Environmental Energy Technologies Division Seminar
LBNL, Berkeley, September 11, 2014

The Norwegian Research Centre
on
Zero Emission Buildings - ZEB

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Department of Energy and Process Technology

NTNU
Norwegian University of Science and Technology

Outline

- Few facts about Norway and NTNU
- The Norwegian Research Centre on Zero Emission Buildings - ZEB
  - Facts
  - Organization
  - Selected research activities
  - Pilot project
  - Laboratories

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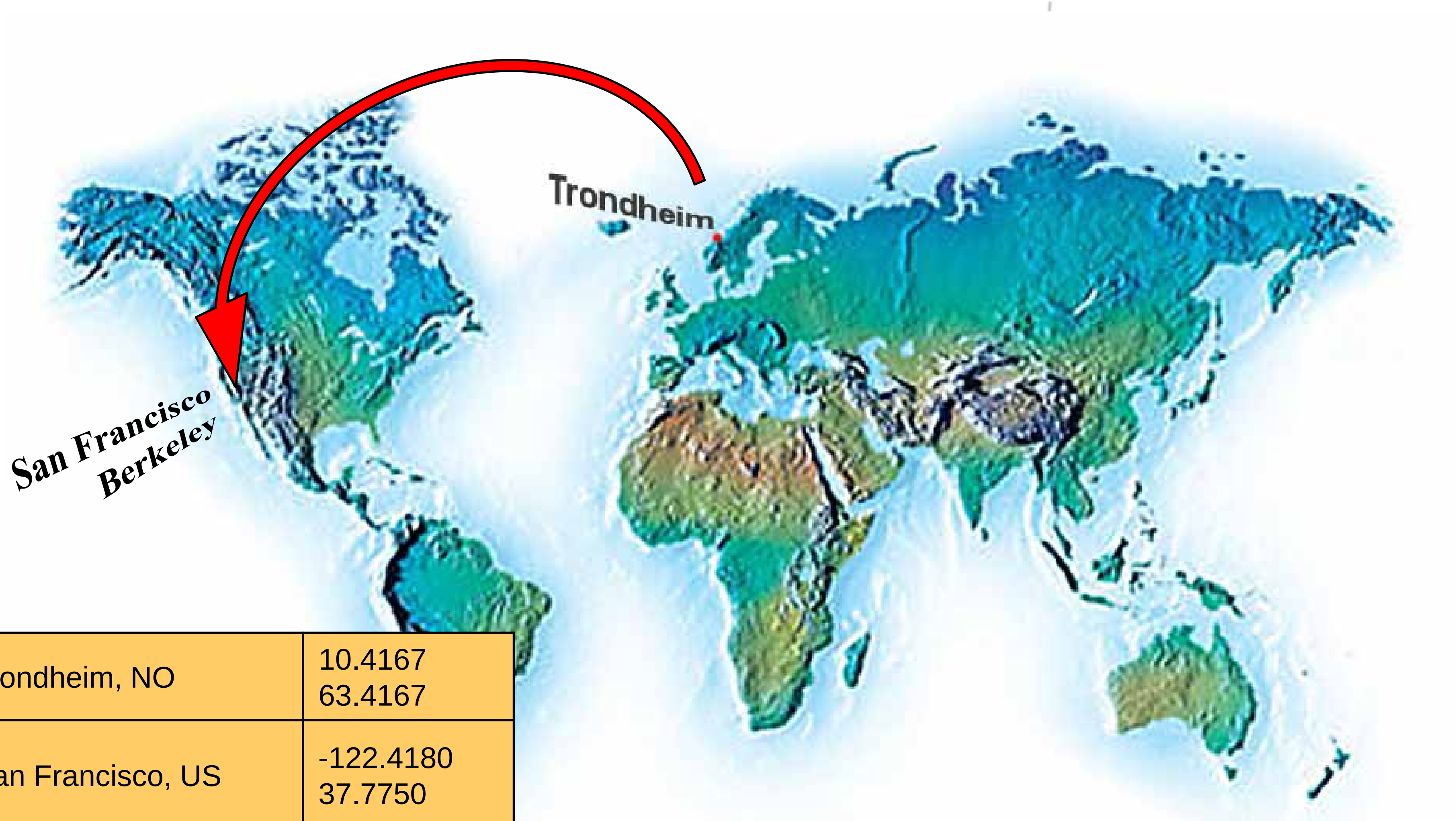

Trondheim, NO	10.4167 63.4167
San Francisco, US	-122.4180 37.7750
Miles:	**~ 5000**
Kilometers:	**~ 8000**
Bearing:	**SW**

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*** Area**

Kingdom of Norway

	385 178 km²
Mainland:	**323 779 km²**
Svalbard:	**61 022 km²**
Jan Mayen:	**377 km²**

*** Compass extremes**

North: 71° 11' 09'' N.Lat.
South: 57° 57' 31'' N.Lat.
West: 04° 29' 57'' E.Long.
East: 31° 10' 07'' E.Long.

*** Shared international borders**

Total	**2 562 km**
with Sweden	**1 630 km**
with Finland	**736 km**
with Russia	**196 km**

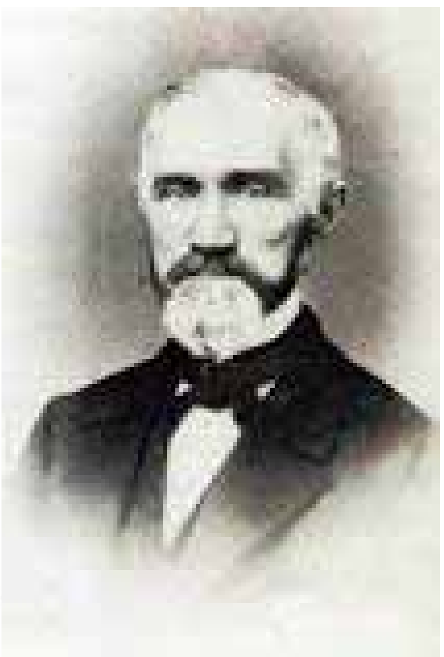
*** Straight-line distance**

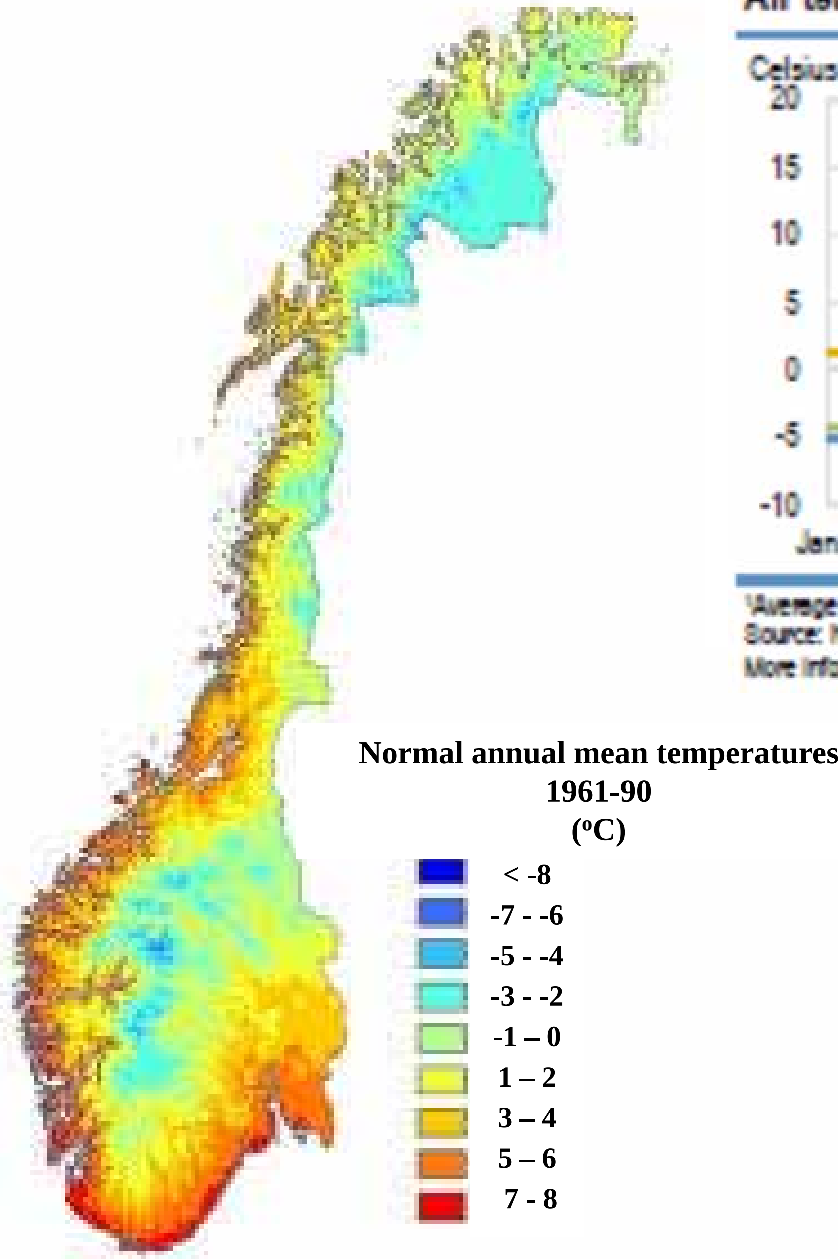
North – South: 1 752 km

*** Length of coastline, mainland 28 953 km**

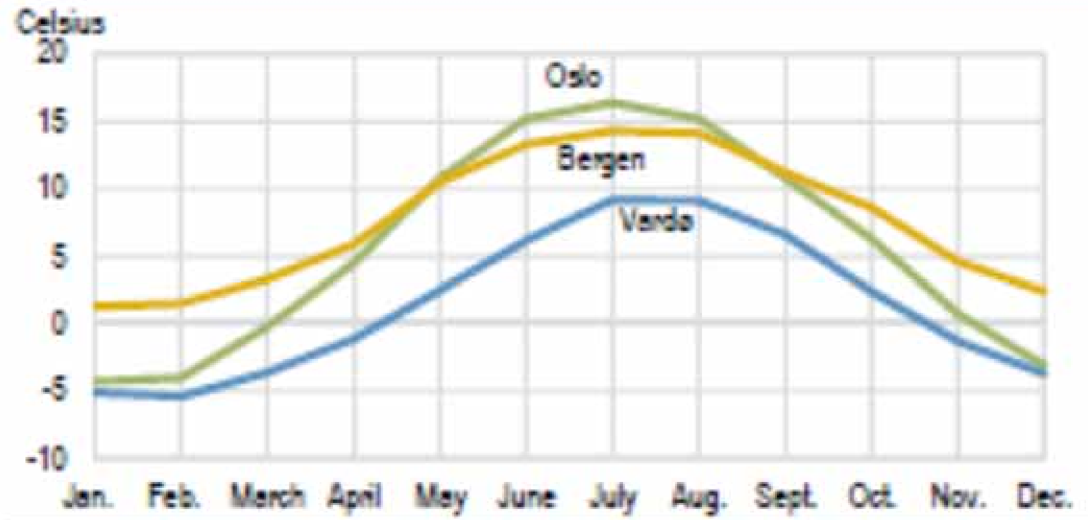
Peder Sather

- was a prominent Norwegian-born American banker who is best known for his legacy to the University of California, Berkeley.
  - Born: September 25, 1810, Trondheim
  - Died: December 28, 1886





Air temperature averages[1]



[1]Average for 1961-1990 (current standard normal period) in degrees C.
Source: Norwegian Meteorological Institute.
More information: http://met.no/English/

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NTNU – Trondheim
Norwegian University of
Science and Technology

NTNU
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Science and Technology

NTNU's vision

NTNU is to be an academic leader that safeguards and expands Norway's technological expertise.

With its strong disciplinary standing and broad academic scope, NTNU will contribute to greater understanding of the interaction between culture, society, nature and technology.

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Norwegian University of Science and Technology

NTNU's history

- **1210: Schola Cathedralis Nidarosiensis**
- **1760: Royal Norwegian Society of Sciences and Letters**
- **1870: Trondheim Technical Educational Institution**
- **1910: Norwegian Institute of Technology (NTH)**
- **1922: Norwegian Teacher Training College**
- **1968: University of Trondheim**
- **1973: Music Conservatory in Trondheim**
- **1979: Trondheim Academy of Fine Art**
- **1984: College of Arts and Science**
- **1996: Norwegian University of Science and Technology**

- **2010: 100 Years Anniversary of NTNU**
  250 Years of Trondheim being an academic city

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Norwegian University of Science and Technology

NTNU key figures

- 53 departments in 7 faculties

- 20 000 registered students
- 7 000 admitted/year
- 3 000 degrees awarded/year
- 240 doctoral degrees awarded/year

- 4 300 man-labour years
- 2 500 employees in education and research
- 550 professors
- Budget: US $ 625 million
- 555 000 m^2 owned and rented premises

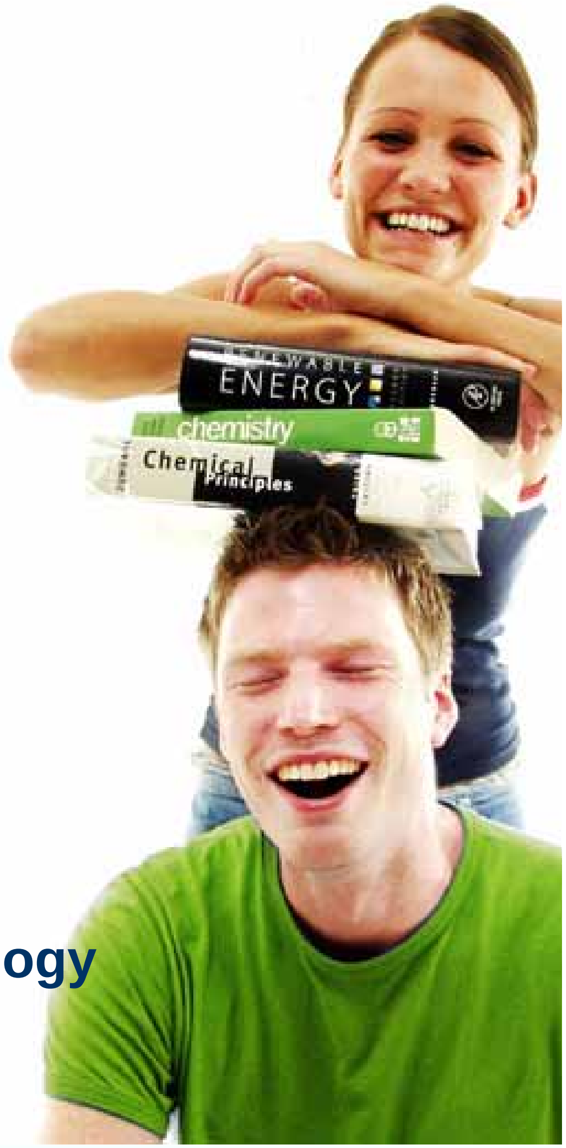
NTNU
Norwegian University of Science and Technology

Education

- 20 000 registered students
- 58 000 student applications
- 9 500 have NTNU as their first choice
- 7 000 students are admitted

- 3 000 courses
- 3 000 degrees awarded
- 244 doctoral degrees awarded

- 100 two-year Master's programmes
- 23 five-year Master's programmes
- 22 Bachelor's programmes
- Professional degrees in medicine and psychology

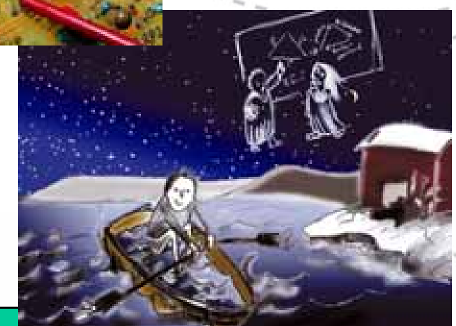


Ten areas of study

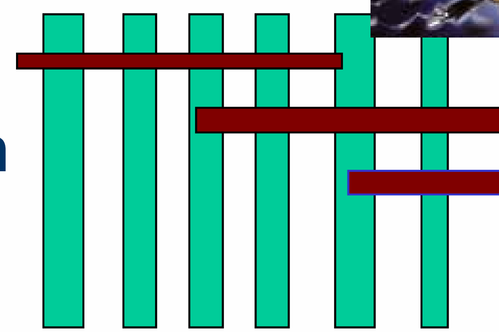
- Architecture
- Technology
- Humanities
- Science
- Social sciences
- Medicine
- Psychology
- Fine art
- Music
- Practical-pedagogical education

Research – a core activity

The fundamental strengths:



- Technology and the natural sciences
- Broad academic base
- Interdisciplinary collaboration



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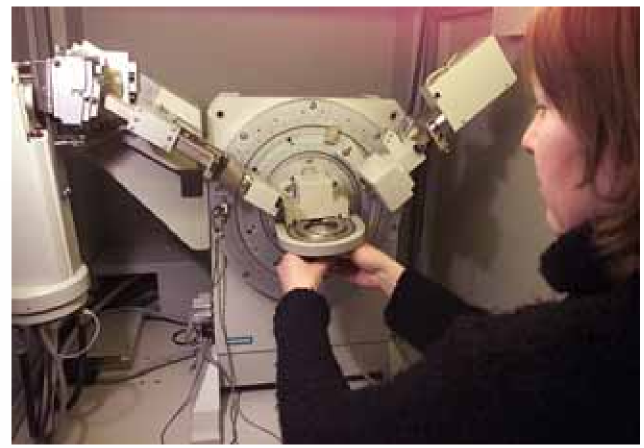

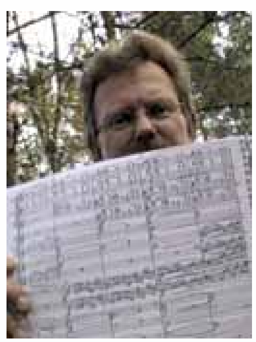

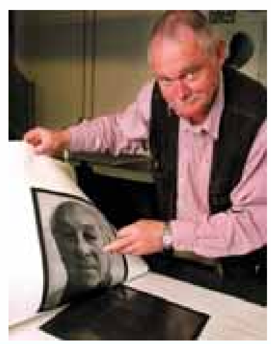

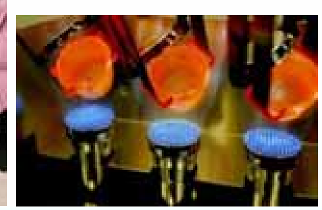

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Science and Technology

Cooperation with SINTEF

- SINTEF is one of Europe's largest independent research organizations
- Budget: US $ 380 mill./year
- 1900 staff
- Established in 1950 as the contract research organization of the Norwegian Institute of Technology
- Contract research in technology, natural sciences, medicine and social sciences
- Cooperates with NTNU in terms of staff, equipment, laboratories and science communication
- 18 Gemini Centres for joint NTNU-SINTEF R&D

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NTNU's six strategic R&D areas

Energy and Petroleum – Resources and Environment

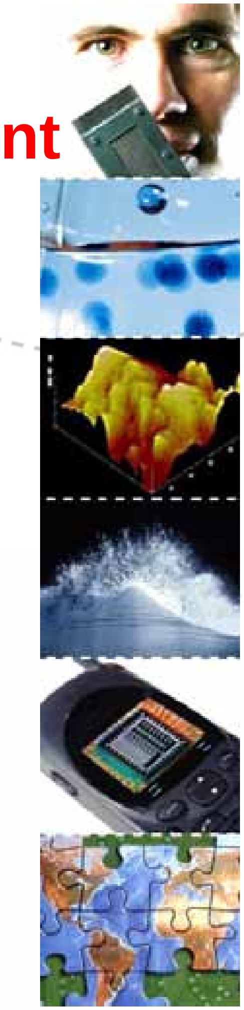
Medical Technology

Materials Technology

Marine and Maritime Technology

Information and Communication Technology

Globalization



Budget:

Seed funding
(US $ 0.7–2 million per area)

Funding of PhD candidates

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Innovative Technologies and Processes for Buildings

– The Research Centre on Zero Emission Buildings

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

Illustration: Snøhetta/MIR

The Research Centre on Zero Emission Buildings

FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI

ZEB Facts

- ZEB is a Centre for Environment-friendly Energy Research (FME), funded by the Research Council of Norway (RCN) and 25 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. US $ 47 mill (+ additional to research infrastructure)

Expertise in the ZEB Centre

ZEB includes experts within material science, building technology, energy technology, architecture, and social science.

Strong industry involvement will put focus on finding cost-effective and competitive solutions.

ZEB encompasses the whole value chain of market players within the Norwegian construction sector.

ZEB cooperates with international well-known research institutions with relevant activities.

The expected volume of formally trained research personnel is
15 PhD-students, 5 post-doctoral fellows and at least 50 MSc-students.

ZEB – A National Team

- Users (the reference group)
- Contractors
- Producers of materials and componenets for the building industry
- Consulting engineers, 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

Other institutions cooperating with ZEB:

International partners:

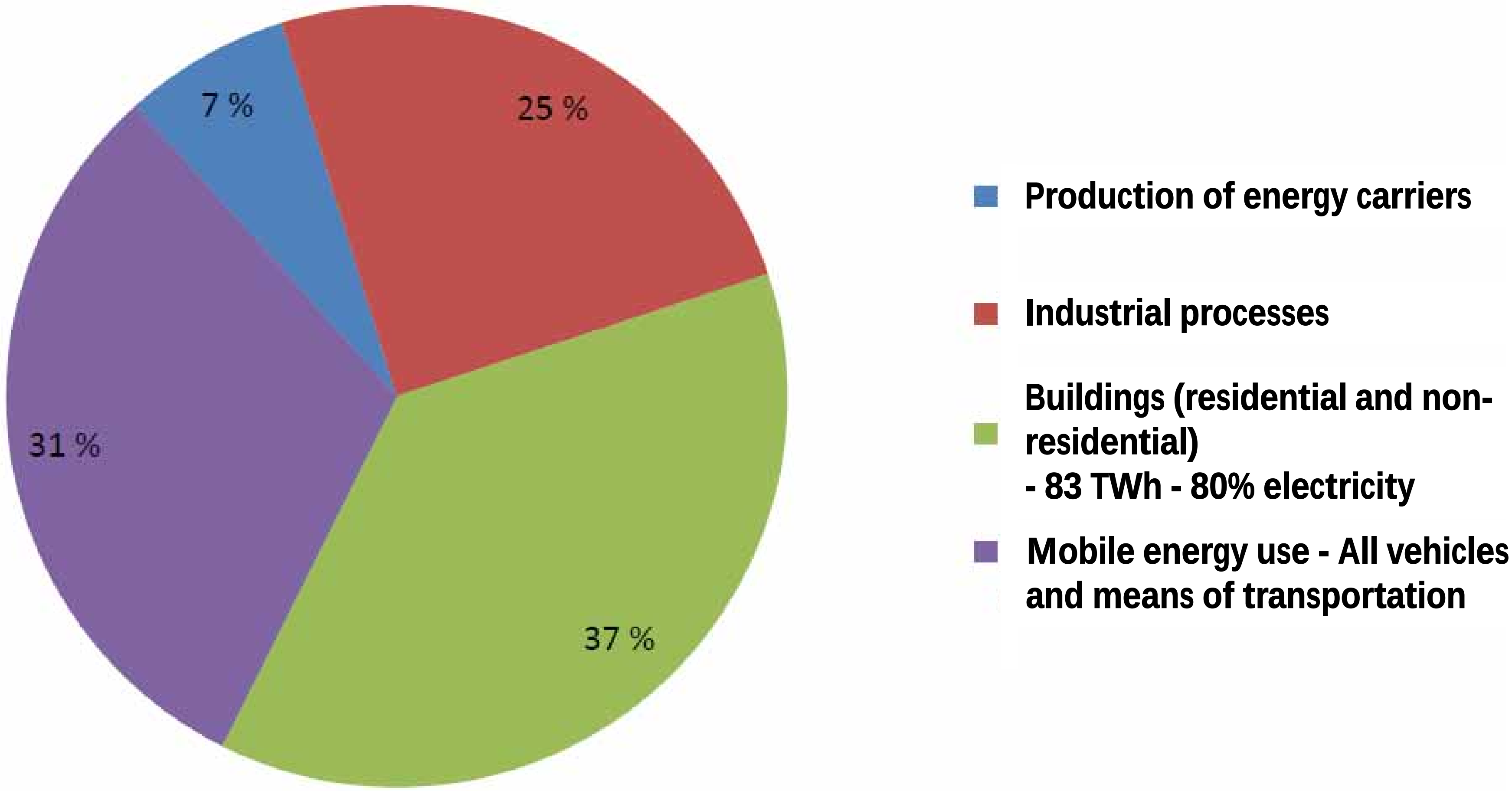
- VTT (Finland)
- Chalmers (Sweden)
- Fraunhofer (Germany)
- TNO (The Netherlands)
- LBNL (USA)
- MIT (USA)
- University of Strathclyde (Scotland)
- Tsinghua University (China)
- Shanghai Jiao Tong University (China)

The reference group:

- Lavenergiprogrammet
- NBBL
- NVE
- Forbrukerrådet
- EcoBox
- Driftsforum
- Enova

In addition, we are actively involved in a number of IEA projects within the SHC and EBC programmes (Tasks 40, 41, 42,…, Annex 53, 58 ..), as well as in a number of EU and Nordic research projects.

Energy Use in Buildings in Norway



Source: Energibruk i Fastlands-Norge, NVE, 2011

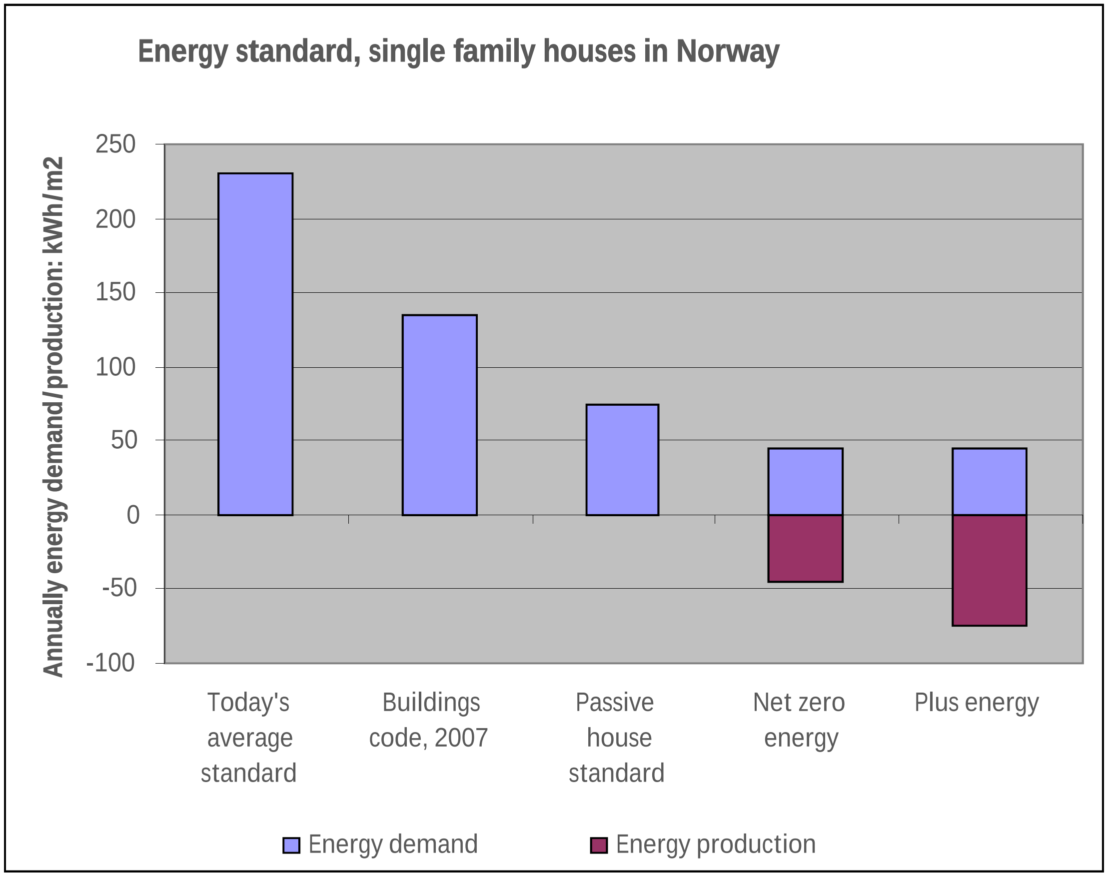
Why Zero Emission Buildings?

- 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 CO_2 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**.



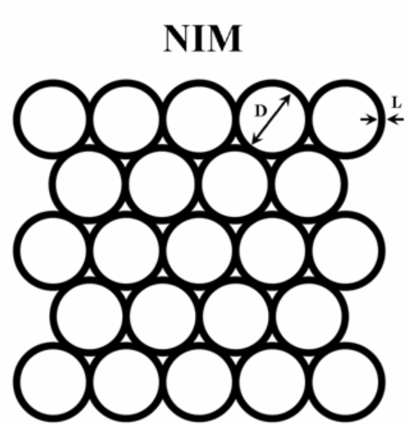
Source: SINTEF Byggforsk

The Research Centre on Zero Emission Buildings

Research Activities with Innovation Examples

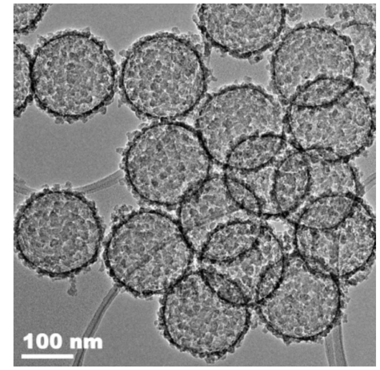
ZEB focuses its work in five areas that interact and influence each other:

- WP1 Advanced materials technologies
- WP2 Climate-adapted low-energy envelope technologies
- WP3 Energy supply systems and services
- WP4 Use, operation, and implementation
- WP5 Pilot buildings, concepts and strategies



Nano Insulation Materials (NIM)

From theoretical concepts to development of new and innovative materials

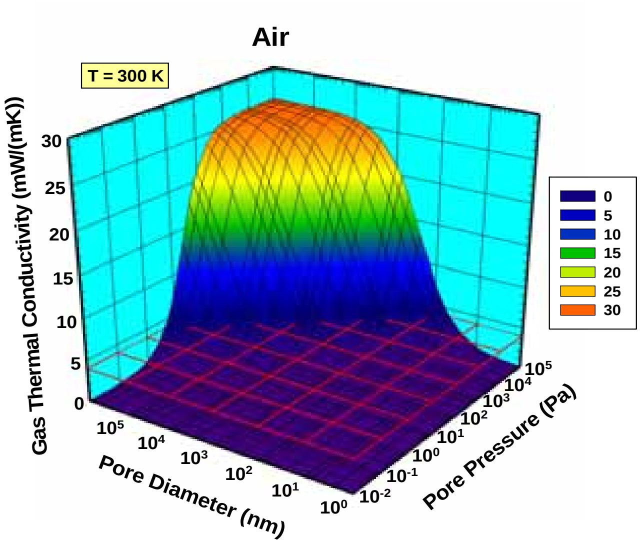


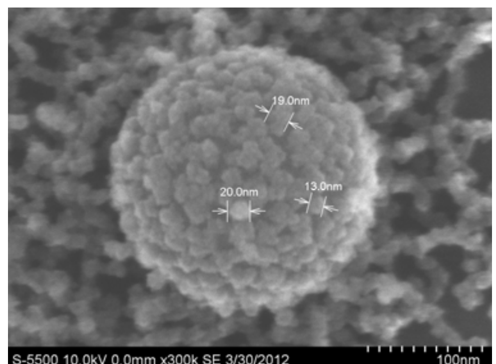
$$\lambda_{gas} = \frac{\lambda_{gas,0}}{1 + 2\beta Kn} = \frac{\lambda_{gas,0}}{1 + \frac{\sqrt{2}\beta k_B T}{\pi d^2 p \delta}}$$

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

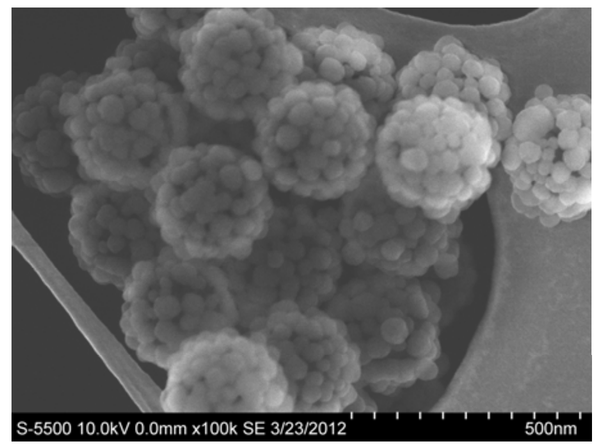
Patent application

- **Controlling:**
- **Sphere inner diameter**
- **Sphere wall thickness**





Without optimizing: So far we have reached 20 mW/(mK)



Development of Sandwich Elements with VIPs (Leca Isoblock)

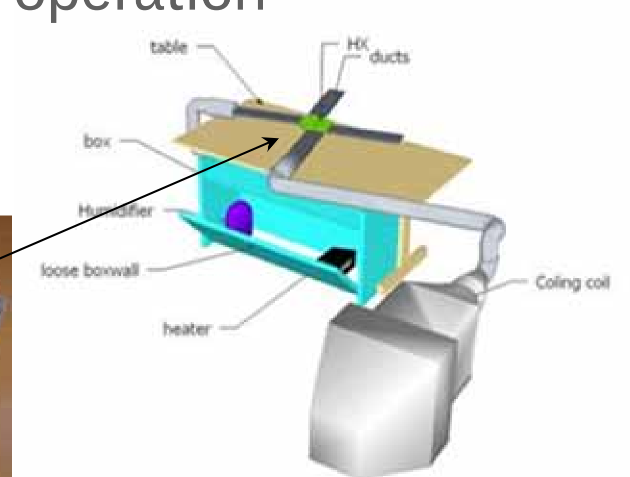
- Development of thinner building components

- Leca Isoblokk 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

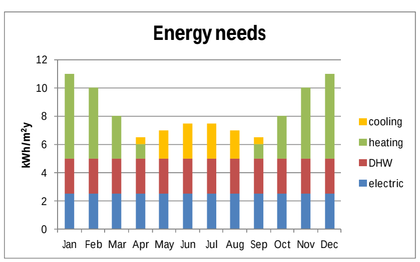
New Type of a Cross Flow Energy Exchanger using Membrane Technology

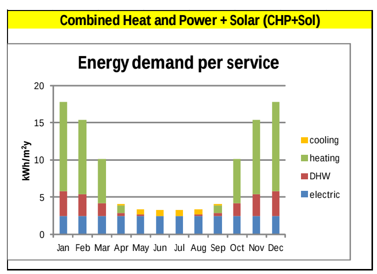
- Development of improved energy exchanger using membrane technology
- Recovery of moisture in addition to sensible heat will increase the overall energy efficiency of the exchanger.
- This will also reduce frosting problems in operation but it demand very careful design of the exchanger.

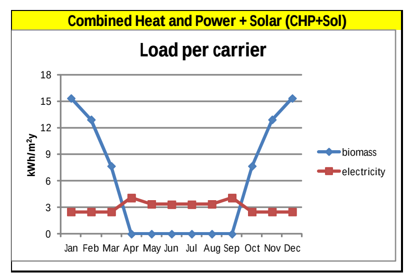


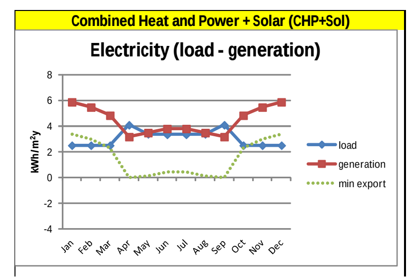
Simple decision support tool for selection of energy supply solutions in an early project design phase

- 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.

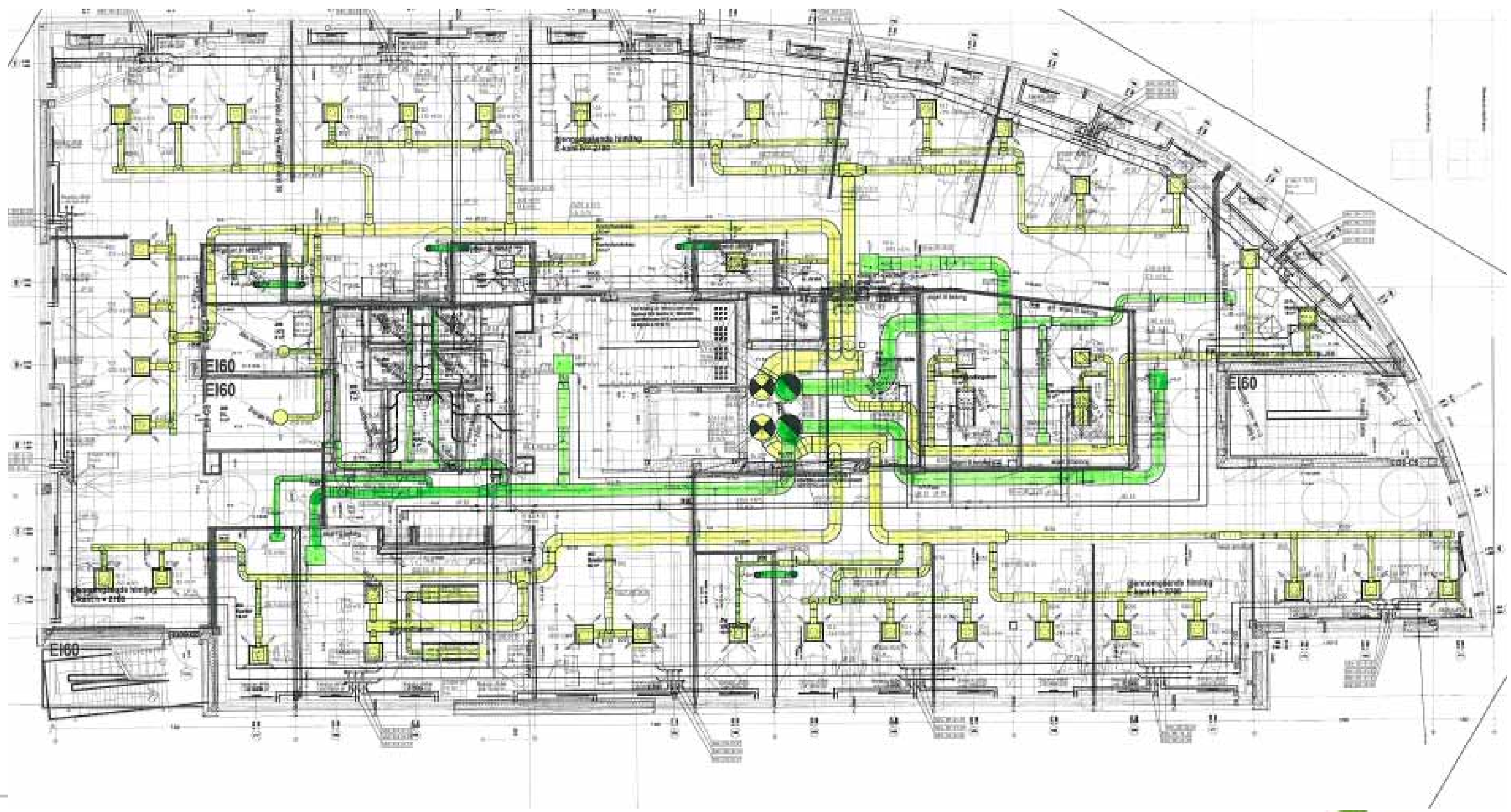








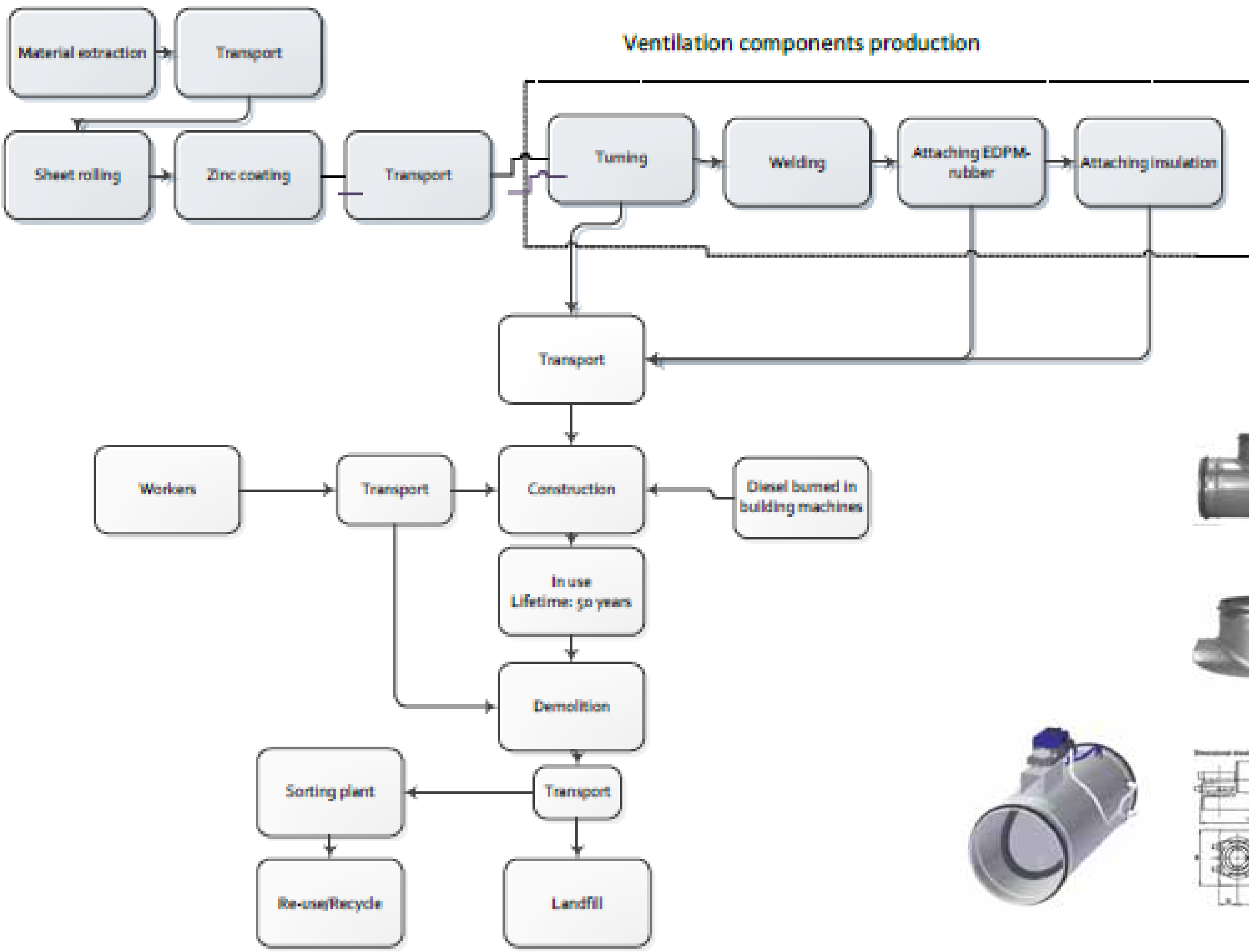
Life Cycle Assessment as a tool for comparison of building services systems
Case: VAV/DCV versus CAV in office buildings

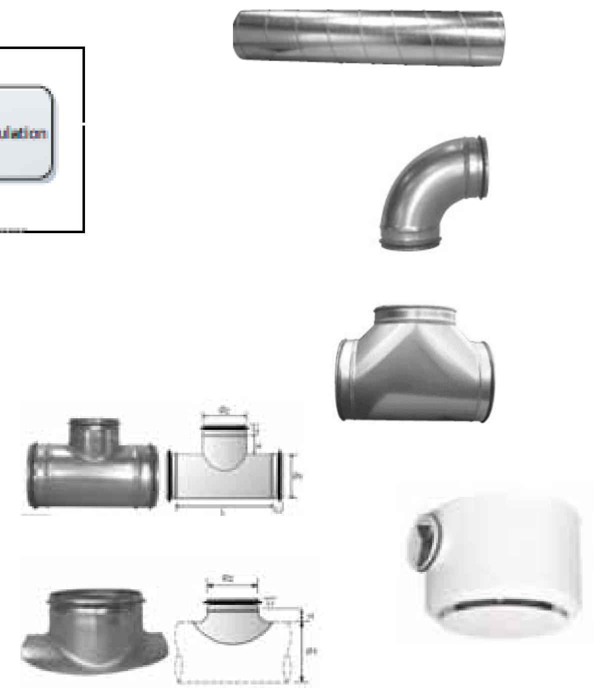


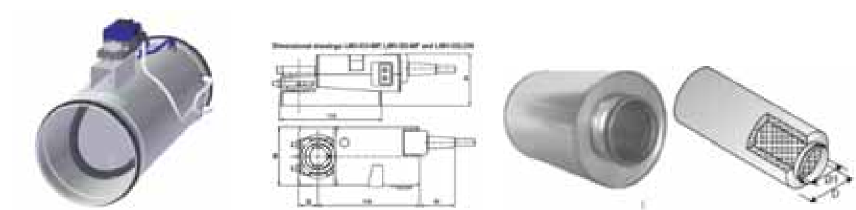
ZEB The Research Centre on Zero Emission Buildings

FME FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI

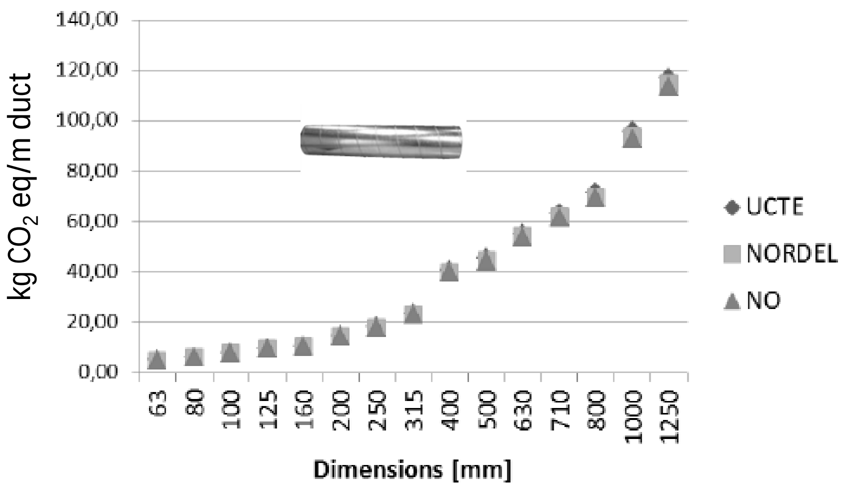
Life Cycle Inventory for ventilation ductwork components

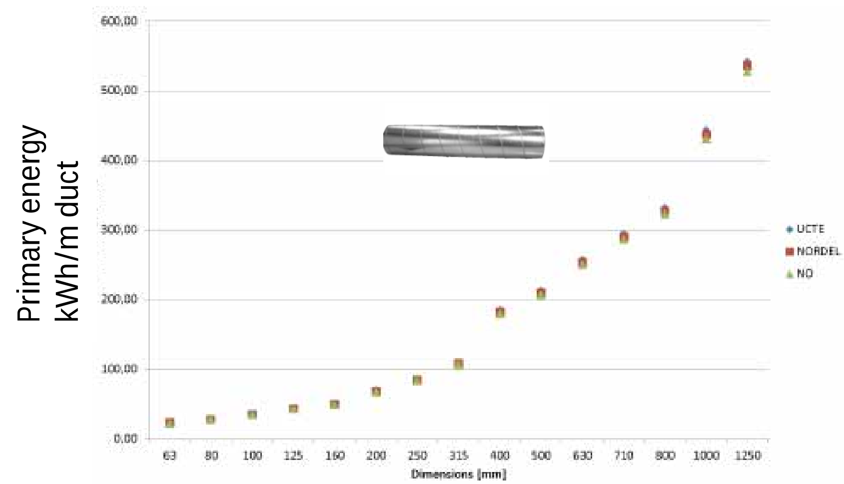


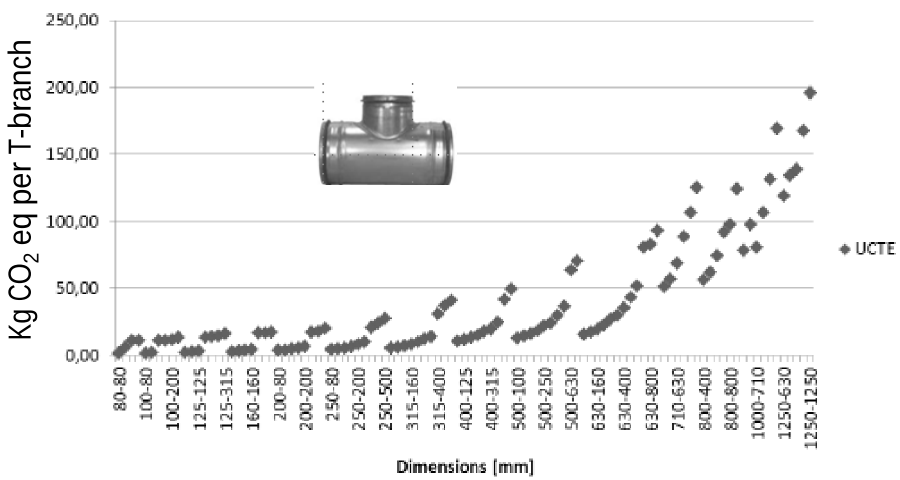


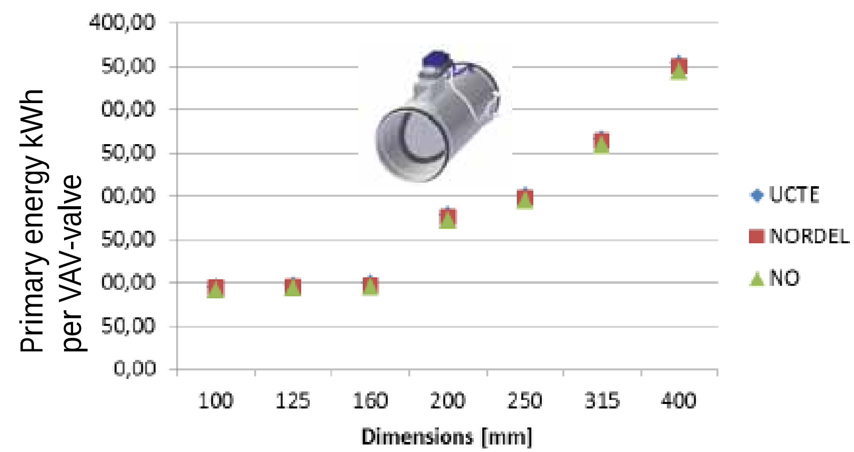


LCI-data – embodied energy and CO_2-eq



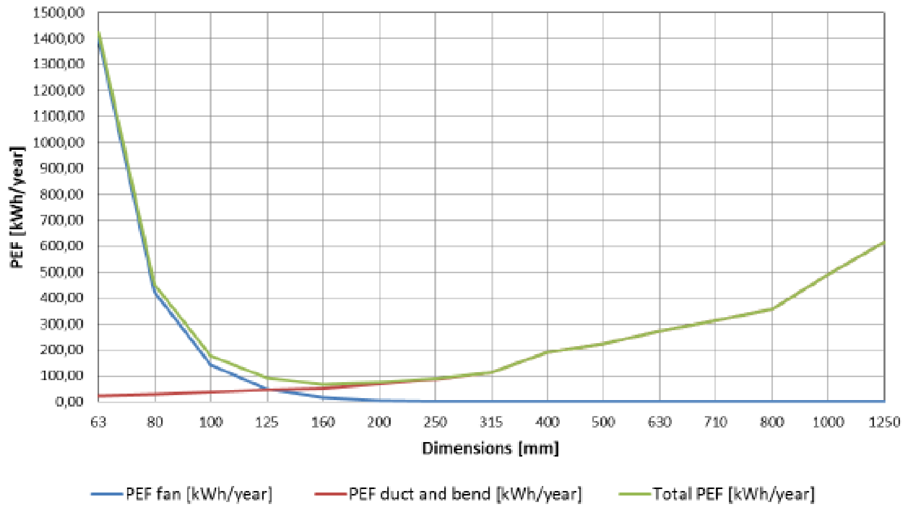


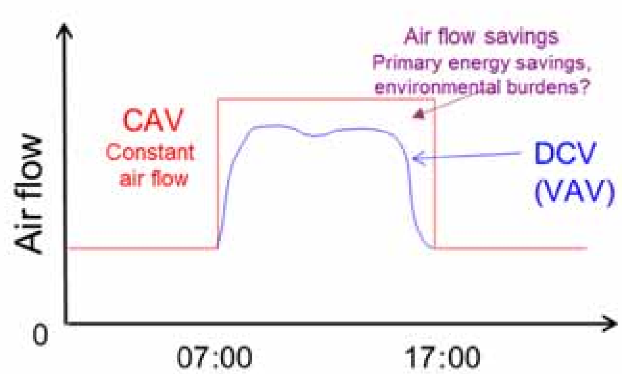




The Research Centre on
Zero Emission Buildings

A systematic approach to LCA for the sizing of ventilation ductwork





Based on: J. Halvardsson & HM Mathisen, NTNU

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)
  - Deeply rooted values and attitudes
  - Negotiations within the household

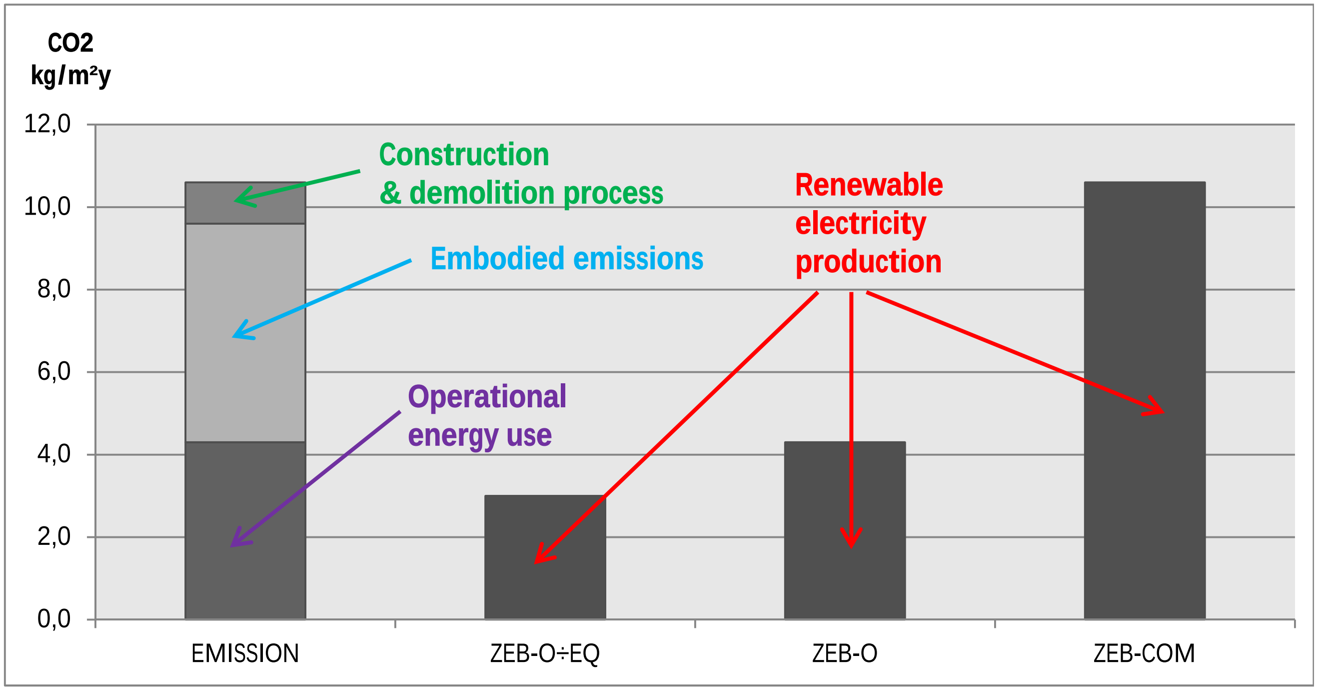
ZEB-Pilot Buildings

ZEB PILOT BUILDINGS:

1. Skarpnes, Arendal: 37 dwellings.
2. Powerhouse Kjørbo, Sandvika. Renovation of 2 office blocks.
3. Mulitkomfort, Larvik. Single family house.
4. Ådland, Bergen. 500-800 dwellings.
5. Powerhouse Brattørkaia, Trondheim. Large office building.
6. Depotbygget Haakonsvern, Bergen. Small office building.
7. ZEB Living Lab, Trondheim.

ZEB-Definition

ZEB-DEFINITION:
1. Ambition level
2. Rules for calculation
3. System boundaries
4. CO2-factors
5. Energy quality
6. Mismatch production and demand
7. Minimum requirement energy efficiency
8. Requirement indoor climate
9. Verification in use

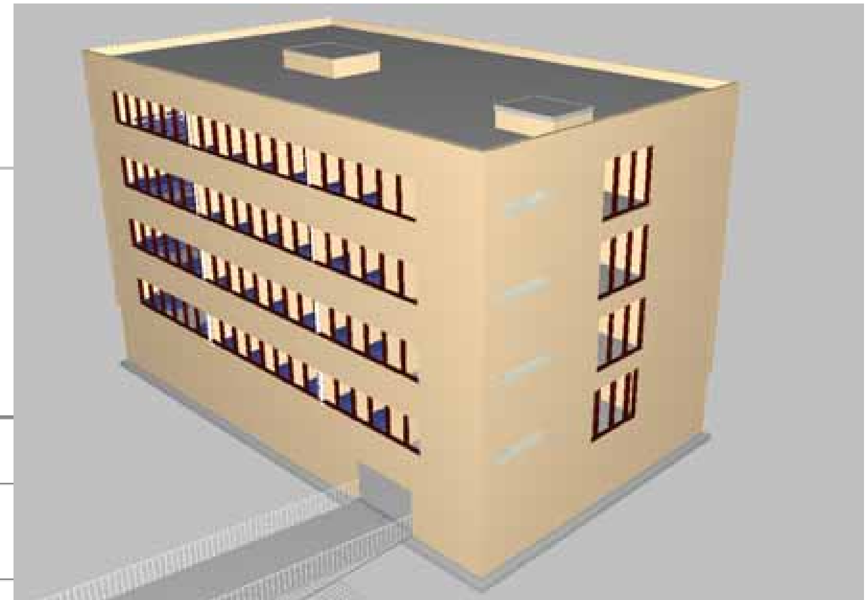


ZEB-O÷EQ: Balancing operational energy use exclusive equipment.
ZEB-O: Balancing operational energy use inclusive equipment.
ZEB-COM: Balancing operational energy, embodied emissions , construction and demolition processes

The main concept of a zero emission building is that renewable energy sources produced or transformed at the building site have to compensate for CO_2 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.

The Research Centre on Zero Emission Buildings

Concept work
Office Building



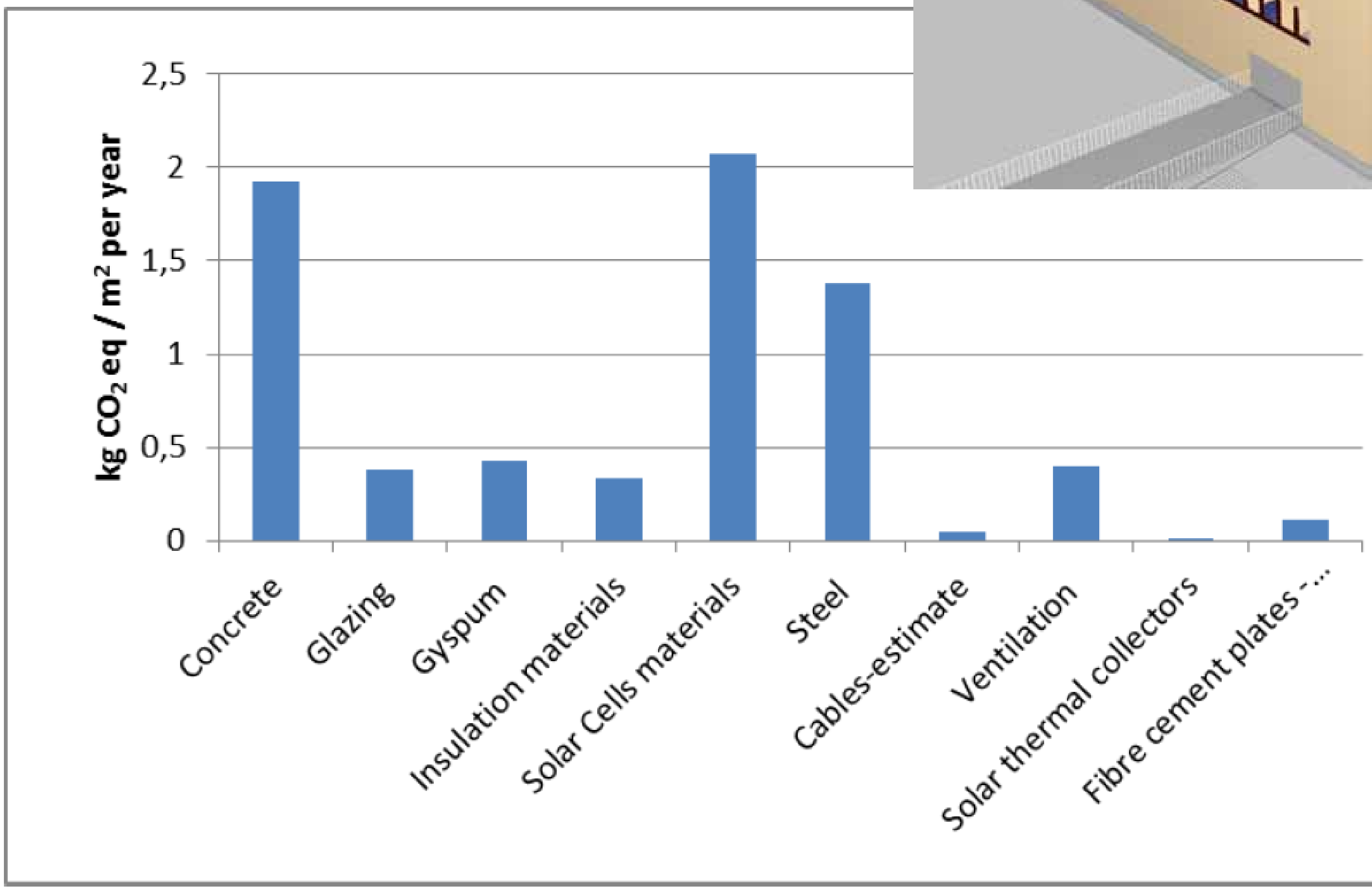
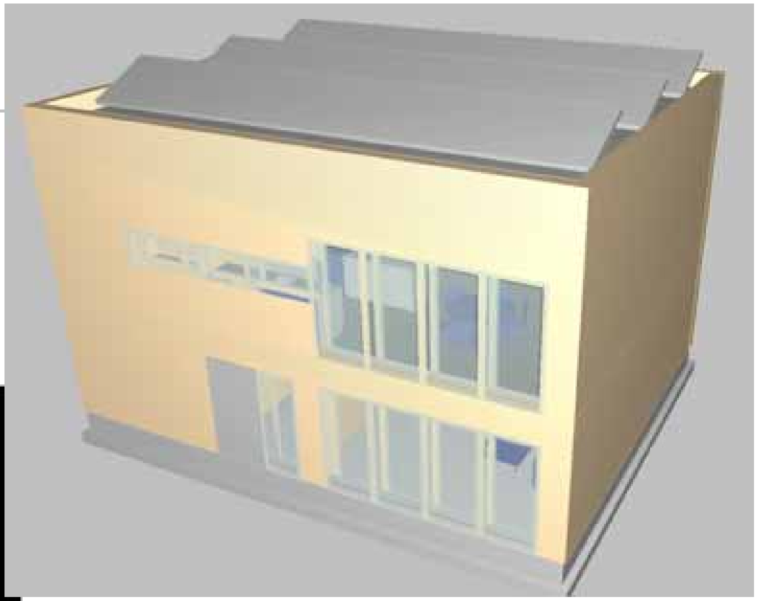
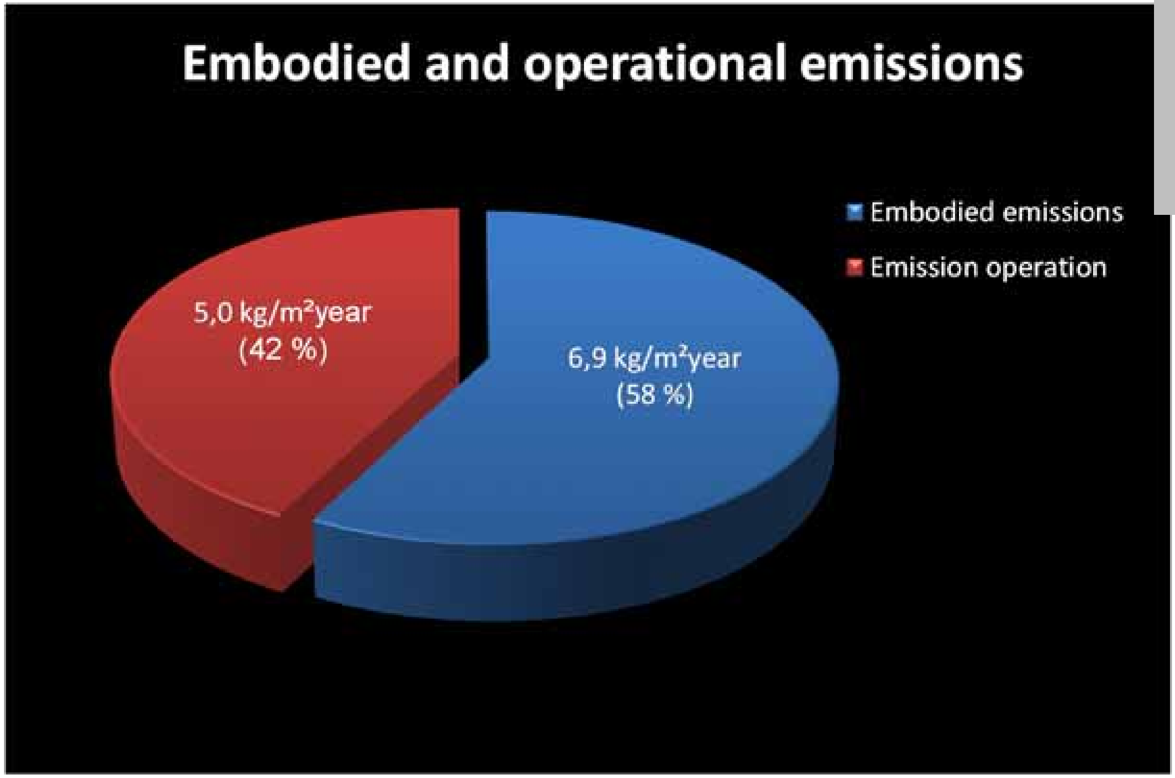


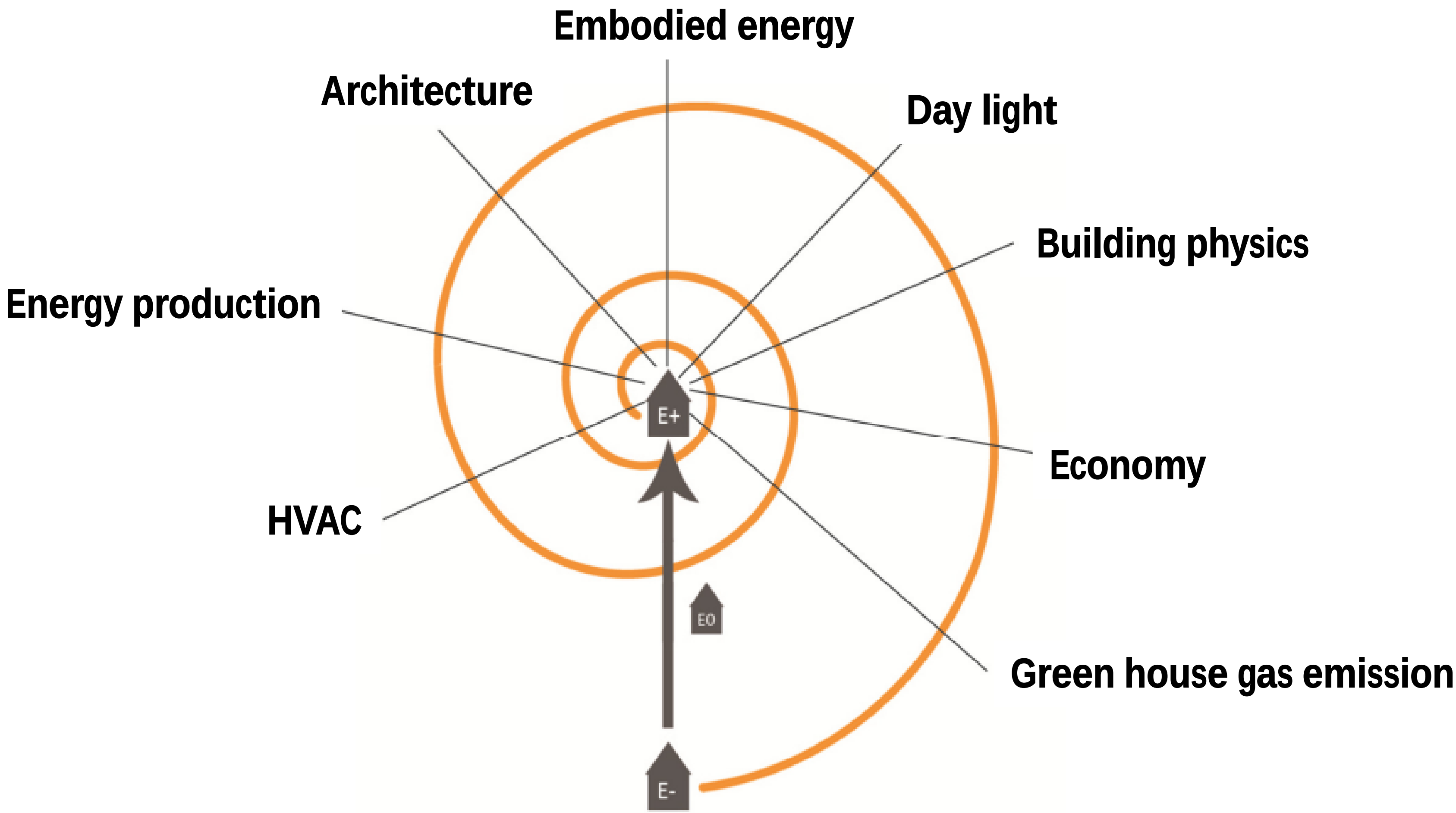
Figure 6.6 Green house gas emissions divided on main material and technical inputs

Concept Work - Dwelling

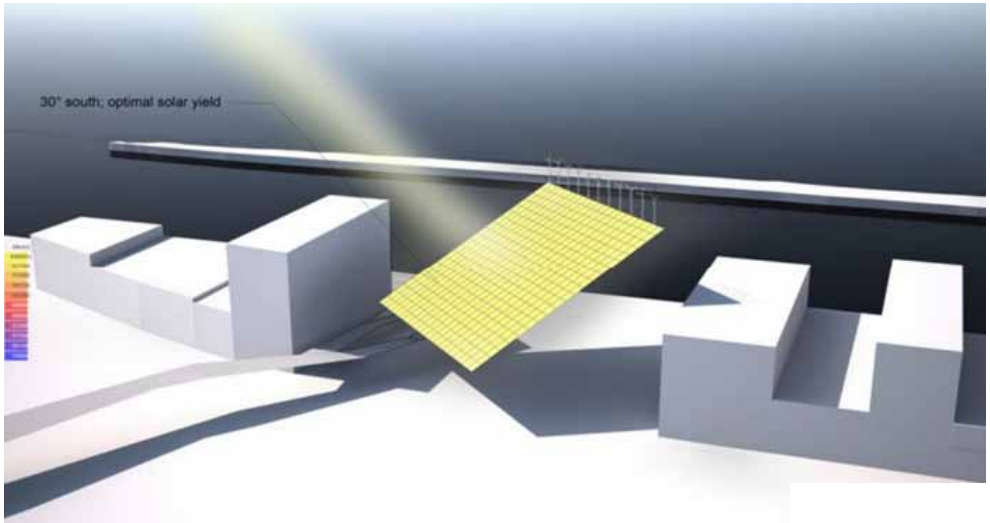




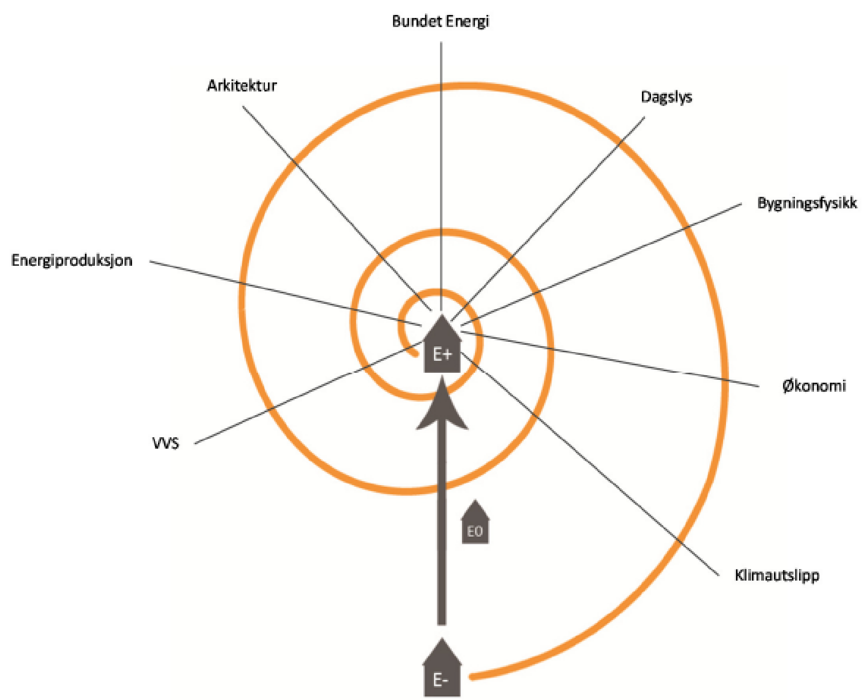
ZEB design process



Powerhouse Brattørkaia - Trondheim



Area	Electricity Production per Solar Cell Area [kWh/m² year]
Roof 26 degrees	191
Roof 20 degrees	185
Roof 18,9 degrees	184
Roof 17,3 degrees	182
Roof flat	136
Roof towards north	97
Western facade	95
Southern facade	155

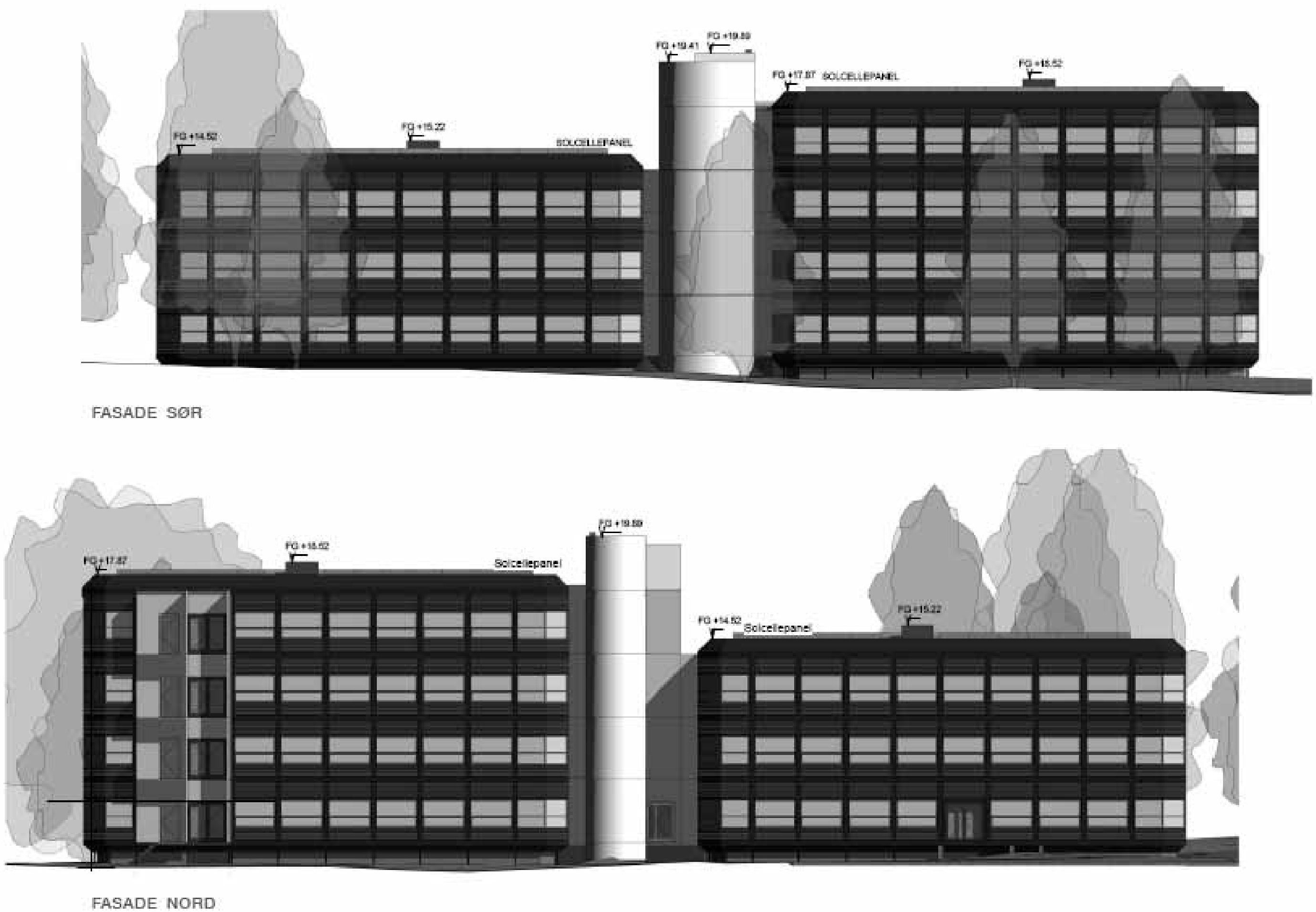


Powerhouse Brattørkaia - Trondheim

2013 version

- Roof angle 20 degrees
- Heated area 13 114 m^2
- Average yearly solar energy 607 212 kWh
- Average yearly energy balance during the life of the building divided by heated area: +3.0 $kWh/m^2 year$
- Height C + 42.8

Upgrading of existing buildings
Pilot building in Sandvika – Powerhouse Kjørbo



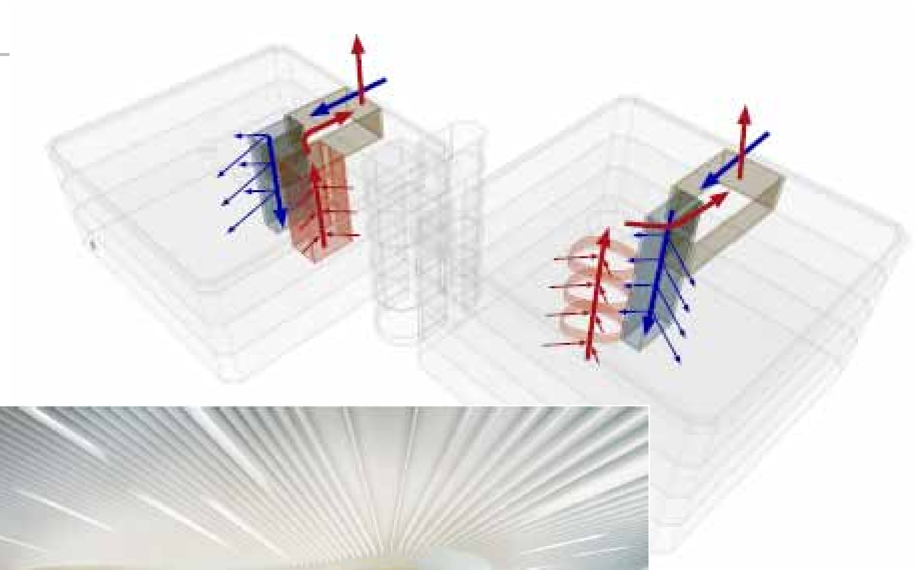
The Research Centre on Zero Emission Buildings

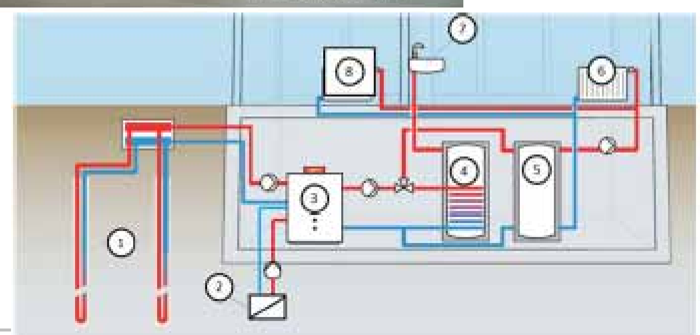
POWERHOUSE #2

POWERHOUSE # 2 CONCEPT:

1. VENTILATION: Innovative building integrated low pressure solution.
2. CONSTRUCTION: Optimised building envelope.
3. THERMAL PRODUCTION: High performance geothermal system for space heating, cooling and DHW production.
4. HEATING: Innovative simpified hydronic heating system.
5. COOLING: Optimised thermal mass, low internal loads and use of free cooling from the bore holes.
6. DAYLIGHT: Optimised facade solution and floor plan for good daylight condition.
7. PV-PRODUCTION: PV-production on roof and nearby parcking facility.
8. MATERIAL CHOICES: Materials with low embodied energy chose where possible, extencive reuse of materials.

Detaljutsnitt av ny klimavegg





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Outcome of ZEB: Innovation in the building industry

- Verification of calculation procedures for indoor climate and energy
  - All pilot buildings will be instrumented and measured: Do the buildings perform as planned/calculated?
- Methods for calculations of emissions from production, operation and materials
  - There is hard to find (good) material data
- Development and testing of new materials/building assemblies/façade solutions
- Verification of technical installations
  - Heating, ventilation, lighting, control systems
  - Energy supply (e.g. solar cells, solar thermal)
- Demonstration and testing of integrated solutions/the entire building including user studies
- Transfer of knowledge to the Norwegian building industry

Outcome of ZEB: Innovation in the building industry

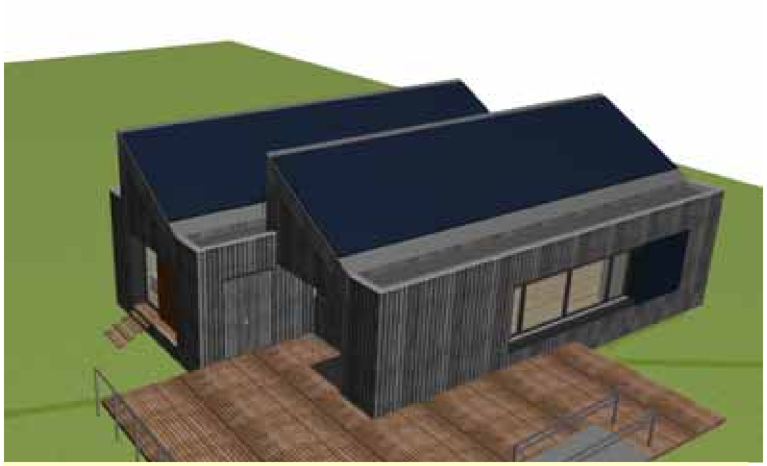
- Through this research centre on renewable energy the building industry is directly involved in the research and development activities.

- The ZEB partners also starts their own development activities outside the research centre, but then based on the knowledge developed in ZEB. This is especially shown through the success of the Powerhouse alliance.

And maybe the most important:

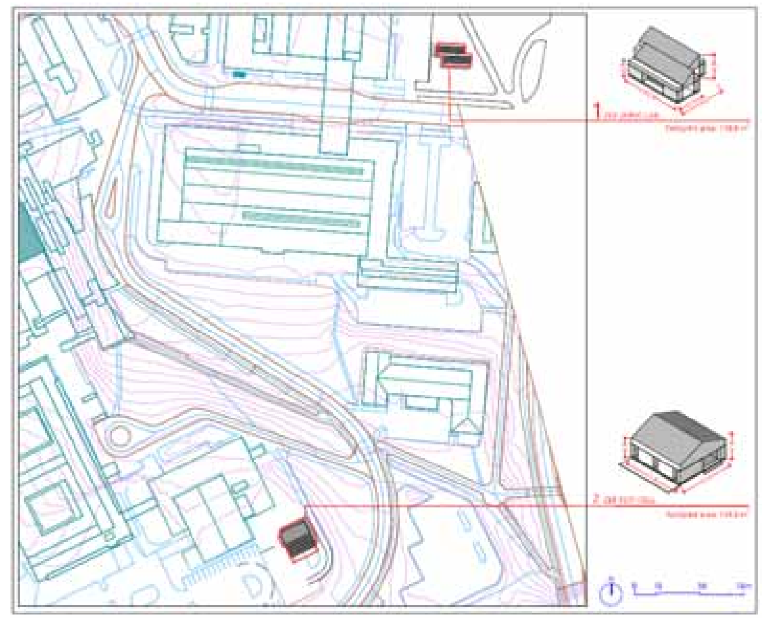
- ZEB has triggered the Norwegian building industry

Establishment of Test Buildings at NTNU – ZEB Living Lab and Test Cell



ZEB Living Lab – A dwelling for user-technology studies

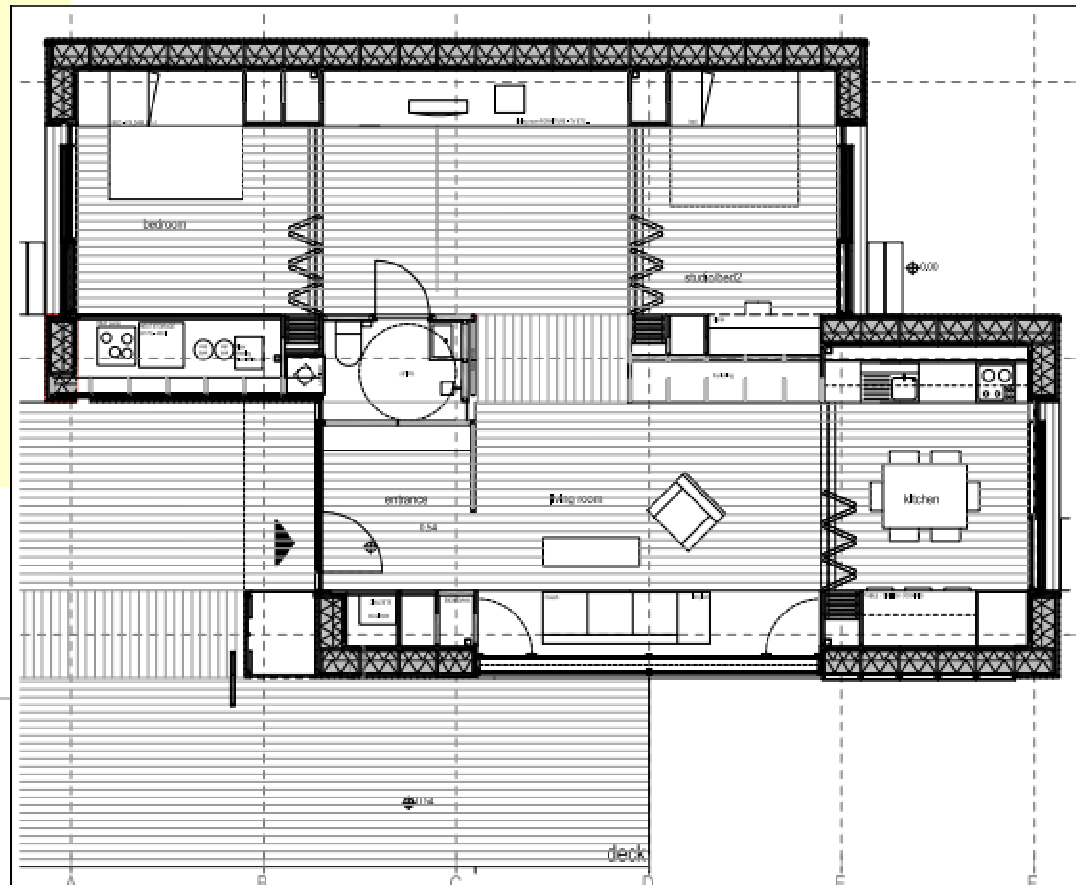
ZEB Test Cell for testing different technologies



ZEB Living Lab

- 100 m² living area
- Building Integrated Photo-voltaics: 80 m²
- Solar panel in the facade
- Ground to water heat pump
- Heat recovery system

- A part of student work



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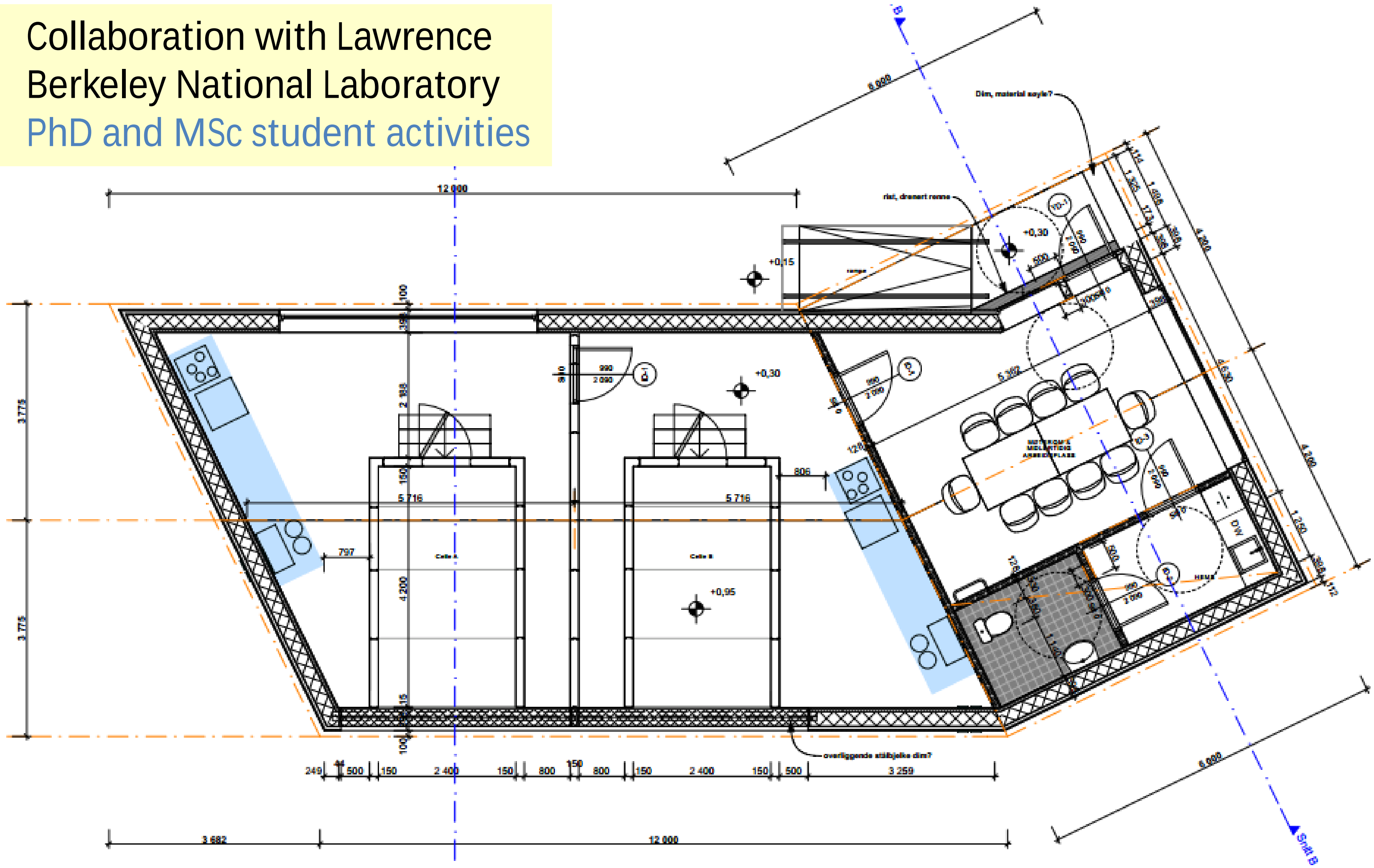
ZEB Test Cell

- Collaboration with Lawrence Berkeley National Laboratory
- PhD and MSc student activities



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Thank you for your attention

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