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.


Illustration: Snøhetta/MIR

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

www.zeb.no

ZEB Facts

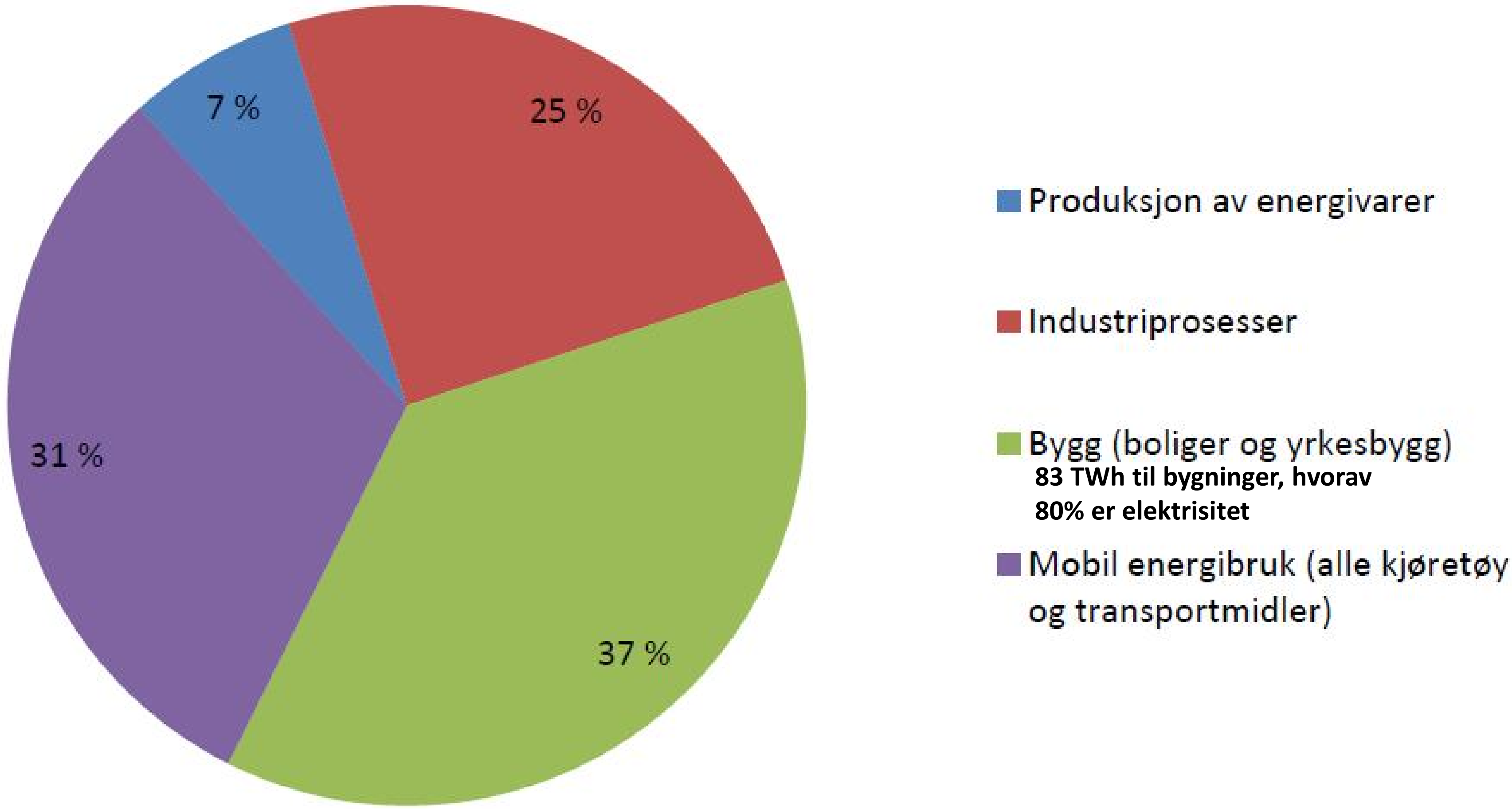
- ZEB is a Centre for Environment-friendly Energy Research (FME), funded by the Research Council of Norway (RCN) and 26 partners.
- Host institution is NTNU with SINTEF Building and Infrastructure and SINTEF Energy Research as research partners.
- Centre started in November 2009, and RCN funds the Centre 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



Source: Energibruk i Fastlands-Norge, NVE, 2011

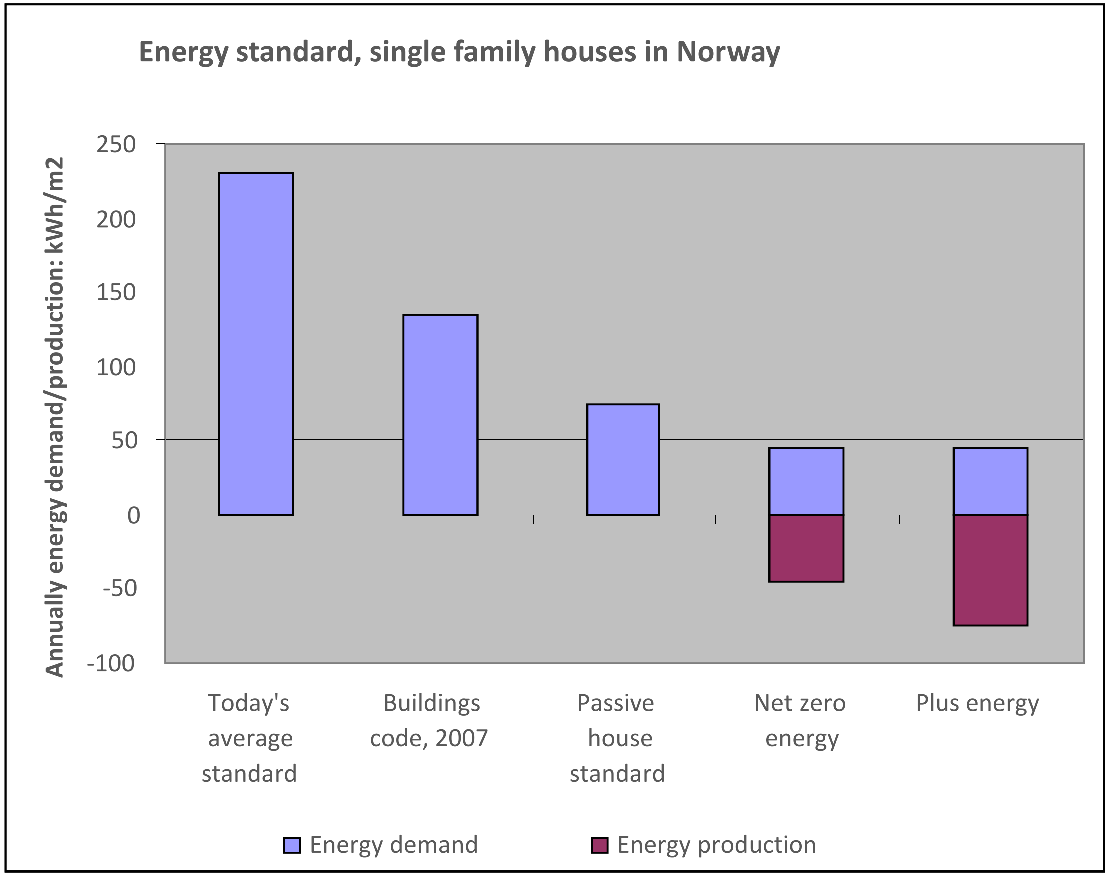
Why Zero Emission Buildings?

- 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

Research Activities

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

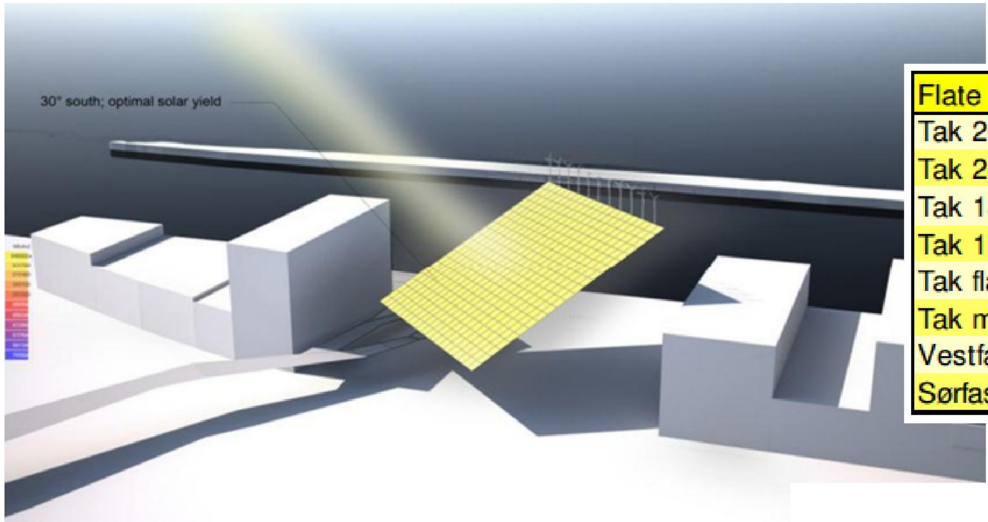
- WP1 Advanced materials technologies
- WP2 Climate-adapted and energy efficient envelope technologies
- WP3 Energy supply systems and services
- WP4 Use, operation, and implementation
- WP5 Zero emission building concepts and strategies
- WP6 Pilot buildings

ZEB Pilot Buildings

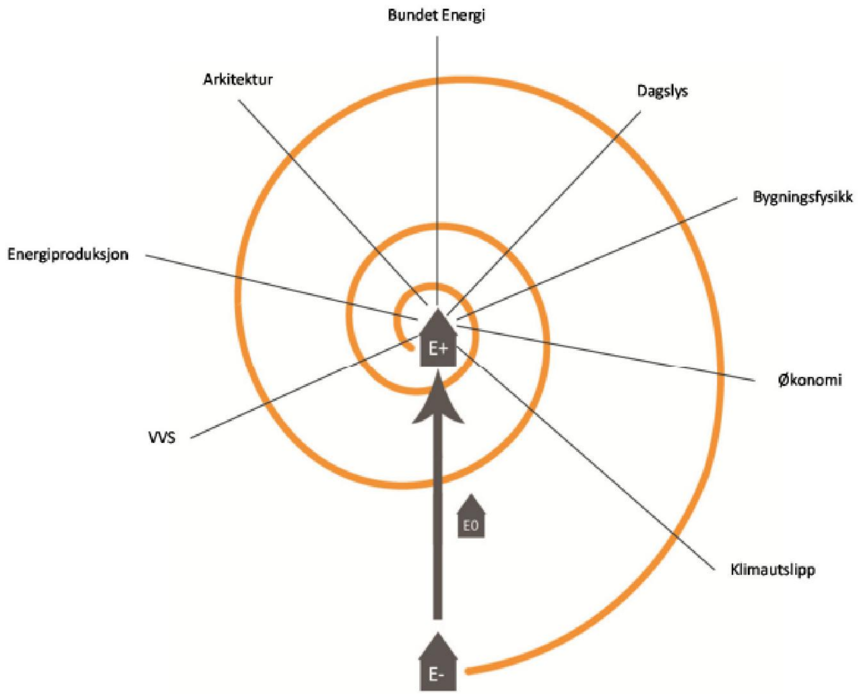
ZEB PILOT BUILDINGS:

1. Skarpnes, Arendal: 37 dwellings.
2. Powerhouse Kjørbo, Sandvika. Renovation of 2 office blocks.
3. Mulitkomfort, Larvik. Single family house.
4. Ådland, Bergen. 720 dwellings.
5. Powerhouse Brattørkaia, Trondheim. Large office building.
6. Depotbygget Haakonsvern, Bergen. Small office building.
7. ZEB Living Lab, Trondheim.
8. Heimdal Highschool
9. Campus Evenstad

Powerhouse Brattørkaia - Trondheim



Flate	Produksjon per solcelleareal [kWh/m^2·år]
Tak 26 grader	191
Tak 20 grader	185
Tak 18,9 grader	184
Tak 17,3 grader	182
Tak flatt	136
Tak mot nord	97
Vestfasade	95
Sørfasade	155

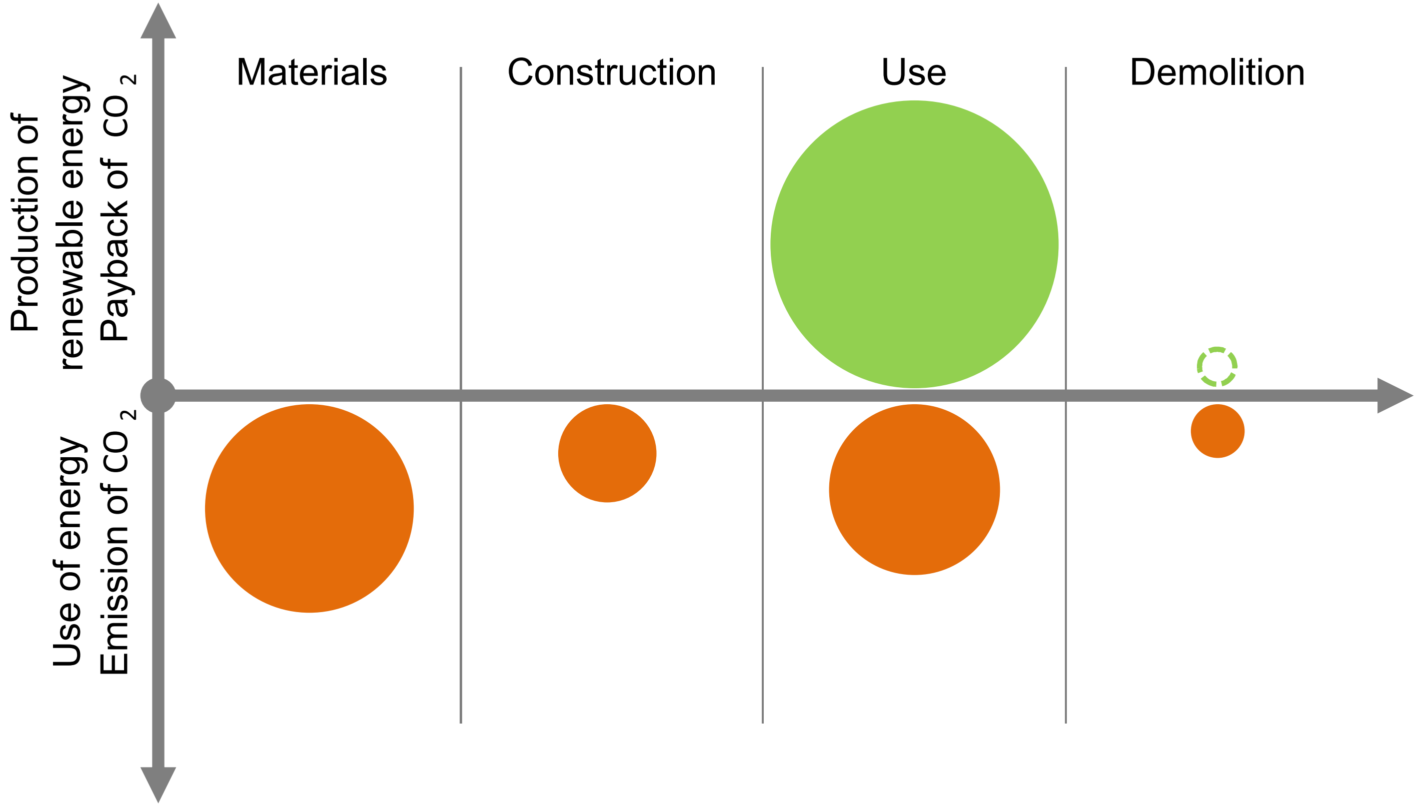


Powerhouse Brattørkaia - Trondheim

2013 version

- Roof angle 20 degrees
- Heated area 13 114 m^2
- Average yearly solar energy 607 212 kWh

Zero Emission Buildings Definition

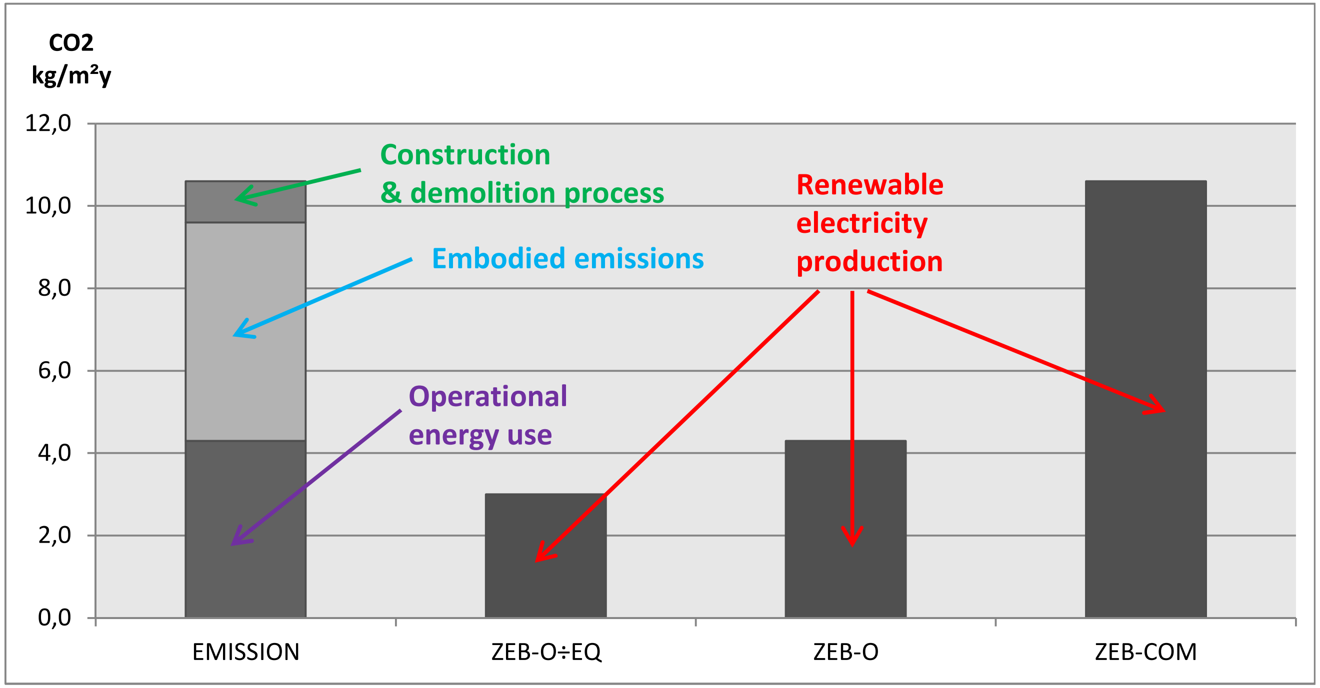


Ref: B. Risholt et al.

Zero Emission Buildings Definition

ZEB-DEFINITION:

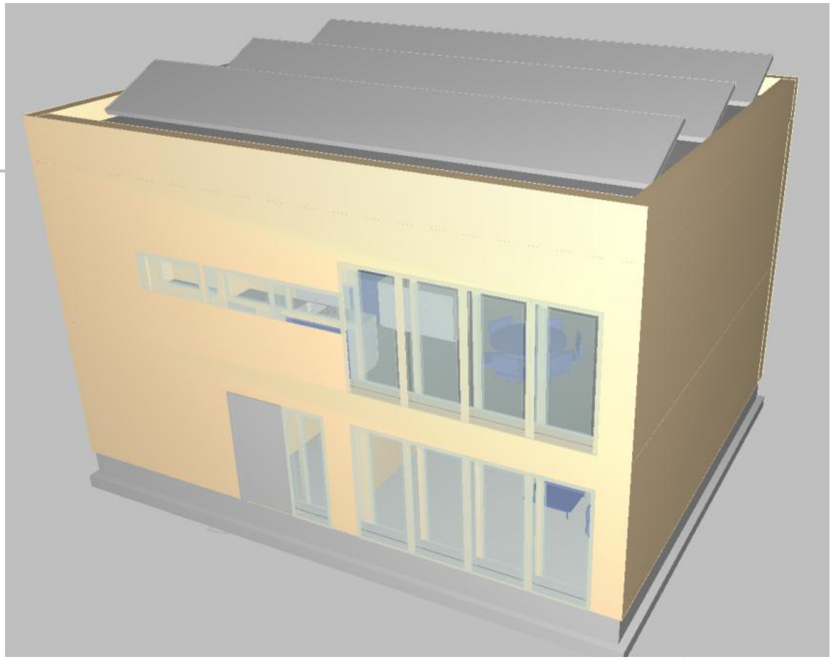
1. Ambition level
2. Rules for calculation
3. System boundaries
4. CO2-factors
5. Energy quality
6. Mismatch production and demand
7. Minimum requirement energy efficiency
8. Requirement indoor climate
9. Verification in use



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 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



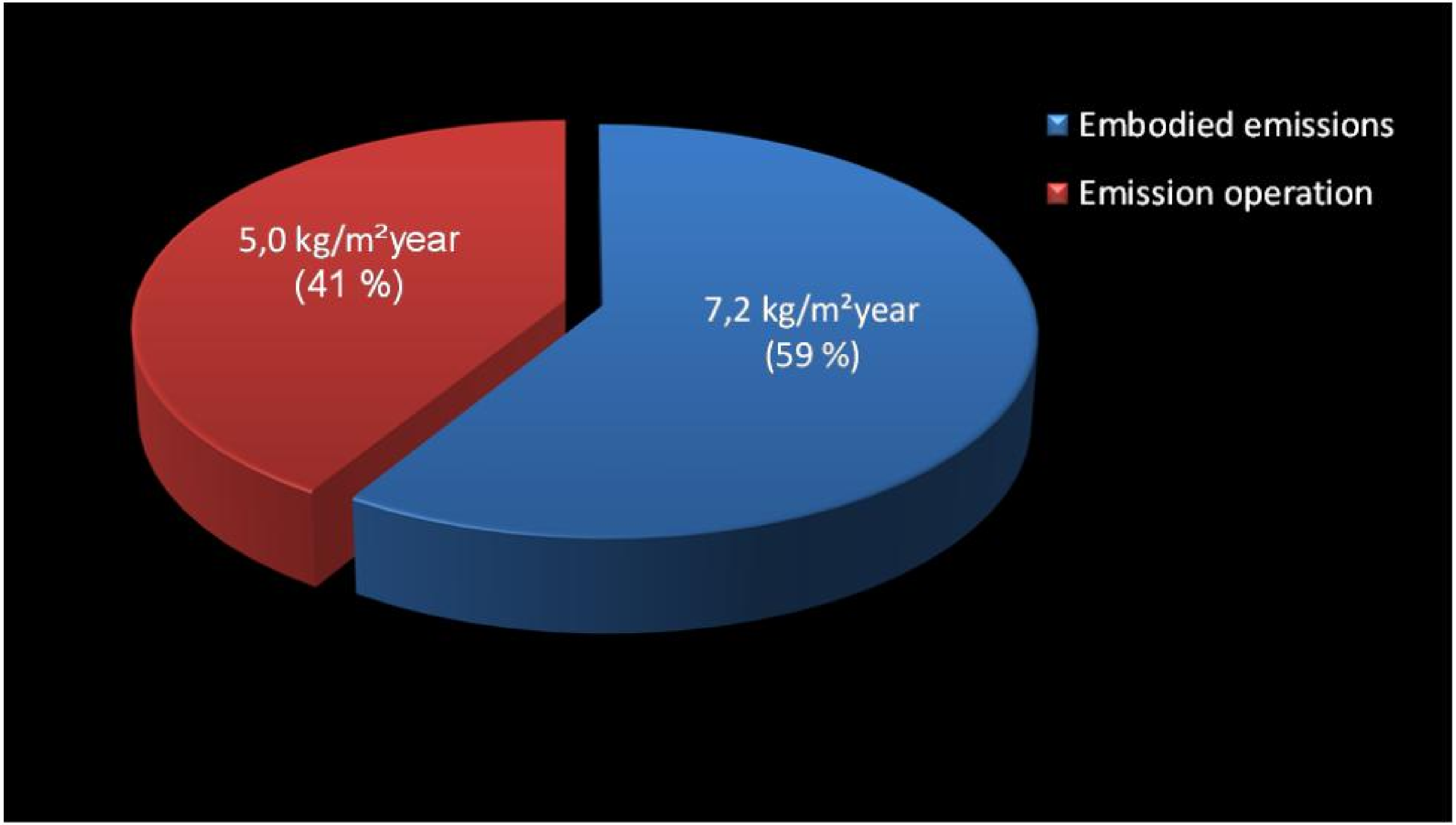
160 m², 2 story high single family house which is assumed located in Oslo

	Values	Solution
External walls	U = 0.12 W/m²K	Timbered wall with 350 mm insulation.
External roof	U = 0.10 W/m²K	Compact roof with approximately 450 mm insulation.
Slab on ground	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.
Windows	U = 0.65 W/m²K	Three layer low energy windows, with insulated frame.
Doors	U = 0.65 W/m²K	Well insulated doors.
Normalized thermal bridge value	ψ" = 0.03 W/m²K	Detailed thermal bridge design
Air tightness	N50 < 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).

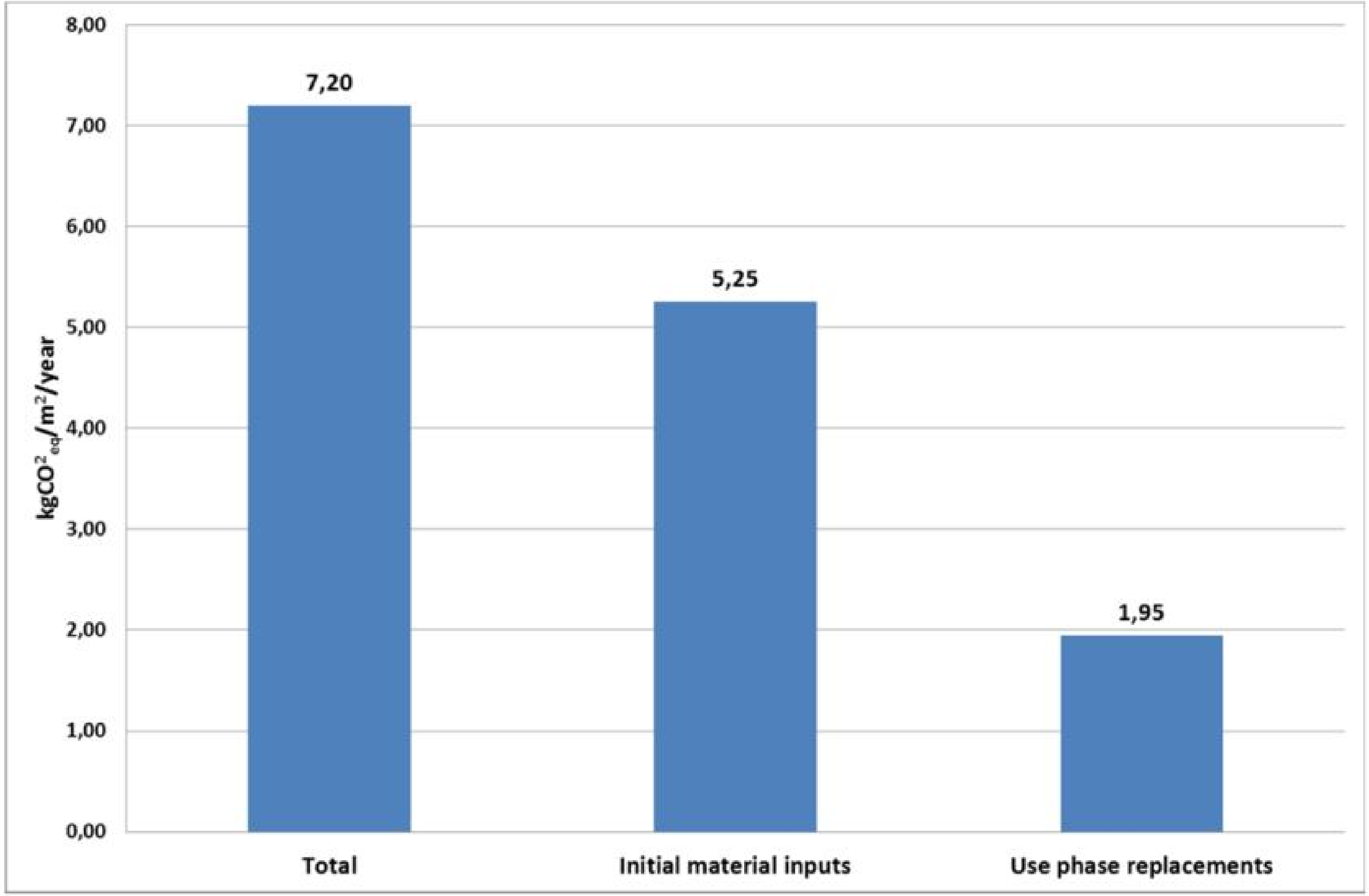
Concept Work – Building Services and Energy Supply

- Efficient ventilation system, η = 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

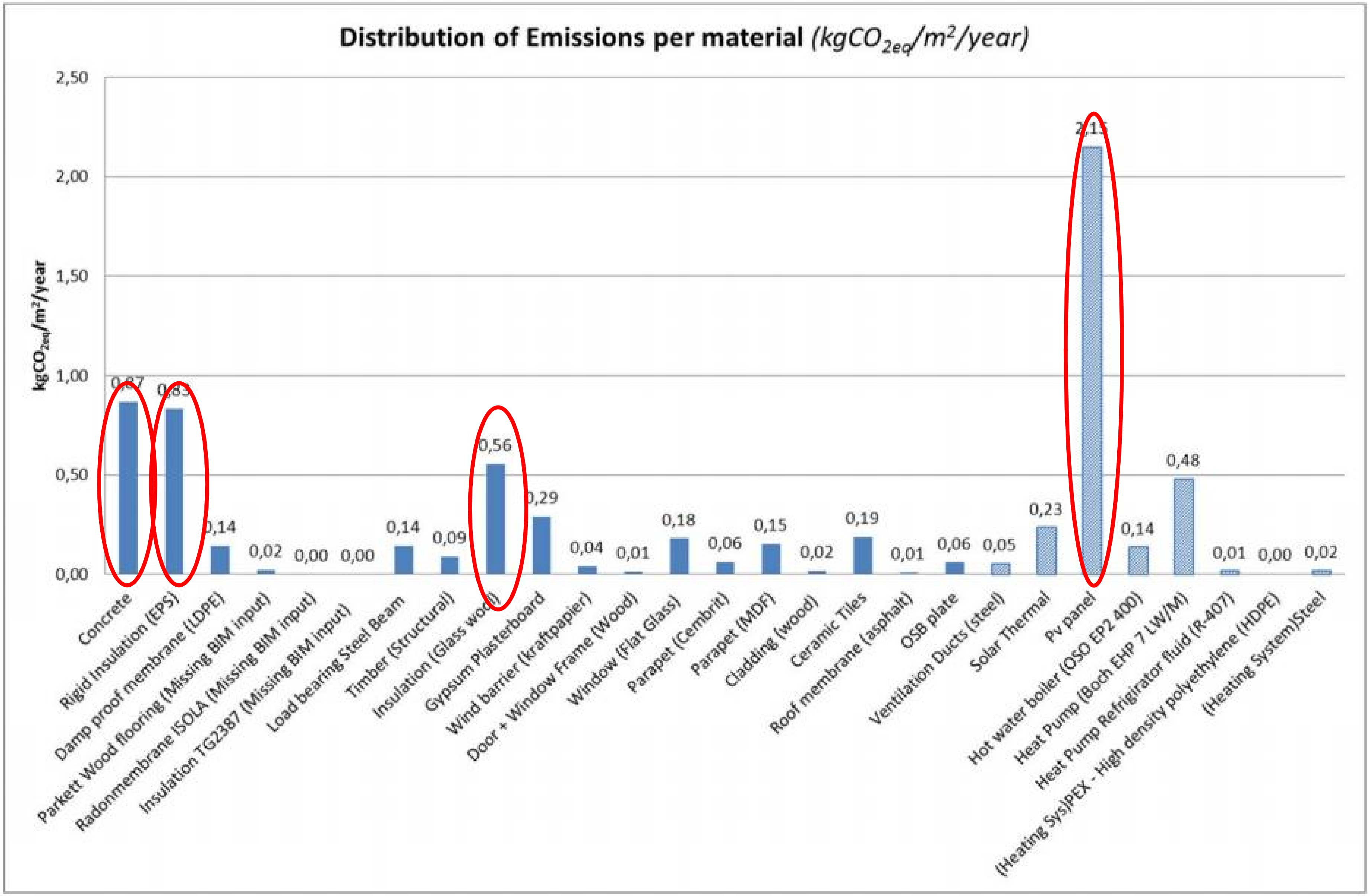
Concept Work –
Embodied and Operational GHG-emissions



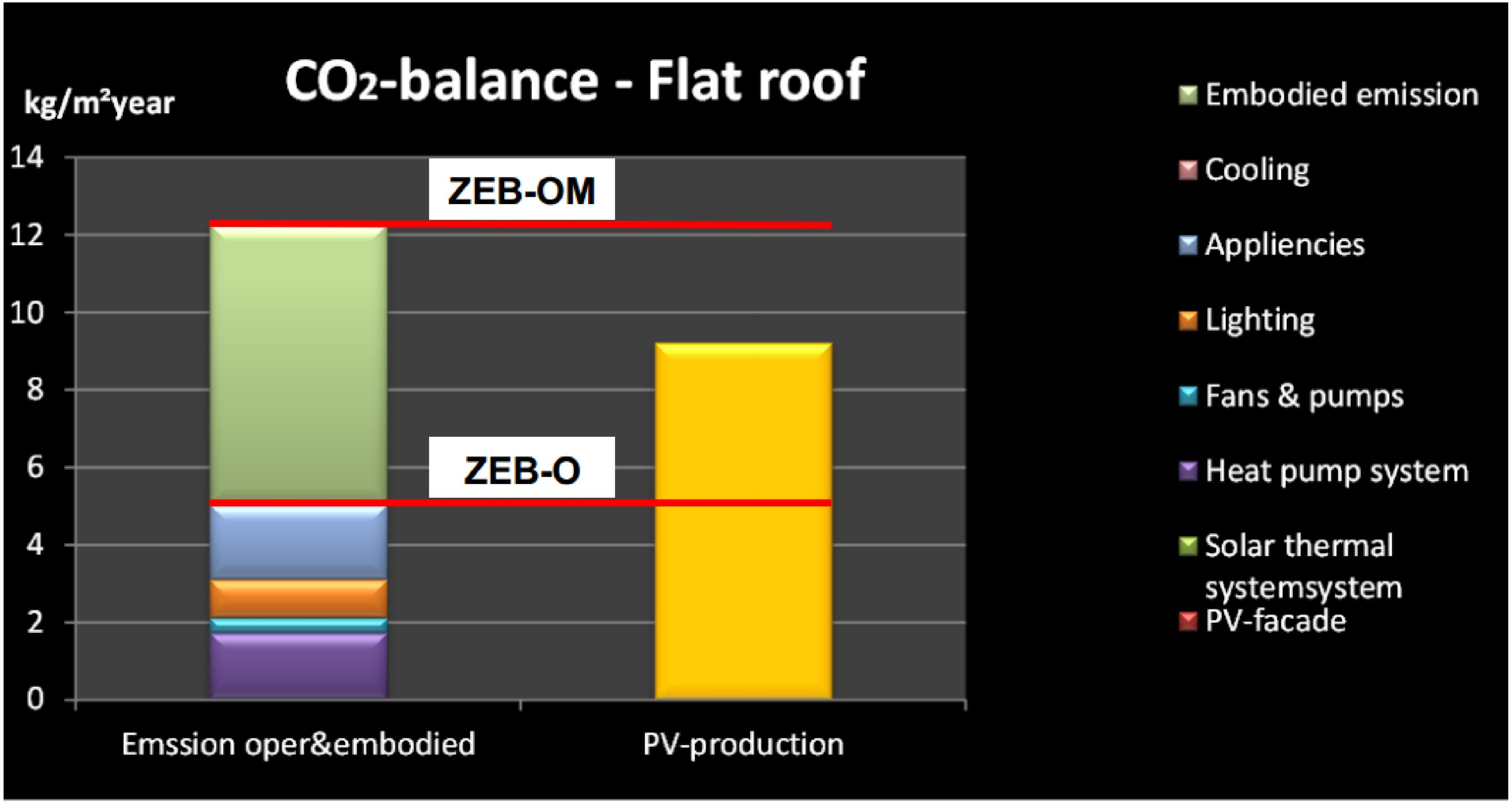
Concept Work – Embodied GHG-emissions



Concept Work – Embodied GHG-emissions per Material



Concept Work – GHG Emissions Balance



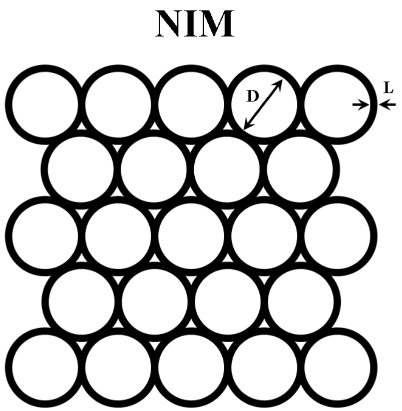
The Research Centre on Zero Emission Buildings

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

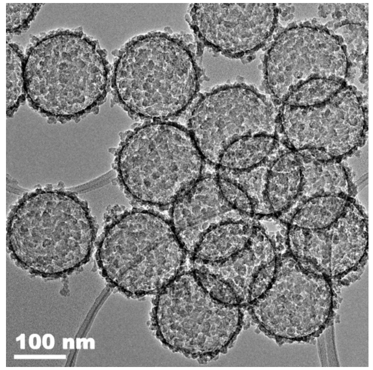


Nano Insulation Materials (NIM)

From theoretical concepts to development of new and innovative materials

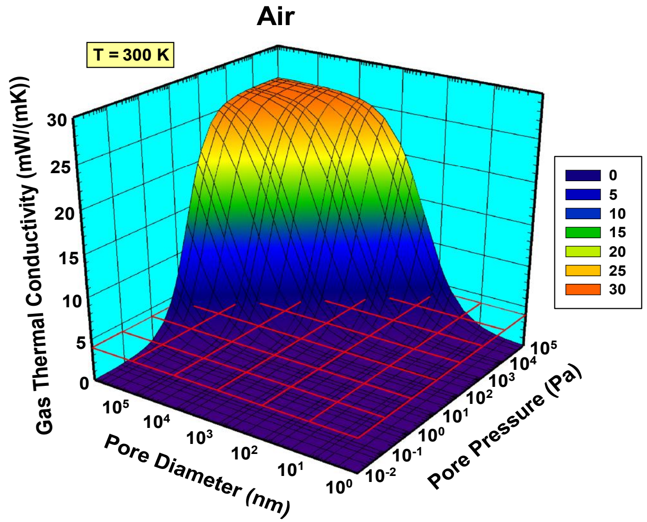
$$\lambda_{gas} = \frac{\lambda_{gas,0}}{1 + 2\beta Kn} = \frac{\lambda_{gas,0}}{1 + \frac{\sqrt{2}\beta k_B T}{\pi d^2 p \delta}}$$

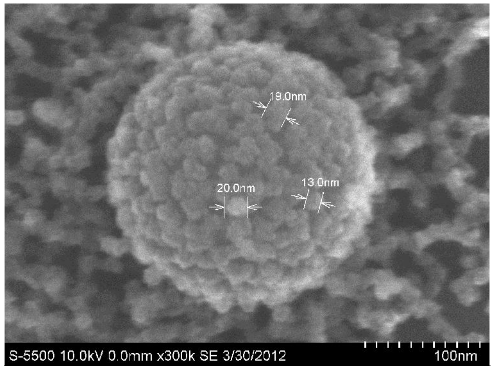
$$Kn = \frac{\sigma_{mean}}{\delta} = \frac{k_B T}{\sqrt{2}\pi d^2 p \delta}$$



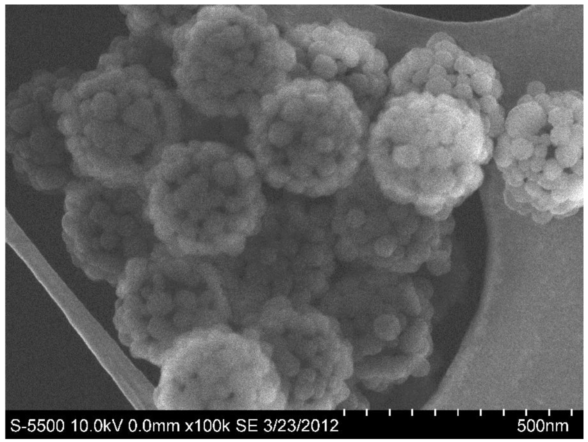
Patent application

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





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



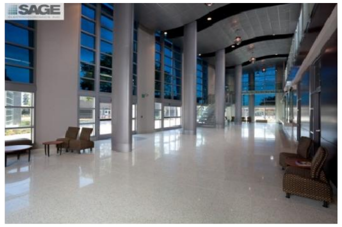
A new glass material

- 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







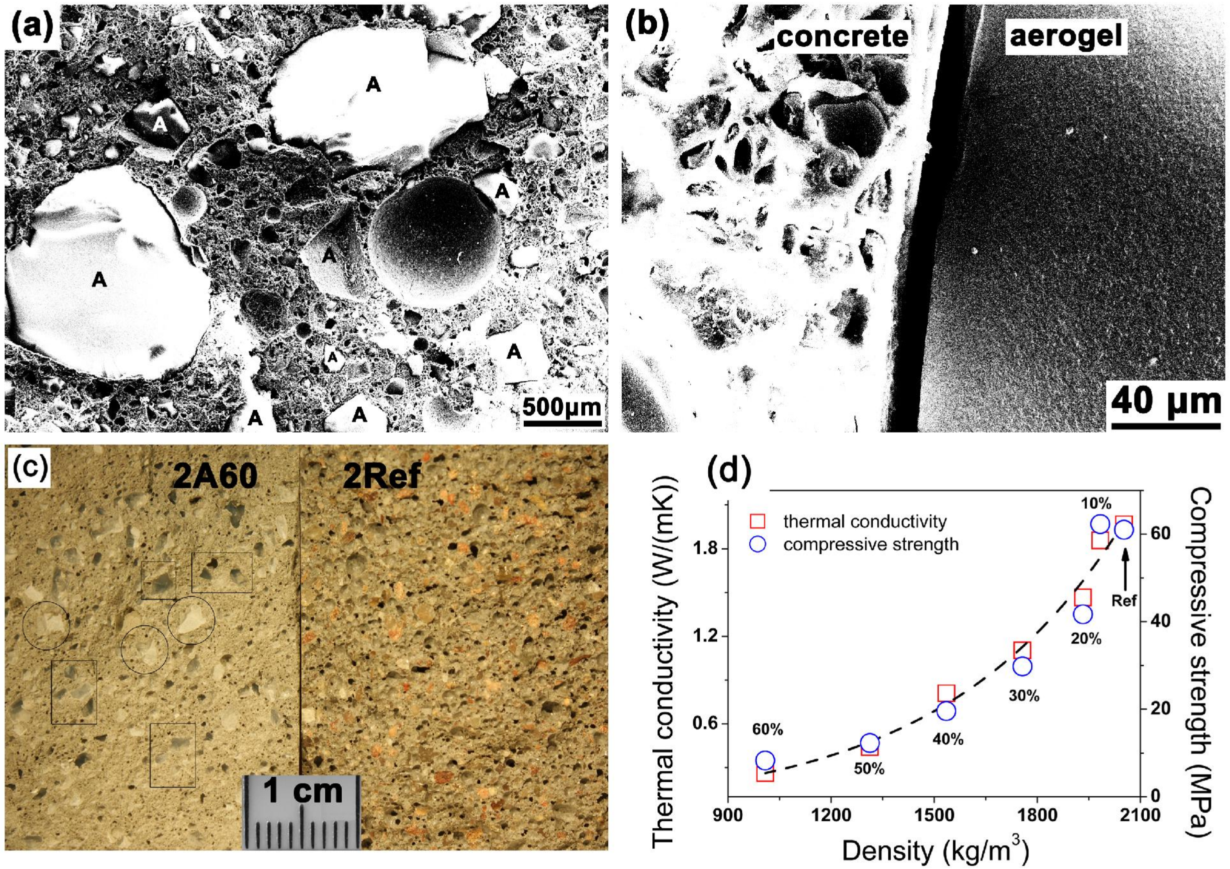
Increasing the thermal resistance of concrete

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.

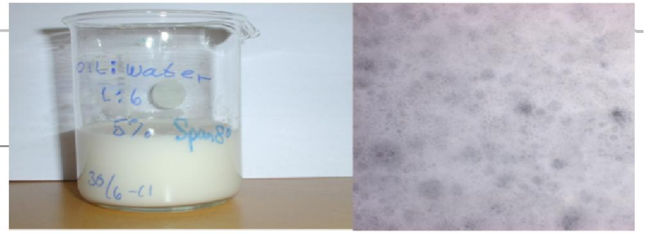


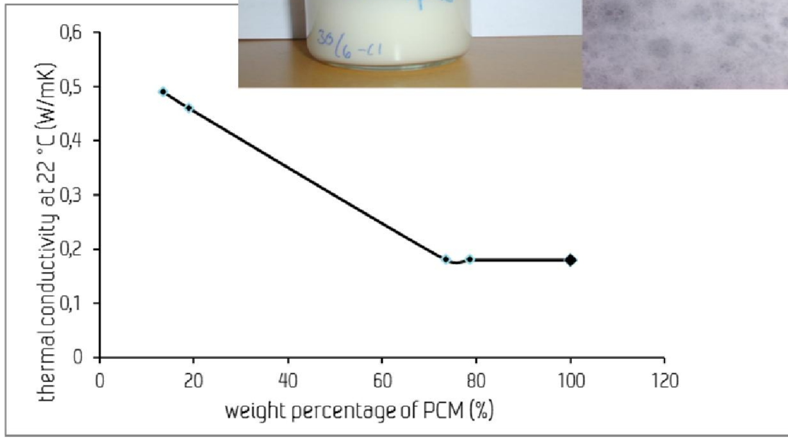
(a) and (b) SEM photos of aerogel incorporated in concrete, (c) photo comparing concrete with (60 vol%) and without aerogel, and (d) thermal conductivity and compressive strength as a function of mass density and aerogel content in vol%.

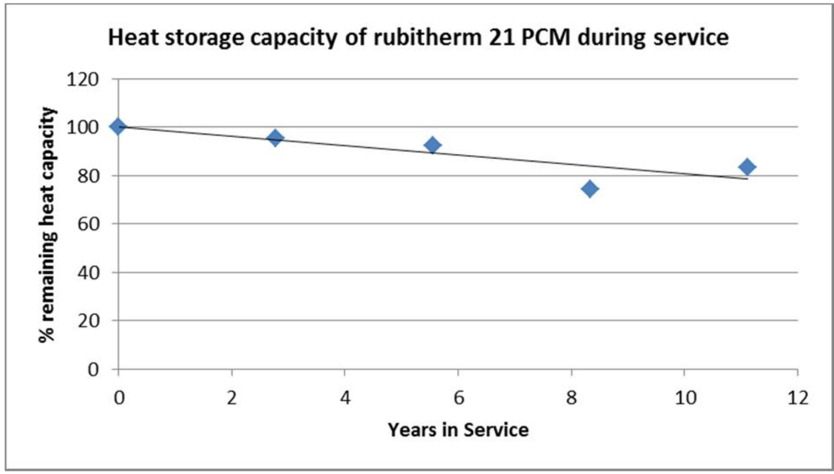
Phase change materials

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

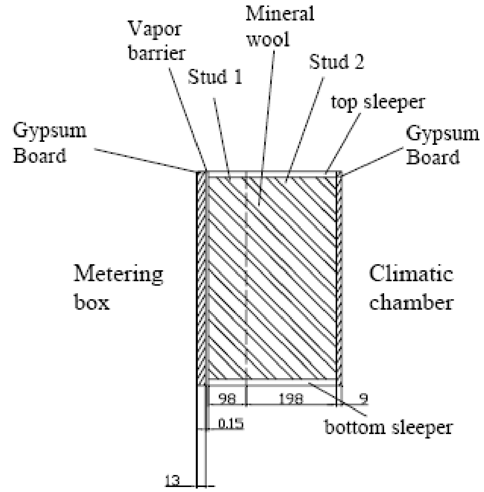
Development of Sandwich Elements with VIPs (Leca Isoblock)

- Development of thinner building components

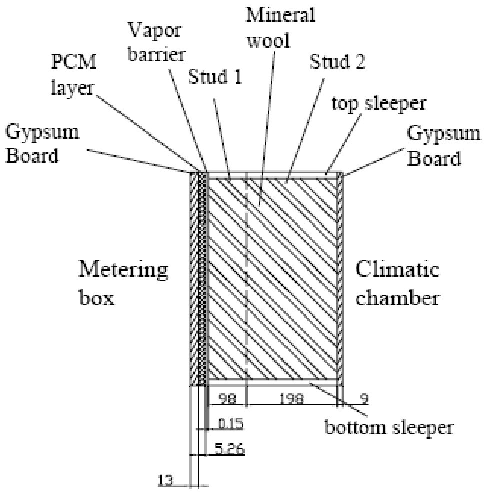
- Leca Isoblokk (concrete building system) with VIP - Prototype developed by ZEB partner Weber (patent has been applied for)

NorDan and Aventa Solar have developed a solar thermal collector that can be easily integrated in the facade

Phase change material experiments

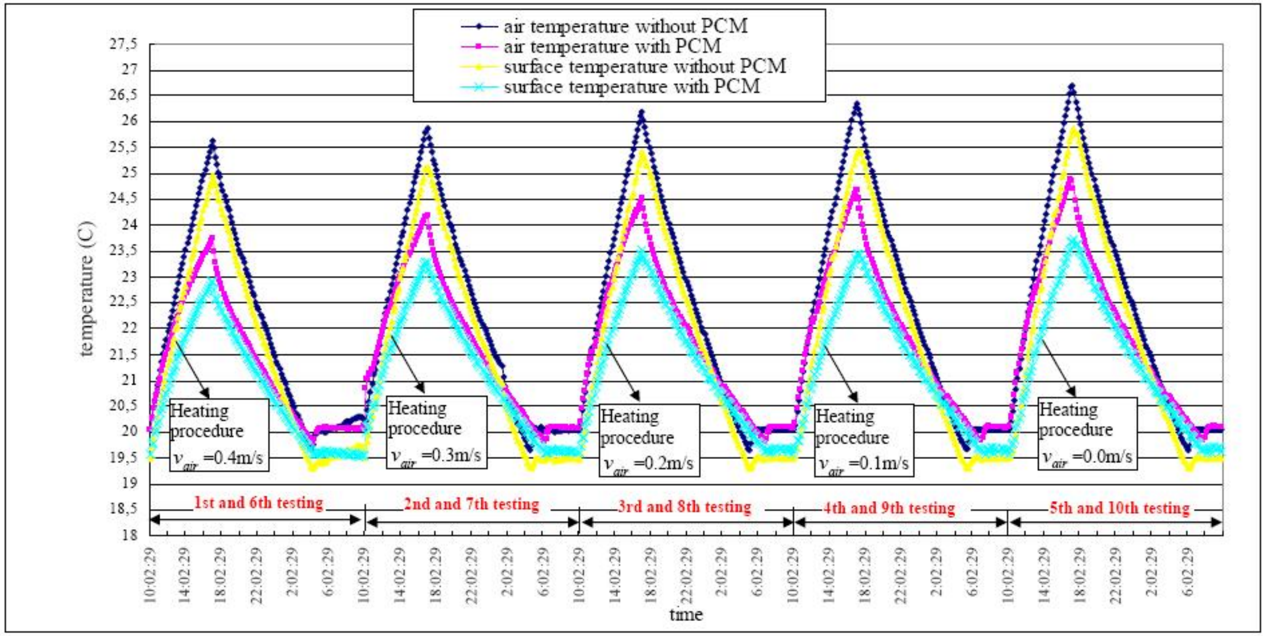


(a)



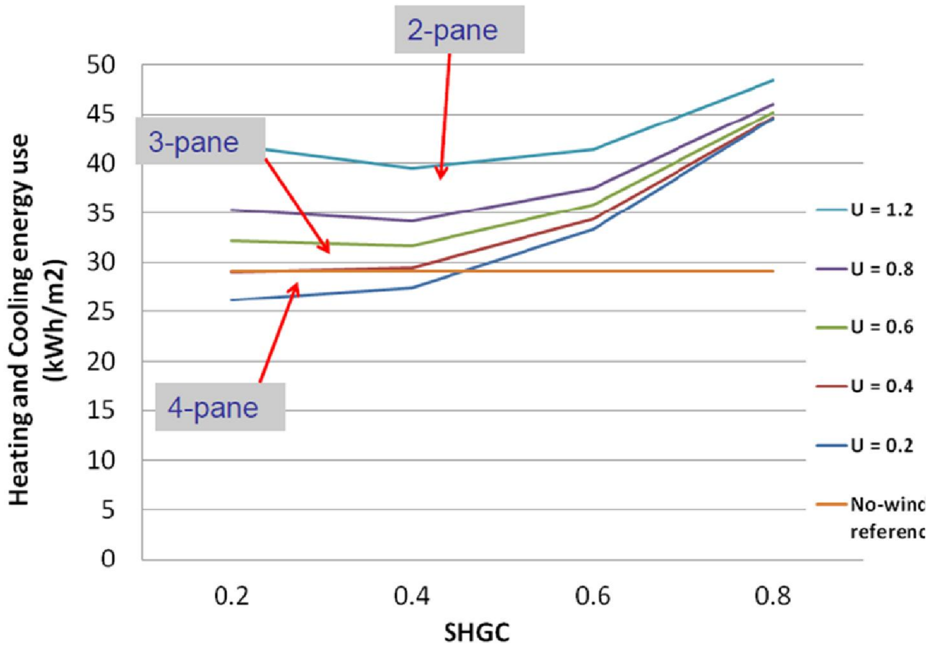
(b)

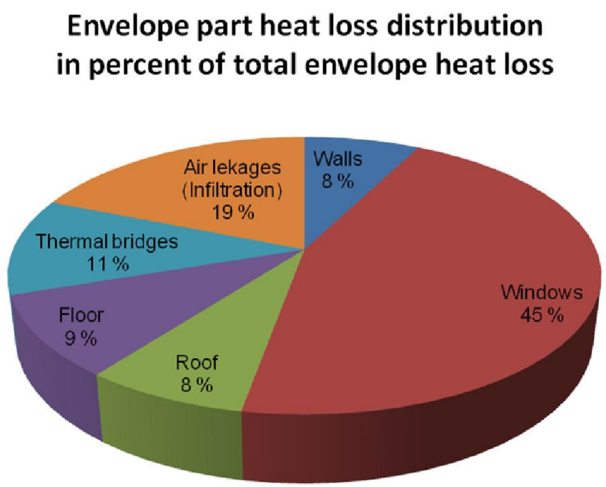
Used to validate e.g. EnergyPlus PCM models.



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

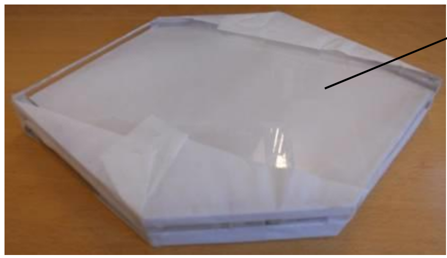


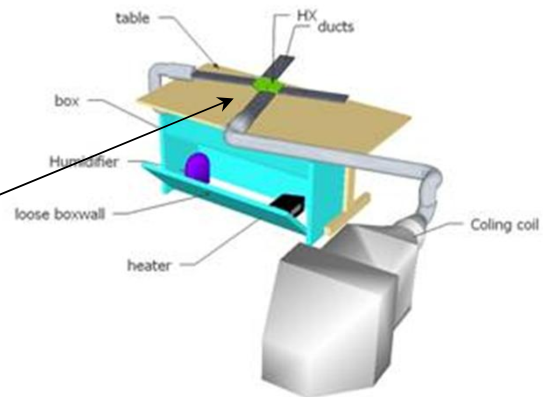


New Type of a Cross Flow Energy Exchanger using Membrane Technology

- Development of improved energy exchanger using membrane technology

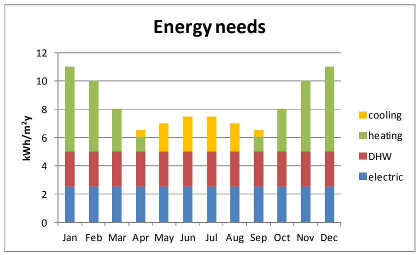
- Recovery of moisture in addition to sensible heat will increase the overall energy efficiency of the exchanger. This will also reduce frosting problems in operation but it demands very careful design of the exchanger.

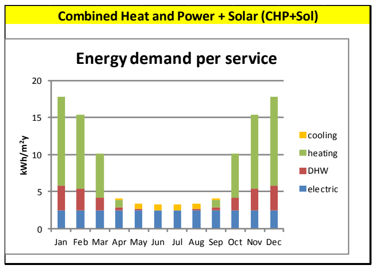


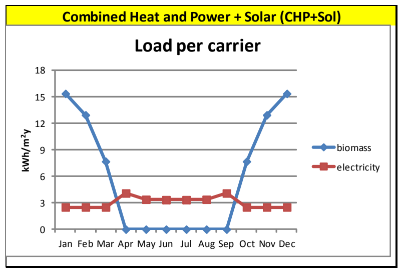


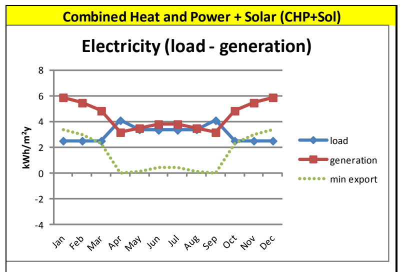
Simple decision support tool for selection of energy supply solutions in an early project design phase

- 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.







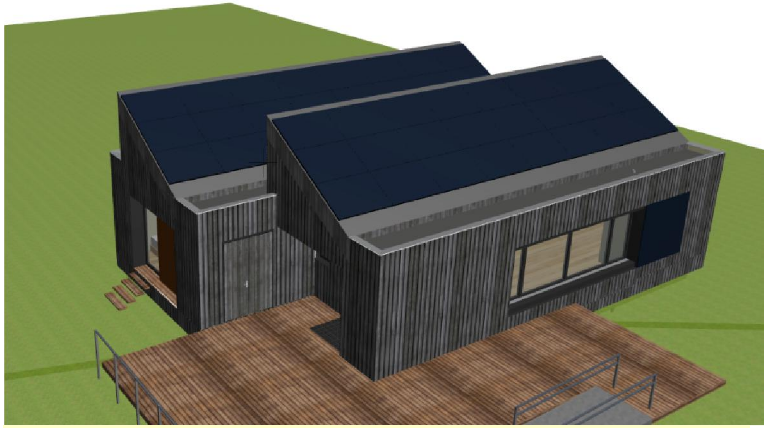


Analyses of End-Use in Energy Efficient Buildings

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

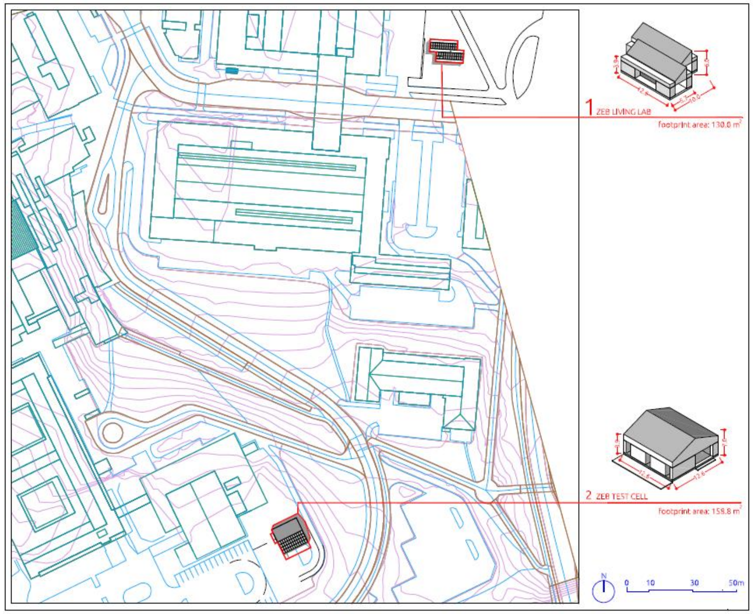
- Unintended persistence of energy wasting behaviors (when refurbishing/upgrading systems)
  - Deeply rooted values and attitudes
  - Negotiations within the household

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 av different technologies



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FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI

ZEB Living Lab

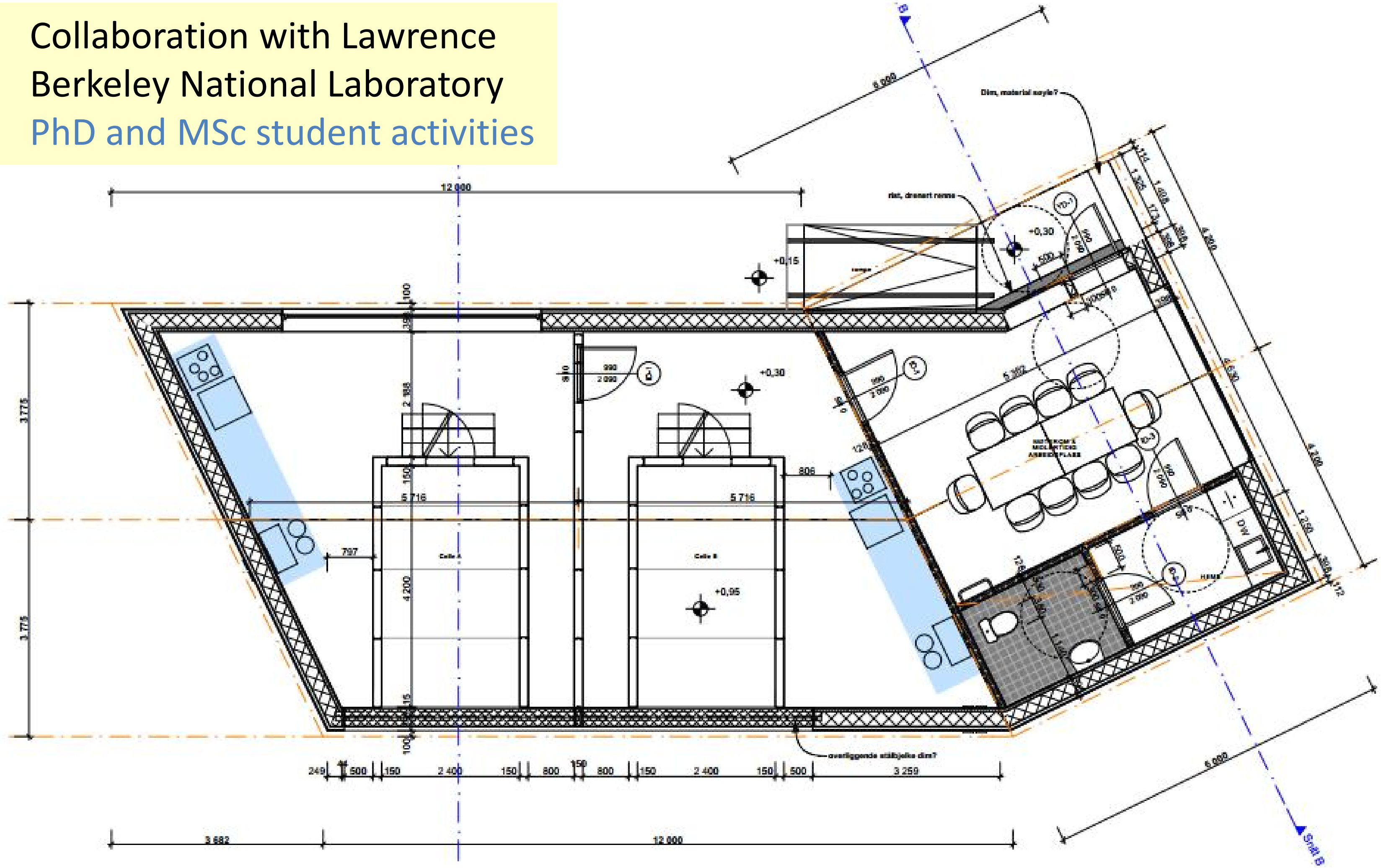
- 100 m² living area
- Building Integrated Photo-voltaics: 80 m²
- Solar panel in the facade
- Ground to water heat pump
- Heat recovery system

- A part of student work

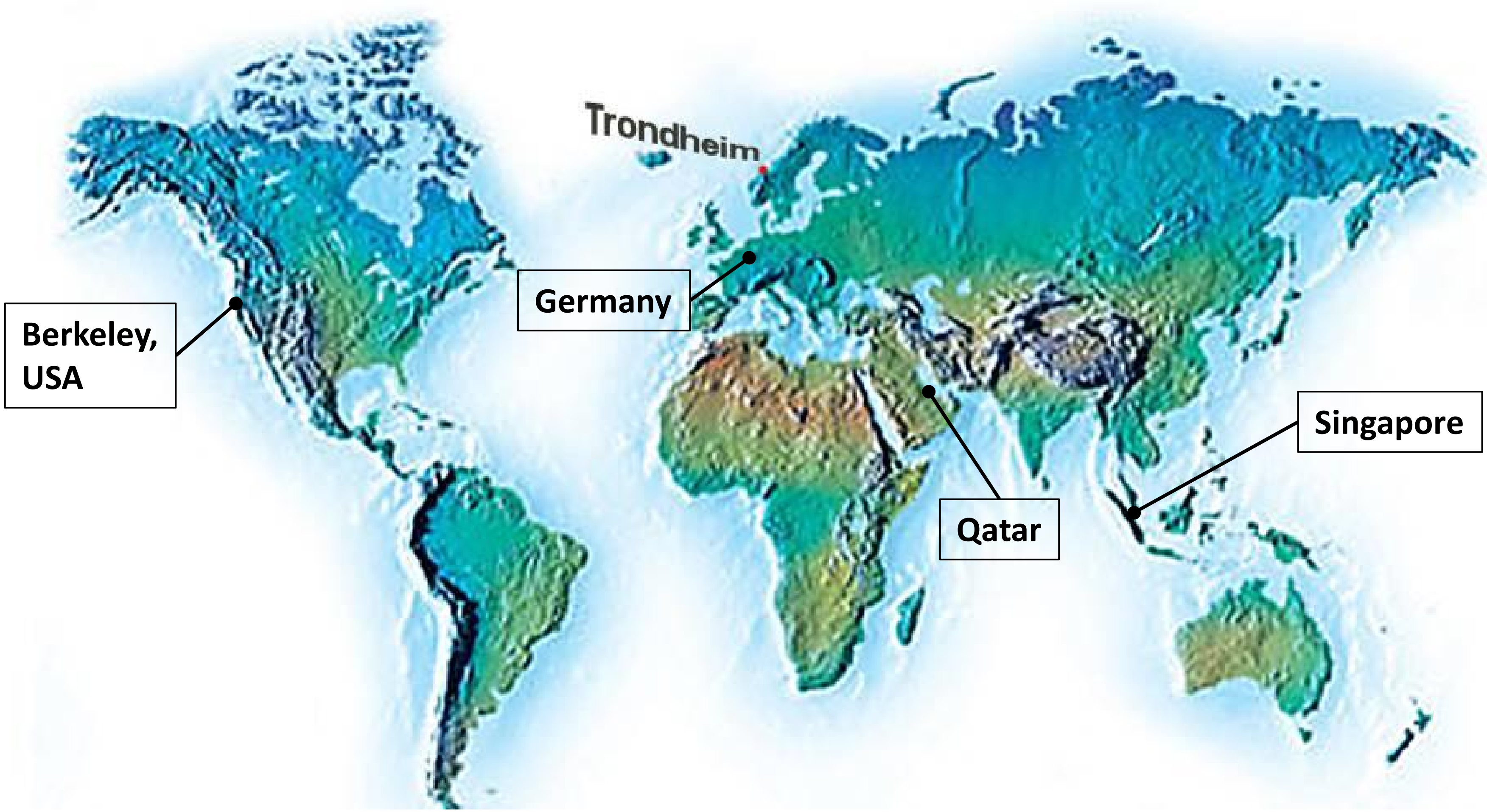
The Research Centre on
Zero Emission Buildings

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



Thank you for your attention

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