Zero Emission Buildings –
Examples and Research Challenges

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ZEB’s Main Objective

is to develop competitive products and solutions for existing and new buildings that will lead to market penetration of buildings with zero greenhouse gas emissions related to their production, operation, and demolition.

The centre will encompass both residential, commercial, and public buildings.

www.zeb.no
ZEB Facts

- ZEB is a Centre for Environment-friendly Energy Research (FME), funded by the Research Council of Norway (RCN) and 26 partners.

- Host institution is NTNU with SINTEF Building and Infrastructure and SINTEF Energy Research as research partners.

- Centre started in November 2009, and RCN funds the Centre for 8 years. 50% funding from industry.

- Total budget: ca. 290 MNOK (+ additional to research infrastructure)
ZEB Centre Partners

- Users (the reference group)
- Contractors
- Producers of materials and products for the building industry
- Consultants, architects
- Property managers
- Public administration
- Trade organizations
- University and research institutions
- The Research Council

Skanska
Caverion
Weber
Isola
Glava
Protan
Sapa Building Systems
NorDan
Velux
DuPont
Brødrene Dahl
Multiconsult
Snøhetta
ByBo
Entra Eiendom
Forsvarsbygg
Statsbygg
Enova
Husbanken
Direktoratet for byggkvalitet
Byggenæringens landsforening
Norsk Teknologi
NTNU
SINTEF Byggforsk, SINTEF Energi
Norges forskningsråd
Energy Use in Buildings in Norway

- 37%: Mobil energibruk (alle kjøretøy og transportmidler)
- 31%: Bygg (boliger og yrkesbygg)
- 7%: Produksjon av energivarer
- 25%: Industriprosesser

83 TWh til bygninger, hvorav 80% er elektrisitet.

Source: Energibruk i Fastlands-Norge, NVE, 2011
Why Zero Emission Buildings?

• Norwegian Policy documents
  – Two White Papers from the Norwegian government in 2012 stress all new buildings should be nearly zero energy buildings before 2020. Stricter requirements will also apply to rehabilitation of existing buildings

• EU Regulation: The Energy Performance of Buildings Directive 2010/31/EU (EPBD)
  – Member States shall ensure that by 31 December 2020, all new buildings are nearly zero-energy buildings
The Challenge:

Renewable energy sources produced or transformed at the building site have to compensate for CO₂ emissions from operation of the building and for production, transport and demolition of all the building materials and components during the life cycle of the building.

Energy standard, single family houses in Norway

![Energy standard bar chart](source: SINTEF Byggforsk)
Research Activities

ZEB focuses its work in six areas that interact and influence each other:

- WP1 Advanced materials technologies
- WP2 Climate-adapted and energy efficient envelope technologies
- WP3 Energy supply systems and services
- WP4 Use, operation, and implementation
- WP5 Zero emission building concepts and strategies
- WP6 Pilot buildings
ZEB Pilot Buildings

ZEB PILOT BUILDINGS:

4. Ådland, Bergen. 720 dwellings.
7. ZEB Living Lab, Trondheim.
8. Heimdal Highschool
9. Campus Evenstad
Powerhouse Brattørkaia - Trondheim
Powerhouse Brattørkaia - Trondheim

2013 version

• Roof angle 20 degrees
• Heated area 13 114 m²
• Average yearly solar energy 607 212 kWh
Zero Emission Buildings Definition

Ref: B. Risholt et al.

The Research Centre on Zero Emission Buildings
The main concept of a zero emission building is that renewable energy sources produced or transformed at the building site have to compensate for CO2 emissions from operation of the building and for production, transport and demolition of all the building materials and components during the life cycle of the building.
Example – Residential Dwelling

160 m², 2 story high single family house which is assumed located in Oslo

<table>
<thead>
<tr>
<th>Values</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>External walls</td>
<td>U = 0.12 W/m²K, Timbered wall with 350 mm insulation.</td>
</tr>
<tr>
<td>External roof</td>
<td>U = 0.10 W/m²K, Compact roof with approximately 450 mm insulation.</td>
</tr>
<tr>
<td>Slab on ground</td>
<td>U = 0.07 W/m²K, (U = 0.06 W/m²K), Floor construction with 500 mm insulation. U-value in brackets takes into account the thermal resistance of the ground.</td>
</tr>
<tr>
<td>Windows</td>
<td>U = 0.65 W/m²K, Three layer low energy windows, with insulated frame.</td>
</tr>
<tr>
<td>Doors</td>
<td>U = 0.65 W/m²K, Well insulated doors.</td>
</tr>
<tr>
<td>Normalized thermal bridge value</td>
<td>ψ&quot; = 0.03 W/m²K, Detailed thermal bridge design</td>
</tr>
<tr>
<td>Air tightness</td>
<td>N50 &lt; 0.3 ach@50 Pa, Detailed design of a continuous vapour and wind barrier, good quality assurance and pressure testing of the building in two stages (when the wind barrier is mounted and when the building is finished).</td>
</tr>
</tbody>
</table>
Concept Work –
Building Services and Energy Supply

- Efficient ventilation system, $\eta = 85\%$, SFP = 1 kW/(m\(^3\)/s)
- Hydronic floor heating and radiators
- LED-lights
- Energy efficient technical equipment
- Domestic hot water is pre-heated using a grey water heat exchanger
- Vacuum tube solar collectors on the vertical south façade (8.3 m\(^2\)).
- Air-to-water heat pump
- Tilted PV-panels on the flat roof. Monocrystalline cell type with very high nominal efficiency (20.3 %). A total of 49 m\(^2\) south facing and 20 m\(^2\) north facing PV-panels.
- 60 year lifetime for building, 30 year lifetime for PV, 20 year lifetime for solar collectors and 20 year lifetime for heat pump
Concept Work –
Embodied and Operational GHG-emissions

5.0 kg/m²/year (41 %)

7.2 kg/m²/year (59 %)
Concept Work – Embodied GHG-emissions
Concept Work – 
Embodied GHG-emissions per Material

![Graph showing distribution of emissions per material (kgCO₂eq/m²/year)]
Concept Work –
GHG Emissions Balance

CO₂-balance - Flat roof

- Embodied emission
- Cooling
- Appliances
- Lighting
- Fans & pumps
- Heat pump system
- Solar thermal system
- PV-facade

EMISSION OPER&EMBODIED: 8 kg/m²/year
PV-PRODUCTION: 12 kg/m²/year
Some Challenges

• Thick insulation layers – Might be OK in new buildings, but is challenging in existing buildings (alternatives like aerogel and vacuum insulation panels can be considered).

• Material emissions are large – more efficient use and reuse of materials are necessary. More environmental friendly materials are needed.

• Use building integrated solar energy harvesting systems (avoids having separate roofing and PV system)

• Good alternatives to PV?

• Mismatch of renewable energy production and use

• Next step: **Area** optimization instead of **building** optimization
Some examples of specific technologies
Nano Insulation Materials (NIM)

From theoretical concepts to development of new and innovative materials

\[
\lambda_{\text{gas}} = \frac{\lambda_{\text{gas,0}}}{1 + 2\beta \text{Kn}} = \frac{\lambda_{\text{gas,0}}}{1 + \sqrt{2\beta k_B T}}
\]

\[
\text{Kn} = \frac{\sigma_{\text{mean}}}{\delta} = \frac{k_B T}{\sqrt{2\pi d^2 p \delta}}
\]

Patent application

- Controlling:
  - Sphere inner diameter
  - Sphere wall thickness

Without optimizing:
So far we have reached 20 mW/(mK)
A new glass material

- A new glass material has been made:
  - Reduced mass density (weight) by a factor 2
  - Reduced thermal conductivity by a factor 2
  - Increased solar transmittance

Various other glass and coating properties being investigated
Increasing the thermal resistance of concrete

Mixtures of aerogel and concrete have been investigated
- Conductivity decreases with increased aerogel content.
- Compressive strength decreases with aerogel content.

Material composition
- Aerogel granulates have been mixed into concrete
- The aerogel seems to maintain its initial properties when mixed with concrete.

(a) and (b) SEM photos of aerogel incorporated in concrete, (c) photo comparing concrete with (60 vol%) and without aerogel, and (d) thermal conductivity and compressive strength as a function of mass density and aerogel content in vol%.
An innovative and new type of PCM emulsion was developed
  • Flowable and able to integrate in circulating heating systems, as a higher heat capacity alternative to water.
  • Greater thermal conductivity improves heat transfer.

The long-term performance of several PCM materials used in construction was measured
  • Thermal degradation of the PCM means a reduction in heat storage performance
Development of Sandwich Elements with VIPs (Leca Isoblock)

- Development of thinner building components

- Leca Isoblokk (concrete building system) with VIP - Prototype developed by ZEB partner Weber (patent has been applied for)
NorDan and Aventa Solar have developed a solar thermal collector that can be easily integrated in the facade.
Phase change material experiments

Used to validate e.g. EnergyPlus PCM models.
Windows in the buildings of tomorrow; Energy losers or energy gainers?

- Thermal performance of transparent areas; beneficial effects of incident solar radiation and reduced demand for artificial lighting
- Numerical case study of an office building
New Type of a Cross Flow Energy Exchanger using Membrane Technology

• Development of improved energy exchanger using membrane technology

• Recovery of moisture in addition to sensible heat will increase the overall energy efficiency of the exchanger. This will also reduce frosting problems in operation but it demands very careful design of the exchanger.
Simple decision support tool for selection of energy supply solutions in an early project design phase

- Study among partners and relevant players in the building industry in Norway focusing on obstacles for wider use of new technologies and solutions for energy supply discovered a great lack of necessary knowledge regarding practical application.
- A simple decision support tool focusing on selection of energy supply solutions in an early project design phase supported by a database on energy supply technologies which are good and robust for the near future under Norwegian conditions will enhance market penetration of new technologies and solutions.
Analyses of End-Use in Energy Efficient Buildings

• Evaluation of new buildings with high energy ambitions
  – Bad interfaces
  – Lack of knowledge

• Unintended persistence of energy wasting behaviors (when refurbishing/upgrading systems)
  – Deeply rooted values and attitudes
  – Negotiations within the household
Establishment of Research Buildings at NTNU – ZEB Living Lab and Research Cell

ZEB Living Lab – A dwelling for user-technology studies

ZEB Test Cell for testing of different technologies
ZEB Living Lab

- 100 m² living area
- Building Integrated Photovoltaics: 80 m²
- Solar panel in the facade
- Ground to water heat pump
- Heat recovery system
- A part of student work
ZEB Test Cell

- Collaboration with Lawrence Berkeley National Laboratory
- PhD and MSc student activities
Research building collaboration – To investigate and develop building technologies for different climates

- Berkeley, USA
- Germany
- Singapore
- Qatar
Thank you for your attention

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