning and improvements.

The passive house concept, originally developed in Germany in the 1990s and implemented successfully in thousands of buildings mainly in Austria and Germany, is rapidly gaining ground in Norway. With the Norwegian climatic and cultural context being slightly different from the German and Austrian one, the question is legitimate whether the concept will work at least as well as traditional building types also in Norway. Passive house principles will play an important role within zero emission buildings, therefore it is important to be sure that these principles do not do any harm to the building's occupants.

The instrument of choice for the test of occupants' experiences with buildings is the so-called Örebro questionnaire, which is based on the WHO definition of indoor climate. In our case, we could refer to a tailored version of the questionnaire that was developed for use in Norwegian schools. This had the additional advantage of us being able to compare our case, Marienlyst School in Drammen, with other schools directly. Since a quantitative survey may very well miss some of the more subtle experiences made by the occupants we also interviewed teachers in two rounds: one during winter and one during summer. Finally, making this evaluation even more comprehensive we talked with building operators to understand more about how this particular building performs and conducted measurements of moisture in the building's envelope.

Marienlyst School - commissioned to use in 2010 - is Norway's first school that complies with passive house principles, housing some 50 employees and 470 students (age 13-15). Its main technical features are that it uses balanced and demand controlled ventilation based on CO2 and temperature sensors. The lighting is based on LED technology and is controlled by motion sensors.

The questionnaires compared to other Norwegian schools revealed no signs of problematic indoor environment. The only results that were statistically significant (i.e. little likely to be due to random factors) were that the passive house school performed better when it comes to dry air, dust and dirt, and stale air. Of the non-significant findings from the questionnaires, above all cold temperature, static electricity and variations in temperature are the most important ones. In addition, the students' reports indicate problems with the sun shading.

The qualitative study confirmed the overall positive impression, but it also confirmed the (non-significant) concerns about static electricity, temperature (especially during the first winter and on sunny days in the rooms located at the upper levels). Additionally, occupants complained about difficulties to open doors because of pressure differences. There were also some interesting differences between the first and the second round of interviews that indicate that some problems had either been solved or that the respondents have become used to them: this was above all the case with the noise of the ventilation system.

Since we want to learn how to improve, of the results of the study, the general satisfaction that we have found in both the quantitative and qualitative inquiry is less useful than the problems. These fall into two categories: First, there was problems that can be connected to well known problems with demand controlled, balanced ventilation systems. They have to be carefully calibrated and adapted to the uses of the different rooms to deliver optimal results. Here, a comprehensive evaluation like the one conducted by us provides important inputs. Second, there are problems - such as the low temperatures in the first winter - that have their origin in a hectic initial adjustment phase. The pitfalls of the assumption that a building is ready for use right away are well documented for all kinds of buildings and methods to support the initial adjustment have been proposed (such as the so-called “Soft landings” method). Arguably, the more a building concept introduces new technical concepts and the more its components are interacting in a complex manner the more urgent it is to prepare for a “soft landing”, i.e. to help occupants and building operators to adjust the new building to their uses and needs.

All in all our comprehensive study gives the impression that Marienlyst School is a success. Students and teachers expressed pride in the brand new school building with its environmental profile. Still, we would miss an important learning opportunity - both for the operation of the school itself but also for the Norwegian introduction of buildings with high energy ambitions - if we did not focus on problematic areas. We have seen that there is potential for improvements in the adjustment of the balanced, demand controlled ventilation system, and that buildings with innovative solutions should be introduced into use with even more care than conventional buildings.

The FUTURE of efficient building operation: Managing millions of square meters from one room

Professional building operation increasingly includes digital control and monitoring of buildings from central control rooms. Our researchers have observed how the 2.4 million m^2 of one of the largest European airports are managed from one control room in order to learn about the future of efficient operation of non-residential buildings and to propose improvements.

It is in the nature of the term zero emission building that we picture these buildings as physical entities. And making these walls, roofs, windows, and heating systems more energy efficient is indeed an important part of the centre's mission. However, if we focus on the "zero emission" instead of the "building" part of the centre's title, the performance of the building becomes the main concern. Buildings in this sense are in constant flow as they interact with their occupants, climate and the context they are located in. Building operation is the art of managing this flow in a way that makes sure that a broad range of performance criteria is reached - not only zero emission.

Over a period of three days we have been part of the fixtures of the building operation control room of one of Europe's largest airports. During this observation period we talked to virtually everyone learning about how exactly the operators use their tools to make sure that the airport's buildings are operated in the best possible ways. The resulting 60+ pages report was then presented to the operators that confirmed that our impressions were accurate.

The size of this operation is overwhelming: 300 buildings with 28.000 rooms are operated from one control room. This is possible through 14.000 automated subsystems (ventilation, heating, electricity, sun shading, lifts, etc) that are equipped with 220.000 sensors. The main tool for failure detection is the software that constantly compares the data from the sensors for unacceptable deviations. In addition, another software is used to receive and process failure reports from occupants.

- The overall efficiency of such a centralized system that is based on automation is obvious. The critical point in terms of the performance of such a complex system, however, is failures and how they are dealt with. Here, "old-fashioned", local building

Illustration photo from a Norwegian airport (Photo: Jarne Nyttingnes/Oslo Lufthavn AS).

> operation has the advantage of local knowledge about the systems, their location, their immediate context, their history, and their quirks. The local janitor "knows" the building in a completely different way than a distant operator who sees the building as set of data points.

For fault repair, clearly formalized rules are in place that prescribe who reacts how and when on what kind of failure.

But our observation showed that this formalized system in practice struggles with four main problems that are solved through the use of improvisation and additional tools:

- The buildings and installations change over time and receive new functions and names.
- A large fraction of the failures is unique and does not fit into predetermined schemes.
- The organizational structure changes continuously leading to

Illustration photo from a Norwegian airport (Photo: Øyvind Markussen/Oslo Lufthavn AS).

ambiguous and unclear competences and responsibilities.

- Occupants' failure reports are not in compliance with the categories, terms and structures of the other systems used for failure detection and repair.

The additional tools that we have observed fall into two categories:

- In order to find out what lies behind a failure report, "decisiveness, frustration tolerance, and stubbornness" (from an interview with an operator) is needed. Experience plays an important role when the occupants' reports and sensor readings are translated into a failure that can be repaired, but also extensive communication with colleagues and the documentation of what has been done in a logbook which exists electronically but which in addition also is printed out to make sure that some older reports are not forgotten.
- When a failure is identified sufficiently, the repair team has to find the right room and the right installation to fix. In many cases, the control room is helping in the localization using a book that provides a plan of the whole airport, and several other databases. Telephones and radios are used excessively in these failure hunts.

These observations enabled us to propose improvements to the operation of the airport's buildings. Above all we recommended to build up a database which connects sensor names, their location in the buildings (including the official room name), the responsible group, and the current (and sometimes also previous) official names of the building (parts).

Building operation is changing and we have many reasons to believe that future non-residential zero emission buildings will be operated in similar ways as the buildings of the airport that was object of our study. We have observed a huge potential for efficient operation through automatization and advanced fault detection. But the technology is only one part of the story. As buildings and their occupants change over time, the experience of the operators, their ability to communicate and a broad range of information sources is needed to keep the operation as efficient as possible. We will continue the research on how to provide the best possible tools to make sure that zero emission buildings remain zero emission buildings during their whole operation.

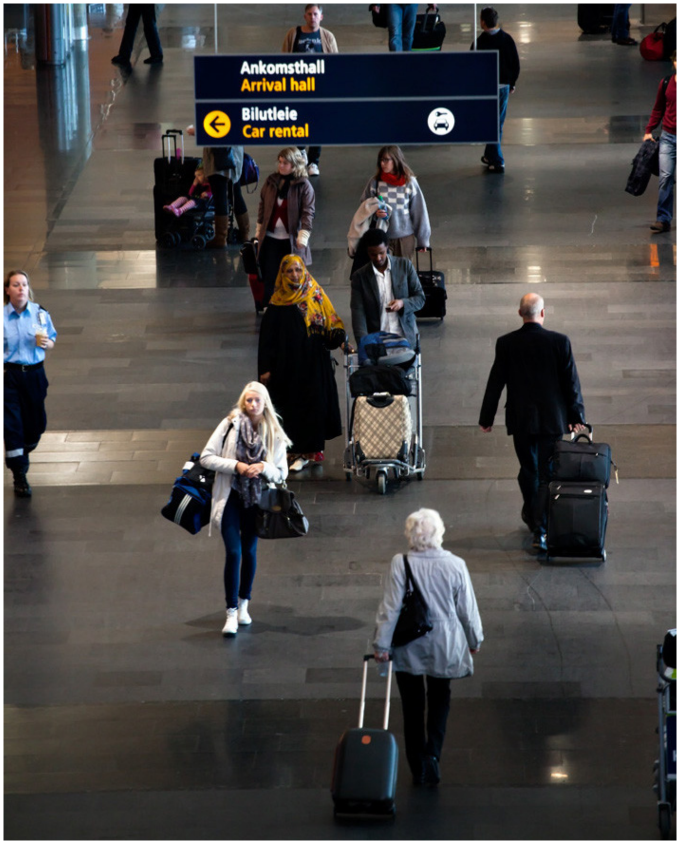


Illustration photo from a Norwegian airport (Photo: Øyvind Markussen/Oslo Lufthavn AS).

ZERO emission energy systems for Ådland is planned for 500-800 homes

Ådland in Bergen is the largest pilot building project in ZEB. The goal is to develop a large new residential area with no greenhouse gas emissions. This means that the houses are built with high quality and very low energy demands. It also means that local production of renewable energy will meet the demand for heating and electricity for the operation and construction of the houses. Use of materials with low CO_2 emissions from production is also important.

The building site is planned to meet the zero emission goals. Energy supply without CO_2 emissions must be planned according to costs, robustness of operation, life cycle, and installations that can be adapted to available roof area and infrastructure. The match or mismatch between energy production and energy need over the year must also be considered.

Two alternative energy supply systems have been investigated for Ådland. The first one is a combination of solar collectors for production of hot water, bioCHP (Combined Heat and Power) for production of thermal energy and electricity, and photo voltaic (PV - solar cells) for production of electricity. The other one is a combination of solar collectors, heat pumps and PV. Solar collectors for production of hot water are the cheapest installation and can cover 30% of the heating demand for room heating and domestic hot water. The PVs produce electricity for lighting, equipment, and operation of the heat pumps. The PV electricity has the highest cost and is limited by the available south facing roof area. BioCHP consists of engines fuelled by biogas, or other liquid biofuels. The bioCHP solution that is investigated has an output of 35% electricity and 55% heat (10% loss). Limitations for bioCHP can be access of biogas or availability of operational expertise. A heat pump requires electricity amounting to 30% of the heat that is produced. This electricity need must be covered by PV and increases the need for available roof area.

Facts

490 dwellings | 45 700 m² BRA | Average size of 90 m² (can be up to 800 homes through regulatory work) | South facing roof surface: 10 600 m² | Bergen is 60 ° north, and the climate is mild and cloudy | Mean temperature: 7.5 °C

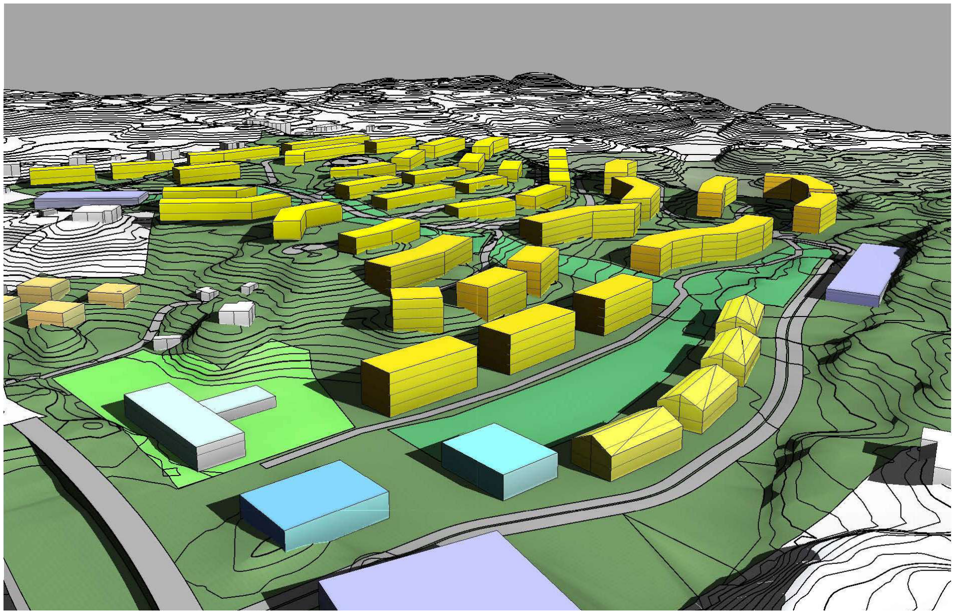


Illustration: Norconsult.

The choice of energy system

The primary advantage of the bioCHP system is the good match in annual variation in production and energy demand. Limitations are access to biogas at a reasonable price and availability of operational expertise. Solar collectors and PV cover nearly all the need for thermal energy and electricity during the summer and the bioCHP cover both the need for thermal energy and electricity during winter. The BioCHP unit is optimized for heating, and the electricity production can be seen as a (wanted) by-product of the heat production. Even with a good annual balance between production and demand, in some periods electricity will be exported to the grid, while import will be necessary in other periods. Buying and selling to the electricity grid (net metering) and a reasonable rate is necessary. The alternative system with solar collectors, heat pumps and PV will have larger annual variations in energy production and comprehensive exchange towards the grid is necessary. A dialog with the local energy company is started to discuss ownership, operation and financing of the energy system for Ådland. During the project period new business models will be developed and tried out to give the house owners incentives to save energy.

A lighthouse project

ByBo is an ambitious developer with experience from building the passive houses at Løvåshagen. Løvåshagen was the first major residential area with passive houses in Norway. ByBo is a partner in ZEB and has for a long time wanted to build a residential area with higher ambitions than passive houses. There is also an ambition for Ådland to create a learning arena for building homes for the future. Learning and experience from the project will be disseminated to the construction industry. The Ådland project will be built over a period of time in order to learn from each step and increase the ambitions for the project.

Office buildings with ZERO emissions of CO_2

Designing an office building with no CO_2 footprint throughout its lifetime, is extremely difficult, but results from a concept study show how this might be realised.

Buildings that produce as much energy as they consume, so called zero energy buildings, are quite challenging for the building industry. The goal for The Research Centre on Zero Emission Buildings (ZEB) is far more ambitious, though. The aim for ZEB is to develop zero emission buildings where absolutely all greenhouse gases are included. This means that the building's own production of energy must offset the emissions and energy use from the production and transport of the building materials and the operation of the building for 60 years until the demolition of the building.

In ZEB several buildings are being studied, real pilot buildings and so-called concept buildings. The aim for the concept work is to model theoretical buildings with technical solutions that can be used in real buildings. The first results show that it is possible to reach extremely low demands for energy use both for office buildings and for residential buildings. To find out what kind of materials that should be used to reach zero emission is just started though.

A concept work with analysis of a theoretical building model is carried out. A typical four story office building is modeled. Data for all aspects of emissions are put into the model, both data from the building materials, from the technical installations and the design of the building.

Is it possible to reach zero emission for materials?

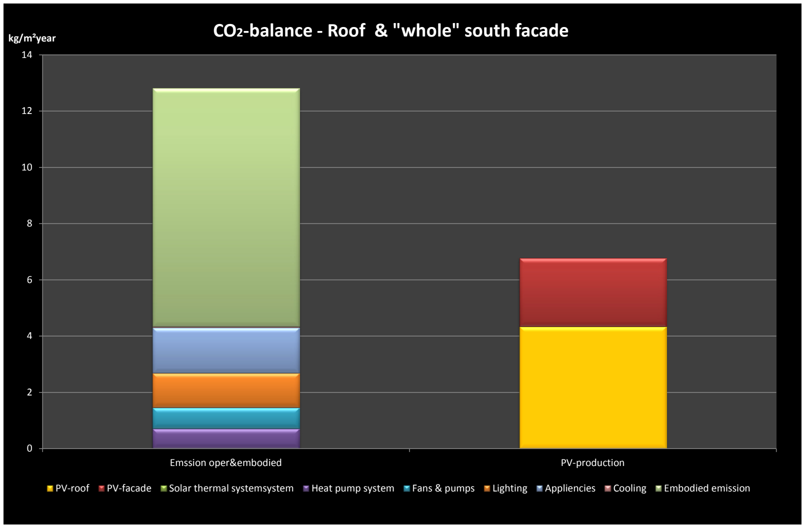
The analysis shows that the four-story office building can not produce enough energy to offset the CO_2 emissions both for the energy use and the production and transportation of materials. It is very difficult to reach zero emission over the lifetime for buildings with many floors. The first step has been to optimize energy use and energy production on a conventional building design. The Materials are not optimized yet. With a building form optimized for energy production and materials optimized for low CO_2 footprint, the goal might be reached.

The demand for materials with a low CO_2 footprint may result in a change from concrete based to wooden based materials. However, wood may not be the best solution. Studies show that some wood based boards are worse off than gypsum board. The use of glue and the drying process increase the CO_2 emissions for wooden boards. Improvements in the production process will most likely reduce the CO_2 emissions in the future. Cement and concrete materials may also be significantly improved by the use of new additives in so-called “green concrete”.

Easier for detached houses

The same analysis is also done for a model of a detached house of 160 m^2 on two stories. The two story building can produce a larger share of solar energy since the roof area is larger in relation to the floor area compared to the four story office building. The energy demand per square meter is however quite similar for the office building and the detached house. An interesting result is that the PV panels (photovoltaic – solar cell) contribute more to the CO_2 balance than the solar collectors. Since the thermal energy demand is very low, it is more important to produce electricity.

Other reasons for detached houses to reach zero emission easier is that office buildings need heavier materials both for the load bearing of the substructure and for the sound protection. With heavier materials the CO_2 emission per square meter are higher.



Figur 1 *CO_2 balance between embodied- and operational emission, and PV-production for the concept office building. With both roof and all available area of south façade used for PV-panels.*

In some of the pilot buildings planned in ZEB alternatives to concrete in the floors and gypsum board and mineral wool in the walls has been investigated. The challenge is that the documentation of the alternative materials is not good enough. Requirements for fire protection, sound protection and environmental impact are a tough challenge for new materials. Another challenge is the CO_2 footprint for the technical installations. In the next phase of the concept work alternative materials and solutions for ventilation and heating systems will be analysed.

Reference: *Claude Olsen: “Kontorbygg med null utslipp av CO2”, ZEB nyhetsbrev 2013*

Key figures

Personnel

In 2012 a total of 54 persons where involved in ZEB 10 % or more of their total working hours. In addition, ZEB had 13 PhD and 4 Postdocs in 2012, where 7 of them are Norwegian, and 6 females. 3 of the postdocs finalized their work in 2012.

Further, 5 PhD are working close to the centre, with financial support from other sources.

In total, then were 21 ZEB-related master graduates in 2012.

Publications

Type of publication	2012	Total
Journal papers	12	35
Published Conference Papers	19	64
Conference and seminar presentations	60	169
Popular Science Articles	2	12
Books and books chapters	1	3
Reports incl. Master thesis	18	34
Media contributions	12	25

Funding and cost

The total funding and cost in 2012 was NOK 49 074 200, included the in-kind contribution.

Funding in 2012

Funding	Amount	Amount
The Research Council		20 091
The Host Institution (NTNU)		6 111
Research Partners (SINTEF)		1 891
Enterprise partners		13 504
Brødrene Dahl AS	*412*	
ByBo AS	*1 742*	
Byggenæringens Landsforening	*238*	
DuPont de Nemours	*146*	
Glava AS	*429*	
Hydro Aluminium AS	*761*	
Isola AS	*349*	
Multiconsult	*417*	
NorDan AS	*327*	
Norsk Teknologi	*177*	
Protan	*100*	
SINTEF	*2 168*	
Skanska Norge AS	*4 137*	
Snøhetta AS	*270*	
Velux AS	*800*	
Weber	*1 034*	
YIT AS	*400*	
Transferred from 2012 to 2013	*-403*	
Public partners		7 567
Direktoratet for byggkvalitet	*24*	
Enova	*500*	
Entra Eiendom AS	*5 598*	
Forsvarsbygg	*255*	
Statsbygg	*1 145*	
Transferred from 2012 to 2013	*-45*	
Total		49 074

Cost per partner 2012

Cost	Amount	Amount
The Host Institution (NTNU)		19 438
Research Partners (SINTEF)		12 136
Enterprise partners		7 351
Brødrene Dahl AS	*162*	
ByBo AS	*1 292*	
Byggenæringens Landsforening	*188*	
Dupont de Nemours	*33*	
Glava AS	*129*	
Hydro Aluminium AS	*261*	
Isola AS	*224*	
Multiconsult	*217*	
NorDan AS	*77*	
Norsk Teknologi	*127*	
Skanska Norge AS	*3 137*	
Snøhetta AS	*120*	
Velux AS	*550*	
Weber	*634*	
YIT AS	*200*	
Public partners		5 274
Direktoratet for byggkvalitet	*24*	
Entra Eiendom AS	*5 000*	
Forsvarsbygg	*105*	
Statsbygg	*145*	
Equipment		4 875
Total		49 074

Cost per activity 2012

Activity	2012
Management and administration of the Centre	3 541
WP1: Advanced materials and technologies	3 481
WP2: Climate-adapted low-energy envelope systems	2 145
WP3: Energy systems for zero-emission buildings	2 004
WP4: Energy efficient use and operation	1 720
WP5: Concepts and strategies for ZEB	4 107
Dissemination of knowledge (conferences, seminars, workshops)	1 972
Training of research personnel, professor position	10 713
In kind contribution from the user partners	12 624
Ongoing projects within the Centre (only public funding)	1 891
Equipment	4 875
Total costs	49 074

SINTEF

ZEB

NTNU
Det skapende universitet