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 CO2 management in close cooperation between prominent research communities and users.

ZEB

The Research Centre on Zero Emission Buildings

Annual report 2010

Date of delivery: 2011-04-01

SUMMARY

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.

During 2010 main activities started for all the work packages:

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

The Centre has a General Assembly and an Executive Board. *The General Assembly* includes all partners. 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 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.

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.

Seven PhD students and two post doctoral fellows have been hired and have started working in 2010. This is in addition to the two PhD students and one post doctoral that started in 2009.

The accumulated cost in 2010 was NOK 34,5 mill.

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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 demands 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 PLAN - STATUS, BACKGROUND AND MOTIVATION

Environmental Impact and Security of Supply

Both worldwide and in Europe buildings account for about 40% of all primary energy use and therefore contribute to significant greenhouse gas emissions. A combination of making buildings more energy-efficient and use a larger fraction of renewable energy is therefore a key issue to meet the global challenges related to climate change and resource shortages. However, achieving substantial reductions in energy use and greenhouse gas emissions from this sector requires much more than incremental increases in energy efficiency. Currently, a prominent vision proposes so called "net zero energy", "net zero carbon" or even "plus energy" buildings. Although these terms have different meanings and are poorly understood, several IEA countries have adopted the vision of zero emission buildings as a long-term goal of their building energy policies (CA, DE, UK, USA, NL, NZ). According to the Recast of the Directive on energy performance of buildings (EPBD)[1], member states will be required to actively promote the higher market uptake of buildings of which both carbon dioxide emissions and primary energy consumption are low or equal to zero, by producing national plans with clear definitions and targets for their uptake.

Reducing the demand for energy may be more cost-efficient than extending the capacity in the energy supply system, In the IPCC's Fourth Assessment Report, Working Group III[2], it is indicated that there is a global potential to cost-effectively reduce approximately 29 % of the projected baseline emissions by 2020 in the residential and commercial building sectors, the highest among all sectors studied in the report. In Norway the most cost-efficient measures for greenhouse gas emission reductions are probably also in the building sector[3]. The new energy performance requirements for buildings as part of the Technical Regulations imply a significant improvement of the energy performance of new buildings. The CO2 abatement costs associated with the requirement level have been estimated to be between 100 and 260 NOK/ton CO2. This is compared to the 360 NOK/ton CO2 if CO2 sequestration technology should be included in the Kårstø gas-fired power plant[4].

Buildings in Norway are accountable for about 40% of the country's total energy use and about 50% of the electricity use. A special feature of energy use in Norwegian buildings is that a large share (around 70%) of the heating load is covered by direct electric heating. Efforts to reduce the heating load and substitute electric heating with heat from new renewable energy sources are paramount in the Norwegian energy policy. Present policy aims to improve the security of supply, and to make electricity available for other high-value purposes within the industry and transport sectors. Reduced electricity demand in the building stock leads to less demand for increased capacity in the power production and for infrastructure. New electricity production may result in several unwanted environmental consequences, such as increased greenhouse gas emissions (by use of fossil fuels), intervention in the natural landscape (e.g. wind and hydro power), use of non-renewable energy sources, etc. Avoiding such negative effects has a positive value that is difficult to quantify.

Compared to a business-as-usual scenario, and given that all existing buildings and new buildings towards 2035 gradually achieve passive house standard, the energy reduction potential in the Norwegian building stock is about 23 TWh per year in 2035. The corresponding reduction potential for the electricity demand is

[1] Recast of the Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings, November 2008.
[2] IPCC (2007), Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
[3] Norwegian Pollution Control Authority (2007), Reduksjon av klimagasser i Norge. En tiltaksanalyse for 2020 (Reduction of greenhouse gas emissions in Norway. Mitigation options of reduction potential in 2020.)
[4] Ministry of Local Government and Regional Development, "Changes in Technical Regulations under the Planning- and Building Act, Discussion document", June 2006.

about 15 TWh[5]. The reduced electricity demand corresponds to approximately four to five Kårstø gas-fired power plants, or about 2400 windmills (each 2MW). If all buildings achieved a zero emission standard in the future, the energy and electricity saving potential would be even higher.

Innovation

The construction industry represents a large part of Norway's value creation, with an annual turnover of 45 billion Euros. The BAE-council estimates that innovation within the construction sector can result in an additional annual value creation of 3-4 billion Euros[6]. Moreover, the number of people employed in the construction industry adds up to about 320.000 people. As much as two thirds of the physical capital in the country is created by the construction industry (buildings and infrastructure).

Realizing zero-emission buildings will require development of new, very high quality building products and systems that are robust with respect to future user requirements and future climate and political changes. Due to rather harsh and variable climate conditions and a high quality building tradition, the Norwegian industry has a competitive edge with respect to developing and exporting high performance products and services. Facing the future risks of climate change, Norway also provides a unique "laboratory" for testing the robustness of new building envelope solutions.

The industrial partners within the ZEB Centre all have very high ambitions with respect to energy and environment. Several of the R&D environments in ZEB are in the forefront of international research within their fields. Our combined expertise within material science, building technology, renewable energy, architecture and social sciences represent a real competitive edge.

By creating the research centre encompassing the R&D environment and the building industry, Norway has the opportunity to be a central player in the very important future international arena of sustainable energy use.

State-of-the-art of Zero Emission Buildings

There is no common understanding or agreed-upon definition of a zero (greenhouse gas) emission building[7]. A variety of different expressions are used, e.g. "zero energy building", "carbon neutral building" and "equilibrium building". Torcellini et. al.[7] define a net zero energy emission building as "*a building that produces as least as much emissions-free energy as it uses from emissions-producing energy sources.*"

Several building projects around the world have been constructed in this non-defined context of "zero energy/emission". Some even more ambitious projects have used the label "plus energy buildings"[8]. The majority of these buildings are small residential buildings, and they are mostly new houses. Most of them rely on grid-connected photovoltaic power supply combined with solar low energy (passive) designs. Some solar low energy apartment buildings combine this with the use of natural gas or diesel driven cogeneration units and are claimed to reach "zero energy". This is justified based on the claim that the national grid is based on fossil fuels with a low fraction of central cogeneration, and emission credits are thus gained by feeding electricity from renewables into the electricity grid[9]. Thus, on a yearly basis, their energy demand is outweighed by the amount of renewable energy that they feed into the electricity grid.

"Zero energy" in the interpretation of a fully autonomous energy supply for a building with locally available sources only, has also been demonstrated[10]. So far, this concept has not proved to be technically, economically or environmentally viable in view of wide scale application [9,10,11].

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[5] Sartori, I., "Modelling energy demand in the Norwegian building stock", Doctoral thesis at NTNU, 2008:18

[6] BAE-Council: "Research and development in the construction industry. Challenges and value creation potential". Part 1 of 2, Oslo, Sept 2002.

[7] Torcellini, P. et al.: "Zero Energy Buildings. A critical look at the definition", Conference Paper NREL/CP-550-39833, June 2006.

[8] Voss, K. et al.: "Building Energy Concepts with Photovoltaics – Concepts and Examples from Germany", Advances in Solar Energy, Vol. 15, 2002, ASES.

[9] Voss, K. and M. Kranz: "Net Zero Energy Buildings. A Concept Paper for an International Research and Demonstration Activity in the IEA SHCP Framework", 3rd draft, January 2008.

[10] Voss, K. et al, "The Self-Sufficient Solar House in Freiburg. Results of 3 years of operation", Solar Energy, Vol 58, no 1-3, 1996, Elsevier.

The first step towards achieving zero emission buildings is to reduce the energy demand to a minimum. In Norway, and in many other European countries, so called "passive houses" are entering the market. These are buildings with a very low energy demand (about ¼ of normal standard) achieved through "passive strategies" such as high insulation, high air tightness, and effective heat recovery. Often, these houses also have solar systems and heat pumps that cover parts of the energy load[12,13].

The global climate is likely to undergo changes, regardless of the implementation of abatement policies. The full range of impacts resulting from these changes is still uncertain; however, it is becoming increasingly clear that adaptation to climate change is necessary and inevitable within the building sector[14],[15]. Thus, our zero emission buildings have to be designed to meet the challenges of potential future climate changes. Some researchers have begun to investigate the challenge of low energy buildings in future climates[16,17], but much work still remain.

The exact definition of a "zero emission building" within the ZEB Centre will have to be established through an integrated analysis of building types, climate, technologies, economics, and social issues. Probably, different goals have to be defined for different types of buildings, e.g. some types of buildings may have the potential to be net energy producers and some may be energy autonomous.

A Research Centre for the construction sector

The Norwegian Research Centre for Zero Emission Buildings encompasses the whole value chain of market players within the Norwegian construction sector. In total, the companies in the Centre have a yearly turnover of more than 200 billion NOK and over 100,000 employees. As such, ZEB represents a historical effort in this area, which is outstanding also in an international perspective. Moreover, several of the industrial participants that operate in other countries have expressed that the establishment of such a centre is instrumental in attracting and increasing their R&D activities in Norway. The user partners have emphasized the importance of such a centre to coordinate, enhance and strengthen the R&D and innovation within the important field of energy efficient buildings. Recruitment, job-creation, visibility and sustainability are other keywords that have been expressed. Furthermore, the Research Centre is a breeding ground for new industries, both within the established construction sector and beyond.

[11] Sartori, I. and A. G. Hestnes, "Energy use in the life cycle of conventional low-energy buildings – A review article", Energy and Buildings, Vol 39, 2006, Elsevier.
[12] Andresen, I. et al: "Passive House Projects in Norway – an Overview", Paper at the 11th International Passive House Conference, April 13-14, 2007, Bregenz, Austria.
[13] http://www.cepheus.at
[14] Lisø, K.R. et al.: "Preparing for climate change impacts in Norway's built environment", Building Research and Information, 31 (3-4), , 2003.
[15] Roberts, S. "Effects of climate change on the built environment", Energy Policy, Article in Press, 2008, Elsevier.
[16] Nazaroff, W.W.: "Climate change, building energy use and indoor environmental quality", Indoor Air, Vol. 18, No 4, 2008, Blackwell Publishing.
[17] Holmes, M.J. and J.N. Hacker: "Climate change, thermal comfort and energy: Meeting the design challenges of the 21st century", Energy and Buildings, Vol 39, 2007, Elsevier.

ORGANIZATION

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

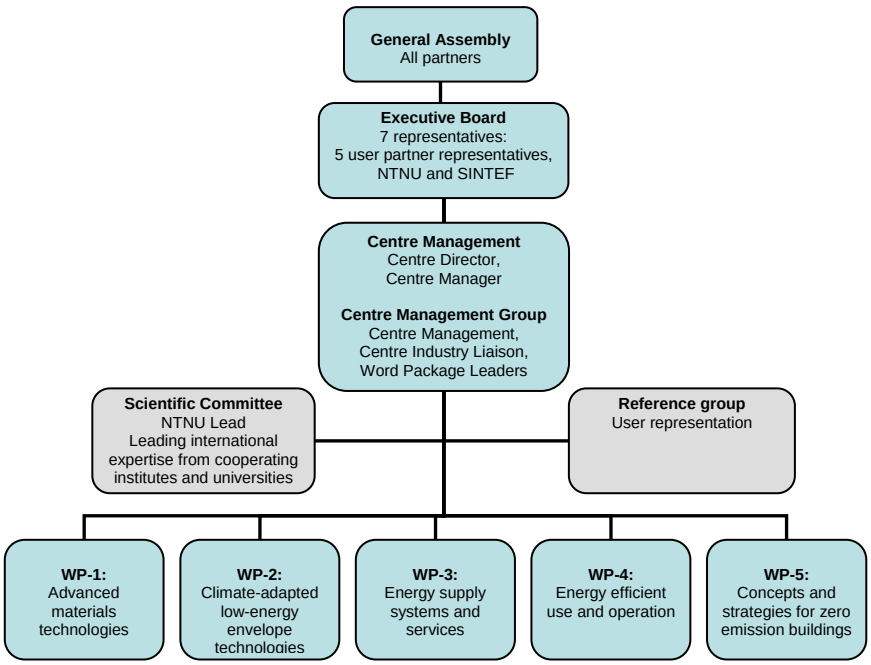
Centre Manager: Senior researcher, PhD Anne Gunnarshaug Lien, SINTEF Building and Infrastructure, Energy and Architecture

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

European Research Contact: Professor Øyvind Aschehoug, 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 approval 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 Scientific 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

will be established with other relevant FMEs, as described in section 3. 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 Arild Gustavsen, Dept. of Architectural Design, History and Technology, NTNU
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: Associate Professor, PhD Thomas Berker, Dept. of Interdisciplinary Studies of Culture, NTNU
WP-5: Senior researcher, PhD Tor Helge Dokka, SINTEF Buildings and Infrastructure

For each of the user partners, the Centre's importance regarding innovation and value creation is described below.

Weber (building products producer/supplier): *The building industry will be facing radical new challenges with respect to more energy efficient and robust products and solutions. The company's ambition is to continuously offer new solutions to the market, fulfilling future requirements and strengthening its position in the Norwegian and European market. The company expects "ZEB-Research Centre" to be a hub and catalyst in the development, and to be an important partner for the company.*

Isola (building products producer/supplier): *A large range of new products can benefit from basic R&D in cooperation with the ZEB Centre. Innovative new products will be instrumental in further growth and development of the company.*

Glava (producer of insulation materials): *New superior insulation materials and thermal protection building systems for the future will lead to new market shares.*

Protan (manufacturer of building materials): *For the company's efforts in marketing sustainable roofing systems world wide it is a necessity to be in the front with the best technology and solutions. Even if the target for ZEB involving Protan's scope is not described in detail so far, all improvements and new achievements will be useful.!!*

Hydro Aluminium (producer of aluminium products and solar systems): *An increased value added from additional investment in product development, including both active solar energy generation and improvement in more established passive energy efficient products and building envelope solutions, is foreseen.*

Skanska (large building contractor and developer): *A national centre as proposed, with a joint effort from universities, research institutes and the building industry, will contribute to sustainable construction through increased awareness and competence combined with development of new quality assured concepts, components and materials.*

ByBo (housing developer): *The win-win situation created by increased knowledge and better products at competitive prices is a driving force for the company to search innovative solutions in a traditional market. The company expects that cooperation with the proposed centre will greatly improve its ability to identify such innovations*

YIT (technical installations contractor): *The company will continuously develop its own solutions and be able to use the results from the FME Centre in this work. YIT expects demand for energy-efficient buildings and solutions in the future and that it will increase the company's sales in energy-related technology.*

Brødrene Dahl (HVAC equipment supplier): *A cluster like the ZEB Centre consortium would create synergy effects for all the different industries by developing optimal solutions together. This will help the company to bring knowledge to it's manufacturers to guide them to optimize their products. Through the Centre the products can be tested and the results documented and used to show the market that building environmentally friendly is possible and profitable.*

Multiconsult (consulting company): *The development of new tools that can provide analysis of the environmental impact of new products or services may lead to new standards, guidance, and analysis models that will help introduce new services to the construction sector.*

Snøhetta (architect): *The Centre will expand the office's competence in designing buildings with very low impact on the environment, with special focus on climate. Generation of sustainable solutions will be implemented and multiplied in projects all over the world.*

Statsbygg (Directorate for Public Construction and Property): *The ZEB Centre provides an opportunity to develop knowledge needed by Statsbygg to fulfil Statbygg's existing and future requirements for energy use and greenhouse gas emissions. Innovation and higher efficiency in the Norwegian property, building, and construction industry is of vital importance for Statsbygg as well as for the Norwegian society.*

Forsvarsbygg (Norwegian Defense Estates Agency): *NDEA as a public-owned building client is under considerable political pressure to act as a role model for private building clients. By applying the latest technology in order to reach superior energy performance, public construction activities are targeted to be demonstration objects for the whole construction industry.*

Norsk Teknologi (Norwegian Technology; Confederation of companies within the technical and technological sector): *Norsk Teknologi is a federation of 1550 companies with a total of 32,800 employees and annual revenue of 3.8 billion Euros. A significant potential for innovation and value creation is possible related to investments in energy efficiency measures.*

BNL - Federation of construction industries (incl. Construction products association): *The potential for social profit from increased innovation within the industry is considerable, and it is to a large degree the society itself that will benefit from the innovative efforts to be addressed by the Centre. Rethinking construction and stimulating renovation is of utmost importance for a healthy development of the industry.*

Husbanken (The Norwegian Housing Bank): *The Centre has the potential to play a decisive role concerning reduced energy use and emissions from the building stock, both by research and other related activities. Husbanken especially sees a huge potential in using pilot projects as centre points and arenas for regional dissemination of ambitions, knowledge and for regional market development. This will be an essential foundation for innovation and value creation and implementation of results and experiences done by the research Centre and its partners.*

BE - National Office of Building Technology and Administration: *Practical and user targeted research activities are the basis for standardization, and the results can be transformed into regulations. Development of building requirements regarding energy efficiency and energy supply will undoubtedly contribute to significant benefits for society. Research on actions to be taken in the existing building stock should be a part of the research activities and will be of importance for further development of building regulations and building practise on this field.*

The Centre disseminates research results through the Reference Group, which represents private and public institutions and agencies that have dissemination as a major objective. The Reference Group members are not expected to contribute financially to the Centre. The Reference Group members are:

- Forbrukerrådet (Norwegian Consumer Council)
- NBBL (Norwegian Federation of Co-operative Housing Associations)
- NVE (Norwegian Water Resources and Energy Directorate)
- EcoBox (environment information agency, Norwegian Association of Architects)
- Lavenergiprogrammet for bygg og anlegg (The Construction Industry Low-Energy Programme)
- Driftsforum (Forum for Building management, operation and maintenance of buildings at The Norwegian Society of HVAC)
- Enova SF (Public enterprise owned by the Royal Norwegian Ministry of Petroleum and Energy)
- Byggemiljø (The environmental secretariat of the construction industry)

Partner participation and exchange of researchers

Close cooperation between many of the partners of the consortium has been established within ongoing projects but also through industry representatives with part time positions at NTNU. The ZEB Centre allows the consortium to enhance and expand this cooperation. It is important for the industry partners to take active part in the research and development at the Centre to ensure the relevance of the work and to

facilitate implementation, and an exchange program within the various research tasks is therefore established. It is likewise important that the researchers support the companies in their development of new commercial products and solutions.

Transfer and utilization of competence and results

ZEB ensures active participation by the user partners through the following means:

- The General Assembly, consisting of all consortium partners, has at least two meetings per year.
- The work to be carried out is discussed in workshops within the five work package areas with all partners present. In these workshops, the main opportunities, challenges and success factors are identified. Project activities are defined and organized and, when relevant, executed together with collaborating consortium partners.
- Project meetings where results are presented and discussed with respect to utilization by the industrial partners are organized on a regular basis.
- Exchange of personnel between collaborating consortium partners and the Centre are organized.
- Field testing of new materials and technical solutions are carried out.
- All information is made available on the project web site for easy access and use by the partners.

The partners cooperate through the work in the projects (technical work and joint projects meetings) and in AC. Four partners or more are represented in all projects.

TECHNICAL ACTIVITIES, RESULTS

Administrative activities and results

The activities include detailed planning of the various activities in ZEB. This has been carried out in cooperation with the Partners and resulted in the ZEB Work Plan.

Five board meetings were held, at 18th of January, 16th of March, 8th of June, 10th of September and 25th of November 2010.

Two General Assembly meetings were held, and workshops were organised in connection to these meetings. The first meeting were held 18th of January at Thorbjørnsrud Hotell, Jevnaker. Agenda for that meeting was constitution of the General Assembly and status for the ZEB work.The workshop dealt with developing concrete plans for the work in the work packages.

The second meeting were held 10th of September at the premises of Weber in Lillestrøm. Agenda for that meeting was status for the ZEB work and the ZEB project in the perspective of the Chair of the General Assembly. The workshop had definitions on the agenda, with presentations and discussions of work regarding the ZEB-definitions and of the results of the scenario analyses of the European energy system towards 2050.

In October an excursion was organised to Germany and Switzerland for the ZEB board, -administration and work package leaders. The group visited Wicona in Bellenberg, building projects in Ulm, FhG-ISE (Fraunhofer Institut für Solare Energiesysteme) in Freiburg, housing projects in Vauban, and the Marche International zero energy office building in Kempthal, Switzerland.

Activities in the Work Packages

The Work Package Leaders have summarized the main activities in the Work Packages as described below:

WP1 Advanced Material Technologies

Opaque and transparent solutions:

New concepts for insulation materials have been identified, e.g. nano insulation materials and vacuum insulation materials. Introductory experiments on the production of nano-porous insulating materials have been carried out, and some candidates for new insulation materials have been prepared, but several tests need to be carried out in order to check the material properties and thermal performance. Several development tests together with Glava on improving the thermal performance of some of their products has also been carried out. Most of the tests were done at the facilities of Glava, but with input from ZEB researchers.

An evaluation of the energy saving potential of using roof coatings with various properties has indicated that changing the solar absorptivity of a roof surface has little to no effect on the indoor climate as the indoor surface temperature remains practically unchanged (for well insulated roofs). The outdoor surface temperature does, however, decrease significantly. Further studies will be performed to look at the effect this may have on the ventilation intake air temperature.

In December 2010 a new KMB project on improved windows for energy efficient buildings received funding from RENERGI (a program under the Norwegian Research Council). The aim of the new project is improved thermal insulation and dynamic properties. Lawrence Berkeley National Laboratory is one of the partners also in this one.

Controllable materials and solutions:

Possible nano-technologies (WO_3 nano-particle films) for improvement of smart windows using electrocromic (EC) materials have been identified. Nano-structured EC materials or assemblies have revealed remarkable improvement on coloration efficiency and switching time due to their small featured sizes and large surface areas. Combined EC and photovoltaic systems are also considered.

A paper on dynamic solar radiation control by applying EC materials has been published. The paper presents the solar radiation factors (e.g. visible solar transmittance, solar transmittance, and solar factor) most important when choosing glass material for building applications and shows an example on how these factors may be used to examine two EC windows. A paper on the energy saving potential of application of controllable materials has also been written. It shows that application of EC windows instead of regular windows can result in energy savings. More studies will be performed, also on the energy saving potential of dynamic insulation materials.

Energy storage solutions:

ZEB has started to participate in the IEA ECES Annex 23: Energy Storage Application in Low Energy Buildings. This activity is quite useful as it allows us access to information about energy storage solutions that can be used in zero emission buildings.

An MSc student from the University of Jyvaskyla, Finland, completed his thesis work at the Centre, carrying out experiments on phase change materials (PCMs) provided by DuPont. A review of materials that may improve the conductivity of PCM has also been carried out, and a selection of new materials has been ordered. Preliminary blending tests have already been carried out, while conductivity test will be carried out when a new conductivity measurement apparatus able to measure small samples has been purchased.

Energy producing materials and solutions:

A material development laboratory for smart energy producing windows has been established, and the first initial developments have started. Initial synthesis has been carried out on various materials for electrocromic EC devices, which will be further investigated for utilization in combined EC and photovoltaic devices.

WP2 Climate Adapted and Low Energy Envelope Technologies

Optimal thermal performance:

The potential and limitations of vacuum insulation panels (VIPs) in building envelopes have been investigated in the laboratory. Hygro-thermal performance and the effects of aging have been reported in two papers, where the possibilities and limitations of use in real constructions are shown. Co-operation with a PhD-student at Chalmers Technical University has been initiated on investigations of solutions for retrofit applications. Investigation of the hygro-thermal performance of an improved VIP building system from Weber for Nordic climates is being performed. A work on future potential for VIPs in sandwich wall elements is undertaken.

A workshop with relevant partners discussing what had been obtained so far and how to proceed was arranged in August, with 28 participants. A list of ideas was collected and the list used as input for the planning of future activities.

A study of the potential effect on energy performance of better utilization of the building envelope elements has been carried out, a draft report is finished, and the findings have been presented at workshops.

A PhD study on strategies for renovation of single family dwellings from the 1980s towards zero energy levels is being conducted. This has particular emphasis on measures on the building envelope.

Complementary work on improvements of the existing building envelope technologies has so far been carried out in the related projects ROBUST, CAB, and Aerto. Relevant results from this work were also presented at the workshop.

A Fulbright exchange student from the University of Minnesota has joined the team. His thesis work, on low energy wood based façade systems, is quite complementary and useful for ZEB.

Integration of elements in the building envelope:

This work is being carried out in co-operation with IEA SHC Task 41: Solar Energy and Architecture, which is looking into suitable integration methods for Norwegian climatic conditions and building practices.

Solar energy systems (solar collectors and PVs) are still relatively rare in Norway, and costs are high. A task is set up to investigate the challenges related to building integrated solar energy systems and building process. A workshop together with Isola and DuPont was arranged in November to discuss products, development and experiences. It has become clear that feed-in tariffs and similar public/governmental instruments are necessary to increase the use of PV systems in Norway.

An experimental investigation of PCMs in a traditional Norwegian wall construction has been performed in the laboratory. The results confirm that the PCM reduces temperature peaks, thereby improving thermal comfort. Numerical simulations are being performed to see whether the PCM board has an effect on the annual energy demand of the building.

A workshop together with experts from Hydro was arranged in April in order to discuss common activities and inclusion of work on Hydro's intelligent façade system TEmotion. Common interests within the area of solar energy supply systems in facades and on principles related to their intelligent facade systems were identified. A PhD-study related to this is initiated.

Daylighting and solar shading systems:

A key activity here is participation in ISO TC163/SC 2 item "Calculation of the impact of daylight utilization on energy demand for lighting".

A small workshop with Snøhetta has been conducted on the topic of how to join principles for good energy design and best possible daylight and solar shading conditions. The conclusion was to focus on development of a daylighting design method for facades with a high degree of outdoor obstruction.

Windows and glazing systems:

A state-of-the-art study of super insulating windows has been performed in the recently finished MOT-project. Verification of passive house windows has been performed in a complimentary project. How to proceed in ZEB on this topic will be based on the conclusions of this work and in cooperation with NorDan as a new ZEB partner.

WP3 Energy supply and building services systems

Available technologies for renewable energy:

The following technologies for renewable energy supply have been studied so far: bio energy, polygeneration (micro CHP and CCHP), district heating, fuel cells, geothermal systems, heat pumps, micro wind turbines, solar thermal systems, PV systems, and combined PV/thermal systems.

A first version of a methodology for evaluating these and other energy supply options has been produced and is presently being discussed in internal workshops. The criteria the team proposes to use are:

- Climate & Building integration
- Load Coverage
- Durability
- Economics
- Emission levels

A workshop with the partners facilitated the coupling of the experience from the industry with the proposed methodology for evaluating energy supply options.

High performance building services:

Available technologies and future trends for building services have been studied. Some useful findings are:

- New motor technologies improves the fan efficiency considerably, especially in the case of smaller fans
- Solutions for VAV need improvements of efficiency in part load operation
- Earth coupling and/or free cooling in combination with passive thermal or thermo-active elements meets cooling demands
- Combination of more efficient light sources, non-uniform lighting designs, occupancy scheduling, and daylight harvesting could, within the next 10 years, provide savings of up to 90%.

Test and pilot buildings – follow up:

A key activity in this Work Package is participation in IEA ECBCS Annex 53: Total Energy Use in Buildings - Analysis & Evaluation Methods. This provides a good basis for the development of plans for evaluation of the pilot buildings. Plans have been made for how to co-ordinate these monitoring and evaluation activities, as they will take place in both WP 3, 4, and 5.

An assessment of simulation needs and available simulation tools for use in ZEB has been carried out. The tools assessed so far are: TRNSYS, EnergyPlus, Esp-r, IDA, SIMIEN, and eTransport.

A draft of Guideline for quality assurance of solutions through the design, construction, and operation phases (life time commissioning) is completed. Quality control and follow-up of pilot buildings and renewable energy systems is necessary. In the guideline, lifetime commissioning is explained as an intrinsic part of integrated design process.

WP4 Use, Operation and Implementation of ZEBs

Use:

A paper based on the survey of existing evaluations of zero emission buildings has been accepted for publication in the international journal ABER (Advances in Building Energy Research).

An evaluation of five European zero/plus energy buildings has been conducted. The cases were Løvåshagen (Norway), Dragen barnehage (Denmark), Les hauts de Feuilly (France), La cité de l'environnement (France), and Marché International Support Office (Switzerland). The evaluations have been documented in case reports which will be used to create publications summarizing the results.

A workshop with industry partners has been organized where the work done in 2009 was presented and further research was discussed. Another workshop conducted in December brought together social scientists and historians from seven countries working on a conceptual level with energy technologies.

Operation and maintenance:

An exploratory report on existing technical solutions to human-building interfaces has been written. It focuses on technologies similar to those developed in WP3 (such as the different HVAC systems) and identifies areas for further research both on the side of the technical interfaces and on the side of the professional operation of building technologies.

The work package leader has participated in the creation of a Nordic network for sustainable facilities management.

Implementation:

An MSc thesis comparing US-American and European implementation strategies for "smart grids" has been prepared. It has identified several differences, such as a focus on military aspects in the US and the hope that European integration will be driven by smart grids, but also one alarming commonality: both strategies are based on stunning misconceptions of end users.

An article on sustainable innovation in the building sector has been published in the International Journal on Innovation and Sustainable Development. In this work, advanced daylight systems and the Shecco heat pump were studied. It found and described two different strategies to overcome uncertainty: mainstreaming and substitution.

An annotated bibliography of literature on learning in the building sector is compiled, and a report on formal barriers to the implementation of zero emission buildings has been written.

WP5 Concepts and Strategies for Zero Emission Buildings

Definition of zero emission buildings:

A scenario analysis of the European energy market has been carried out. The scenarios are created on variations in demand and in production portfolios of electricity. The scenarios are
"Red", with high demand and limited growth in RES-E production, "Yellow", with limited demand and some growth in RES-E production, "Green" with limited demand and high growth in local and regional RES-E

production, “Blue”, with high demand, high growth in large-scale RES-E production, and “Ultra Green” with decreased demand, some increase in nuclear production, and increased RES-E production (mainly small scale). All scenarios except “Red” are assumed to have more than 50% RES-E in 2050. Emissions of CO2 are analysed by the European Multi-area Power Market Simulator (EMPS). Important sources for input data have been “World Energy Outlook” from IEA and reports from Eurelectric. The “Ultra Green” scenario represents a nearly emission free electricity system in 2050. The total emissions from “Ultra Green” are less than 10% of the emissions in 2010. This scenario will be used for further work on concepts for zero emission buildings.

A paper on scenario analyses used to develop a ZEB definition was accepted for oral presentation at the EuroSun2010 Conference. This work has been carried out in cooperation with IEA Task 41: Net Zero Energy Solar Buildings, the IEA Task in which ZEB is strongly involved.

A case study using Statsbygg’s ”klimagassregnskap” to calculate the embodied energy of low energy and passive house dwellings (Løvåshagen) has been carried out. This provided useful knowledge of the pros and cons of using Statsbygg’s calculation tool and has also been used as a starting point for the development of a ZEB database of emission factors.

Pilot buildings:

A memo on preliminary criteria for selection of pilot buildings has been prepared, and a working group with active participation from Statsbygg, Snøhetta, ByBo, and Skanska has been established to further develop this.

Five potential pilot building projects have so far been identified:

- A large residential development area in Bergen (ZEB partner: Bybo) – this is well under way
- Framsenteret (ca. 9000 m² office and laboratory building) in Tromsø (ZEB partner: Statsbygg) – this is in the programming phase, and an early phase analysis has been carried out
- A potential office pilot project near Lillehammer (ZEBB partner: Forsvarsbygg), an early phase analysis has been carried out
- A large complex of office buildings in Sandnes (ZEB partner: YIT), an early phase analysis has been carried out
- An office building in Arendal (ZEB partner: Skanska), this are in the very initial stages of discussion.

An activity on monitoring existing passive house buildings has been planned and will be carried out in co-operation with WPs 3 and 4. Buildings to be evaluated are:

- Løvåshagen (new passive house residential buildings). Data for total energy use for this case has already been obtained by an MSc student.
- Marienlyst school in Drammen (passive house building),
- Myhrerenga Borettslag (renovated residential building blocks).

Design and construction processes:

An analysis of the construction processes for realized building projects with passive house standard is almost completed. The projects studied include:

- Løvåshagen, Bergen: In situ built construction with load bearing concrete.
- Storøya barnehage, Fornebu: In-situ built under cover (tent)
- Marielunden, Stavanger: Prefabricated wooden elements.

Strategies for implementation of ZEB from pilot buildings to volume market:

A study of the potential energy performance in the Norwegian building sector towards 2040 has been carried out. This has been used as input to the Arnstad-report (http://www.regjeringen.no/nb/dep/krd/aktuelt/nyheter/2010/Rapport-fra-arbeidsgruppa-for-energieffektivisering-av-bygg.html?id=612776).

A Nordic Project "Analysis of Climate Friendly Buildings" for Nordic Innovation has been carried out. The results indicate that there is a significant potential for increased value creation from Nordic cooperation on climate friendly buildings. The report recommends the following focus areas for cooperation: principles for codes, standards and incentives, demonstration buildings, and new technologies (in particular building envelope technologies and energy supply systems for low loads). The report was presented at the World Climate Solutions in Copenhagen in September.

Related Activities

In the research project "Sustainable upgrading of the mid- and postwar period's residential apartments", which is a four-year project constituting a part of Husbanken's financial/in kind contribution in ZEB, the main research activities/results in 2009 are a report on background knowledge (a working document in Norwegian) and a collection of data from several case studies. The reports, presentations etc. are collected on the project's web-site www.sintef.no/projectweb/boligoppgradering. The project involves WP2, WP3, WP4 and WP5.

LABORATORY FACILITIES/RESEARCH INFRASTRUCTURE

The ZEB researchers do analysis and testing of the materials, components, structures, and solutions they develop in the laboratories, in-situ at a field station, and in pilot buildings. The functionality, usability and robustness of the developed concepts will be investigated and tested in test cells and in pilot buildings, while between the phases of material and component R&D and of experimental buildings, outdoor test facilities will be used to test systems and building concepts under realistic climatic conditions. In total, five laboratories will be developed and/or expanded:

- Advanced Material Technologies Laboratory
- Climate and Building Technologies Laboratory
- Energy and Environmental Laboratory
- Full Scale Test Cell Laboratory
- Pilot Building Measurement In Situ Laboratory

The budgeting and the priorities for laboratory equipment are in place. Together with the extra funding of 5 + 6 mill NOK from the Research Council, 42 mill NOK is allocated to laboratory equipment and pilot project measurement equipment. NTNU and SINTEF have also been granted a pre-project on "Sustainable Building Laboratories – Large-scale Infrastructure for The Research Centre on Zero Emission Buildings".

Main developments of the laboratories in 2010

Advanced Material Technologies Laboratory:
A nano-materials laboratory is currently being built up for the immediate purpose of making and characterizing electrochromic materials with the potential for material or functional combinations with photovoltaic materials. Future work in this laboratory may also include investigations of nanoinsulation materials (NIMs). Among the purchased equipment are an electrochemical workstation, i.e. including

potentiostat, galvanostat, sweep generator, and frequency (impedance) analyser. Various small apparatuses include weight scale, hot plate, magnetic stirrer, oven, furnace, ultrasound mixer, and centrifuge.

An advanced Fourier transform infrared (FTIR) microscope with attenuated total reflectance (ATR) and transmittance and reflectance sample area scanning capabilities is also purchased. This FTIR microscope is directly linked with material characterization libraries and inherits versatile and powerful particle and multi-component software tools.

Climate and Building Technologies Laboratory:
A rotatable hot box apparatus for measurements of thermal transmittance (U-value), thermal conductivity, natural convection in thick porous insulation layers, and high resolution temperature measurements (infrared thermography), where the rotation angle may be varied between 0º and 180º, is presently being constructed.

Apparatus for air tightness measurements of walls and building components has been built, and testing of the apparatus is being conducted.

A Double Room Test Equipment for Building Walls Thermal Performance Testing will be acquired. The tender is in place and the final negotiations with the vendor have been carried out. The equipment will both be a Large Scale Accelerated Climate Simulator Ageing Apparatus and a Test Equipment for Building Walls Thermal Performance. A solar simulator is included in the equipment in addition to heat, frost and water spray. The apparatus is funded via a separate project plus support from NTNU, SINTEF and ZEB (400 kkr).

INTERNATIONAL COOPERATION

Our international partners are the following:

- VTT (Finland)
- Chalmers University (Sweden)
- Fraunhofer Institutes for Building Physics and for Solar Energy Systems (Germany)
- TNO (The Netherlands)
- Lawrence Berkeley National Laboratories (USA)
- Massachusetts Institute of Technology (USA)
- University of Strathclyde (Scotland)
- Tsinghua University (China)

We are cooperating with these in different ways, depending on their, and our, expertise and interest.

With VTT and the Fraunhofer IBP we have prepared EU-proposals (on demonstration buildings and on building envelope technologies). We have also discussed joint EU-proposals with TNO, but so far no concrete proposal has been developed. LBNL was, on the other hand, also involved in one of the proposals we submitted with VTT and Fraunhofer IBP.

We have also hosted an MSc student from VTT who has been doing his experimental work at our Centre, and we are cooperating with Chalmers on the use of vacuum insulation panels and have hosted a PhD-candidate from there on two occasions.

Some members of the ZEB management team visited LBNL in November, in part to study their laboratory facilities (in preparation for the further development of laboratory facilities at the ZEB Centre) and in part to discuss cooperation in general. The Work Package Leader of WP1 on advanced material technologies is cooperating closely with LBNL on these subjects and has been for several years.

The ZEB management team and Board also visited the Fraunhofer ISE in October. As a result of that visit, we have agreed to host one of their researchers for half a year in 2011 and to co-supervise one of their PhD-candidates.

So far, our cooperation with the University of Strathclyde and Tsinghua University has mainly taken place through our joint participation in IEA projects. This is, however, also very useful. We are therefore actively participating in several IEA projects, partly with funding from the ZEB Centre and partly with other funding.

The most important so far is the participation in IEA Solar Heating and Cooling Task 40: Net Zero Energy Buildings. In addition, we are participating in IEA SHC Task 41: Solar Energy and Architecture, in IEA Energy Conservation in Buildings and Community Systems Annex 53: Total Energy Use in Buildings – Analysis and Evaluation Methods, and in IEA Energy Conservation through Energy Storage Annex 23: Applying Energy Storage in Ultra-low Energy Buildings.

In addition to working with our international partners mentioned in the contract, we have also established cooperation with a number of other institutions in the course of the work in the Centre. We have for instance agreed to work quite closely with the similar, albeit significantly smaller, Strategic Research Centre on Zero Energy Buildings established at Aalborg University. And we have just recently signed a Cotutelle agreement for a joint PhD with the Politecnico di Torino, agreeing to sharing the costs, and hosting a candidate from there 50% of the time.

As mentioned above, we have submitted two proposals to EU FP7 together with our international partners VTT and Fraunhofer. One is for the topic EeB.Energy.2011.8.1-1 Demonstration of very low energy new buildings and is called NZEB: Elderly (Housing for the elderly -Nearly zero energy with high indoor comfort). This one is coordinated by VTT. The other one, for the topic EeB.NMP.2011-3 Energy savings technologies for building envelope retrofitting, is called ENVELOPE (European Normalised Ventilated Light Opaque Envelopes). This one is coordinated by the European Aluminium Association (EAA).

In addition, we are participating in a proposal for the topic EeB.NMP.2011-1 Materials for new energy efficient building components with reduced embodied energy. This one is called PEER (Project for Embodied Energy Reduction): A design driven research project for developing new components for energy efficient buildings based on material innovations. It is coordinated by Uni of Twente.

As follow-up of the KIC-application to EU (named SEEIT) submitted last year, we participated in an application for an Erasmus Mundis programme this spring (named Prove-It), with the Copenhagen Business School as coordinator. This application was not accepted, but we will try again with a revised version next spring. The participants in this consortium will also apply for a Marie Curie Initial Training Network with Aalto University, Finland, as coordinator.

In addition, we are participating in the EU-network AERTO (Associated European Research and Technology Organizations): Prefabricated multifunctional façade systems for building renovation. Our international partner Fraunhofer IBP is also participating in this activity.

RECRUITING

We started announcing PhD- and postdoc positions already before the contract was signed and have by now announced openings three times. The number of applicants has been exceptionally high every time. As usual, a relatively high number of applicants do not have the required qualifications or do not have relevant backgrounds, but even so, the number of highly qualified applicants has been high enough to make selection difficult. We have therefore interviewed quite a few applicants.

By the end of 2010, nine PhD candidates and three postdocs were working at the Centre. We have been encouraging the ZEB partners to find potential candidates from within their organizations. As a result, one of the PhD candidates comes from our partner Snøhetta, and another one is cooperating closely with our partner ByBo and is partly funded by them. In addition, we have established an agreement with the Technical University in Torino, using the Cotutelle Agreement for joint degrees, for one PhD candidate.

The recruitment of a ZEB professor in civil engineering is, unfortunately, delayed. The position was announced once, but only two applicants responded. The Management Team and the Executive Board did not find that satisfactory and decided to make a new announcement. This has now been prepared.

In addition to PhDs and postdocs, several MSc-students have been involved in the work in ZEB. These include students at NTNU as well as students from the universities we cooperate with abroad. In 2009 NTNU also approved the establishment of an international, two-year MSc programme in Sustainable Architecture (with the specific title “Towards Zero Emission Built Environment”). This is directly based on the work program in ZEB, and many of the researchers in ZEB also teach in this programme. The number of applicants was also for this very high, and the first 20, highly qualified students have now started. These will provide a good basis for future recruitment of personnel both for NTNU and SINTEF and for the other ZEB partners.

ACCOUNTS

The table below shows the costs for the different activities.

Cost report for 2010 (1000 NOK)

Activities	2010
Management and administration of the Centre	3005
WP1: Advanced materials and technologies	2 082
WP2: Climate-adapted low-energy envelope systems	1 453
WP3: Energy systems for zero-emission buildings	1445
WP4: Energy efficient use and operation	1 097
WP5: Concepts and strategies for ZEB	2491
In kind contribution from the user partners[1]	5 916
Dissemination of knowledge (conferences, seminars workshops, Buildings design sheets)[2]	606
Training of research personnel, professor position	6 270
In kind contribution, SINTEF and NTNU (scientific personnel, common for all Work Packages)	2 526
Ongoing projects within the Centre (only public funding)	3 300
Equipment	4 327
Total costs	34 518

KNOWLEDGE DISSEMINATION

The Centre has only been in operation for 13 months, so there are not too many concrete results to present yet. Still, the ZEB researchers are already very active in publishing results from their work - as can be seen from the attached list of publications. In addition, many of the participants have been asked to give general presentations of our activities, in a wide range of forums, and several have also been interviewed for articles in various media. These include both popular media such as newspapers, and more professional magazines, such as Teknisk Ukeblad and the like. In general, the Centre leaders are receiving so many requests to tell about ZEB that time is becoming a problem.

“Internally”, we spend quite a lot of time arranging workshops and meetings with our user partners, making sure they are continuously informed and involved. In addition, we arranged an open ZEB/NTNU seminar on Architecture and Energy in March this year, and we were heavily involved in the International Research Conference on Renewable Energy which took place in Trondheim in June. Many of our researchers also presented papers there.

In the future we intend to use the web more actively for communication. The Centre has its own web site, where news and announcements are placed. This site will naturally include more extensive coverage of the activities as results start to appear and as pilot buildings start to materialize.

APPENDICES

Appendix A1 Personnel
Appendix A2 Statement of Accounts
Appendix A3 Publications