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SINTEF Building and Infrastructure Catherine Grini (editor)

Concrete ideas for Passive Houses

COIN workshop, 26-27 January 2010, Oslo, Norway

COIN Project report 20 - 2010

SINTEF

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FA 1 Environmental friendly concrete structures

P 1.2 Utilisation of concrete in low energy building concepts

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Keywords:
Concrete, Energy use, Passive House, Zero Emission Building

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Preface

This workshop has been carried out within COIN - Concrete Innovation Centre - one of presently 14 Centres for Research based Innovation (CRI), which is an initiative by the Research Council of Norway. The main objective for the CRIs is to enhance the capability of the business sector to innovate by focusing on long-term research based on forging close alliances between research-intensive enterprises and prominent research groups.

The vision of COIN is creation of more attractive concrete buildings and constructions. Attractiveness implies aesthetics, functionality, sustainability, energy efficiency, indoor climate, industrialized construction, improved work environment, and cost efficiency during the whole service life. The primary goal is to fulfil this vision by bringing the development a major leap forward by more fundamental understanding of the mechanisms in order to develop advanced materials, efficient construction techniques and new design concepts combined with more environmentally friendly material production.

The corporate partners are leading multinational companies in the cement and building industry and the aim of COIN is to increase their value creation and strengthen their research activities in Norway. Our over-all ambition is to establish COIN as the display window for concrete innovation in Europe.

About 25 researchers from SINTEF (host), the Norwegian University of Science and Technology - NTNU (research partner) and industry partners, 15 - 20 PhD-students, 5 - 10 MSc-students every year and a number of international guest researchers, work on presently eight projects in three focus areas:

- Environmentally friendly concrete
- Economically competitive construction
- Aesthetic and technical performance

COIN has presently a budget of NOK 200 mill over 8 years (from 2007), and is financed by the Research Council of Norway (approx. 40 %), industrial partners (approx 45 %) and by SINTEF Building and Infrastructure and NTNU (in all approx 15 %).

For more information, see www.coinweb.no

Tor Arne Hammer
Centre Manager

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1 Workshop programme

The workshop was held 26-27 January 2010 at SINTEF Building and Infrastructure in Oslo, Norway.

This report includes the abstracts and the presentations shown at the workshop.

Tuesday 26th of January 2010

11 00	**Opening, welcome and short presentation of COIN** Catherine Grini, SINTEF Building and Infrastructure
11 10	**Presentation of the participants** All participants
11 20	**Phase changing materials in pre-cast concrete** Ane Mette Kjeldsen, Teknologisk Institut, Denmark
11 50	**Possibilities of vacuum insulation panels in concrete buildings** Steinar Grynning, SINTEF Building and Infrastructure
12 20-13 00	*Lunch*
13 00	**Nano Insulation Materials Applied in the Buildings of Tomorrow** Bjørn Petter Jelle, SINTEF Building and Infrastructure
13 30	**How Might Nano Technology Improve the Thermal Performance of the Concrete Buildings of Tomorrow?** Bjørn Petter Jelle, SINTEF Building and Infrastructure
13 45	**Polybetong - insulated concrete produced with recycled expanded polystyrene (EPS)** Arne Olsen, Sustainable Management International, Norway
14 15	**Cement production - environmental challenges** Liv-Margrethe Hatlevik Bjerge, Norcem, Norway
14 45-15 00	*Pause*
15 00	**Research agenda for the concrete materials of tomorrow** Brainstorming / All participants working in groups
16 00	**Summary and discussions**
17 00	**End of the scientific programme**

Wednesday 27th of January 2010

09 00	**Design of passivehouses, combining wood and concrete** Gernot Vallentin, Architekturbüro Vallentin, Germany
09 30	**Utilisation of concrete in passivehouse design** Michael Klinski, SINTEF Building and Infrastructure
09 50	**Concrete constructions and air tightness of the building envelop** Ferry Smits, Rambøll, Norway
10 20-10 30	*Pause*
10 30	**Thermoactive building system (TABS) in concrete slabs** Reto Michael Hummelshøj, COWI Denmark
11 00	**Research agenda for the concrete constructions of tomorrow** Brainstorming / All participants working in groups
12 00-12 45	*Lunch*
12 45	**Research agenda for the COIN's subproject "Utilisation of concrete in low energy building concepts"** Brainstorming / All participants working in groups
14 00	**Summary and discussions**
15 00	**End of the workshop**

2 Workshop participants

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3 Introduction

COIN workshop on Concrete Ideas for Passive Houses

Catherine Grini, SINTEF Building and Infrastructure
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The workshop on Concrete Ideas for Passive Houses belows to the COIN's focus area ”Environmental friendly concrete structures”. The purpose of the workshop is to find out how concrete may participate to reach Passive House standards and/or future standards for the Buildings of Tomorrow (Zero Energy Buildings or Zero Emission Buildings), and to point out the research needs for the use of concrete in energy efficient buildings.

It doesn't exist universal consensus for the definitions of Passive Houses, Zero Energy Buildings and Zero Emission Buildings. The original German definition of a Passive House is that of ”*A building, for which thermal comfort can be achieved solely by post heating or post cooling of the fresh air mass, which is required to fulfil sufficient indoor air quality conditions without a need for recirculated air*". This definition is also expressed as ”*A building where the space heating demand is not more than 15 kWh/m² per year*”, which could be difficult to apply in cold climates and is subject to adjustments. A Zero Energy Building could be defined as a building that produces as much energy as it uses, but it is still unknown if the energy production has to be simultaneous to the consumption (or not), and how the embodied energy during the building stage has to be included to the energy consumption (or not). A Zero Emission Building is usually defined as a building with an energy production that compensates for its CO_2 emissions (CO_2 equivalents) in a life cycle analysis. The way of calculating CO_2 emissions for the different energy sources is a heated debate that is not closed yet.

WELCOME

CONCRETE IDEAS FOR PASSIVE HOUSES

or concrete ideas for the buildings of tomorrow

26th – 27th January 2010
SINTEF Building and Infrastructure – Oslo, Norway
Catherine Grini

SINTEF

Technology for a better society

The SINTEF Group

Size
Largest research institute in Scandinavia
Around 2.100 employees from 64 countries
Located mainly in Trondheim and Oslo
Turnover in 2008: around 325 millions euros

Our distinctive character
The SINTEF Group is a multi-disciplinary institution with international top level expertise in several different areas of research.
We cooperate closely with universities, the authorities and industry, and combine research and business culture.

Organisation of the SINTEF Group

14 SFI – a Norwegian Research Council (NFR) initiative

- Centre for Research-based Innovation (SFI)
- 14 SFI
- Duration of 8 years (5+3)

NFR objective:
- stimulate innovation through long-term research
- attract research activities to Norway
- create an active co-operation between industry and research institutions
- promote development of internationally leading research environments
- stimulate education of researchers in important fields for the industry

COIN's vision: Attractive concrete buildings!

- aesthetic

- functional
- flexible
- robust

- environmentally friendly
- pleasant indoor climate
- energy efficient

- cost efficient

- industrialised construction
- improved work environment

Focus Areas

1) Environmental friendly concrete structures
Binders with low emission and reduced resource consumption
Utilisation of concrete in low energy building concepts

2) Competitive construction
Stable and robust highly flowable concrete
High tensile ductile strength concrete
High quality manufactured sand for concrete

3) Aesthetics & technical performance
Aesthetics
Service life
Structural Performance

Annual funding (NOK)

Norwegian Research Council	9.5 mill
Industry	12.0 mill
SINTEF	2.0 mill
NTNU	4.5 mill
TOTAL	**28.0 mill**

Partners

The Research Council of Norway
NTNU
SINTEF
NORCEM HEIDELBERGCEMENTGroup
unicon CEMENTIR HOLDING
maxit maxit Group
Spenncon
RESCON MAPEI
Statens vegvesen
SKANSKA
VEIDEKKE
AkerSolutions

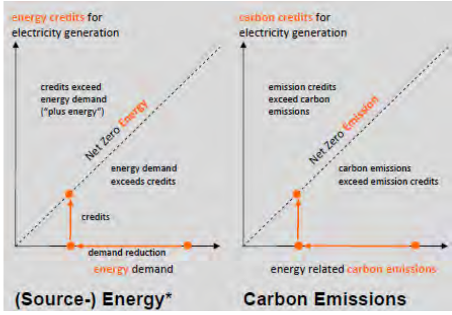
"Staff"

- About 25 researchers from SINTEF, NTNU and industry partners work in the COIN projects
- 10 PhD-students
- 5-10 MsC-students
- International guest researchers

Passive House definition

- Definition from the Passive House Institute: A passive house is a building in which a comfortable interior climate can be maintained without active heating and cooling systems (Adamson 1987 and Feist 1988). The house heats and cools itself, hence "passive".
- Definition in the Norwegian standard draft: A building with a very simple heating system
- Max. heating energy = 15 kWh/m².a

Energy demand, emissions and credits



Source: *University Wuppertal, Prof. Karsten Voss*

Examples

Zero Energy Building, or near to zero, or plus-energy

SMALL HOUSE - 1
Freiburg, Germany
Self-sufficient Solar House, 1992

Off-grid

Passive:
Transparent insulation
Solar thermal collectors
PV on optimally tilted roof
Active:
Seasonal storage with pressurised hydrogen
Energy sources:
Only solar energy

SMALL HOUSE - 2
Thening, Austria
Plus Energy house, 2001

Passive:
Passive house (heating ≤ 15 kWh/m²a)
Heating through ventilation air
Ground heat exchanger
Active:
Heat Pump
Façade solar thermal collectors
PV roof 10 kW_p
Energy sources:
All-electric house

APARTMENTS BLOCK
Heidelberg, Germany
"ZeroHaus", 2004 (1951)

APARTMENTS BLOCK

Heidelberg, Germany
”ZeroHaus”, 2004 (1951)

Passive:
Heating = 21 kWh/m^{2}a (before 166)
Centralized hydronic heating system
Ventilation, heat recovery
Active:
Micro-CHP (50 kW$_{el}$, 80 kW$_{th}$)
+ peak load boilers (2 x 92 kW)
PV balcony roof 10kW$_p$
Energy sources:
Natural gas, electricity

SETTLEMENT / VILLAGE - 1

Freiburg, Germany
”Plusenergie Siedlung”, 2000-2008

Settlement ~ 60 dwellings
3,600 m^2 offices
1,200 m^2 shops, etc.

SETTLEMENT / VILLAGE - 1

Freiburg, Germany
”Plusenergie Siedlung”, 2000-2008

Settlement ~ 60 dwellings
3,600 m^2 offices
1,200 m^2 shops, etc.
Passive:
Heating ~ 15-20 kWh/m^{2}a
Active:
PV roofs
District CHP running on wood
Energy sources:
Wood, electricity

SETTLEMENT / VILLAGE - 2

Wallington, UK
BedZED village, 1999-2001

Settlement ~ 92 dwellings
1,500 m^2 offices
Passive:
Heating 88% less than UK average
Active:
PV roofs providing ~ 10% of electricity
District CHP running on wood
Energy sources:
Wood, electricity

4 Phase changing materials (PCMs) in pre-cast concrete

Phase changing materials (PCMs) in pre-cast concrete

Ane Mette Kjeldsen

Concrete Centre, Danish Technological Institute, Denmark

Phase changing materials (PCMs) in pre-cast concrete

Ane Mette Kjeldsen
Concrete Centre, Danish Technological Institute, Denmark

The use of PCM in buildings

During the last couple of decades, several forms of macro encapsulated organic PCMs have been marketed for energy-accumulation, but the surface area-to-volume ratio of these bulk masses greatly limits the effect of the PCM (Hawlander 2002). Subsequently, micro encapsulated PCM has gained footing, especially for use in gypsum wallboards, making it possible to utilize the walls and ceilings of a room (Feldman (1991). Diekmann (2006) and Bentz (2007) showed that lightweight aggregates (LWAs) saturated with paraffin wax can store large quantities of energy and that they can be successfully used within concrete specimens. In a recent development, aerated concrete blocks have been combined with microencapsulated paraffin already during mixing. The application of PCM both in gypsum wallboards and aerated concrete blocks represent significant advances in the field but results are still challenged by limited thermal mass, limited mass of PCM, as well as their limited field of application.

Prior research using simple test set-ups has proven that mixing PCM with concrete significantly improves the thermal mass and activation hereof (Hunger et al, 2009, Virgone and Kuznik, 2006, Cabeza et al, 2007). Furthermore, the absolute effect of PCMs is much higher when introduced into heavy building materials than in light ones. Calculations show savings in energy consumptions of 15-30%. However, while the theoretical heat capacity in the active temperature interval should be up to 6.5 times that of ordinary concrete, previous studies have indicated much lower values of 2-3.5 times.

Accelerated durability tests have shown that Micronal® PCMs, contrary to earlier products, are highly durable and have showed no reduction in performance over a period equivalent to 30 years. However, Hunger et al (2009) found indications of limited Micronal® capsule durability when exposing the capsules to the concrete production process (shear and high pH). Furthermore, initial experimental work has shown large and uncontrolled changes in cement-based suspension rheology when adding PCM particles. Being able to control the rheology is essential for the industrial production process.

Choosing to work with precast concrete in opposition to ready mixed concrete offers the beneficial effect of controlled and similar production processes while being able to control the surrounding climate much more efficiently. Furthermore, the precast production process offers possibilities to divide the casting itself into several processes and thus use different concrete compositions in top and bottom of the element. This is already done by different precast producers.

Challenges impeding the use of micro encapsulated PCM in concrete

Based on the above, when adding PCM-capsules to a concrete mix, a number of challenges are still unresolved in the hunt for a material composition, facilitating both high energy utilization and concrete properties equivalent to traditional concrete. The primary challenges identified are:

1. The fresh concrete is sticky and difficult to cast
   - ⇒ It is difficult to obtain low w/c-ratios
   - ⇒ Low maximum concrete strength
2. Energy accumulative properties are lower than theory suggests
3. Commercial energy design tools to aid building owners make decisions regarding the cost-benefit of implementing PCM-Concrete are inadequate

A holistic approach is necessary

A number of projects dealing with PCMs in concrete have tended to focus on either concrete technology or energy efficiency and dealt less with the challenges as a whole. However, the different issues are closely connected and in order to make PCMs in concrete a cost-effective material, there is a need to take a holistic approach where the different factors as well as their inter-relation are looked on as a whole.

A new project called "New energy efficient concrete prepared for industrialized production" (short: PCM-Concrete) has recently been launched in Denmark. The project, which has a budget of around 1.7 million Euros, is part financed by the Danish National Advanced Technology Foundation and includes four partners as shown in figure 1. This project is tailored to meet all the scientific challenges impeding the use and commercialization of PCMs in concrete. It is especially important to recognize that while energy utilization is the driving force behind the use of PCMs in concrete, material technology research with an eye on production technology is vital to pave the way for a proper utilization!

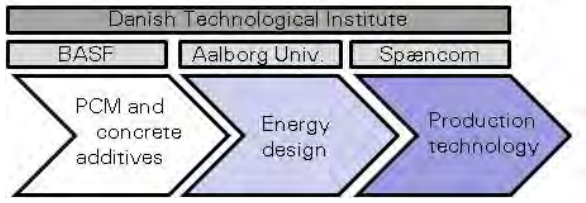


Figure 1 – The scientific areas and partners involved in the PCM-Concrete project

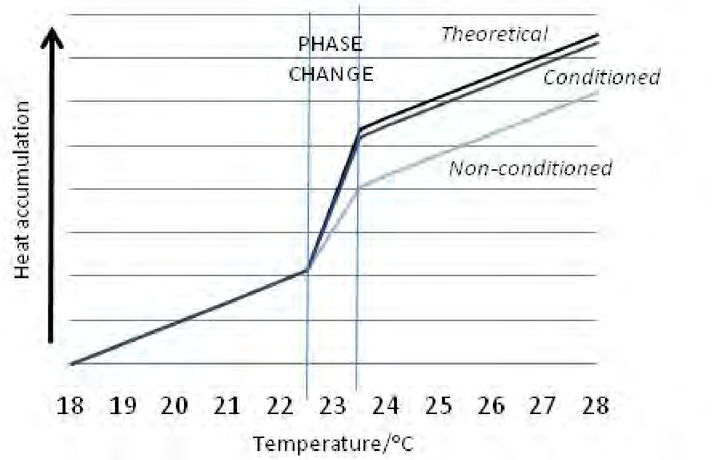


Figure 2 – Increased heat accumulation in conditional samples

Selected preliminary results

Currently, a lot of work is focused on trying to establish capsule properties that, together with the correct choice of superplasticizer and mix composition, facilitate proper fresh state concrete handling properties. This, along with controlling the basic hardened properties, is the key to industrialized production of pre-cast concrete.

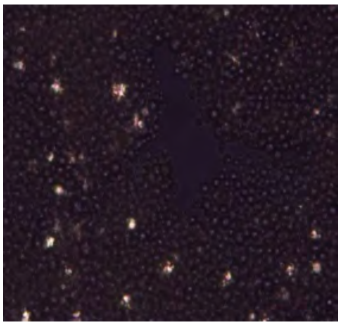


Figure 3 – optical microscopy above the phase change temp.

Figure 4 – optical microscopy below the phase change temp.

For the energy studies, commercially available Micronal® capsules with a melting point of 23°C have been investigated. Preliminary results indicate that there is a vast effect of the temperature of the constituent materials and the temperature during hardening on the energy utilization rate. While a non-conditioned sample, mixed, cast, and cured at lab-temperatures (i.e. non-controlled around 21°C) showed a utilization rate of about 50% of what might be expected, a sample conditioned above the phase change temperature of the Micronal® showed a utilization rate of close to 100%. This is illustrated in figure 2. Further measurements to elucidate and validate this are underway.

In order to be able to identify any degradation of the capsules subjected to chemical and mechanical factors, it is necessary to determine/develop a suitable method to observe these changes. Initial studies show that optical microscopy may be used to identify qualitatively the amount of fractured capsules (if any) after a certain exposure. In figure 3, the single capsules are shown with the temperature above 23°C and the picture shows that the paraffin within the capsules is liquid and thus isotropic. In figure 4, the same image is shown, this time below 23°C. It clearly shows that the paraffin is solid and birefringent. Furthermore, it should be noted that birefringence at temperatures below 23°C is only observed within the capsules, which indicates that the paraffin is not present outside the capsules (no broken capsules).

In figure 5 a polished plane section investigated in an SEM (LFD-mode) clearly identifies the capsule and capsule wall. Figure 6 shows a fractured mortar surface where the surface morphology of each PCM-capsule is very easily identified.

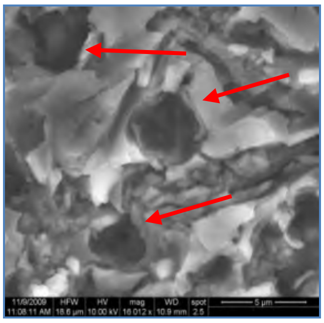


Figure 5 – LFD-image of capsule and gypsum matrix.

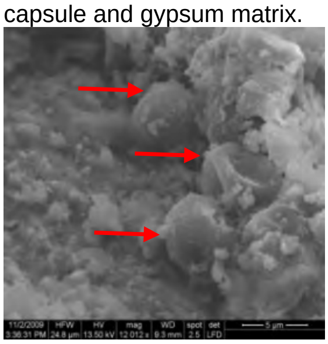


Figure 6 – LFD-image of a fractured mortar surface with PCM capsules.

Summary and conclusions

Studies of PCM have indicated that microencapsulated PCMs may be the most efficient route to precast PCM-concrete. However, for PCMs to be successfully implemented in precast concrete, it is necessary to take a holistic approach in the development of suitable compositions and energy design guidelines. This is the approach taken in the recently started Danish PCM-Concrete project, where both energy design, material technology, and production technology is included.

The project, which is currently in its starting phase, will run into 2012. Initial results show some interesting tendencies regarding the utilization of energy accumulation properties. Furthermore, selected microscopy methods have proven useful in the identification of chemical and/or mechanical degradation of capsules in concrete. Such degradation may impede full utilization of the material potential.

For more information on the PCM-Concrete project, please visit www.dti.dk/inspiration/26870.

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Phase-changing materials (PCMs) in pre-cast concrete

Ane Mette Kjeldsen, Concrete Centre
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Agenda

- Background
- Why PCMs
- PCMs in building materials
  - Types and choice of PCMs
  - Types and choice of encapsulation
  - Choice of host building material
  - Choice of production method
  - Challenges in using PCMs in concrete
- Content of the PCM-Concrete project
- Results so far

Background

Me

- M.Sc. In Civil Engineering (focus on concrete technology)
- Ph.D in inter-particle forces and resulting packing of cement grains
- 3,5 years employment at DTI, recently project leader for the PCM-Concrete project

PCM-Concrete
New Energy Efficient Concrete Prepared for Industrialized Production

- Budget is 13 million DKK over 3 years, 50% funded by the Danish National Advanced Technology Foundation
- Partners are BASF, Aalborg University, Spæncom and DTI
- Duration 1. September 2009 – 31. August 2012

Why use PCMs in building materials

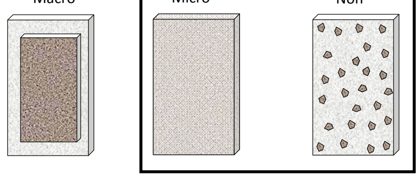
- Increasing the thermal capacity of the building material
- Stabilizing room temperatures and reduce energy for cooling and heating in buildings for several decades with no maintenance

PCMs in building materials
Types and choice of PCM

	Inorganic (e.g. hydrated salts)	Organic (e.g. fatty acids, paraffins)
Advantages	Temperature range High latent heat Inexpensive	No segregation Supercooling may be avoided Chemically stable (increased life time)
Challenges	Corrosive Supercooling Hysteresis (segregation)	Low thermal conductivity (reduced activated layer) Volume change during phase change

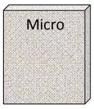
Organic PCMs

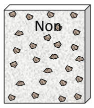
PCMs in building materials
Types and choice of encapsulation



	Macro	Micro	Non
Advantages	Easy production No influence on concrete properties Large amounts of PCM	High surface-to-volume ratio (efficiency)	Easy production Large amounts of PCM
Challenges	Surface-to-volume ratio (efficiency) Limited applicability	Influence on concrete properties (limits fresh state workability, strength) Limited amount of PCM	Limited applicability Leaching to concrete Influence on concrete properties?

PCMs in building materials
Choice of host building material

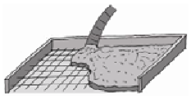




Gypsum wall boards Aerated concrete blocks Concrete	Light-weight concrete	**Limited thermal mass and/or limited market segment**

Material	App. density
Aerated concrete	~500 kg/m^3
Gypsum	~1200 kg/m^3
Light-weight concrete	~1800 kg/m^3
Concrete with 5 w% PCM	~2200 kg/m^3
Traditional concrete	~2300 kg/m^3

PCMs in building materials
Choice of production method

	Ready mix concrete	Pre-cast concrete
		
Advantages	?	Stable production Easy to cast in layers Controlled temperature during casting and curing
Challenges	Varying production Difficult to cast in layers Uncontrolled temperature during casting and curing	Need for high early strengths

PCMs in building materials
Combined choice for future research

Organic PCMs
Micro encapsulated
} BASFs Micronal®
Paraffin encapsulated by an polymethyl methacrylate shell

In traditional concrete

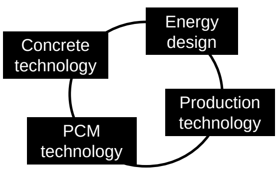
Pre-cast concrete

Challanges impeding the use of PCMs in concrete

The primary challenges identified are:

- The fresh concrete is sticky and difficult to cast
  - It is difficult to obtain low w/c-ratios
  - Low maximum concrete strength
- Static energy accumulative properties are lower than theory suggests
  - theoretical heat capacity in the active temperature interval should be up to 6.5 times that of ordinary concrete
  - Previous studies have indicated much lower values of 2-3.5 times
- Commercial energy design tools are inadequate
  - Position of PCM in the element
  - Position of element in the building
  - Dynamic thermal properties unknown

Holistic approach necessary



The PCM-Concrete project
Purpose and objectives

Purpose
We want to be able to offer system solutions that enable entire structures to be "born" energy efficient (to be cost-efficient).

The scientific objectives are
1)Understanding of the interfacial properties of Micronal® PCM-particles in cement-based suspensions and be able to tailor dispersants/PCM-coating to match these,
2)Understanding of the complicated heat transfer mechanisms in a PCM-concrete mixture to be able to optimize PCM-concrete element composition, and
3)to investigate significant requirements for optimum integration in whole building energy systems.

The technological objectives are
1)to develop and optimize this new composite material to meet legislative standards for e.g. durability and strength,
2)to develop system solutions for energy design, and
3)to ensure a robust industrialized production process based on existing production platform

Holistic approach necessary
Project content

PCM, concrete, and production technology

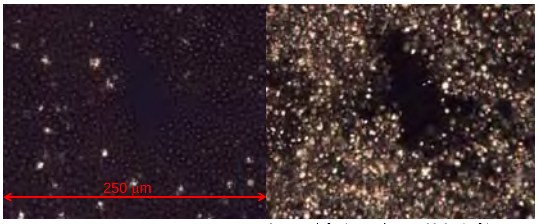
- Capsule durability (chemical and mechanical)
- Development of suitable particle surface properties
- Hardened interfacial properties (thermal dilation)
- Optimization of rheology
- Development of mixing sequence, guidelines for casting and curing
- Precast production process
- Physical and thermal properties of PCM-concrete

Energy

- Thermal properties of PCM-concrete
- Modelling and simulation
- Placement of PCM in element
  Concentration of PCM
  Placement of elements
- Full scale verification of building energy design tools in EnergyFlexHouse at DTI

Capsule durability
Optical microscopy of Micronal Type DS 5008 X

Determine proper test methods

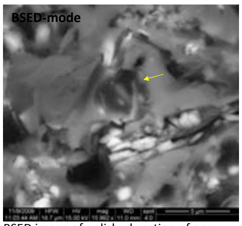


Cluster of non-exposed capsules dispersed in water seen in a petrographic microscope with crossed polars. T > 23 C. Isotropic paraffin, fluid.

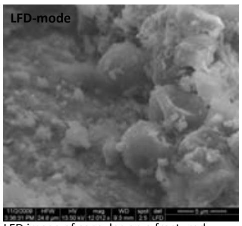
Same as left picture, but T < 23 C. Birefringent paraffin, crystalline.

Capsule durability
SEM-imaging of Micronal Type DS 5008 X

For detection of delamination cracks and surface morphology



BSED image of polished section of epoxy-impregnated PCM gypsum



LFD image of capsules on a fractured surface of PCM mortar. Deformed capsules and capsules with a relatively high sphericity are lying side by side.

Capsule durability
Non-commercial PCMs

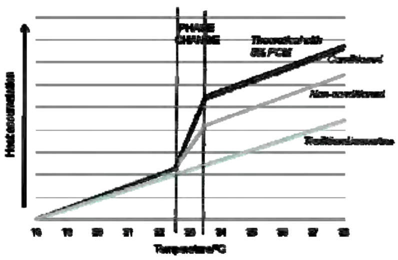
Non-treated PCM. Round, spherical PCM capsules with small deposits on the surface. Small depressions (craters) are observed on the surface. BSE mode.

NaOH treated PCM. Round, spherical PCM capsule more or less free of deposits on the surface. Small depressions (craters) are observed on the surface. BSE mode.

Highly irregular and fractured PCM capsules. The image is distorted due to instability of the paraffin during scan rate. LFD mode.

Initial results indicate that the chosen methods of microscopy are well suited for the purpose of determining chemical, mechanical, and thermal degradation.

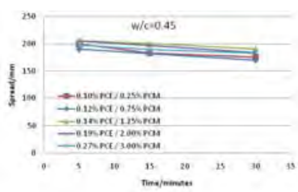
Thermal properties of PCM-Concrete
Static heat accumulation properties



Development of suitable particle surface properties
Screening of possible adjustments

Variables:
- Structure and active groups of superplasticizer (PCE)
- Shell chemistry
- Powder or slurry

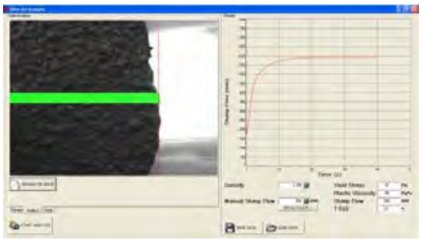
Indications from initial experiments:
- The PCMs are affected by the addition of PCEs
- Setting time is retarded
- Compressive strengths are reduced



Development of suitable particle surface properties

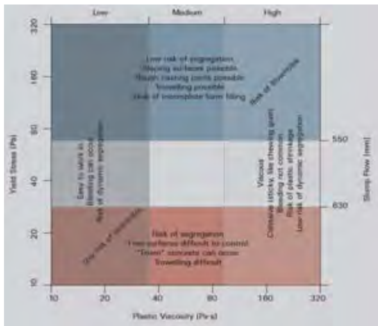
Flow properties - from mortar to concrete

Fluid and semi-fluid concrete (SCC)



Development of suitable particle surface properties

Flow properties - from mortar to concrete



So-called rheology diagram for SCC (practical experience from the use of SCC versus rheological parameters).

Further information

See webpage: http://www.dti.dk/inspiration/26870
Contact: Thomas Juul Andersen, tja@teknologisk.dk

5 Vacuum insulation panels and possible applications in concrete buildings

Vacuum insulation panels and possible applications in concrete buildings

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Vacuum insulation panels and possible applications in concrete buildings

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Keywords: Vacuum insulation panel, VIP, building, concrete

Introduction

Buildings account for a significant part of the energy use and greenhouse gas emissions. Therefore one has to improve the energy efficiency of buildings.
Concepts like passive houses and zero emission buildings are being introduced. Applying traditional techniques and materials in these buildings will significantly increase the amount of traditional thermal insulation, e.g. wall thicknesses up to about 400 mm are expected in passive houses. Such large thicknesses are not desirable due to several reasons, e.g. floor area considerations, efficient material use and need for new construction techniques.

Future Constructions

Vacuum insulation panels (VIPs) are regarded as one of the most promising high performance thermal insulation solutions on the market today. Thermal performance typically ranges 5 to 10 times better than traditional insulation materials (e.g. mineral wool), potentially leading to substantial slimmer constructions.
However, the VIPs have several disadvantages which have to be addressed. The robustness of VIPs in constructions is questioned, e.g. puncturing by penetration of nails etc.
Moreover, the VIPs can not be cut or fitted at the construction site. Finally, degradation of thermal performance due to moisture and air diffusion through the panel envelope is also a crucial issue for VIPs.

Panel Properties

The VIPs are made up of two main parts. A high porous, low thermal conducting core and a low permeable, multi-layer barrier envelope foil.
In addition to these, getters and desiccants are added, which chemically bonds to gas and water that penetrates the envelope foil. An illustration of a typical VIP is shown in fig.1

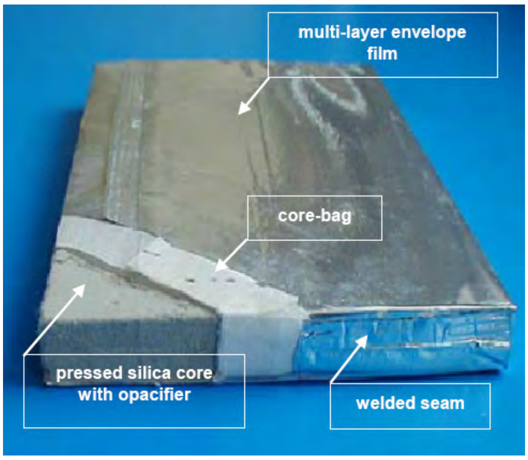

Fig.1. Typical VIP structure, showing the main components (Brunner et al. 2005).

The core material is usually made of aerated silica material, i.e. fumed silica. This material has a continuous pore structure that makes it possible to evacuate the air trapped inside the pores and obtain vacuum. In addition the pores have so small diameters that they retain some of their thermal insulation effects regardless of a higher internal air pressure.
Figure 2 shows how the thermal conductivity of different materials varies with air pressure in the pore system. A typical VIP has an internal core pressure of 1 mbar at delivery from the producer, and will reach a gas pressure of 1 bar if punctured.

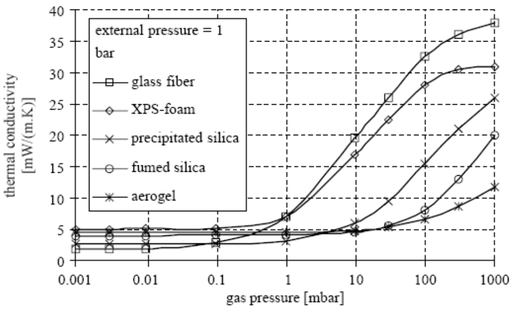

Fig. 2. Thermal conductivity of various materials as function of air pressure in the pore system (Tenpierik et al. 2007).

The envelope foil is made up of a plastic/aluminium laminate. The newest generation applies a triple layer of 30 µm aluminium sheets, embedded in a plastic material, where the entire foil usually is about 0.1 mm thick (Willems et al. 2005).

Service Life

The internal gas pressure and moisture content are the two governing parameters for the service life of the VIP. The envelope foil has to be as gas and water vapour tight as possible. A typical foil gives an increase in internal pressure of 2.5 mbar per year.
On the other hand it has to have an as low thermal conductivity as possible to reduce thermal bridging along the edges of the VIP.

Practical Use

The use of VIPs in buildings gives rise to a large range of possibilities. Nevertheless some challenges have to be addressed. Table 1 gives a summary of some advantages and disadvantages of VIPs applied in buildings.

Table 1. VIP advantages and disadvantages.

Advantages	**Disadvantages**
Highly insulating	Fragile and need mechanical protection against puncturing
Thinner envelope structure	Degradation of insulation capacity over time
Increased floor area $\Rightarrow$ increased property value	Limited service life demands the possibility of replacement
Well suited for rehabilitation	Foil material reduces the effective conductivity of the panels
Thermal bridge insulation in buildings	Reduced performance in timber frame walls and similar, due to thermal bridges from studs etc.
Thin VIP sufficient for insulation capacity in various structures	Limited flexibility. Can not be adjusted at construction site
	Detailed plans must be made for the panel layout

Possible Concrete Applications

As indicated in Table 1, the VIPs need some form of mechanical protection to reduce the risk of puncturing. Sandwich elements seem to be a well suited construction method if one is to apply VIPs in the building envelope.

If one is to apply VIPs in for example a timber frame wall, the VIPs would be placed in the cavities between studs, where the studs will act as thermal bridges. However, used as interior or exterior insulation in combination with a concrete load bearing structure, the VIPs can be placed in a continuous layer.

An existing example of such a construction is shown in fig.3, where the VIPs are glued to the concrete and protected with a layer of polyurethane (PUR). Strips of PUR are laid between VIPs to make fastening of the outer PUR layer possible. This construction gave a reduction of wall thickness by 12 cm, compared to a 24 cm thick wall with the same thermal performance using only traditional insulation (Pool 2009).

Fig. 3. VIP external insulation on a concrete wall (Pool 2009).

However, there are some challenges that must be addressed. The interface between the laminate foil and the alkaline concrete might have negative effects on the foil. On the other hand, the concrete might act as an additional vapour and gas barrier, thus increasing the service life of the VIP, in addition to the mentioned increase of robustness.

Acknowledgements

This work has been supported by the Research Council of Norway and several partners through the SINTEF and NTNU research projects *Robust Envelope Construction Details for Buildings of the 21st Century* (ROBUST) and the *Concrete Innovation Centre* (COIN).

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Vacuum Insulation Panels

Properties and Possible Applications in Concrete Buildings

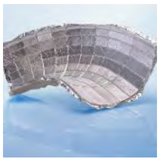
Steinar Grynning and Bjørn Petter Jelle

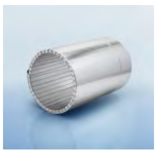
COIN-workshop
Oslo, 26th January, 2010

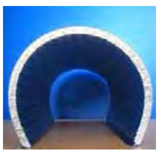
Work at SINTEF Building and Infrastructure

- State-of-the-art article
- Project reports and articles
- Fulls scale measurements on different VIP configurations using a hot box
  - U-values
  - Thermal bridges

Vakuum Insulation Panels VIPs







History

- VIPs have been on the market for several years
- Mostly used in Central Europe and Asia
- Limited use in Norway last 8-10 years

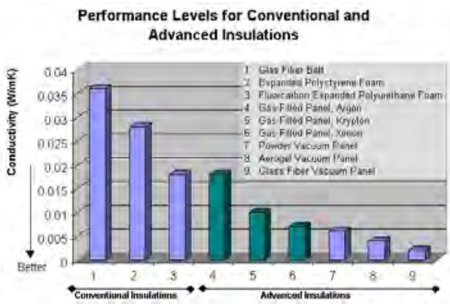
Thermal Conductivity

- Describes the insulation capacity of a material, low conductivity equals a well insulating material

Typical conductivity values for:

	Mineral wool	VIP with vacuum	VIP without vacuum
Konduktivitet (W/(mK))	0.036	0.004	0.020

The Insulation Materials of the Future



(Baetens et al. 2009)

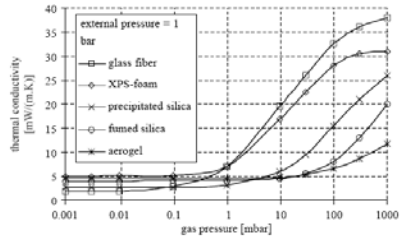
Panel Construction

- Porous core material
- Moisture/gas absorbant materials
- Plastic/metal laminate foil

(Simmler et al. 2005)

The Core Material

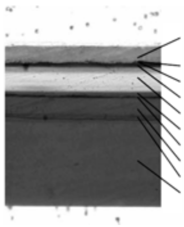
- *Fumed silica*:
  - High porousity makes it possible to evaquate air from the pores
  - Low thermal conductivity in the solid part



(Tenpierik et al. 2007)

The Envelope Foil

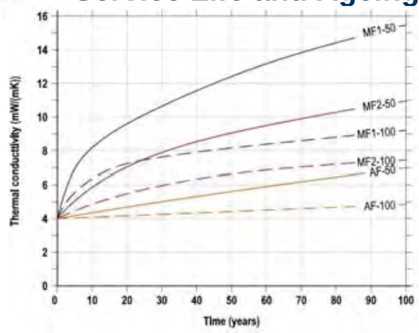
- Laminated plastic/metal foil
  - Air and moisture tight to prevent penetration of air and gas
  - Low thermal conductivity to reduce thermal bridging



Layer #	Material	Function	Thickness
1	PET	Protecting layer (substrate for 2)	12 µm
2	ALU	Barrier layer	30 nm
3	PUR	Glue	2 µm
4	ALU	Barrier layer	30 nm
5	PP	Substrate for 4	18 µm
6	PUR	Glue	2 µm
7	ALU	Barrier layer	30 nm
8	PET	Substrate for 7	12 µm
9	PUR	Glue	2 µm
10	PE-LD	Sealing layer	60 µm

(Simmler et al. 2005)

Service Life and Ageing



Centre-of-panel thermal conductivity for VIPs with a fumed silica core

(Baetens et al. 2009)

How to Ensure a Robust Construction

- Punctures is a large concern
  - Production phase
  - Transport phase
  - On-site handling
  - Operational phase
- Not possible to cut/adapt on building site
- How to solve this?

Robustness continued…

- The robustness must be maintained via:
  - Control routines
  - Robust solutions of details and assemblies in the building envelope (Sandwich elements a good alternative)
  - *Careful* mounting on-site

Consequences for the Building Envelope

- "Slim constructions"
- 4-8 cm VIP sufficient for thermal insulative properties (depending on ageing resistance)
- 15 cm necessary for load bearing purposes?
- Thinner walls can increase floor area

Concrete, Challenges and Possibilities

POSSIBILITES

- Reduced gas and water penetration?
  - Increased Service Life
- Use of larger panels?
  - Reduced thermal bridging
- Sandwich elements
  - Protection

CHALLENGES

- Concrete / VIP interface
  - Alkaline surroundings
- Integration of the VIPs
  - Precast sandwich elements
  - External insulation
  - Internal insulation

Economy

- 100 m² dwelling.
- VIP cost 1600 NOK/m²
- 20 cm reduction in wall thickness

(Grynning et al. 2008)

Performance of VIP in Building Envelopes

- Construction site adaptation not possible
- Vulnerable during transport and assembly
- High cost, but can be cost effective

- Slim building envelopes
- Well insulated building envelopes
- Increased floor area
- Potential for economic profit

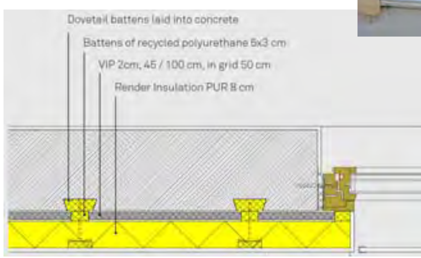
VIP concrete sandwiches

(Heinemann, 2009)

(Kubina, 2009)

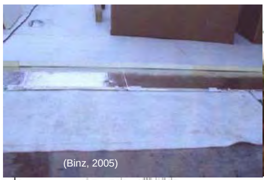
VIP external insulation

- Reduction of wall thickness by 12 cm
- Profitable when market value of heated floor area > 3500 €/m²

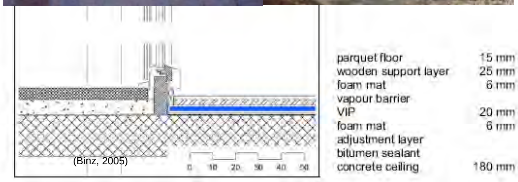


(Pool, 2009)

Floors and terraces


(Binz, 2005)


(Binz, 2005)



(Binz, 2005)

Conclusions

- VIP core material thermal conductivity can reach values as low as 0.004 W/(mK)
- Envelope foil decreases thermal performance slightly
- Ageing, usability and robustness are important factors
- VIP/Concrete interface should be further studied

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6 Nano insulation materials applied in the buildings of tomorrow

Nano Insulation Materials Applied in the Buildings of Tomorrow

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Nano Insulation Materials Applied in the Buildings of Tomorrow

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Keywords: Nano insulation material, NIM, Building, Tomorrow.

Introduction

Buildings constitute a substantial part of the world's total energy consumption, thus savings within the building sector will be essential, both for existing and new buildings. The thermal building insulation materials and solutions constitute one of the key fields. Recent studies (McKinsey 2009) point out that energy efficiency measures are the most cost-effective ones, whereas measures like e.g. solar photovoltaics and wind energy are far less cost-effective than insulation retrofit for buildings.

Today's State-of-the-Art Thermal Insulation

The state-of-the-art thermal insulation materials and solutions of today include:

- **Vacuum Insulation Panels (VIP)**

"An evacuated foil-encapsulated open porous material as a high performance thermal insulating material"

  - Core (silica, open porous, vacuum)
  - Foil (envelope)
  - 4 mW/(mK) fresh
  - 8 mW/(mK) 25 years
  - 20 mW/(mK) perforated
- **Gas-Filled Panels (GFP)**
  - 40 mW/(mK)
- **Aerogels**
  - 13 mW/(mK)
- **Phase Change Materials (PCM)**
  - Solid State ↔ Liquid
  - Heat Storage and Release
- **Beyond State-of-the-Art High Performance Thermal Insulation Materials**

Traditional thermal insulation (e.g. mineral wool) has a conductivity of typical 36 mW/(mK) and concrete conductivities range between 150 - 2500 mW/(mK).

Major Disadvantages of VIPs

VIPs have several advantages, but also several drawbacks:

- Thermal bridges at panel edges
- Currently expensive, but calculations show that VIPs may be cost-effective even today
- Ageing effects – Air and moisture penetration
- Vulnerable towards penetration, e.g nails
- Can not be cut or adapted at building site
- Possible improvements?

Requirements of Tomorrow's Insulation

Proposed requirements for the thermal insulation of tomorrow are given in Table 1.

Table 1. Proposed requirements of the future high performance thermal insulation materials.

Property	Requirements
Thermal conductivity – pristine	< 4 mW/(mK)
Thermal conductivity – after 100 years	< 5 mW/(mK)
Thermal conductivity – after modest perforation	< 4 mW/(mK)
Perforation vulnerability	not to be influenced significantly
Possible to cut for adaption at building site	yes
Mechanical strength (e.g. compression and tensile)	may vary
Fire protection	may vary, depends on other protection
Fume emission during fire	any toxic gases to be identified
Climate ageing durability	resistant
Freezing/thawing cycles	resistant
Water	resistant
Dynamic thermal insulation	desirable as an ultimate goal
Costs vs. other thermal insulation materials	competitive
Environmental impact (including energy and material use in production, emission of polluting agents and recycling issues)	low negative impact

Advanced Insulation Materials

Advanced insulation materials (AIM) and concepts are introduced:

- Vacuum Insulation Materials (VIM)
- Gas Insulation Materials (GIM)
- Nano Insulation Materials (NIM)
- Dynamic Insulation Materials (DIM)

Vacuum Insulation Materials (VIM)

VIM is basically a homogeneous material with a closed small pore structure filled with vacuum with an overall thermal conductivity of less than 4 mW/(mK) in pristine condition (Fig.1).

The VIM can be cut and adapted at the building site with no loss of low thermal conductivity. Perforating the VIM with a nail or similar would only result in a local heat bridge, i.e. no loss of low thermal conductivity.

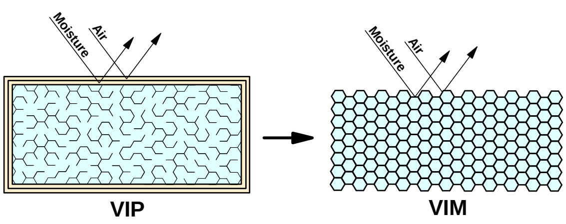

Fig.1. The development from VIPs to VIMs.

Gas Insulation Materials (GIM)

GIM is basically a homogeneous material with a closed small pore structure filled with a low-conductance gas, e.g. argon, krypton or xenon, with an overall thermal conductivity of less than 4 mW/(mK) in pristine condition.

Nano Insulation Materials (NIM)

By decreasing the pore size within NIM below a certain level, i.e. 40 nm or below for air, one may achieve an overall thermal conductivity of less than 4 mW/(mK) in the pristine condition.

That is, a NIM is basically a homogeneous material with a closed or open small nano pore structure with an overall thermal conductivity of less than 4 mW/(mK) in pristine condition (Fig.2).

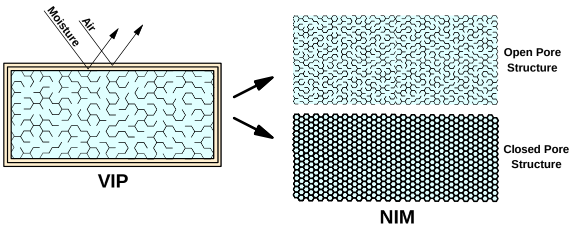

Fig.2. The development from VIPs to NIMs.

Note that the grid structure in NIMs does not, unlike VIMs and GIMs, need to prevent air and moisture penetration into their pore structure during their service life.

The Knudsen Effect – Nano Pores in NIMs

The rapid decrease in thermal conductivity as the pore size decreases below a certain level, even with air-filled pores, is due to the Knudsen effect where the mean free path of the gas molecules is larger than the pore diameter. That is, a gas molecule located inside a pore will ballistically hit the pore wall and not another gas molecule. The gas thermal conductivity λ_{gas} may be written in a simplified way as (Scwab et al. 2005, Baetens et al. 2010):

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

where

λ_{gas} = gas thermal conductivity in the pores (W/(mK))

$\lambda_{gas,0}$ = gas thermal conductivity in the pores at STP (standard temperature and pressure) (W/(mK))

β = coefficient characterizing the molecule - wall collision energy transfer efficiency (between 1.5 - 2.0)

$Kn = \sigma_{mean}/\delta = k_B T/(2^{1/2}\pi d^2 p\delta)$ = the Knudsen number

k_B = Boltzmann's constant $\approx 1.38 \cdot 10^{-23}$ J/K

T = temperature (K)

d = gas molecule collision diameter (m)

p = gas pressure in pores (Pa)

δ = characteristic pore diameter (m)

σ_{mean} = mean free path of gas molecules (m)

The Knudsen effect is visualized in Figs.3-4.

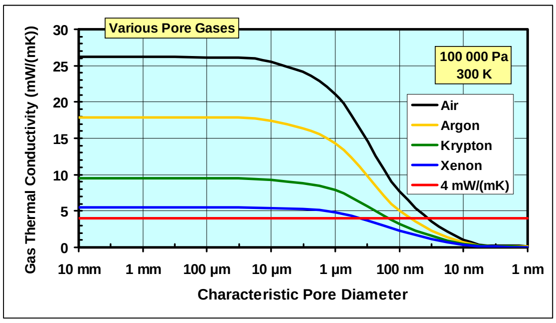

Fig.3. The effect of pore diameter on the gas thermal conductivity for air, argon, krypton and xenon. From Eq.1.

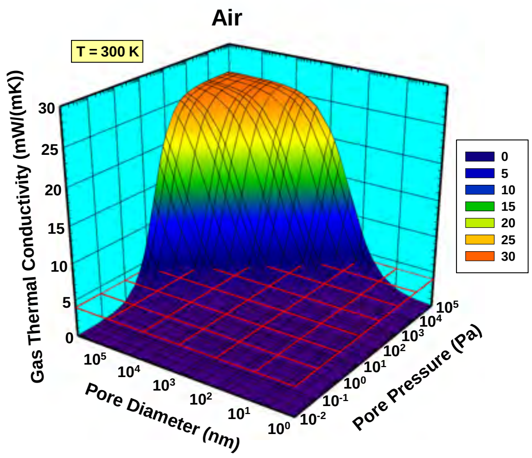

Fig.4. The effect of pore diameter and gas pressure in pores on the gas thermal conductivity visualized for air. From Eq.1.

Dynamic Insulation Materials (DIM)

DIM is a material where the thermal conductivity can be controlled within a desirable range.

- **Thermal conductivity control may be achieved by:**
  - Inner pore gas content or concentration including the mean free path of the gas molecules and the gas-surface interaction
  - The emissivity of the inner surfaces of the pores
  - The solid state thermal conductivity of the lattice
- **What is solid state thermal conductivity? Two models:**
  - Phonon thermal conductivity - atom lattice vibrations
  - Free electron thermal conductivity
- **What kind of physical model could describe and explain thermal conductivity?**
- **Could it be possible to dynamically change the thermal conductivity from very low to very high, i.e. making a DIM?**

Inspiration from other fields of science, e.g.?:

- Electrochromic Materials
- Quantum Mechanics
- Electrical Superconductivity
- Others? *Think thoughts not yet thought of!*

Potential of State-of-the-Art and Beyond

A short summary of the potential of becoming the high performance thermal insulation materials and solutions of tomorrow is given in Table 2.

Table 2. The potential of becoming the high performance thermal insulation materials and solutions of tomorrow.

Thermal Insulation Materials and Solutions	Low Pristine Thermal Conductivity	Low Long-Term Thermal Conductivity	Perforation Robustness	Possible Building Site Adaption Cutting	A Thermal Insulation Material and Solution of Tomorrow ?
Traditional					
Mineral Wool and Polystyrene	no	no	yes	yes	no
Today's State-of-the-Art					
Vacuum Insulation Panels (VIP)	yes	maybe	no	no	today and near future
Gas-Filled Panels (GFP)	maybe	maybe	no	no	probably not, near future
Aerogels	maybe	maybe	yes	yes	maybe
Phase Change Materials (PCM)	-	-	-	-	heat storage and release
Beyond State-of-the-Art – Advanced Insulation Materials (AIM)					
Vacuum Insulation Materials (VIM)	yes	maybe	yes	yes	yes
Gas Insulation Materials (GIM)	yes	maybe	yes	yes	maybe
Nano Insulation Materials (NIM)	yes	yes	yes, excellent	yes, excellent	yes, excellent
Dynamic Insulation Materials (DIM)	maybe	maybe	not known	not known	yes, excellent
Others ?	-	-	-	-	maybe

Conclusions

New concepts of advanced insulation materials (AIM) have been introduced, i.e. vacuum insulation materials (VIM), gas insulation materials (GIM), nano insulation materials (NIM) and dynamic insulation materials (DIM).

Nano insulation materials (NIM) seem to represent the best high performance low conductivity thermal solution for the foreseeable future. Possible applications of NIMs cover all building types including timber frame and concrete buildings.

Dynamic insulation materials (DIM) have great potential due to their controllable thermal insulating abilities.

Acknowledgements

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Nano Insulation Materials Applied in the Buildings of Tomorrow

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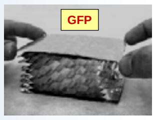
COIN Workshop on Concrete Ideas for Passive Houses, Oslo, Norway, January 26-27, 2010

State-of-the-Art Thermal Insulation of Today - What is Out There?

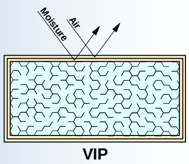
- **Vacuum Insulation Panels (VIP)**
  "An evacuated foil-encapsulated open porous material as a high performance thermal insulating material"
  - Core (silica, open porous, vacuum)
  - Foil (envelope)
- **Gas-Filled Panels (GFP)**
- **Aerogels**
- **Phase Change Materials (PCM)**
  - Solid State ↔ Liquid
  - Heat Storage and Release
- **Beyond State-of-the-Art High Performance Thermal Insulation Materials**



Thermal Insulation of Today

- Traditional Insulation
  - 36 mW/(mK)
- Vacuum Insulation Panels (VIP)
  - 4 mW/(mK) fresh
  - 8 mW/(mK) 25 years
  - 20 mW/(mK) perforated
- Gas-Filled Panels (GFP)
  - 40 mW/(mK)
- Aerogels
  - 13 mW/(mK)
- (Phase Change Materials (PCM))
- Other Materials and Solutions?

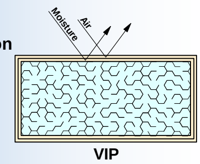
- Vacuum Core
- Air and Moisture Tight Envelope



Major Disadvantages of VIPs

- Thermal bridges at panel edges
- Expensive at the moment, but calculations show that VIPs may be cost-effective even today
- Ageing effects - Air and moisture penetration
  - 4 mW/(mK) fresh
  - 8 mW/(mK) 25 years
  - 20 mW/(mK) perforated
- Vulnerable towards penetration, e.g nails
  - 20 mW/(mK)
- Can not be cut or adapted at building site
- Possible improvements?

- Vacuum Core
- Air and Moisture Tight Envelope



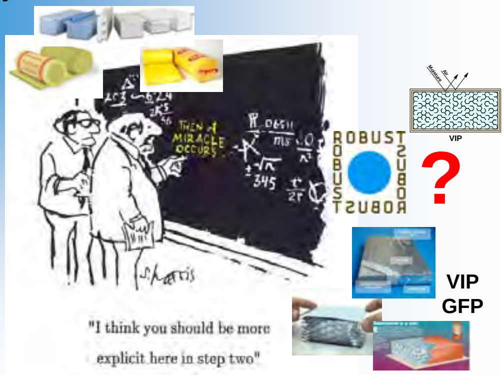
VIPs – The Thermal Insulation of Today ?

- VIPs - Despite large disadvantages - A large leap forward
- Thermal conductivities 5 to 10 times lower than traditional insulation
  - 4 mW/(mK) fresh
  - 8 mW/(mK) 25 years
  - 20 mW/(mK) perforated
- Wall and roof thicknesses up to 50 cm as with traditional insulation are not desired
  - Require new construction techniques and skills
  - Transport of thick building elements leads to increased costs
- Building restrictions during retrofitting of existing buildings
  - Lawful authorities
  - Practical Restrictions
- High living area market value per m^2 ⇒ Reduced wall thickness ⇒ Large area savings ⇒ Higher value of the real estate
- VIPs - The best solution today and in the near future?
- Beyond VIPs?

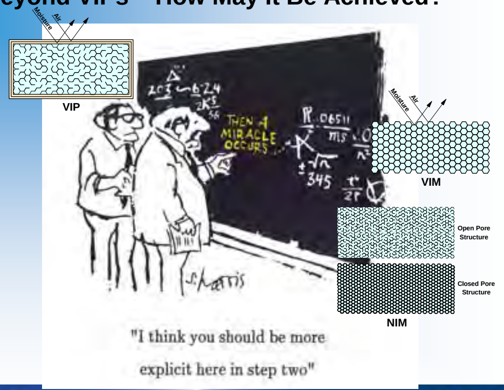
Requirements of the Thermal Insulation of Tomorrow

Property	Requirements
Thermal conductivity – pristine	< 4 mW/(mK)
Thermal conductivity – after 100 years	< 5 mW/(mK)
Thermal conductivity – after modest perforation	< 4 mW/(mK)
Perforation vulnerability	not to be influenced significantly
Possible to cut for adaption at building site	yes
Mechanical strength (e.g. compression and tensile)	may vary
Fire protection	may vary, depends on other protection
Fume emission during fire	any toxic gases to be identified
Climate ageing durability	resistant
Freezing/thawing cycles	resistant
Water	resistant
Dynamic thermal insulation	desirable as an ultimate goal
Costs vs. other thermal insulation materials	competitive
Environmental impact (including energy and material use in production, emission of polluting agents and recycling issues)	low negative impact

Beyond Traditional Thermal Insulation?



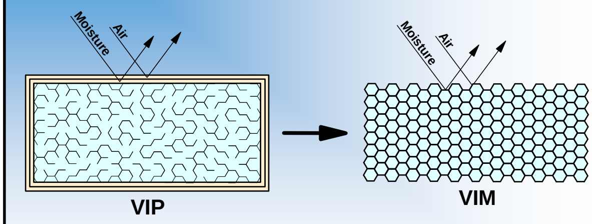
Beyond VIPs – How May It Be Achieved?



Beyond VIPs – How May It Be Achieved?

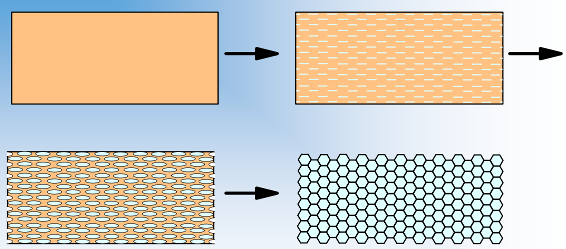
- Introducing New Concepts as Advanced Insulation Materials (AIM):
- Vacuum Insulation Materials (VIM)
- Gas Insulation Materials (GIM)
- Nano Insulation Materials (NIM)
- Dynamic Insulation Materials (DIM)

Vacuum Insulation Material (VIM)



VIM - A basically homogeneous material with a closed small pore structure filled with vacuum with an overall thermal conductivity of less than 4 mW/(mK) in the pristine condition

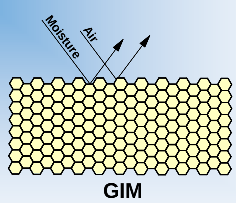
How to Make a VIM ?



A solid state material blowing itself up from within during the formation

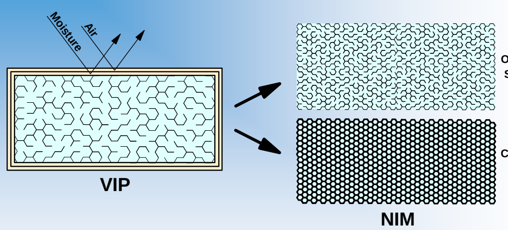
Gas Insulation Material (GIM)

… and analogously with VIM we may define GIM as follows:



GIM - A basically homogeneous material with a closed small pore structure filled with a low-conductance gas with an overall thermal conductivity of less than 4 mW/(mK) in the pristine condition

Nano Insulation Material (NIM)



NIM - A basically homogeneous material with a closed or open small nano pore structure with an overall thermal conductivity of less than 4 mW/(mK) in the pristine condition

The Knudsen Effect – Nano Pores

Gas Thermal Conductivity λ_g

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

$\sigma_{mean} > \delta \Rightarrow$ low λ_g

where

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

λ_g = gas thermal conductivity in the pores (W/(mK))
$\lambda_{g,0}$ = gas thermal conductivity in the pores at STP (standard temperature and pressure) (W/(mK))
β = coefficient characterizing the molecule - wall collision energy transfer efficiency (between 1.5 – 2.0)
k_B = Boltzmann's constant ≈ $1.38 \cdot 10^{-23}$ J/K
T = temperature (K)
d = gas molecule collision diameter (m)
p = gas pressure in pores (Pa)
δ = characteristic pore diameter (m)
σ_{mean} = mean free path of gas molecules (m)

Nano Pores – Thermal Radiation

- Knudsen effect $\Rightarrow \sigma_{mean} > \delta \Rightarrow$ low gas thermal conductivity λ_g
- What about the thermal radiation in the pores?
- "Classical" – from Stefan-Boltzmann's law:

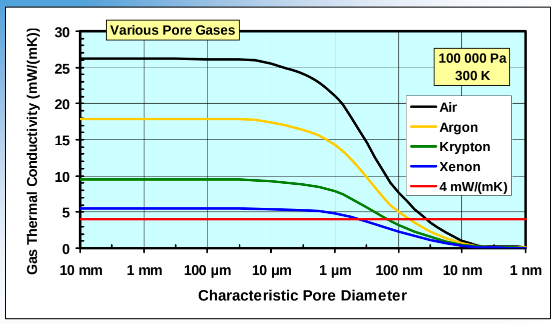
$$\lambda_r = \frac{\pi^2 k_B^4 \delta}{60\hbar^3 c^2 \left[\frac{2}{\varepsilon}-1\right]} \frac{(T_i^4 - T_e^4)}{(T_i - T_e)}$$

λ_r = thermal radiation conductivity in the pores (W/(mK))
σ = = $\pi^2 k_B^4/(60\hbar^3 c^2)$ = Stefan-Boltzmann's constant ≈ $5.67 \cdot 10^{-8}$ W/(m^{2}K^4)
k_B = Boltzmann's constant ≈ $1.38 \cdot 10^{-23}$ J/K
$\hbar = h/(2\pi) \approx 1.05 \cdot 10^{-34}$ Js (h = Planck's constant)
c = light velocity ≈ $3.00 \cdot 10^8$ m/s
δ = pore diameter (m)
ε = emissivity of pore walls
T_i = interior temperature (K)
T_e = exterior temperature (K)
ξ_{ir} = infrared radiation wavelength (m)

- Pore diameter δ small $\Rightarrow$ low thermal radiation conductivity λ_r
- But what happens when $\xi_{ir} > \delta$? (IR wavelength > pore diameter)
- $\xi_{ir} > \delta \Rightarrow$ high thermal radiation conductivity λ_r ?
- Evanescent waves… tunneling… etc. …
- Currently looking into these matters…

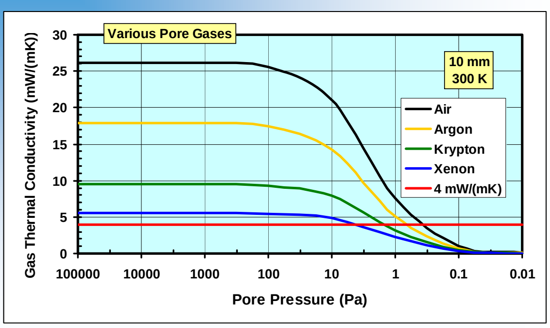
Gas Thermal Conductivity

Conductivity vs. Pore Diameter

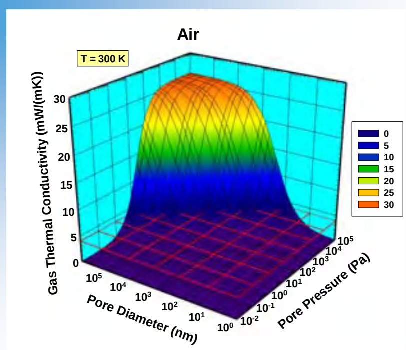


Gas Thermal Conductivity

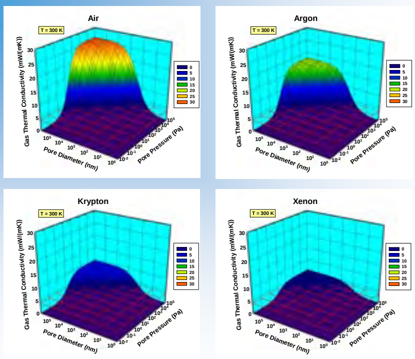
Conductivity vs. Pore Pressure



Gas Thermal Conductivity



Gas Thermal Conductivity



Dynamic Insulation Material (DIM)

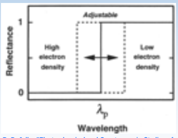
DIM – A material where the thermal conductivity can be controlled within a desirable range

- Thermal conductivity control may be achieved by:
  - Inner pore gas content or concentration including the mean free path of the gas molecules and the gas-surface interaction
  - The emissivity of the inner surfaces of the pores
  - The solid state thermal conductivity of the lattice
- What is really solid state thermal conductivity? Two models:
  - Phonon thermal conductivity - atom lattice vibrations
  - Free electron thermal conductivity
- *What kind of physical model could describe and explain thermal conductivity?*
- *Could it be possible to dynamically change the thermal conductivity from very low to very high, i.e. making a DIM?*

Dynamic Insulation Material (DIM)

- Dynamic Vacuum
- Dynamic Emissivity of Inner Pore Surfaces
- Dynamic Solid Core Thermal Conductivity
  - Is it possible?
  - Fundamental understanding of the thermal conductance?
- Other?

Learning from Electrochromic Materials?:



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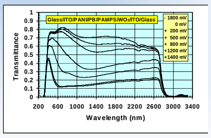

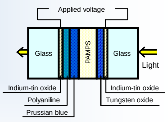

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Materials and Solutions Not Yet Thought Of ?

- *The more we know the more we know we don't know…!*
  - *… and the more we want to know…!*
  - *… and that's the whole fun of it…!*
- *Think thoughts not yet thought of…!*

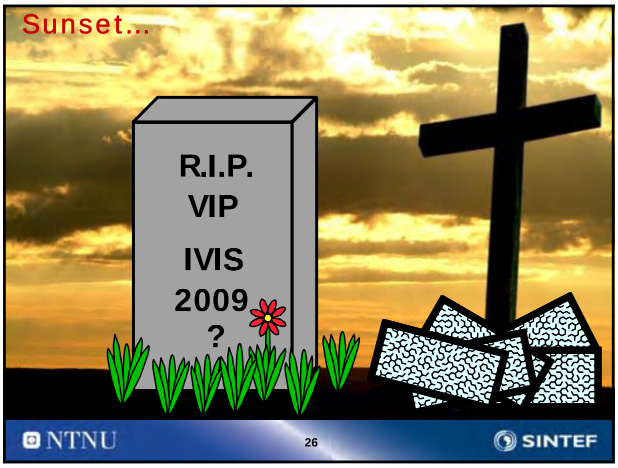
The Thermal Insulation Potential

Thermal Insulation Materials and Solutions	Low Pristine Thermal Conductivity	Low Long-Term Thermal Conductivity	Perforation Robustness	Possible Building Site Adaption Cutting	A Thermal Insulation Material and Solution of Tomorrow ?
Traditional					
Mineral Wool and Polystyrene	no	no	yes	yes	no
Todays State-of-the-Art					
Vacuum Insulation Panels (VIP)	yes	maybe	no	no	today and near future
Gas-Filled Panels (GFP)	maybe	maybe	no	no	probably not, near future
Aerogels	maybe	maybe	yes	yes	maybe
Phase Change Materials (PCM)	-	-	-	-	heat storage and release
Beyond State-of-the-Art					
Vacuum Insulation Materials (VIM)	yes	maybe	yes	yes	yes
Gas Insulation Materials (GIM)	yes	maybe	yes	yes	maybe
Nano Insulation Materials (NIM)	yes	yes	yes, excellent	yes, excellent	yes, excellent
Dynamic Insulation Materials (DIM)	maybe	maybe	not known	not known	yes, excellent
Others ?	-	-	-	-	maybe

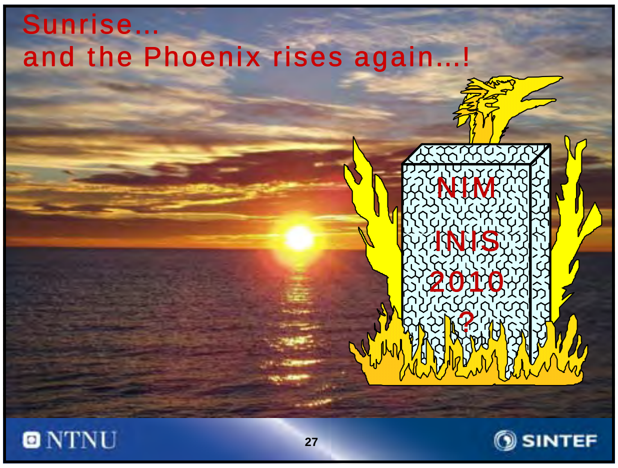
Conclusions

- Beyond the state-of-the-art of today
- New concepts have been introduced
  - Vacuum Insulation Materials (VIM)
  - Gas Insulation Materials (GIM)
  - Nano Insulation Materials (NIM)
  - Dynamic Insulation Materials (DIM)
- Fundamental theoretical studies - basics of thermal conductance
- Requirements of the future high performance thermal insulation materials and solutions have been proposed
- NIMs seem to represent the best high performance low conductivity thermal solution for the foreseeable future
- DIMs have great potential due to their controllable thermal insulating abilities

COIN
ROBUST
Sorry folks…
… we simply couldn't resist
the two following slides…(!)
Originally presented at the 9th International Vacuum
Insulation Symposium, London, September 17-18, 2009
IVIS
2009
www.ivisnet.org
NTNU
25
SINTEF



Sunset…
R.I.P.
VIP
IVIS
2009
?
NTNU
26
SINTEF



Sunrise…
and the Phoenix rises again…!
NIM
INIS
2010
?
NTNU
27
SINTEF

7 How might Nano technology improve the thermal performance of the concrete buildings of tomorrow?

How Might Nano Technology Improve the Thermal Performance of the Concrete Buildings of Tomorrow?

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How Might Nano Technology Improve the Thermal Performance of the Concrete Buildings of Tomorrow ?

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Keywords: Nano technology, Nano insulation material, NIM, Concrete, Building, Tomorrow, NanoCon.

Introduction

Buildings constitute a substantial part of the world's total energy consumption. Hence, savings within the building sector will be essential, both for existing and new buildings. The building thermal insulation materials and solutions constitute one of the key fields. Recent studies (McKinsey 2009) point out that energy efficiency measures are the most cost-effective ones, whereas measures like e.g. solar photovoltaics and wind energy are far less cost-effective than insulation retrofit for buildings.
Concrete constitutes one of the main building materials in the world with respect to both total mass and volume. As concrete has a rather high thermal conductivity, in addition to a large CO_2 emission during cement production (McArdle and Lindstrom 2009, World Business Council for Sustainable Development 2002), one may ask how to improve the thermal performance of concrete. And then ultimately, how might nano technology be applied in order to improve the thermal performance of the concrete buildings of tomorrow?

Properties of Concrete

In Table 1 some key properties of concrete are given. Note that the thermal conductivity of concrete (150 - 2500 mW/(mK)) is much larger than of traditional thermal insulation like mineral wool (e.g. 36 mW/(mK)) and state-of-the-art vacuum insulation panels (VIP) (e.g. 4 mW/(mK)) (Jelle et al. 2009ab, Baetens et al. 2010, Jelle et al. 2010).
As one might imagine to add substitutes to the concrete mix or ultimately replace the concrete with another material or materials, other properties than the thermal conductivity are given in Table 1, e.g. various mechanical properties. In addition, the fire resistance is a crucial property of building materials, where a risk and impact assessment may influence the actual choice of materials.

Table 1. Some key properties of concrete (example values).

Property	With Rebars	Without Rebars
Mass density (kg/dm^3)	2.4	2.2
Thermal conductivity (mW/mK)	2500	1700

Specific heat capacity (J/(kgK))	840	880
Linear thermal expansion coefficient (10^{-6}/K)	12	12
Compressive strength (MPa)	30	30
Tensile strength (MPa) [a]	500 [b]	3
Fire resistance	> 2 h	> 2 h
Environmental impact (incl. energy and material use in production, emission of polluting agents and recycling issues)	large CO_2 emissions	large CO_2 emissions

[a] As a comparison, note that carbon nanotubes have been manufactured with tensile strengths as high as 63 000 MPa and have a theoretical limit at 300 000 MPa. [b] Rebars.

Environmental Impact of Concrete

The cement industry produces 5 % of the global man-made CO_2 emissions of which (World Business Council for Sustainable Development 2002):

- **50 % from the chemical process**
  - e.g.: $3CaCO_3 + SiO_2 \rightarrow Ca_3SiO_5 + 3CO_2$

  $2CaCO_3 + SiO_2 \rightarrow Ca_2SiO_4 + 2CO_2$
- **40 % from burning fossil fuels**
  - e.g. coal and oil
- **10 % from electricity and transport uses**

Nano Technology

Nano technology may be defined as the technology for controlling matter of dimensions between 0.1 nm and 100 nm, that is, at an atomic and molecular scale (Fig.1). How might this nano technology actually improve the thermal performance of the concrete buildings of tomorrow?

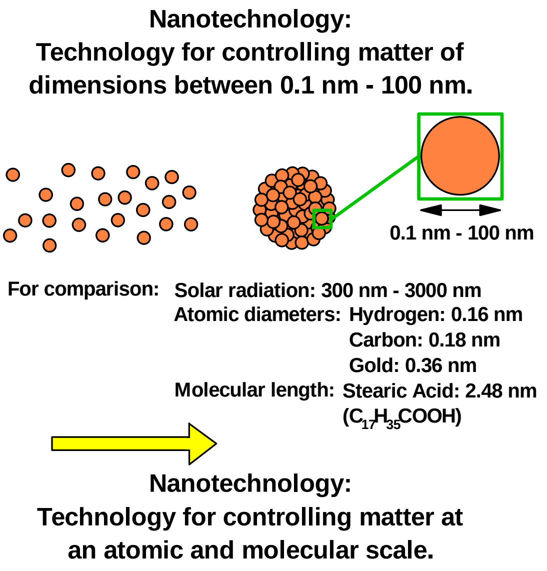

Fig.1. Definition of nano technology.

Nano Technology and Thermal Insulation

Nano technology applied in thermal insulation normally addresses *nano pores* instead of the typical *nano particles*, e.g. see the illustration depicted in Fig.2. The background for applying nano pores in thermal insulation arises from the Knudsen effect.

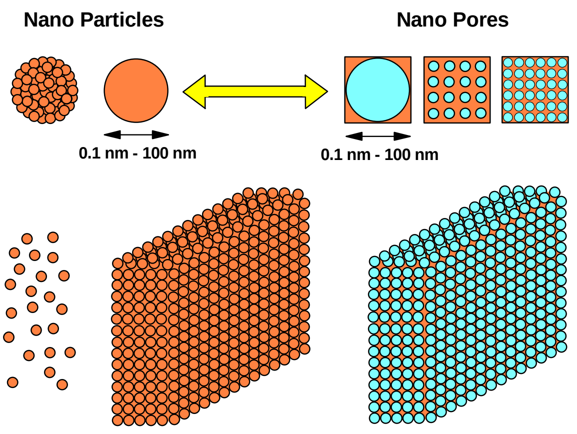

Fig.2. Illustration of *nano particles* vs. *nano pores*, the latter ones for application as thermal insulation.

The Knudsen effect causes a rapid decrease in thermal conductivity as the pore size decrease below a certain level, even with air-filled pores, and is due to the mean free path of the gas molecules becoming larger than the pore diameter. That is, a gas molecule located inside a pore will ballistically hit the pore wall and not another gas molecule. The gas thermal conductivity λ_{gas} may be written in a simplified way as (Handbook of Chemistry and Physics 2003-2004, Scwab et al. 2005, Jelle et al. 2009ab, Baetens et al. 2010, Jelle et al. 2010):

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

where

λ_{gas} = gas thermal conductivity in the pores (W/(mK))

$\lambda_{gas,0}$ = gas thermal conductivity in the pores at STP (standard temperature and pressure) (W/(mK))

β = coefficient characterizing the molecule - wall collision energy transfer efficiency (between 1.5 - 2.0)

$Kn = \sigma_{mean}/\delta = k_B T/(2^{1/2}\pi d^2 p\delta)$ = the Knudsen number

k_B = Boltzmann's constant ≈ $1.38 \cdot 10^{-23}$ J/K

T = temperature (K)

d = gas molecule collision diameter (m)

p = gas pressure in pores (Pa)

δ = characteristic pore diameter (m)

σ_{mean} = mean free path of gas molecules (m)

The Knudsen effect is visualized as 2D and 3D graphical plots in Figs.3-4.

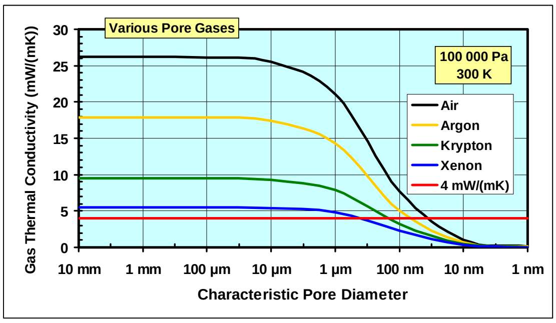

Fig.3. The effect of pore diameter on the gas thermal conductivity for air, argon, krypton and xenon. From Eq.1.

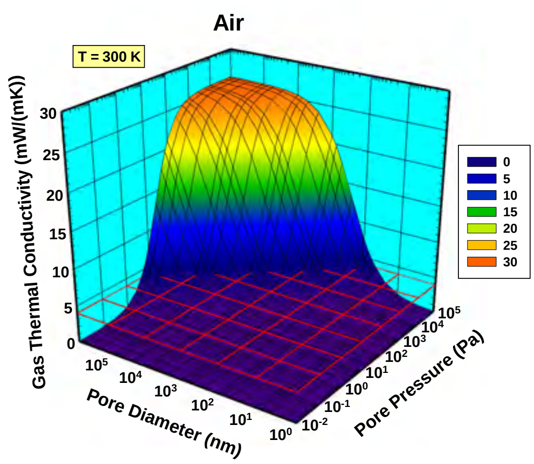

Fig.4. The effect of pore diameter and gas pressure in pores on the gas thermal conductivity visualized for air. From Eq.1.

Nano Insulation Materials (NIM)

The development from VIPs to NIMs is depicted in Fig.5. In the NIM the pore size within the material is decreased below a certain level, i.e. 40 nm or below for air, in order to achieve an overall thermal conductivity of less than 4 mW/(mK) in the pristine condition with an adequate low-conductivity lattice structure.

That is, a NIM is basically a homogeneous material with a closed or open small nano pore structure with an overall thermal conductivity of less than 4 mW/(mK) in the pristine condition (as defined by Jelle et al. 2009ab, Baetens et al. 2010, Jelle et al. 2010).

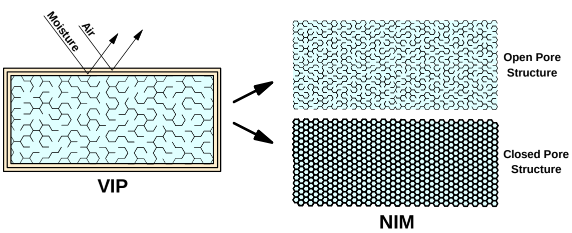

Fig.5. The development from VIPs to NIMs.

Hence, the NIMs utilize the Knudsen effect as given by Eq.1 and illustrated in Figs.3-4 in order to achieve their very low thermal conductivity.

Thermal radiation issues for NIMs are dealt with elsewhere (Jelle et al. 2009b).

The NIMs do not inherit the several drawbacks of VIPs as noted by Jelle et al. (2009ab, 2010) and Baetens et al. (2010). That is, the NIMs are in principle neither vulnerable to air and water vapour diffusion into the pores, nor to any perforations (e.g. by nails) of the material. That is, the NIMs may readily be cut and adjusted at the building site without any loss of thermal resistance.

Concrete and Application of NIMs

Various applications of NIMs as thermal insulation for concrete are given in the following chapters, both as retrofitting of the concrete, applied in the midst of the concrete and mixed together with the concrete.

Concrete with NIM Outdoor Retrofitting

In Fig.6 outdoor thermal insulation retrofitting of concrete with NIMs is depicted.

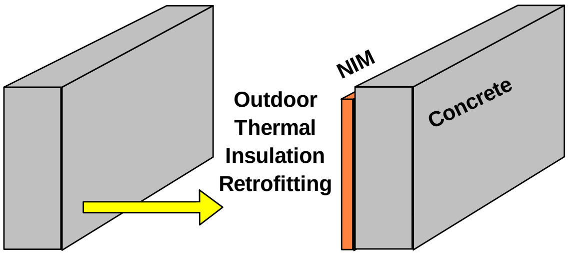

Fig.6. Outdoor thermal insulation retrofitting of concrete with NIMs.

Concrete with NIM Indoor Retrofitting

In Fig.7 indoor thermal insulation retrofitting of concrete with NIMs is shown (important with frost resistant concrete as the temperature will decrease).

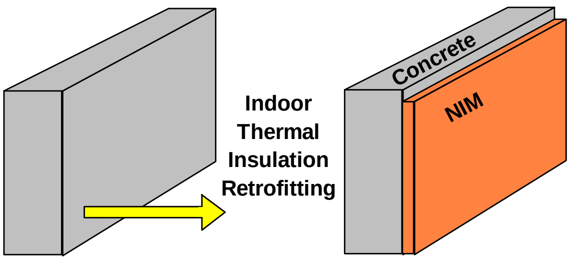

Fig.7. Indoor thermal insulation retrofitting of concrete with NIMs.

Concrete with NIM Indoor and Outdoor

In Fig.8 both indoor and outdoor thermal insulation retrofitting of concrete with NIMs is shown.

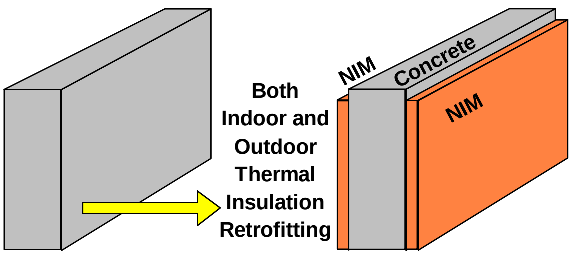

Fig.8. Both indoor and outdoor thermal insulation retrofitting of concrete with NIMs.

NIM in the Midst of Concrete
In Fig.9 the application of NIMs as thermal insulation in the midst of the concrete is shown.

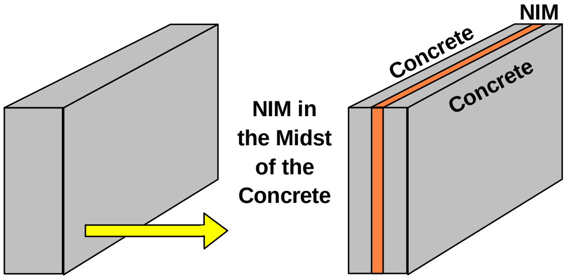

Fig.9. Thermal insulation with NIMs in the midst of the concrete (sandwich construction).

NIM and Concrete Mixture
In Fig.10 NIMs are mixed into the concrete in order to decrease the overall thermal conductivity of the building element.

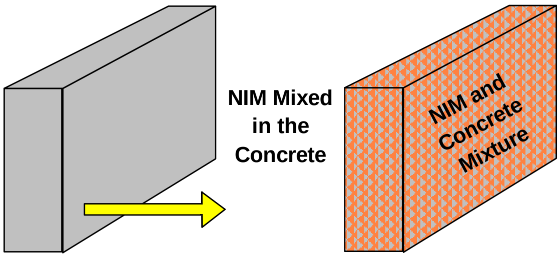

Fig.10. Thermal insulation with a NIMs and concrete mixture.

Thinner Concrete Buildings with NIMs
As NIMs have a very low thermal conductivity, the concrete building envelopes incorporating thermal insulation layers may be made substantially thinner by applying NIMs in various ways as depicted in Figs.6-10 instead of traditional thermal insulation.
In principle, by employing NIMs with a thermal conductivity of e.g. 3.6 mW/(mK) instead of mineral wool or expanded or extruded polystyrene with 36 mW/(mK), the thermal insulation thickness reduces with a factor 10, e.g. a 4 cm thick NIM retrofitting instead of a 40 cm traditional thermal insulation retrofitting. That is, a vast reduction of the the thermal insulation layer and thereby the total building envelope thickness.

Aerogels – Approaching the NIMs
Nevertheless, in order to be able to apply NIMs, they have to be developed and proven first.
So far, the closest commercial approach to NIMs seems to be aerogels, which at the moment have achieved thermal conductivities as low as 13 to 14 mW/(mK) at ambient pressure (Aspen Aerogels 2008ab).
However, the production costs of aerogels are still high. Aerogels have a relatively high compression strength, but is very fragile due to its very low tensile strength. The tensile strength may be increased by incorporation of a carbon fibre matrix. Note also that aerogels may be produced as either opaque, translucent or transparent materials, thus enabling a wide range of possible building applications.

To Envision Beyond Concrete
Concrete has a high thermal conductivity, i.e. a concrete building envelope always has to utilize various thermal insulation materials in order to achieve a satisfactory low thermal transmittance (U-value). That is, the total thickness of the building envelope will often

become unnecessary large, especially when trying to obtain passive house, zero energy building or zero emission building standards.

In addition, the large CO_2 emissions connected to the production of cement, imply that concrete has a large negative environmental impact with respect to global warming due to the man-made CO_2 increase in the atmosphere. Concrete is also prone to cracking induced by corrosion of the reinforcement steel.

On the positive side concrete has a high fire resistance, i.e. concrete does not normally burn, but note that under certain circumstances spalling may occur and lead to early loss of stability due to exposed reinforcement and reduced cross-section. Furthermore, concrete is easy accessible and workable, has low cost and enables local production.

To envision a building and infrastructure industry without an extensive usage of concrete, is that at all possible? Not at the moment and perhaps not for the near future, but maybe in a long-term perspective?

Emphasis on Functional Requirements

In principle, it is not the building material itself, i.e. if it is steel, glass, wood, mineral wool, concrete or another material, which is important.

On the contrary, it is the property requirements or functional requirements which are crucial to the performance and possibilities of a material, component, assembly or building.

Thus, one might ask if it is possible to invent and manufacture a material with the essential structural or construction properties of concrete intact or better, but with substantially (i.e. up to several decades) lower thermal conductivity? Furthermore, it would be beneficial if that new material would have a much lower negative environmental impact than concrete with respect to CO_2 emissions. Such a material may be envisioned with or without reinforcement bars, depending on the mechanical properties, e.g. tensile strength, of the material.

NanoCon – Introducing a New Material

With respect to the above discussion we hereby introduce a new material on a conceptual basis:

NanoCon is basically a homogeneous material with a closed or open small nano pore structure with an overall thermal conductivity of less than 4 mW/(mK) (or another low value to be determined) and exhibits the crucial construction properties that are as good as or better than concrete (Fig.11).

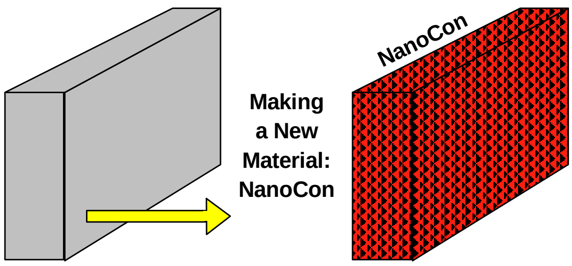

Fig.11. NanoCon is essentially a NIM with construction properties matching or surpassing those of concrete.

Note that the term ”Con” in NanoCon is meant to illustrate the *construction* properties and abilities of this material, with historical homage to concrete.

Essentially, NanoCon is a NIM with construction properties matching or surpassing those of concrete.

Dependent on the mechanical or construction properties of the NanoCon material, it may be envisioned both with or without reinforcement or rebars as depicted in Fig.12.

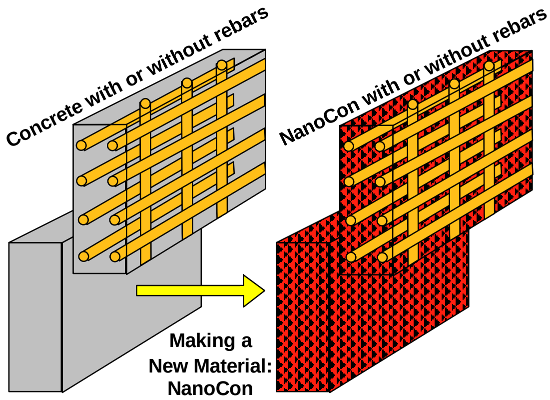

Fig.12. NanoCon with or without reinforcement bars.

It may take a long time to invent and develop a material like NanoCon, but that does not mean it is impossible. Ideas might also be gained from other research fields, e.g. note the extremely large tensile strength of carbon nanotubes (Table 1), maybe we even have to *think thoughts not yet thought of*.

Conclusions

Several possibilities of applying nano technology and nano insulation materials (NIM) in order to improve the thermal performance of the future concrete buildings have been presented.

Furthermore, NanoCon as essentially a NIM with construction properties matching or surpassing those of concrete has been introduced and defined.

Acknowledgements

This work has been supported by the Research Council of Norway and several partners through the SINTEF and NTNU research projects *Robust Envelope Construction Details for Buildings of the 21st Century* (ROBUST) and the *Concrete Innovation Centre* (COIN).

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How Might Nano Technology Improve the Thermal Performance of the Concrete Buildings of Tomorrow ?

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COIN Workshop on Concrete Ideas for Passive Houses,
Oslo, Norway, January 26-27, 2010

Properties of Concrete

- **Thermal Conductivity**
- **Concrete**
  - **150 – 2500 mW/(mK)**
- **Traditional Thermal Insulation**
  - **36 mW/(mK)**
- **Vacuum Insulation Panels (VIPs)**
  - **4 mW/(mK)**

Properties of Concrete

Some key properties of concrete (example values)

Property	With Rebars	Without Rebars
Mass density (kg/dm^3)	2.4	2.2
Thermal conductivity (mW/mK)	2500	1700
Specific heat capacity (J/(kgK))	840	880
Linear thermal expansion coefficient (10^{-6}/K)	12	12
Compressive strength (MPa)	30	30
Tensile strength (MPa) [a]	500 [b]	3
Fire resistance	> 2 h	> 2 h
Environmental impact (incl. energy and material use in production, emission of polluting agents and recycling issues)	large CO_2 emissions	large CO_2 emissions

[a] As a comparison, note that carbon nanotubes have been manufactured with tensile strengths as high as 63 000 MPa and have a theoretical limit at 300 000 MPa. [b] Rebars.

Environmental Impact of Concrete

Large CO_2 emissions from cement production

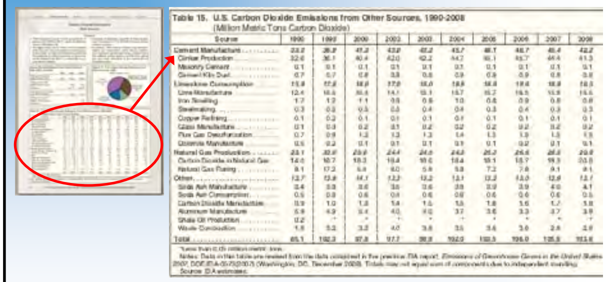


Table 15. U.S. Carbon Dioxide Emissions from Other Sources, 1990-2008
(Million Metric Tons Carbon Dioxide)

Source	1990	1995	2000	2002	2003	2004	2005	2006	2007	2008

P. McArdle and P. Lindstrom, "Emissions of greenhouse gases in the United States 2008", U.S. Energy Information Administration, DOE/EIA-0573(2008), December 2009.

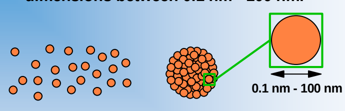
Large CO_2 Emissions from Cement Production

- **The cement industry produces 5 % of the global man-made CO_2 emissions of which:**
- **50 % from the chemical process**
  - e.g.: $3CaCO_3 + SiO_2 \rightarrow Ca_3SiO_5 + 3CO_2$
    $2CaCO_3 + SiO_2 \rightarrow Ca_2SiO_4 + 2CO_2$
- **40 % from burning fossil fuels**
  - e.g. coal and oil
- **10 % split between electricity and transport uses**

World Business Council for Sustainable Development, "The cement sustainability initiative – Our agenda for action", July 2002.

Nano Technology

Nanotechnology:
Technology for controlling matter of dimensions between 0.1 nm - 100 nm.

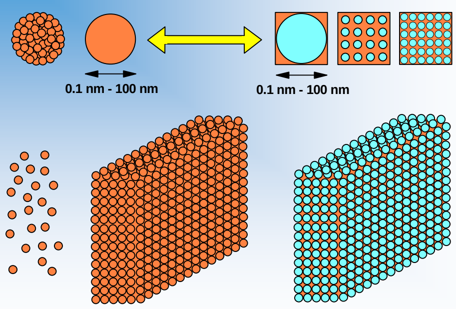


For comparison: Solar radiation: 300 nm - 3000 nm
Atomic diameters: Hydrogen: 0.16 nm
Carbon: 0.18 nm
Gold: 0.36 nm
Molecular length: Stearic Acid: 2.48 nm
($C_{17}H_{35}COOH$)

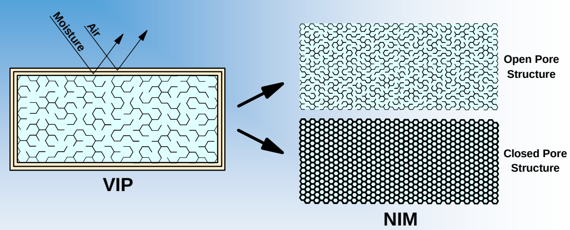
Nanotechnology:
Technology for controlling matter at an atomic and molecular scale.

Nano Technology and Thermal Insulation

Nano Particles | Nano Pores



Nano Insulation Material (NIM)



NIM - A basically homogeneous material with a closed or open small nano pore structure with an overall thermal conductivity of less than 4 mW/(mK) in the pristine condition

The Knudsen Effect – Nano Pores

Gas Thermal Conductivity λ_g

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

$\sigma_{mean} > \delta \Rightarrow$ low λ_g

where

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

λ_{gas} = gas thermal conductivity in the pores (W/(mK))
$\lambda_{gas,0}$ = gas thermal conductivity in the pores at STP (standard temperature and pressure) (W/(mK))
β = coefficient characterizing the molecule - wall collision energy transfer efficiency (between 1.5 - 2.0)
$Kn = \sigma_{mean}/\delta = k_BT/(2^{1/2}\pi d^2 p\delta)$ = the Knudsen number
k_B = Boltzmann's constant ≈ $1.38 \cdot 10^{-23}$ J/K
T = temperature (K)
d = gas molecule collision diameter (m)
p = gas pressure in pores (Pa)
δ = characteristic pore diameter (m)
σ_{mean} = mean free path of gas molecules (m)

Nano Pores – Thermal Radiation

- Knudsen effect $\Rightarrow \sigma_{mean} > \delta \Rightarrow$ low gas thermal conductivity λ_g
- What about the thermal radiation in the pores?
- "Classical" – from Stefan-Boltzmann's law:

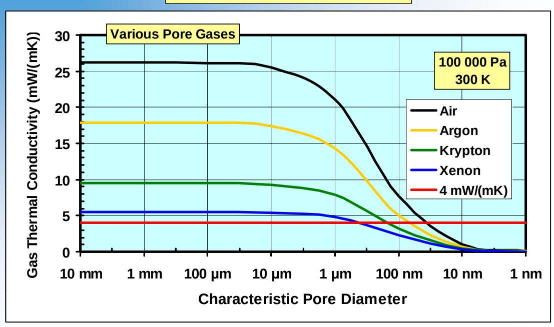
$$\lambda_r = \frac{\pi^2 k_B^4 \delta}{60\hbar^3 c^2\left[\frac{2}{\varepsilon}-1\right]}\frac{(T_i^4 - T_e^4)}{(T_i - T_e)}$$

λ_r = thermal radiation conductivity in the pores (W/(mK))
σ = = $\pi^2 k_B^4/(60\hbar^3 c^2)$ = Stefan-Boltzmann's constant ≈ $5.67 \cdot 10^{-8}$ W/(m²K⁴)
k_B = Boltzmann's constant ≈ $1.38 \cdot 10^{-23}$ J/K
$\hbar = h/(2\pi) \approx 1.05 \cdot 10^{-34}$ Js (h = Planck's constant)
c = light velocity ≈ $3.00 \cdot 10^{8}$ m/s
δ = pore diameter (m)
ε = emissivity of pore walls
T_i = interior temperature (K)
T_e = exterior temperature (K)
ξ_{ir} = infrared radiation wavelength (m)

- Pore diameter δ small $\Rightarrow$ low thermal radiation conductivity λ_r
- But what happens when $\xi_{ir} > \delta$? (IR wavelength > pore diameter)
- $\xi_{ir} > \delta \Rightarrow$ high thermal radiation conductivity λ_r ?
- Evanescent waves… tunneling… etc. …
- Currently looking into these matters…

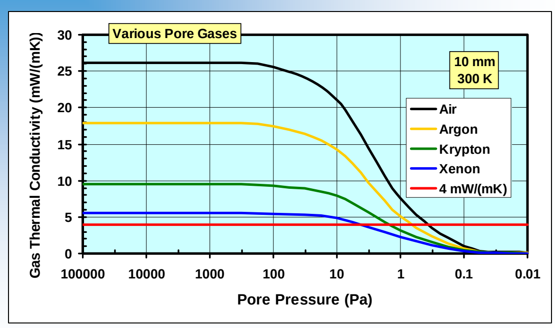
Gas Thermal Conductivity

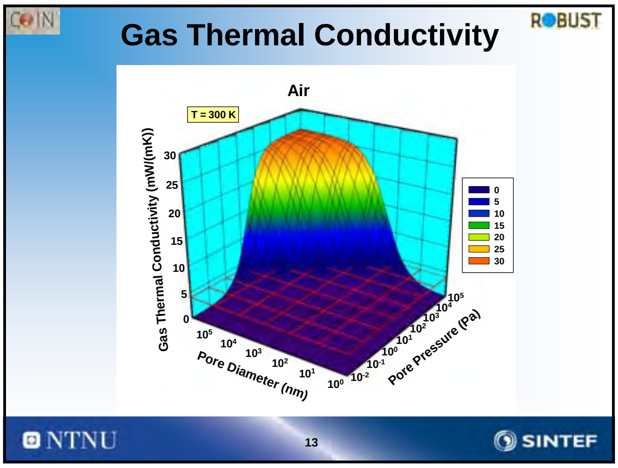
Conductivity vs. Pore Diameter



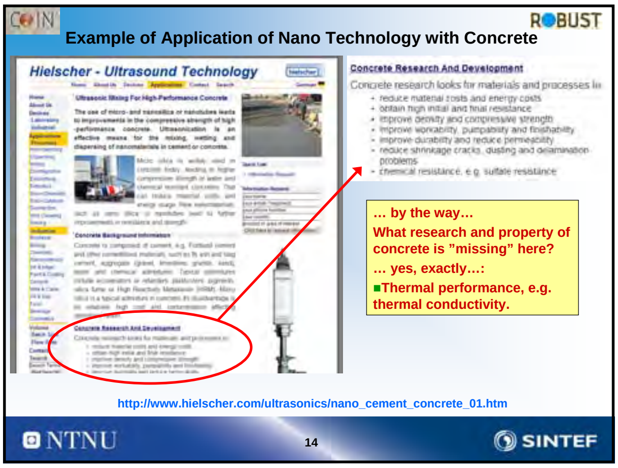
Gas Thermal Conductivity

Conductivity vs. Pore Pressure

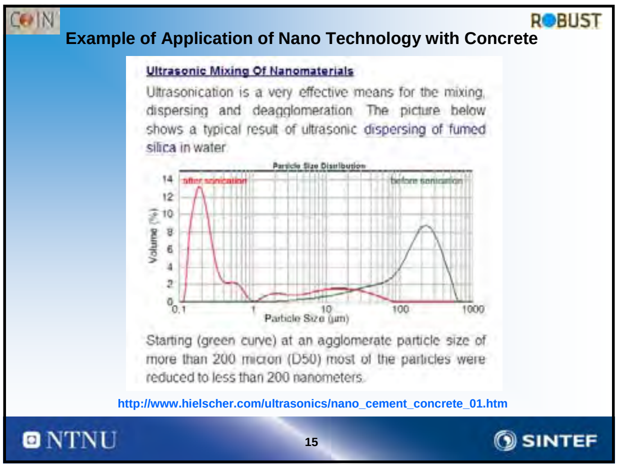




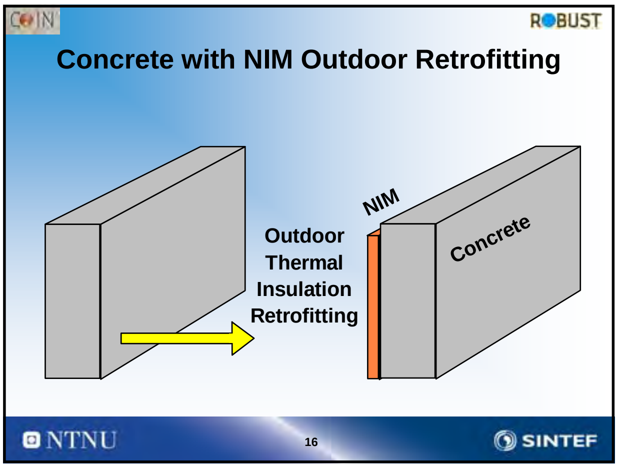
Gas Thermal Conductivity
Air
T = 300 K
Gas Thermal Conductivity (mW/(mK))
Pore Diameter (nm)
Pore Pressure (Pa)
0
5
10
15
20
25
30
NTNU
13
SINTEF



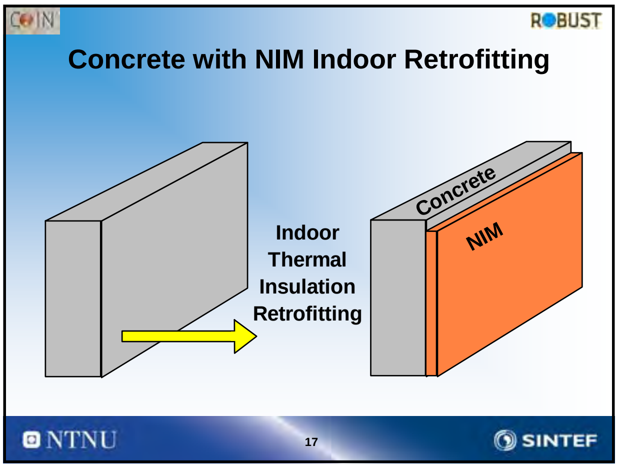
Example of Application of Nano Technology with Concrete
Hielscher - Ultrasound Technology
Concrete Research And Development
Concrete research looks for materials and processes in
reduce material costs and energy costs
obtain high initial and final resistance
improve density and compressive strength
improve workability, pumpability and finishability
improve durability and reduce permeability
reduce shrinkage cracks, dusting and delamination problems
chemical resistance, e.g. sulfate resistance
... by the way...
What research and property of concrete is "missing" here?
... yes, exactly...:
Thermal performance, e.g. thermal conductivity.
http://www.hielscher.com/ultrasonics/nano_cement_concrete_01.htm
NTNU
14
SINTEF



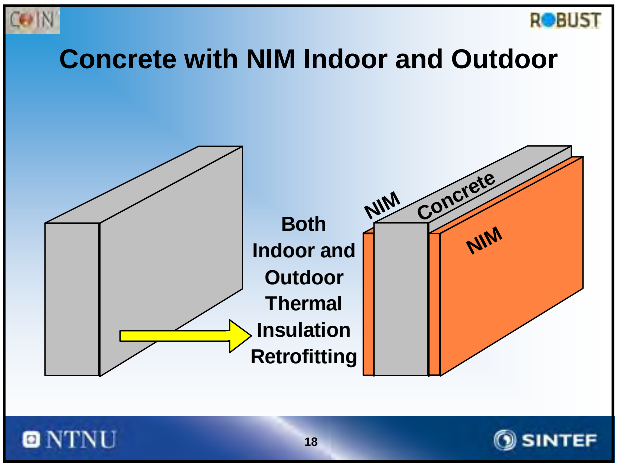
Example of Application of Nano Technology with Concrete
Ultrasonic Mixing Of Nanomaterials
Ultrasonication is a very effective means for the mixing, dispersing and deagglomeration. The picture below shows a typical result of ultrasonic dispersing of fumed silica in water
Particle Size Distribution
after sonication
before sonication
Volume (%)
Particle Size (µm)
Starting (green curve) at an agglomerate particle size of more than 200 micron (D50) most of the particles were reduced to less than 200 nanometers.
http://www.hielscher.com/ultrasonics/nano_cement_concrete_01.htm
NTNU
15
SINTEF



Concrete with NIM Outdoor Retrofitting
Outdoor Thermal Insulation Retrofitting
NIM
Concrete
NTNU
16
SINTEF

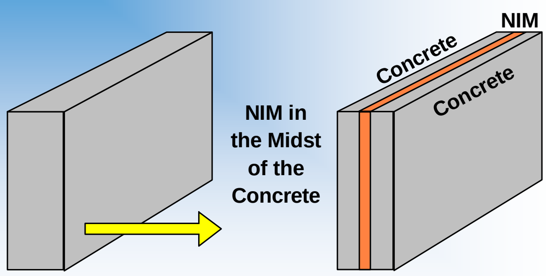


Concrete with NIM Indoor Retrofitting
Indoor Thermal Insulation Retrofitting
Concrete
NIM
NTNU
17
SINTEF

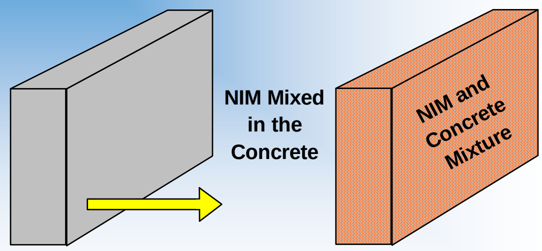


Concrete with NIM Indoor and Outdoor
Both Indoor and Outdoor Thermal Insulation Retrofitting
NIM
Concrete
NIM
NTNU
18
SINTEF

NIM in the Midst of Concrete



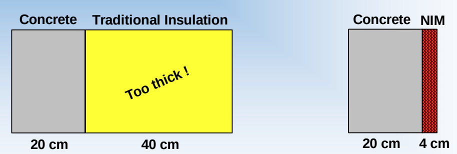
NIM and Concrete Mixture



Thinner Concrete Buildings with NIMs

- Mineral Wool or Polystyrene
- 36 mW/(mK)
- 40 cm traditional thermal insulation retrofitting

- NIM
- 3.6 mW/(mK)
- 4 cm NIM thermal insulation



- A vast reduction – factor 10 – of the thermal insulation layer and thereby the total building envelope thickness.

Aerogels – Approaching the NIMs

- Aerogels – At the moment the closest commercial approach to NIMs
- 12 – 14 mW/(mK)
- Aspen Aerogels
  - Spaceloft
- Cabot Aerogel
  - Nanogel

- Production costs still high
- Relatively high compression strength
- Very fragile due to very low tensile strength
- Tensile strength may be increased by incorporation of a carbon fibre matrix
- May be produced as either opaque, translucent or transparent materials
  - → Thus enabling a wide range of possible building applications

To Envision Beyond Concrete ?

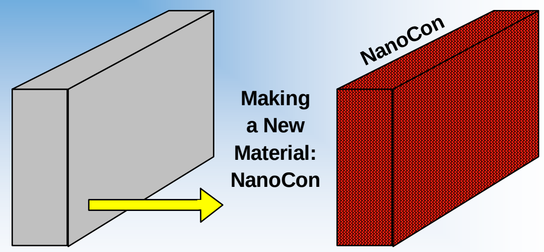
- *In the community of concrete it might be compared to using profane language in the church and close to blasphemy to suggest that maybe the answer is not concrete after all…* ☺
- Concrete:
- High thermal conductivity.
- Total thickness of the building envelope will often become unnecessary large (passive house, zero energy building or zero emission building).
- Large CO_2 emissions connected to the production of cement.
- Prone to cracking induced by corrosion of the reinforcement steel.
- Easy accessible and workable, low cost and local production.
- High fire resistance.

  - Is it possible to envision a building and infrastructure industry without an extensive usage of concrete?

Emphasis on Functional Requirements

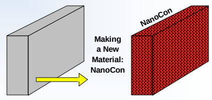
- Not the building material itself which is important.
- Property or functional requirements are crucial.
- Possible to invent and manufacture a material with the essential structural or construction properties of concrete intact or better, but with substantially lower thermal conductivity?
- Beneficial with a much lower negative environmental impact than concrete with respect to CO_2 emissions.
- Envisioned with or without reinforcement or rebars.

NanoCon – Introducing a New Material



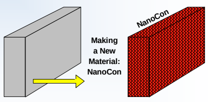
NanoCon – Introducing a New Material

- Defining a new material on a conceptual basis:
- *NanoCon* is basically a homogeneous material with a closed or open small nano pore structure with an overall thermal conductivity of less than 4 mW/(mK) (or another low value to be determined) and exhibits the crucial construction properties that are as good as or better than concrete.
- Note that the term "Con" in NanoCon is meant to illustrate the *construction* properties and abilities of this material, with historical homage to concrete.

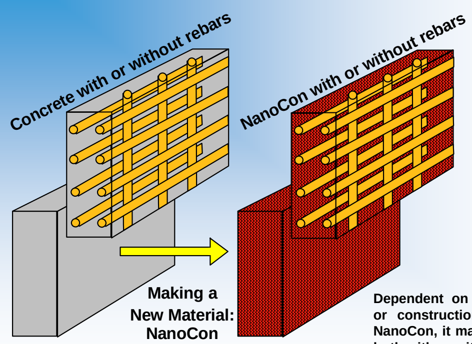


NanoCon – Introducing a New Material

- NanoCon
- Homogeneous material
- Closed or open small nano pore structure
- Overall thermal conductivity < 4 mW/(mK) (or another low value to be determined)
- Exhibits the crucial construction properties that are as good as or better than concrete.
- Essentially, NanoCon is a NIM with construction properties matching or surpassing those of concrete.



NanoCon – Introducing a New Material



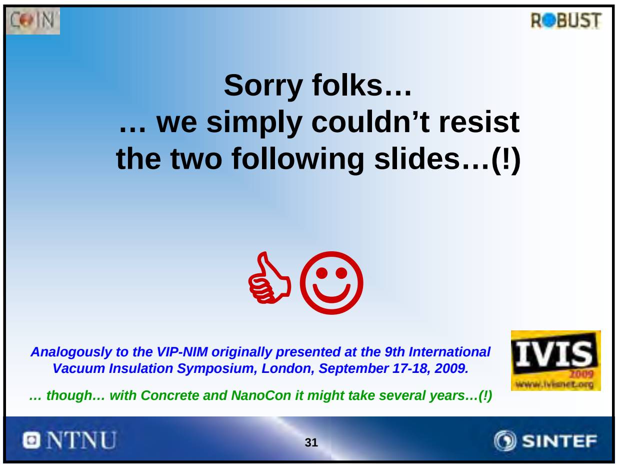
Dependent on the mechanical or construction properties of NanoCon, it may be envisioned both with or without rebars.

Materials and Solutions Not Yet Thought Of ?

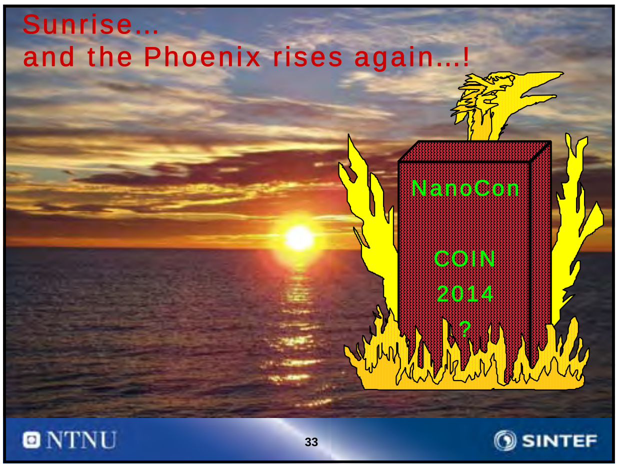
- *The more we know the more we know we don't know…!*
  - *… and the more we want to know…!*
  - *… and that's the whole fun of it…!*
- *Think thoughts not yet thought of…!*

Conclusions

- Several possibilities of applying nano technology and nano insulation materials (NIM) in order to improve the thermal performance of the future concrete buildings have been presented.
- NanoCon as essentially a NIM with construction properties matching or surpassing those of concrete has been introduced and defined.


COIN
ROBUST
Sorry folks…
… we simply couldn't resist
the two following slides…(!)
Analogously to the VIP-NIM originally presented at the 9th International Vacuum Insulation Symposium, London, September 17-18, 2009.
… though… with Concrete and NanoCon it might take several years…(!)
IVIS 2009
www.ivisnet.org
NTNU
31
SINTEF


Sunset…
R.I.P.
CONCRETE
coin
2010
?
NTNU
32
SINTEF


Sunrise…
and the Phoenix rises again…!
NanoCon
COIN
2014
?
NTNU
33
SINTEF

8 Polybetong – insulated concrete produced with recycled expanded polystyrene (EPS)

Polybetong – insulated concrete produced with recycled expanded polystyrene (EPS)

Arne Olsen

on behalf of Lothe Bygg AS and Polybo AS

Polybetong – insulated concrete produced with recycled expanded polystyrene (EPS)

Arne Olsen, project manager,
on behalf of Lothe Bygg AS and Polybo AS about Polybetong development projects.
Arne.Olsen@smigruppen.no

Polybetong projects

The following developments have been made in the period of 2006 to 2010:

- Development of production plant facilities for Polybetong raw material and Polybetong products.
- Development and technical verifications of Polybetong material for construction elements.
- Polybetong house constructions and logistic system development, in cooperation with Selvaagbygg AS.
- 3 year full scale research project for evaluation of energy aspects for different building systems.
- Establishment of Polybo AS for introduction of house concept on international market.

Polybetong material:

Consists of 80% grounded and impregnated EPS (waste) and 20% cement. The material is well known and marketed under various trade names.

Project purpose for Polybetong AS

Evaluate possibilities for use of Polybetong material as construction elements in buildings.
Main focus areas for Polybetong AS

- Facade elements
- Apartment houses with Polybetong walls, floor and roof

Possibilities with Polybetong:

- Lightweight material gives efficient transportation and installation advantages.
- Cost efficiency using recycled EPS and less cement, gives an environmental friendly and low price material with recycling possibilities.
- Homogeneous inorganic material with good insulation qualities gives possibilities for energy efficiency and good indoor air quality.

Main challenges and solutions for Polybetong AS

a) Mechanical aspects of a "new material". How to design for loads in transport phase and as a constructive element in buildings
   - Model for static calculation and solutions with low tensile strength steel reinforcement systems established in cooperation with SINTEF Betongforsk.
   - Details for anchoring points in elements developed.

b) Fire resistance
   Tests performed by Polybetong AS shows excellent fire resistance qualities.

c) Energy qualities
   Insulation factors (u-values) have been established for Polybetong by SINTEF Byggforsk. Polybetong AS has also made some tests indicating that Polybo material may have special thermal qualities that can improve dynamic insulation values (thermal mass) and hence reduce need for heating and cooling. SINTEF Byggforsk has, on behalf of Polybetong, performed a 3 year research project for full scale testing, measuring and comparing of thermal qualities for 4 different building

systems with concrete sandwich elements, wood, steel and Polybetong. These results will soon be available.

d) Environmental qualities
In a life cycle perspective, Polybetong has excellent qualities in production phase and in reuse/recycling.
The main environmental qualities for different building systems (80%) depend however on performance in “operational phase”. In this phase, concrete with high thermal mass has potential advantages. Polybetong potential connected to thermal mass is being evaluated in the research project mentioned. LCA documentations have not yet been made for Polybetong houses.

e) Life span
Polybetong is a flexible material with excellent building qualities, which is easy to repair and modify. Polybetong AS therefore assumes that life span for Polybetong buildings is at the least similar to wood and steel buildings.

Conclusions and further development in Polybetong AS

Facade elements

The use of Polybetong as facade elements in Norway is a practical and good solution that can be verified technically. However, due to the latest insulation requirements in Norway, there will be a need to combine Polybetong with supplement insulation materials. This may lead to increased costs. Therefore the market possibilities in Norway have to be further investigated.

The research project results combined with further evaluations made by Polybetong as (Lothe Bygg AS), have concluded that the best option for cost and energy effective building systems in Norway from a life cycle perspective (LCA, LCC) probably is concrete sandwich elements.
Advantages with thermal mass and potential for reducing the need for cooling systems gives interesting perspectives.
Lothe Bygg AS, in cooperation with AS Betong and Hå element AS, will therefore take an initiative to a new Coin Project for further testing and development of these possibilities for concrete sandwich elements in buildings.

Apartment houses with Polybetong material

Polybo AS has been established with the aim of developing a “Polybo apartment house” concept for the international market. The purpose is to develop an energy efficient self sustained house (energy, water, waste) with high technical standard (Smart house concept).

For this concept the special advantages with Polybetong material gives possibilities for container packaging and transport, efficient installation and industrial production in an “open system” with many different suppliers of components.

In cooperation with a consortium of well qualified Norwegian suppliers, a prototype house has been designed and built in Klepp, Rogaland.

Polybo houses will be introduced to an international market in July 2010, in connection with a presentation on the Norwegian pavilion at Expo 2010 in Shanghai.

Coin workshop 26.–27. jan. 2010

Presentasjon:

Polybetong — Insulated concrete produced with recycled expanded polystyrene (EPS)

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1. Introduction
2. Polybetong material
3. Polybetong, product scope
4. 3 year research project:
   ”Energy properties for Polybetong compared to other materials”
5. Polybo as
   House consept for international market

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2. Polybetong material

–Composition

–Production facilities

–Material properties

Produksjon av Polybetong

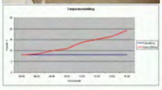
Med den store blandemaskinen, til høyre, kan man støpe gulv og dekker med en kapasitet på 250 m3 til dagen. Den lille blandemaskinen, nede til høyre, har en kapasitet på 1m3, den kan lett fraktes på en tilhenger.

Oppmaling av isopor

For å male opp isopor har vi tatt i bruk en silorive, byttet om på kniver og fått en rimelig og effektiv løsning.

Blanding i betongbil til homogen masse

Varmegjennomgang



Før seminaret, kl 0800 ble det satt på 60 C inne i kassen. halvparten er dekket med 20 cm Rockwool, andre halvdel med 30 cm Polybetong. I løpet av dagen steg temperaturen på oppsiden av rockwool med 11 grader, mens temperaturen på oppsiden av polybetong ikke steg. Under fasadeplater når solen står på er det 60 C, ved bruk av materiale med treg varmegjennomgang vil kjølebehovet om sommeren bli mindre. I moderne bygg med kjøling, bruker man ofte mer energi til kjøling på sommeren, enn man bruker til oppvarming på vinteren.

Kl	Polybetong	Glava 200mm
0800	8,1	8,1
0900	8,1	8,4
0945	8,1	9,9
1000	8,1	10,8
1100	8,1	13,8
1200	8,1	15,1
1300	8,1	16,5
1500	8,1	19,3

Test med flammekaster

Under seminaret satte vi en flammekaster på en blokk av polybetong, 30 cm. Denne stod på i en time. Det var satt inn ett termometer som gikk 20 cm inn i blokken, 10 cm fra brenner. Ved start viste termometeret 8 C etter 1 time viste denne en temperatur på 14 C.

3. Polybetong Project scope

A. Traditional areas:

B. New development:

- Roof insulation
- Slab construction
- Facade elementes
- Polybetong houses

Transport

Polybetong elementene på bildene har en overflate på ca 19kvm, tykkelsen er på 30 cm. Vekten på hvert element er ca 3 tonn. Man kan frakte flere elementer på hver tur. På denne turen ble det fraktet fem elementer på samme tralle, det utgjør ca 15 tonn.

Det er heller ikke behov for mobilkrane, da kranen som er på lastebilen er tilfredstillende.

Til sammenligning har ett betongelement en egenvekt på ca 8,5 tonn.

Dekke med stålplate og Polybetong

Stålplate med akse på 6m og støpetykkelse på 20 cm over stålplate. Nedbøyning ved utstøping uten understøtte ble på 2 cm. Ved belastning med 250kg/m2 ble nedbøyning på 3mm i tillegg, totalt 2,3 cm. Vi plasserte i tillegg ca 25 personer oppå dekket, da ble nedbøyning på totalt 2,5 cm. Egenvekt av dekke er 150 kg/m2.

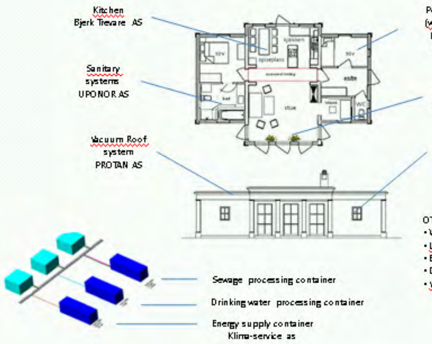
4. Øksnevad Næringspark

- Research project:
  Energy efficiency for various building systems

5. Polybo house concept

Polybo prototype

Demonstration elements



OTHERS:
- Wind turbine, Covent
- Logistics and installation, Luster betong
- Energy monitoring system, smi
- Data Design System, DDS
- Visualisation, PXO

9 Production of cement – Environmental Challanges

Production of cement – Environmental Challenges Summary

Liv-Margrethe Bjerge

Norcem AS

Production of cement – Environmental Challenges
Summary

Liv-Margrethe Bjerge
Norcem AS

Norcem AS is part of Heidelberg Cement Northern Europe which is a business area within HeidelbergCement Group. HeidelbergCement Northern Europe has six plants located in Norway, Sweden and Estonia respectively.

Climate change is one of today's most pressing issues. While cement offers numerous environmental benefits from a lifecycle perspective, production is energy-intensive, representing as much as 4-5 percent of global CO_2 emissions. To meet this key challenge, HeidelbergCement Northern Europe is increasing the use of alternative fuels and work to improve the process efficiency.

HeidelbergCement Group has set a target of 15 percent reduction in specific net CO_2 emissions by 2010 (CO_2/ton cement), compared to levels in 1990. Norcem has already reached this target and are continuously working to do even better.

Most of the cement industry's CO_2 emissions derive from the calcination process, when limestone is heated and split into calcium oxide and CO_2. These emissions are an inevitable result of this key chemical reaction and account for about 60 percent of total CO_2 emissions from the cement production process. The remaining CO_2 emissions derive from the fuel used to generate the energy needed for the limestone to react and become cement.

Increased use of alternative fuels
Although fossil fuels are still the principal energy source, Norcem want to increase the use of alternative fuels. By continuously replacing nonrenewable fuels with alternative energy sources, we can preserve natural resources and decrease fossil CO_2 emissions. By also increasing the use of biomass, which is neutral in the CO_2 accounting, Norcem can reduce the negative greenhouse gas impact from cement production by the same proportion. Significant sources of biomass include forest products, agricultural crops, paper and textiles, sewage sludge and food production waste.

Turning waste into energy
Since cement kilns require high temperatures, they are ideal for the combustion of alternative fuels – especially residual products. By using waste, which would otherwise have been disposed of in landfill, we can replace fossil fuels and turn a problem into a resource creating a win-win situation for us and society.

Testing of waste derived fuel (RDF) and hazardous waste was first started at the Brevik plant in 1987. Today, almost 50 percent of the energy needed in Brevik comes from alternative fuels and the goal is to increase the substitution level to 60 percent by 2010. In Slite alternative fuels have been used since early 1990's and today almost 30 percent of fossil fuels are replaced by alternative fuels such as car tyres, pellets and animal meal. The Kunda cement plant began using alternative fuels in 2000 and the, residual products used, such as waste oils, waste from the oil shale chemical industry and benzoic acid residue provide today about 10 percent of energy requirements at Kunda.

Sustainable cements
In order to reduce the CO_2-footprint from cement even further, the HeidelbergCement Group and Norcem seeks to develop more environmental friendly cements for the Scandinavian market, without destroying or reducing the cement properties. One of the possibilities is to

replace parts of the energy-intensive clinker with alternative raw materials, as fly ash and lime. Fly ash is a by-product from coal-fired power plants and Norcem started to produce cement with 20% fly ash in the early 1980's.

Due to the overall sustainability plan, Norcem will in few years offer only blended cements (CEM II cements) to the Norwegian market. Norcem are about to develop an alternative Norcem Industri cement, with up to 10 % clinker replacement. It has to be mentioned that it will probably take several years before the quality is ready for the Scandinavian market.

In addition Norcem has produced a pilot cement of standard clinker and with 35 % clinker replacement (30 % fly ash and 5 % lime). In parallel to the planned laboratory test program, the cement will be used in different commercial building project (field tests), to experience the cement properties in practical use. Norcem has never before produced a cement with such a high clinker replacement. It has to be pointed out that this cement is not available for the commercial market yet.

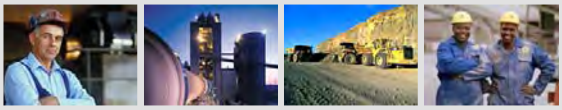
Cement Production
Environmental Challenges

Liv-Margrethe Bjerge
COIN Workshop; 26.-27. Januar 2010

NORCEM HEIDELBERGCEMENT Group

HeidelbergCement

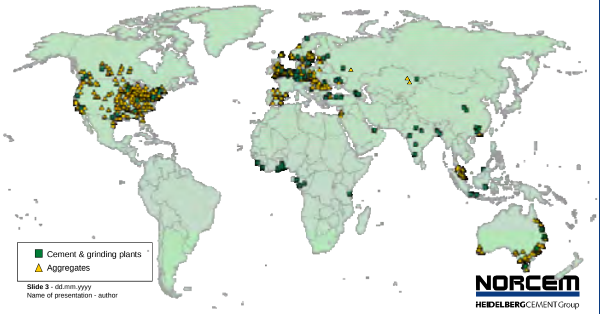
- **68,000 employees**
- **Core business:**
  - Cement
  - Concrete (Ready-mix/ prefab)
  - Aggregates
  - Downstream activities
- **2,800 locations in 50 countries:**
  - 650 production sites for sand, gravel and hard rock
  - 102 cement and grinding plants
  - 1,400 ready-mixed concrete plants
  - 134 asphalt plants
- **Cement capacity 100 million tonnes**



NORCEM HEIDELBERGCEMENT Group

HeidelbergCement in the world

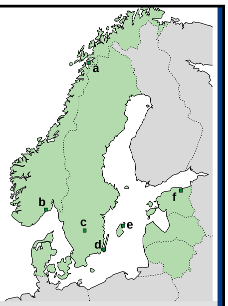
- **No 1 in aggregates**
- **No 3 in cement**
- **No 2 in ready-mixed concrete**

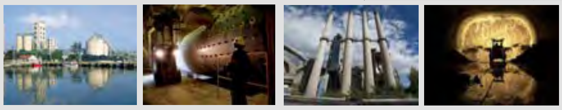


NORCEM HEIDELBERGCEMENT Group

Cement production, NE

Plant	Production 2008 (i 1 000 tons)
a) Kjøpsvik, Norway	437
b) Brevik, Norway	1 362
c) Skövde, Sweden	541
d) Degerhamn, Sweden	330
e) Slite, Sweden	2 070
f) Kunda, Estonia	806
Northern-Europe, total	5 546





NORCEM HEIDELBERGCEMENT Group

The cement industry's biggest challenge

- **Cement industry globally:**
  - 4-5 % of the total CO_2 emission
- **Target Heidelberg Cement Company:**
  - 15 % reduction (ref. 1990)
- **Norcem:**
  - 18 % reduction in 2007 (ref. 1990)

↓

Keep up the work to obtain further reduction of the CO2-emissions

NORCEM HEIDELBERGCEMENT Group

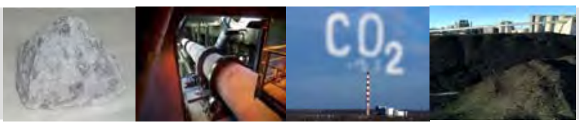
Sources to CO_2 emissions

- **Limestone related, ~60%:**

  CaCO3 → CaO + CO2 ↑
  Calcination process
  No substitution possibilities with other raw materials!!
  Only alternative: CCS - technology

- **Fuel related, ~40%:**

  Replace fossil fuels, coal → alternative fuels
  Today: ~ 50 % replacement
  Future goal: 75 % replacement



NORCEM HEIDELBERGCEMENT Group

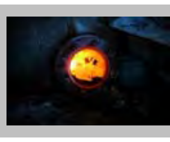
Initiatives – CO_2 reduction – focus areas

1. **Environmental friendly production**
   - Increased utilization of alternative fuels
   - BAT
2. **Environmental friendly products**
   - Replace energy-intensive clinker with alternative raw materials
3. **Environmental friendly construction**
   - Energy efficient buildings (Utilize inherent properties -Thermal mass)



1. Environmental friendly production

- **Cement production – an energy-intensive industry**
- **Production of cement:**
  – 3503 KJ/kg clinker
  – 152 kWh/tons cement
- **Traditionally coal is main fuel supply**
- **If only coal was used as fuel at the Brevik plant, the yearly consumption would be ~ 123.000 tons**

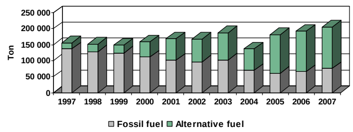

Climate challengers in the future

- **Coal will be the main energy source the next 500 years**
- **We will experience that several new coal power plants will be built in Europe over the next years**
- **CCS technology is the only way to handle these high point emissions**
- **Pilot plant in Brevik:**
  – Capture and Release
  – Handle 100 tonn CO_2



Alternative fuels

- **Alternative fuels can be:**
  – Biomass, such as animal meal, woodchips, charcoal
  – Retrieved waste from household/industry such as paper, textiles and plastic
  – Other waste materials such as car tires, waste oil
  – Hazardous waste, paint and chemicals (processed by Renor AS)
- **Alternative fuels is an environmental friendly way to take care of waste**
  – Reduce emissions of CO_2
  – Reduces waste deposits



Example from Brevik (specific volumes)



2. Environmental friendly products (cements)

1. **CEM I → CEM II**
   - Reduce % clinker in cement
   - HE Company target: 65 %
   - Substitution: Fly ash/ lime

Fly ash:
Waste from coal fired power plants

- **Norcem Standard → Norcem Standard FA (20%)**
- **Norcem Anlegg → Norcem Anlegg FA (20%)**
- **Norcem Industri → Norcem Industri FA (10%) (R&D project ongoing)**

2. **Pilot cement, standard clinker with 30 % FA + 5 % limestone**



A good example

- **The Bjørvika tunnel:**
  – 70 000 m³ concrete in the elements
  – 26 660 tons of Norcem Anlegg cement with 30 % fly ash
  – 8 000 tons CO_2 saved compared with traditionally concrete



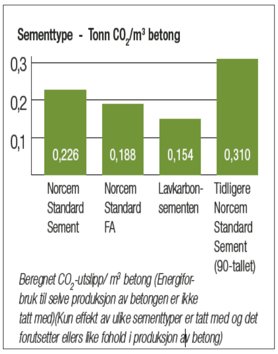
CO_2 savings – cement production

Cement type	Ton CO_2/ ton cement	Comments	CO_2-savings
Norcem Standard CEM I	0,730	No substitution EPD (2007)	
Norcem Standard FA CEM II	0,607	20% FA (EPD 2007)	
Pilot cement CEM II/ V-B	0,498	Standard clinker with 30 % FA og 5 % lime	- 32 % CO_2-reduction (CEM I) - 18 % CO_2-reduction (CEM II)
Norcem Standard Cement CEM I (ref. 1990)	0,9 – 1,0	No substitution Less use of alternative fuels	- 50 % CO_2-reduction (CEM I ref. 1990)

NORCEM HEIDELBERGCEMENT Group

CO_2-savings in concrete (M60)

- The energy consumption of the production of 1 m³ concrete is not included!
- 310 kg cement /m³ concrete



NORCEM HEIDELBERGCEMENT Group

EPD for ready-mix concrete

- EPD for ready-mix concrete finalized 2009
- Data program:
  - "Own recipe"
  - Local conditions
  - Aggregate
  - Transport distances
  - Additions
- Fabeko (trade ass.) Administrate/ update the program)

NORCEM HEIDELBERGCEMENT Group

Design of passive houses – combining wood and concrete

Dipl.-Ing., Architekt, Gernot Vallentin: Author
Dipl.-Kauffrau, CAD Renate Vallentin: CoAutor

Architekturbüro Vallentin

Design of passive houses – combining wood and concrete

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At the first sight wood and concrete appear to be contrary. Our project reports reveal however that the combination of both building materials is a very conclusive ecological, economical and technological solution for the construction of passive houses.

Project reports of several projects designed by Architekturbüro Vallentin show the advantages/ application/ possibilities /utilisation and importance of concrete and mixed concrete constructions in Passive house design. Concrete is either used in a mixed construction or as the main material of a building. The introduced projects are realized buildings or projects in planning.

The **Montessori school in Aufkirchen** of the Montessori Friendly Society Erding is a ten class elementary and secondary school with the possibility to obtain a secondary school certificate.
The Montessori school in Aufkirchen is the first new built school in Germany, planned and constructed according to passive house standard. The school is realized without higher costs in comparison to a conventional building.

Fig. 1 View from the south – entrance and classrooms

The decision concerning the load-bearing construction was made in favour of a house built in a solid manner. The requirements for noise insulation and fire protection were also easier and cheaper to solve in case of a solid building. It is also an advantage for the climate within the building and the energy concept, if you have a large storage mass.
The basement is constructed in waterproof concrete and all inner walls and ceilings are made of fair-faced concrete, thus the building appears clear and dematerialized. With regard to maintenance costs this is an inexpensive solution.
Special attention was given to joint design during the planning phase and the execution phase of the building. So thermal bridges could be avoided and requirements of air-tightness could be fulfilled:

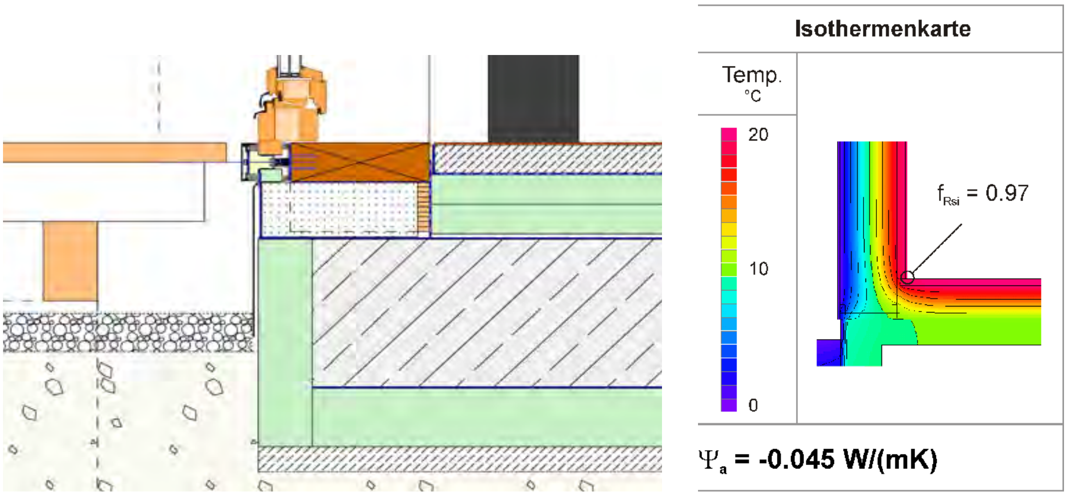

Fig. 2 Detail of the base: construction and isotherms

Because of the geometric curved form of the building in floor plan and elevation, all details were solved in a simple matter. The facade detail section shows the simple and clear concrete and the wooden construction:

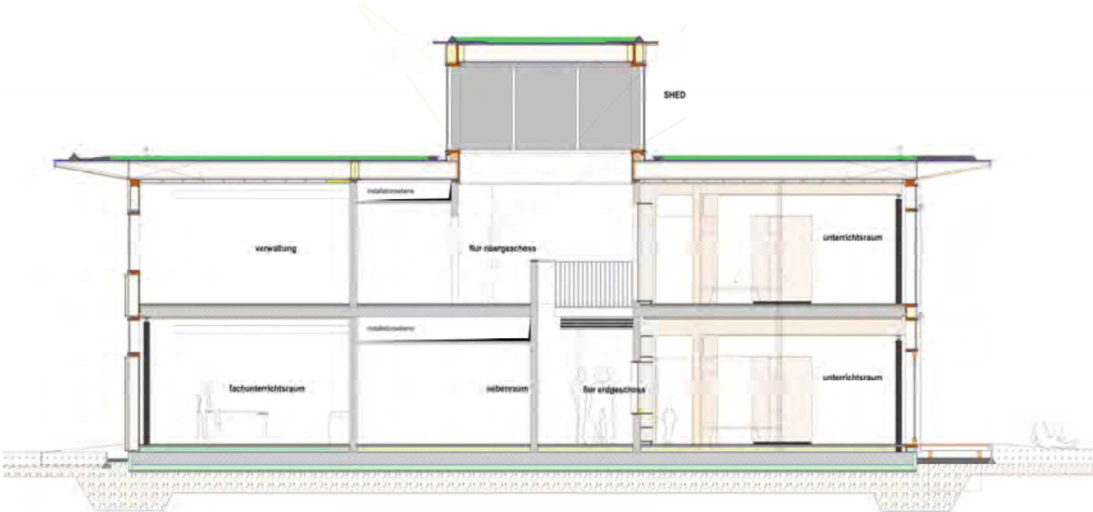

Fig. 3 Section of the classroom area

The outer wall and roof of the building was planed as a wooden construction. The heat protection is cheaper and more effective to build. On the other hand prefabrication is usual, safes time and reduces costs. However an exact planning is necessary to achieve air-tightness and avoids thermal bridges.
As far as possible wood should not only be used to build the facades, it is also useful for the interior construction. The combination of concrete and wood creates a homelike atmosphere.
Because of the mixed construction the advantages of concrete and wood are used in the best way. The basic construction of the building is formed by the inner walls. Most of them carry the construction together with the outer walls, which are wood made. By intention a secondary structure for the roof was abandoned, in order to build a roof with a large span length allows an effective construction. The spacing between the roof grids are dammed with cellulose. The static height creates space, which is necessary to reach the requirements of heat protection for a Passive house. Because the horizontal areas of the construction shell require the most space, it is possible to achieve an inexpensive heat protection.

Fig. 4 View to the concrete construction

Fig. 5 View in the upperfloor

Technical data:
10 Classrooms, 9 Special Rooms, one Gymnasium

Useful areas:	**3.649 m²**
Cubic Contents:	**18.486m³**
Heating Demand:	**13 kWh/m²a**
Primary Energy Demand:	**89 kWh/m²a**
Airtightness:	**0,09- h (during the construction phase)**
Owner:	**Montessoriverein Erding e.V.**
Location:	**Aufkirchen, Germany**
Year of Construction:	**2003 - 2004**

The **townhouses at Poing** are constructed for the well known housing association SÜDHAUSBAU Munich/ Berlin. In this case a Passive house standard is required according to high ecological standards and an extraordinary and creative design.
All ceilings and partitions are constructed in concrete. The external walls and the roof are built out of timber elements. Again special attention is given to the joints in order to reach an efficient passive house standard.
After all 5 townhouses were sold other 22 houses are to be planned.

Fig. 6 View to the south

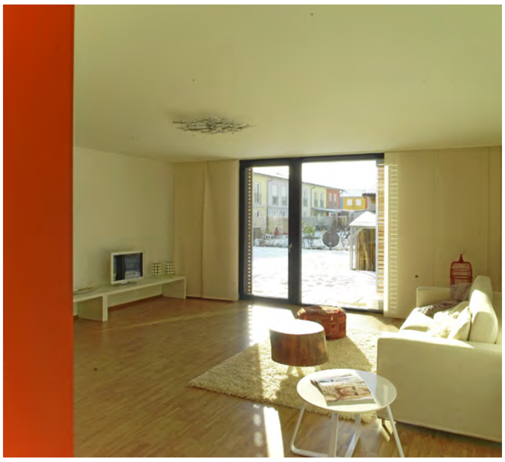

Fig. 7 Interior view of the living room

The isometry of the construction shows that the important needs of the passive house standard are solved in an effective matter - excellent thermal protection, air-tightness, thermal mass.

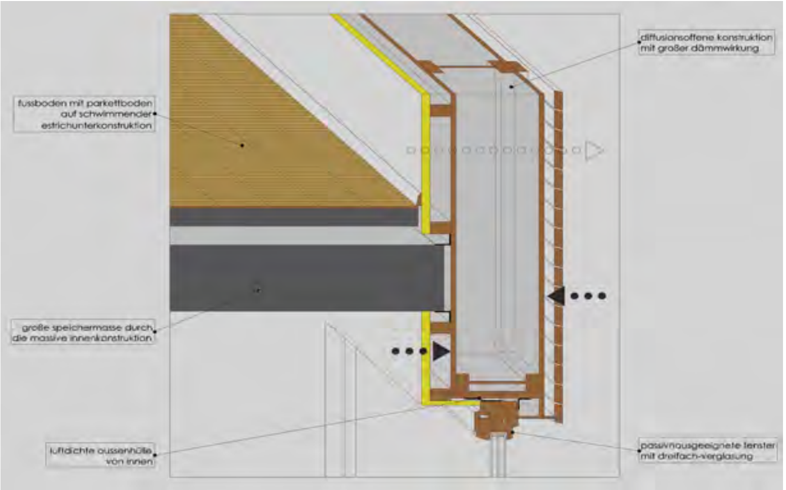

Fig. 8 Isometry of the joint of wooden and concrete construction

Technical data:	
5 townhouses	
Useful areas:	**908 m²**
Cubic Contents:	**3.680 m³**
Heating Demand:	**14 kWh/m²a**
Primary Energy Demand:	**108 kWh/m²a**
Air-tightness:	**0,24 - h (during the construction phase)**
Owner:	**SÜDHAUSBAU GmbH Munich/Berlin**
Location:	**Poing, Germany**
Year of Construction:	**2009**

The **passive house depot for arts** is planned as a preproduction model (prototype) and will be constructed as a concrete building. In this building works of art and cultural assets shall be stored. Here high requirements concerning constant temperature and moisture in summer and wintertime must be met. The passive house standard is the most economical construction to fulfil all the physical requirements. Because the high safety requirements, especially the fire protection and the necessary use of the thermal masses, all components should be of concrete. Here is the use of PCM-materials (Graphite Composite Materials for Latent heat storage) planned. The building services at this pilot project is based on a heat pump for heating and cooling. This is supported by a water controlled photovoltaic system.

Fig. 9 View of the entrance

Technical data:
20 storage rooms/ function area/offices
Useful floor space: 5.800 m²
Heat demand: 15 W/m²a
Primary heat demand: 118 W/m²a

The project report of the Architekturbüro Vallentin shows the efficient application of concrete construction and the mixed use of wood and concrete constructions in the design of passive houses. In particular both building materials reveal their formative and creative potential. Here as an example the interior and the facades of the Montessori school in Aufkirchen, Germany:

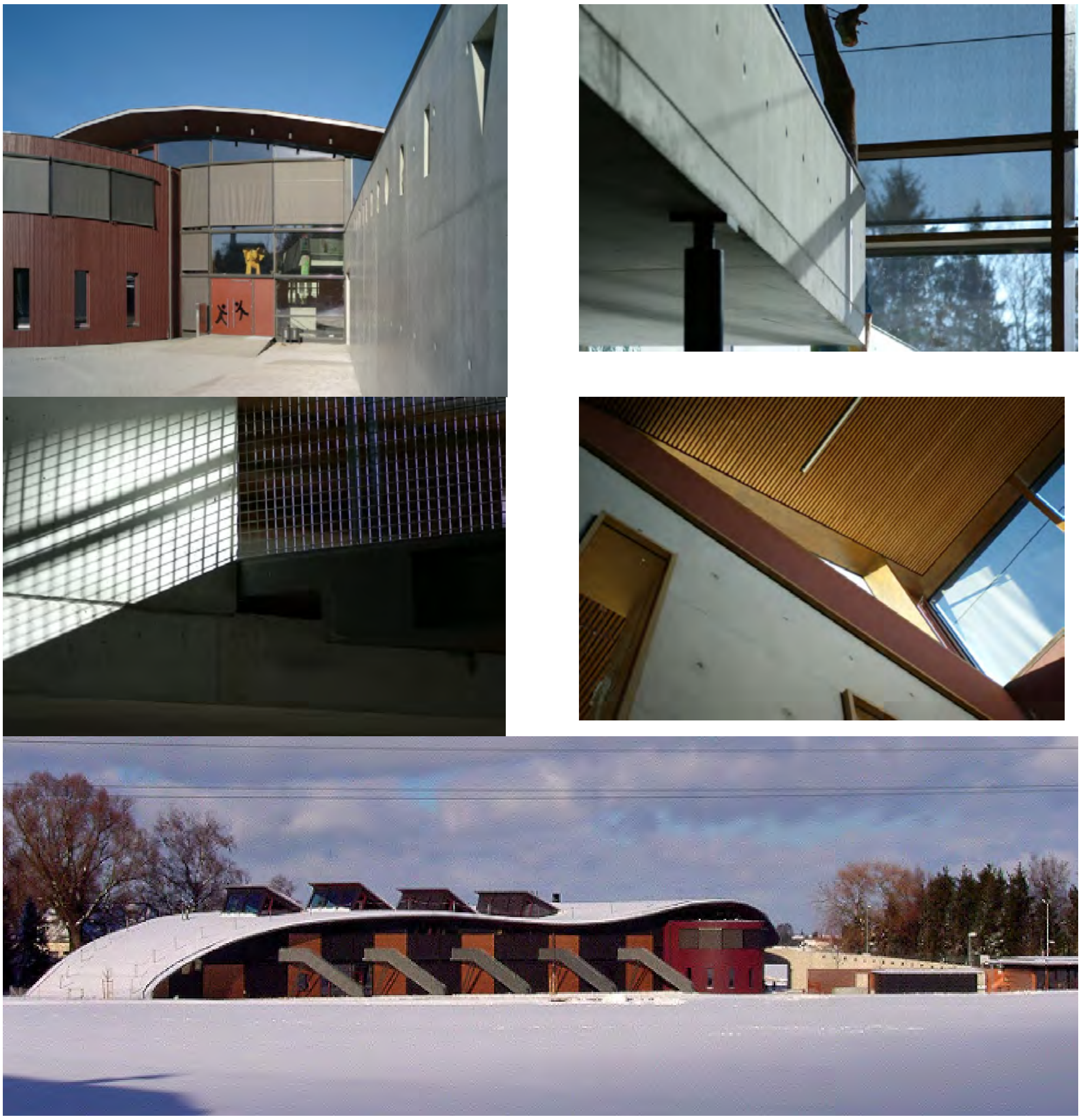

Fig. 10-14 Montessory school, Aufkirchen, Germany

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design of passive houses

- combining wood and concrete –

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design of passive houses * combining wood and concrete

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At the first sight wood and concrete appear to be contrary. Our project reports reveal however that the combination of both building materials is a very conclusive ecological, economical and technological solution for the construction of passive houses.

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Project reports of several projects designed by Architekturbüro Vallentin show the advantages/ application/ possibilities /utilisation and importance of concrete and mixed concrete constructions in Passive house design. Concrete is either used in a mixed construction or as the main material of a building. The introduced projects are realized buildings or projects in planning.

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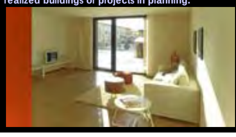

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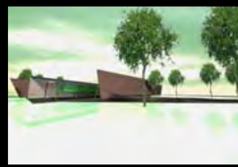

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The Montessori school in Aufkirchen of the Montessori Friendly Society Erding is a ten class elementary and secondary school with the possibility to obtain a secondary school certificate. The Montessori school in Aufkirchen is the first new built school in Germany, planned and constructed according to passive house standard. The school is realized without higher costs in comparison to a conventional building.

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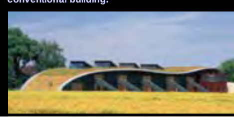

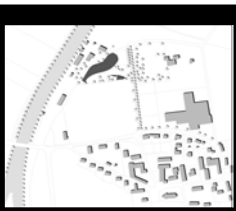

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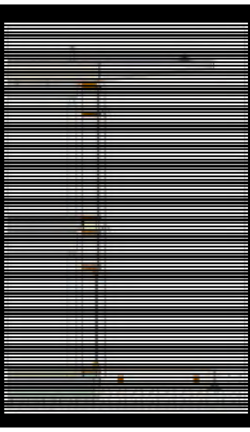

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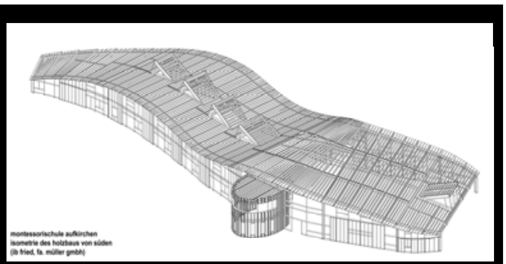

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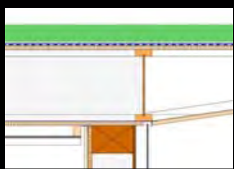

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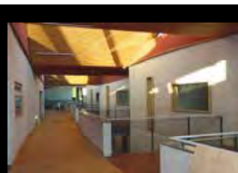

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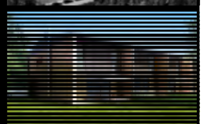

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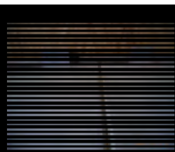

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All ceilings and partitions are constructed in concrete. The external walls and the roof are built out of timber elements. Again special attention is given to the joints in order to reach an efficient passive house standard.
After all 5 townhouses were sold other 22 houses are to be planned now for execution this year.

passive houses – combing wood and concrete * coin workshop*oslo 2010
a r c h i t e k t u r b ü r o v a l l e n t i n am marienstift 12 d-84405 dorfen

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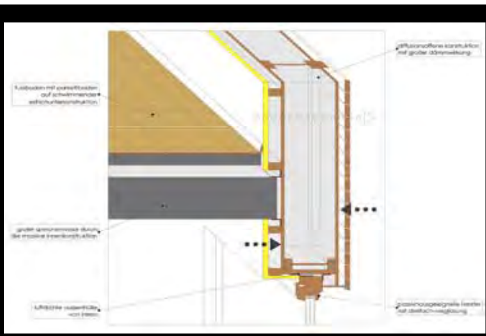
The isometry of the construction shows that the important needs of the passive house standard are solved in an effective matter - excellent thermal protection, air-tightness, thermal mass.



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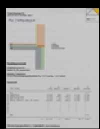

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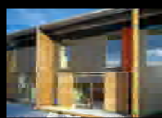
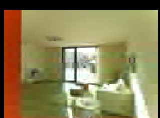


Technical data:
5 townhouses

Useful areas:	908 m²
Cubic Contents:	3.680 m³
Heating Demand:	14 kWh/m²a
Primary Energy Demand:	108 kWh/m²a
Air-tightness:	0,24 - h
Owner:	SÜDHAUSBAU Munich/Berlin
Location:	Poing, Germany
Year of Construction:	2009



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passive houses – combing wood and concrete ¥ coin workshop*oslo 2010
a r c h i t e k t u r b ü r o v a l l e n t i n am marienstift 12 d-84405 dorfen

The passive house depot for arts is planned as a preproduction model (prototype) and will be constructed as a concrete building. In this building works of art and cultural assets shall be stored.

passive houses – combing wood and concrete ¥ coin workshop*oslo 2010
a r c h i t e k t u r b ü r o v a l l e n t i n am marienstift 12 d-84405 dorfen

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passive houses – combing wood and concrete ¥ coin workshop*oslo 2010
a r c h i t e k t u r b ü r o v a l l e n t i n am marienstift 12 d-84405 dorfen

The passive house standard is the most economical construction to fulfil all the physical requirements. Because the high safety requirements, especially the fire protection and the necessary use of the thermal masses, all components should be of concrete. Here is the use of PCM-materials (Graphite Composite Materials for Latent heat storage) planned.

passive houses – combing wood and concrete ¥ coin workshop*oslo 2010
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Here high requirements concerning constant temperature and moisture in summer and wintertime must be met. The building services at this pilot project is based on a heat pump for heating and cooling. This is supported by a water controlled photovoltaic system.

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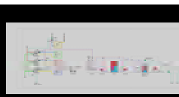

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Design for a larger storage building in the town near Munich. Here the passive house standard is also the best possibility for an effective and ökonomical solution.

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Technical data:
20 storage rooms/ function area/offices

Useful floor space:	5.800 m²
Heat demand:	15 W/m²a
Primary heat demand:	118 W/m²a
Owner:	SÜDHAUSBAU Munich/Berlin
Location:	Bergham, Germany Wasserburg, germany
Year of Construction:	2011

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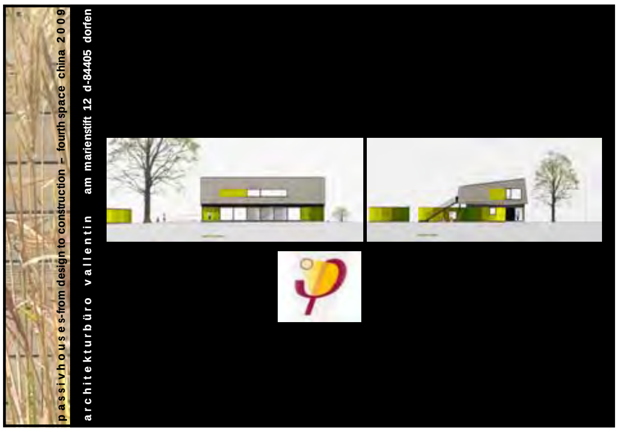
passivhouses-from design to construction – fourth space china 2009
architekturbüro vallentin am marienstift 12 d-84405 dorfen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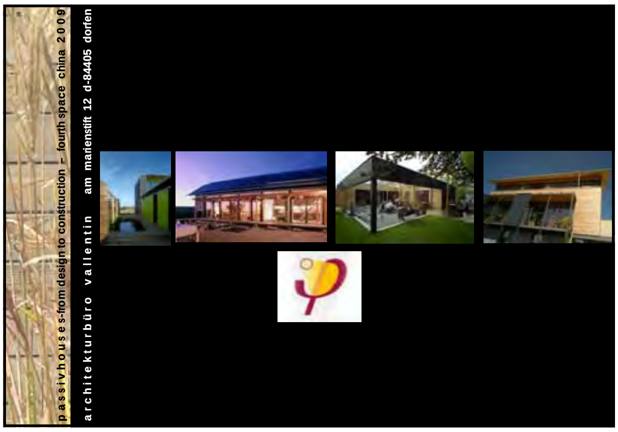
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design of passive houses
- combining wood and concrete –
„coin workshop“ oslo 26. + 27.01.2010
gernot vallentin
dipl. ing. architect +
zertified passivhousplaner
architekturbüro vallentin
unterer markt 1a
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11 Utilisation of concrete in Passive House design

Utilisation of concrete in Passive House design

Michael Klinski

SINTEF Building and Infrastructure

Utilisation of concrete in Passive House design

Michael Klinski
SINTEF Building and Infrastructure
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The *Passive House* is not an energy performance standard, but a concept. The original “German” definition is: "A Passive House is a building, for which thermal comfort can be achieved solely by post heating or post cooling of the fresh air mass, which is required to fulfil sufficient indoor air quality conditions without a need for recirculated air" (Passive House Institute). This means, an ordinary heating system is not needed. The proposed Norwegian Passive House standard is based on a corresponding functional definition, but here the goal is to be able to achieve indoor comfort in the wintertime by using a very simplified water based heating system, for instance with only one radiator per apartment. Both in the German definition and in the future Norwegian standard the main requirement is a space heating demand not more than 15 kWh/m² per year[1]. However, in Norway it will be some adjustments for smaller detached houses and for buildings in very cold regions.

Passive Houses do not need a completely different construction method. In fact, all new construction can be realized in Passive House standard as well. In Central Europe it is more common to use brick and concrete also in smaller residential houses. So, there are examples of built Passive Houses in concrete or combinations of concrete and brick or wooden constructions in many building categories.

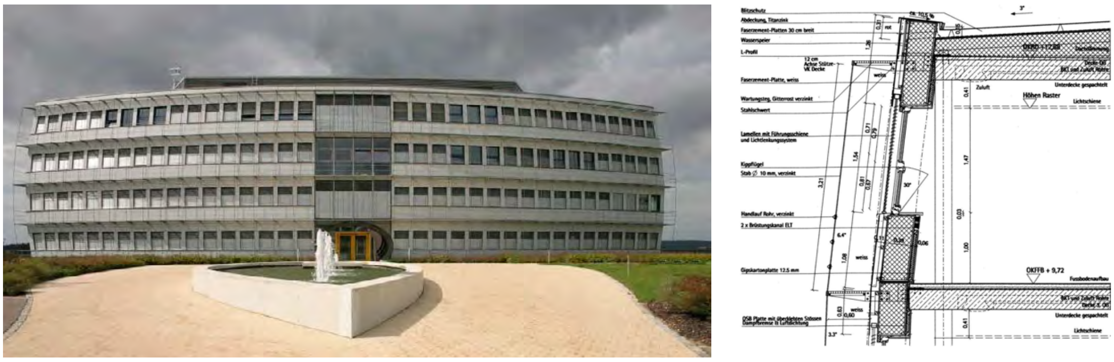


Fig. 1 Energon, office building in Ulm, Germany. Concrete in combination with wooden façade elements (http://www.enob.info/de/neubau/projekt/details/passivbuerogebaeude-energon/).

Fig. 2 Science College Overbach, Germany. Concrete façade with plastered insulation (http://www.enob.info/de/neubau/projekt/details/science-college-im-bildungszentrum-overbach/).

[1] Basically, this is the requirement for residential buildings. The numbers for non-residential buildings are under discussion in Germany as well as in Norway.

Fig. 3 Primary school and kindergarten Frankfurt-Riedberg, Germany. Concrete façade with curtain wall (http://www.passiv.de/04_pub/Literatur/Riedberg/PH-Schule_Monitoring.pdf).

Since a lot of energy is needed to produce concrete, and especially reinforcing steel, concrete construction should be used where it is particularly advantageous – load bearing, sound damping, heat (and humidity) storage capacity. The latter is particularly important e.g. in schools and office buildings to avoid overheating in summer, and maybe in spring and autumn as well. To maintain a comfortable interior summer climate is much more complicated in lightweight constructions, and additional measures are required to avoid the need of active cooling. This is of special importance in Nordic countries, where façades are more exposed to the sun than in Central and South Europe.

In spite of the advantages – to avoid thermal bridges can be a big challenge in concrete constructions suitable for energy efficient buildings. Crucial joints are for instance wall/foundation/slab on ground, wall/cellar ceiling, wall/balcony/floor, junctions around staircases and curtain wall fixings.

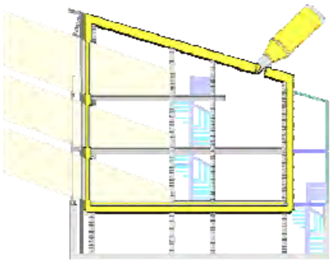
The U-value of curtain wall systems can be more than tripled if poor fixing devices are used. “Ordinary good” solutions are not sufficient for Passive Houses, but better ones are available today. For balcony constructions it should preferably be used a system with its own support. However, the German company Schöck has recently developed an updated, thermally efficient load-bearing balcony connection element, suitable for unsupported cantilevered balconies in Passive Houses. The Passive House Institute certificated the new “Isokorb XT” as a construction with low thermal bridge value. Characteristic features are 120 mm insulation (instead of 80) and a thermal transmission coefficient ψ between 0.11 and 0.25 W/mK. As a typical result for row houses and apartment buildings, the U-value for the relevant external wall will increase by less than $\Delta U=0.025$ W/m²K (http://www.schoeck.de/de/neubau/schoeck-isokorb-xt-107; not available on Norwegian or English website).

A particular problem are joints between walls and ceilings, if continuous steel reinforcement is required from the ground floor wall to the cellar wall, breaking the insulation layer. As an example, a cellar ceiling construction with 30 cm insulation under, normally has a U-value of 0.125 W/m²K. A continuous reinforced concrete wall through the insulation layer would increase the U-value by $\Delta U=0.125$ W/m²K, so that the resulting U-value for the whole ceiling would be doubled to 0.25. In case of single reinforced concrete supports instead of a cellar wall, the resulting U-value would be just 0.162 W/m²K. This could be optimized to 0.142 by using slim supports. In addition, the supports should be insulated 100 cm down and 10 cm thick. In this case, the resulting U-value of 0.135 would be acceptable in most Passive House projects.

[Tanja Schulz, *Erfordernisse der Statik*; in: Protokollband Nr. 35, Passive House Institute 2007, http://www.passiv.de]

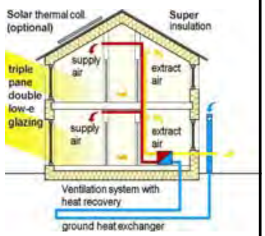
Utilisation of concrete in Passive House design

COIN Workshop Oslo
January 27, 2010



Michael Klinski, SINTEF
Building and Infrastructure

The Passive House concept



- A Passive House is a building, for which thermal comfort can be achieved solely by post heating or post cooling of the fresh air mass, which is required to fulfil sufficient indoor air quality conditions without a need for recirculated air (Passive House Institute)
- >>> Ordinary heating system not needed
- >>> Heating demand ≤15 kWh/m²a (residential)

Proposed Norwegian PH-standard

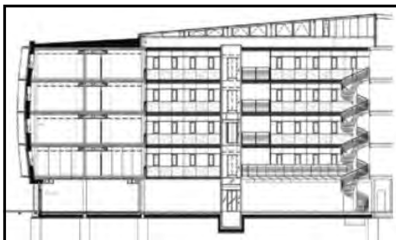
- Functional goal: to be able to achieve winter indoor comfort by using a very simplified water based heating system
- >>> Heating demand ≤15 kWh/m²a (residential)
- Adjustments for smaller detached houses and for buildings in very cold regions

Requirements for non-residential buildings are under discussion in both Norway and Germany

Office building Energon, Ulm, Germany

- Concrete skeleton in combination with prefabricated wooden façade elements
- Concrete core temperature control
- Photovoltaic
- Heated net floor area 6.911 m²
- Completion10/2002

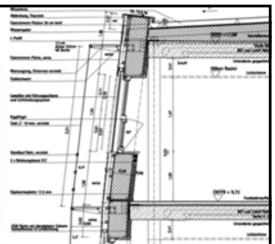
Certificated Passive House



Sources: www.enob.info and Steinbeis-Transferzentrum Energietechnik Ulm Architect: oehler + arch

Energon, Ulm: Section and floor plan

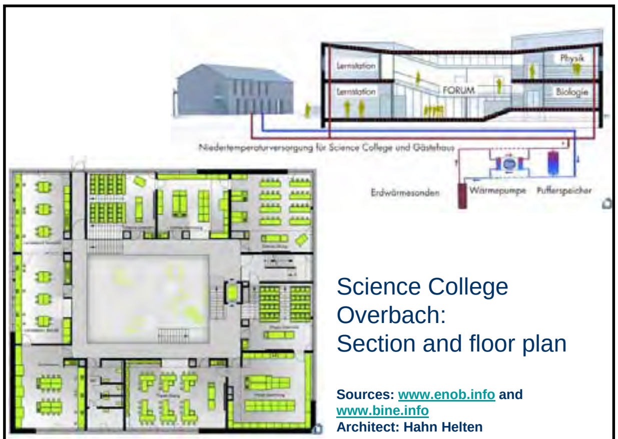
Energon: Façade elements



Science College Overbach, Germany

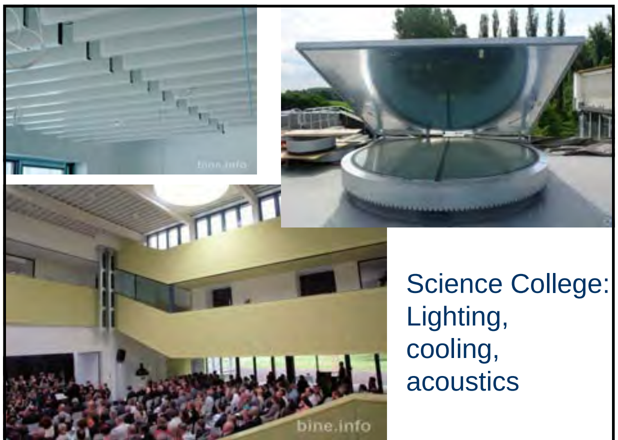
- Concrete façade with plastered insulation
- Concrete core temperature control
- Light directing reflectors
- Heated net floor area 1.730 m²
- Completion 6/2009

Nearly Passive House standard



Science College Overbach: Section and floor plan

Sources: www.enob.info and www.bine.info
Architect: Hahn Helten



Science College: Lighting, cooling, acoustics

Primary school and kindergarten Frankfurt-Riedberg, Germany

Certificated Passive House

- Concrete façade with curtain wall
- Heated net floor area 5.541 m²
- 2 Pellet boilers; PV
- Completion10/2004

School and kindergarten Frankfurt: Section and floor plan

Source: www.passiv.de
Architect: Architekten 4 a

School and kindergarten Frankfurt: Sun shading and summer ventilation

School and kindergarten Frankfurt: Classroom and concrete façade with curtain wall

- A lot of energy needed to produce concrete and steel

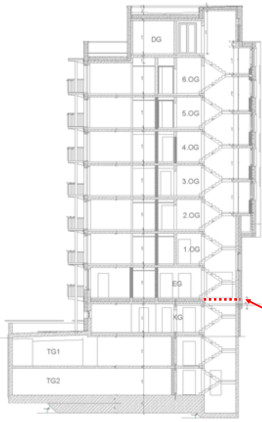
Use concrete where it is advantageous:

- Load-bearing
- Fire protection
- Sound damping
- Heat (and humidity) storage capacity
  - Comfortable interior summer temperatures easier to maintain than in lightweight constructions
  - Important in schools and office buildings, especially in Nordic countries

Façades in Oslo more exposed to the sun than in Roma

South-facing façades in different cities	Direct	Diffuse	Global	Addition for bright surroundings	Total
	Sun radiation [W/m²]				
Oslo					
March 10, 12.00	750	150	900	110	1010
June 15, 12.00	540	180	720	0	720
Berlin					
March 10, 12.00	720	150	870	110	980
June 15, 12.00	440	180	620	0	620
Roma					
March 10, 12.00	680	180	860	0	860
June 15, 12.00	300	180	480	0	480

Source: www.enova.no



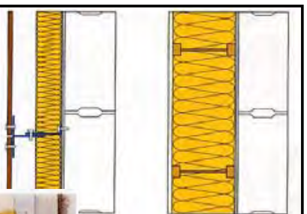
Big challenge: thermal bridges

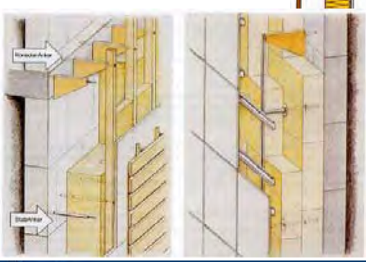
- Curtain wall fixings
- Balconies
- Cellar ceiling
- Foundation, slab on ground
- Staircases

Without measures:
U=12 W/m²K down through stair case and lift area

Curtain walls:

Poor fixing devices can double or triple the U-value of the wall





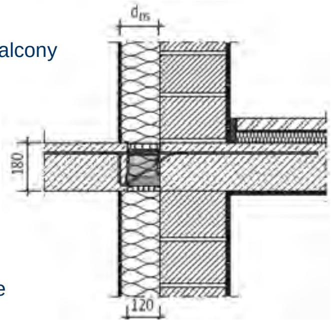
Particularly good solutions required – and available – for Passive Houses

Preferable for balconies:

A system with its own support and only point wise penetration of the insulation layer

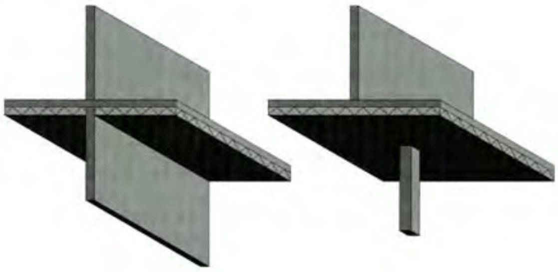
Acceptable alternative in many cases:

- Updated load-bearing balcony connection element Schöck "Isokorb XT"
- 120 mm insulation
- ψ=0.11– 0.25 W/mK
- ΔU=0.025 W/m²K for a typical connected wall
- Certificated by PHI as a construction with low thermal bridge value



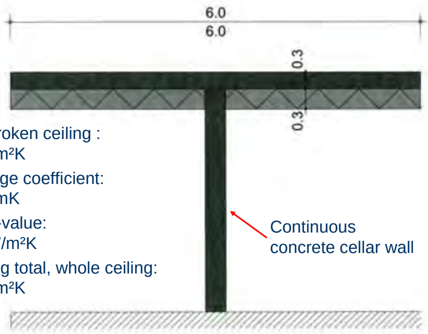
Source: www.schoeck.de

Particular problem: cellar ceiling with wall reinforcement through insulation layer



- Generally not acceptable in PH
- Possibly acceptable

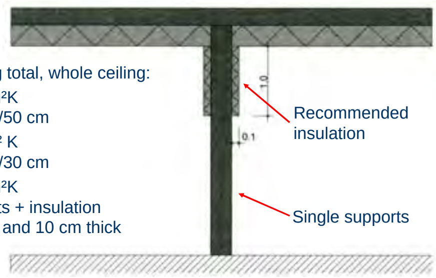
Example: 6 x 6 m ceiling, 30 cm insulation



- U-value unbroken ceiling : U=0.125 W/m²K
- Thermal bridge coefficient: ψ = 0.74 W/mK
- Additional U-value: ΔU=0.125 W/m²K
- >>> Resulting total, whole ceiling: U=0.250 W/m²K

Same ceiling – single supports in the cellar

- U-value unbroken ceiling : U=0.125 W/m²K
- >>> Resulting total, whole ceiling:
- U=0.162 W/m²K if supports 50/50 cm
- U=0.142 Wm² K if supports 30/30 cm
- U=0.135 W/m²K if slim supports + insulation 100 cm down and 10 cm thick



References

- Tanja Schulz, *Erfordernisse der Statik – vermeidbare Wärmebrücken*
- and other articles in this brochure
- www.passiv.de
- www.passivhaustagung.de

(most in German, but some material in English available)


Protokollband Nr. 35

Arbeitskreis kostengünstige Passivhäuser Phase IV

Wärmebrücken und Tragwerksplanung – die Grenzen des wärmebrückenfreien Konstruierens

12 Concrete constructions and air tightness of the building envelop

Concrete constructions and air tightness of the building envelop

Ferry Smits

Rambøll Norge AS

Concrete constructions and air tightness of the building envelop

Ferry Smits, M.Sc./ Consulting Engineer Building Physics
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Keywords: Building Physics, air-tightness, concrete, air-pressure testing

SUMMARY:
During the last few years Rambøll in Trondheim has executed several air-pressure tests of both minor and larger buildings in Norway. These test have shown that concrete elements and building envelopes executed in concrete, both prefabricated as well as on site precast, have a good air-tightness. It is mainly the connection between the concrete elements and the surrounding elements which can cause some challenges to obtain a good air-tightness.
The paper describes the experiences from air-pressure testing of 3 different projects in Trondheim. To get a better understanding of the problems, challenges and possibilities more tests should get executed. The overall air-tightness of the buildings was very good for the 2 latest projects. This might be partly because of the building envelop has been executed in concrete.
The challenge of securing a good air-tightness is to have focus on the details around and connecting the concrete façade elements. At this moment no standard details have been developed showing how to obtain a good air-tightness. Good details will increase the buildings air-tightness and fully use the possibilities of concrete.

1 Introduction

Rambøll Norway is a multidisciplinary consulting engineering company working mainly in the Nordic region as well as Great Britain and the Middle East. Our building physics department in Trondheim has during the last few years been involved in the design and control of many buildings, especially low-energy and passive house buildings. In addition we have been involved in the control of existing buildings, building mistakes / errors etc.
In this paper we would like to discuss the result and experiences of 3 particular projects, with focus on the air-tightness of the buildings envelop of concrete buildings. The following projects are to be discussed in this paper:

1. Commercial office building in Trondheim at Stiklestadveien (2008), approx 10.000 sqm.
2. Commercial office building in Trondheim at Professor Brochsgate 2 (2009) for Veidekke Entreprenør AS, approx 12.500 sqm.
3. Commercial office building in Trondheim from 1960 for Sluppen Eiendom, approx. 2.500 sqm.

The main objective with the control of these buildings was to check the buildings air-tightness in an air-pressure test according to the Norwegian Building Regulations. It was not specifically done with focus on the usage of concrete in the building.

2 Commercial office building at Stiklestadveien

The commercial office building at Stiklestadveien in Trondheim was completed during 2007 – 2008. The complete building consists of approx 10.000 m^2 with heated area in addition to a full basement for parking. The total volume is estimated to be 30.000 m^3.
In this project Rambøll has been involved to check the buildings envelop and air-leakage factor. Due to the size of the object we have executed the air-pressure test by usage of the

building own ventilation system. The test has been executed according to the international standard NS-ISO 13829 [Standard Norge, 2000].

Figure 1 - Facade office building (ill. Rambøll Norge AS)

Figure 2 - facade office building (ill. Rambøll Norge AS)

The building is constructed of a main load bearing construction of concrete. The Buildings envelop has been constructed of prefabricated concrete sandwich elements. The prefabricated elements consist of a sandwich element construction with concrete on both the inner and outer wall, and EPS insulation in between. Elements are stacked on top of each other and stretch from one floor to the next.
An Air-pressure test resulted in a buildings air-leakage of 1.0 (h^{-1}) at 50 Pa. These results are within the design criteria for air-leakage according to the new building regulation of 2007 [TEK, 2007]. The main objective with this specific project was to find the causes regarding unwanted draft from the windows. People working in the building had complained about cold air infiltrating into the heated area causing discomfort.
The air-pressure test showed that the overall air-leakage of the building was very good but many of the infiltration openings were around the windows. The search for errors in the buildings envelop was done by using an infrared camera, investigation according to NS-EN ISO 13187 [NS-EN ISO 13187, 1998]

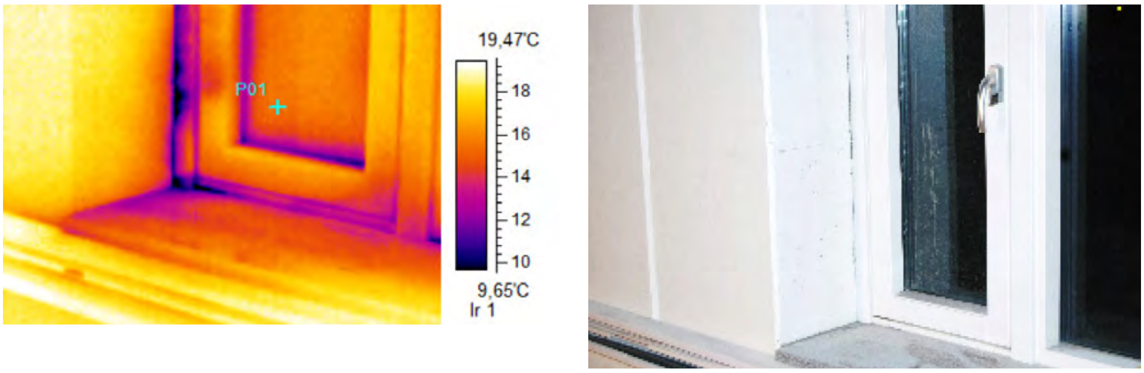


Figure 3- infrared image of a typical leakage around the windows (ill. Rambøll Norge AS)

During the air-pressure test there has been much focus on finding errors in the buildings envelop. There were no errors detected in the connections between the sandwich elements, and the surrounding building elements. The main errors were located around the windows as shown in figure 3. Local air velocity measurements show speeds of 1.5 – 3.0 m/s at the point of leakage. Sintef Byggforsk recommends that air-velocity at 60 cm from the façade not should exceed 0.15 m/s. Air velocity higher than this recommended speed will cause discomfort. [SINTEF Byggforsk, 1999] Measurements taken at approx. 60 cm from the façade had velocities between 0.5 – 1.0 m/s which exceeds the recommended air speed limits.

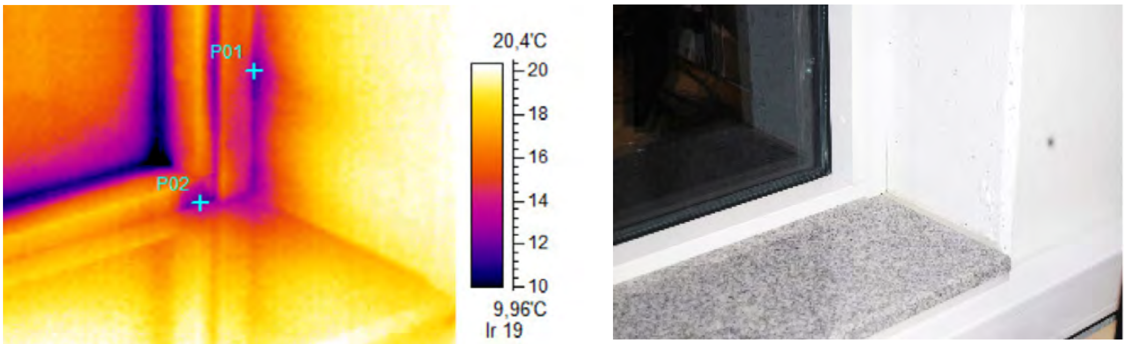


Figure 4 - infrared images window (ill. Rambøll Norge AS)

The building was not intentionally designed to have a lower air-tightness than recommended by the building regulations, but the air-pressure test showed good results which can mainly be caused by the air-tight building envelop; the concrete prefabricated elements.
The local air leakages are most probably the result of deformations of the timber element in the precast element. See also figure 5, Windows are mounted into this timber sill and are tightened with foam or silicon afterwards. The sill is first mounted into the precast shape in the factory and will shrink after a period of time. This will cause an air-leakage around the window sill as shown in the detail figure 5.

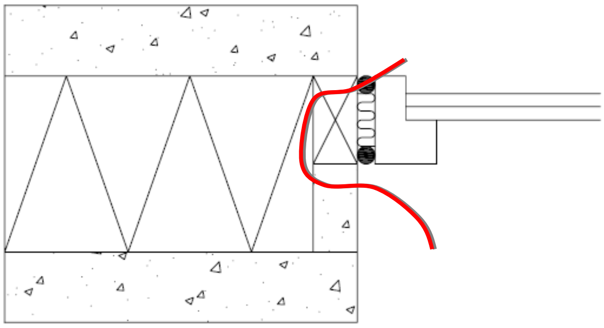


Figure 5 – detail window sill mounted in the prefabricated wall element (ill. Rambøll Norge AS) The red line indicates a possible leakage through the wall. This sill is part of the precast concrete element.

3 Commercial office building at Professor Brochsgate 2

The new office building at Professor Brochsgate 2 in Trondheim is a reference building and example for design of low-energy and passive house in Norway. The building is planned to use approx. 82 (kWh/m^2/yr). The main construction of the building consists of 2 long and slender office areas in 6 and 4 stories. Underneath the entire building there has been executed a parking basement. The main office areas are connected to each other by a large glazed atrium which is to be used as a half acclimatized area.

Figure 6 - entrance view of the building at Prof. Brochsgate 2 (ill. Rambøll Norge AS)

During the earlier stages of the project, the air-tightness of building was planned not to exceed 1.2 (h^{-1}). Rambøll has been involved in the project to execute a 3rd part building physics control of the details, control of the execution and measuring the air-tightness of the building.

The heated area of the building is approx. 12.500 m^2. The building envelop is constructed of both traditional timber framing, and approx. 50% of prefabricated concrete elements. The concrete elements are mounted onto the slabs. Windows are afterwards placed in between the concrete elements by the local contractor. This method enables good insulation of the cold bridges and a very rational building process. Elements are insulated with a total of 250 mm of insulation (EPS).

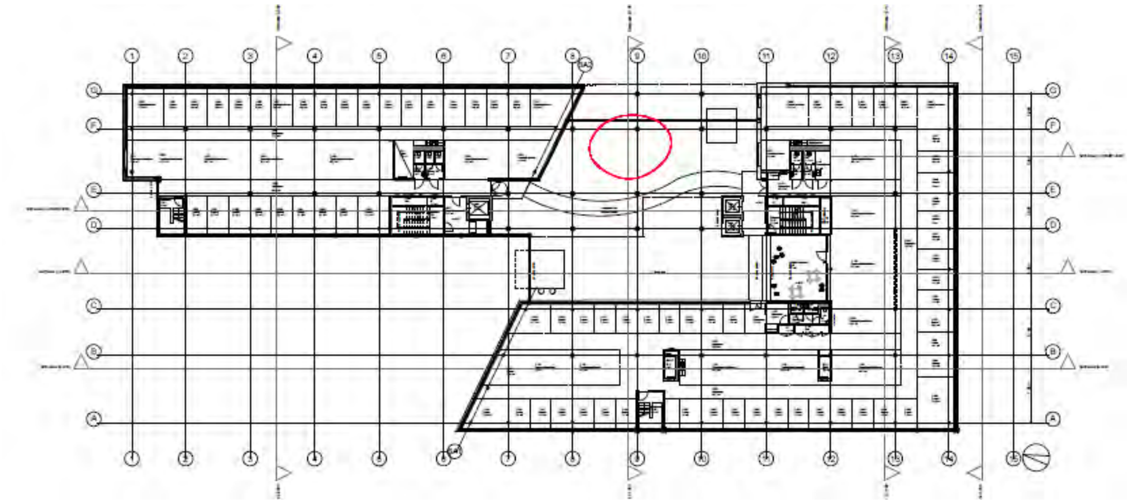


Figure 7 - office building Prof. Brochsgt. 2 typical plan (ill. PKA Arkitekter AS)

Figure 8 - detailed view of the prefabricated concrete facade (ill. Rambøll Norge AS)

Figure 9 - office building prof. Brochgt. 2, timber framing facade (ill. Rambøll Norge AS)

Rambøll Norge AS has during the building period executed the following tests and controls:

1. Building Physics control of all of the technical and architectural details (approx. 100)
2. Course and meeting with the executive personnel on site before execution of the timber framing work
3. Control of air-tightness by air-pressure testing with 50 Pa: a local area of approx. 600 m^2 where the façade was designed with timber framing (see figure 9 and 10) *
4. Control of air-tightness by air-pressure testing with 50 Pa: a local area of approx. 600 m^2 where the façade was designed with prefabricated concrete elements (see figure 8) *
5. Control of air-tightness by air-pressure testing with 50 Pa of the complete building*.

**) all air-pressure test executed according to NS-EN ISO 13187 [NS EN ISO 13187, 1998]*

During the first control there has been much focus on the methods used to achieve a good air-tightness of the building. The overall solution was based on a 2 step sealing including a mechanical enclosure of the wind barrier. In addition has there been used an expansion foam in the gap between the timber sill and window frame. The air-tightening of the prefabricated concrete elements are based on a similar solution, where the sealants used where based on silicone. Workers on site had a good focus on the issues and challenges regarding the buildings air-tightness. The first 2 preliminary air-pressure tests showed good results: 0.6 (h^{-1}) and 0.66 (h^{-1}) at 50 Pa (over- and under pressure). Preliminary tests have been executed by usage of a blower door.

The preliminary test nr. 2 showed only a few minor errors in the building envelop these where mainly caused by errors in the windows and gaskets. No specific errors were found in the connections of the concrete elements, mounting of windows or other parts in the prefabricated concrete elements. The good preliminary results caused an overall test result for the complete building of 0.4 (h^{-1}) which is very low and contributed a lot to the overall reduction of energy consumption of the building.

Thermal camera investigation discovered mainly errors around internal shafts, fire walls and at the thermal boundary towards the parking garage.

Figure 10 - preliminary air-pressure test of a part of the building with the usage of a Blower Door (ill. Rambøll Norge AS)

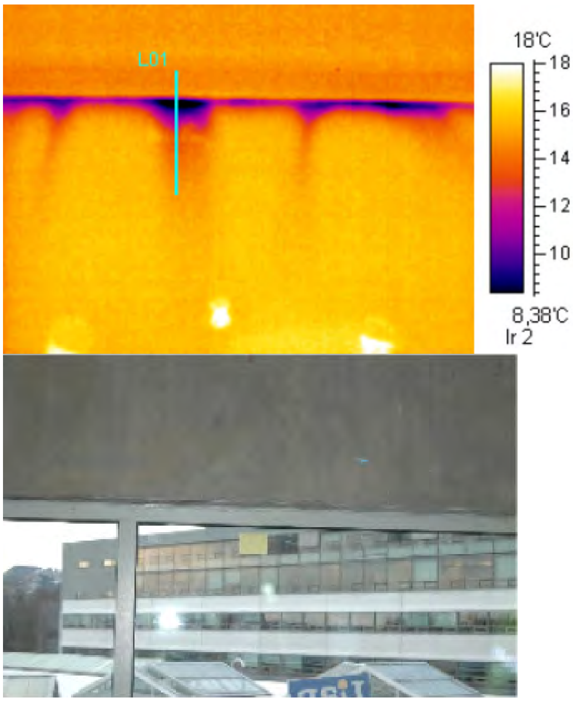


Figure 11 - thermal camera investigation of the buildings envelop. Thermal image shows air leakage through the gasket (ill. Rambøll Norge AS). The thin horizontal edge at the top of line L01, shows the connection between the window frame and concrete element.

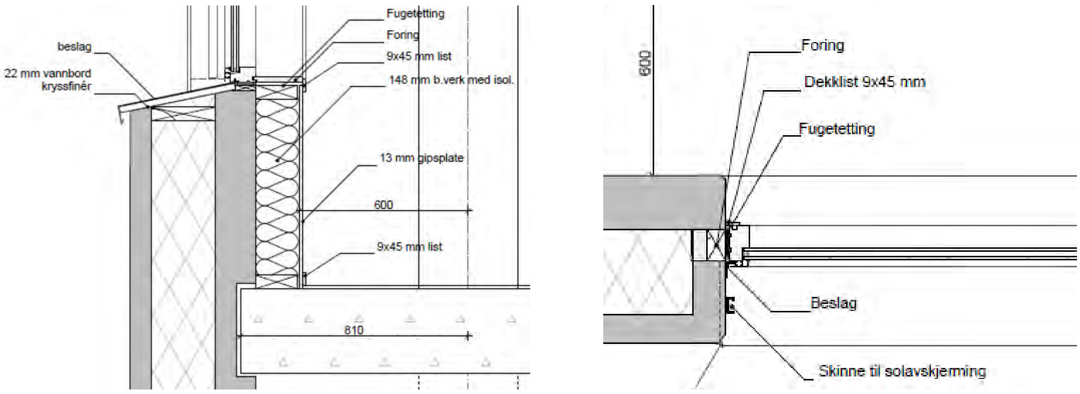


Figure 12 - typical vertical and horizontal detail of window mounted into the prefabricated concrete element (ill. PKA Arkitekter AS, Trondheim). The internal insulation on the warm side of the concrete element has not been executed due to building physical problems; this is a preliminary detail (left image).

4 Commercial office building from 1960

This office building owned by Sluppen Eiendom AS in Trondheim was originally build in 1960 and needed a technical upgrade / rehabilitation. This included increased insulation in walls, roofing, better windows and reduced air-leakage. Rambøll has been involved in the project to do consulting engineering of the building physics. The building's main load bearing construction and slabs were executed in precast concrete. The facades are made of prefabricated sandwich elements which stretch in between the windows.

Due to the reduced possibilities of insulation of the existing construction was the building not rehabilitated and upgraded to today's building regulations. The use of air-pressure testing showed us to be a valuable tool and gave both the engineers as well as contractor a good

view over the location of air-leakage in the building. This way a very effective rehabilitation could be done.
During the first test of the existing situation, air pressure tests according to NS EN ISO 13829 [NS EN ISO 13829, 2001] showed an air-leakage of more than 5.0 (h^{-1}). The main leakages where located between the windows and concrete elements as well as between the concrete elements and the roofing. The roof originally consisted of a horizontally ventilated construction. This construction was minor insulated and the tightening between the slab and the concrete element not solved in a satisfying way.

Figure 13 - Facade towards the North East of the existing building showing the prefab concrete elements (ill. Rambøll Norge AS)

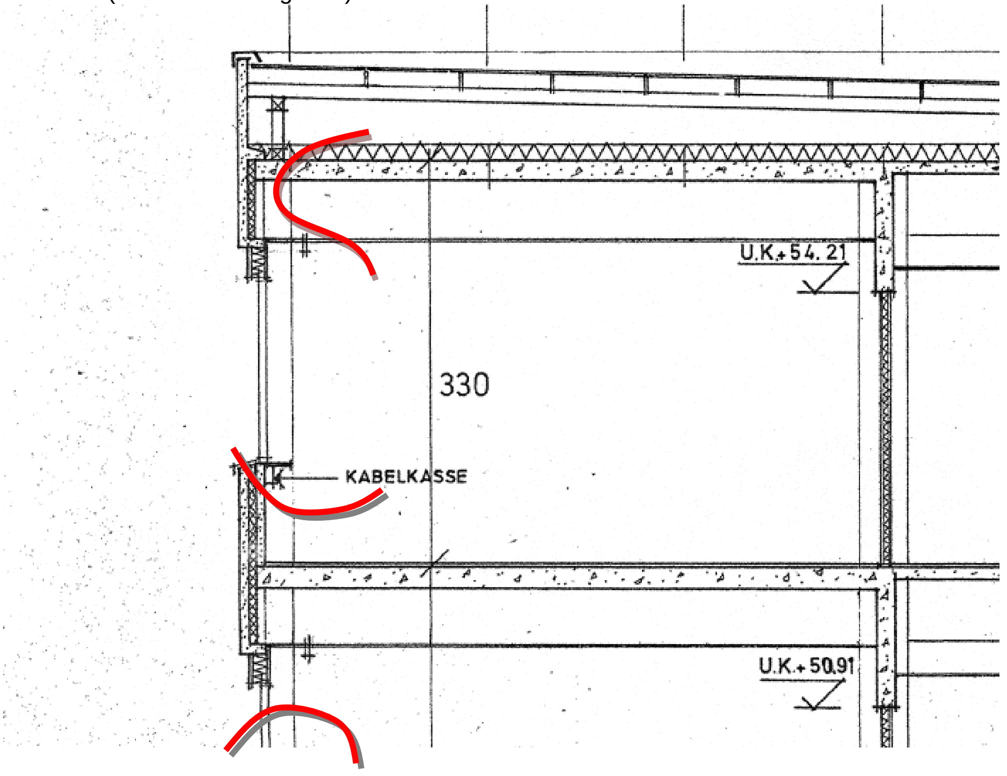


Figure 14- typical section of the original design of the building (ill. Harboe og Leganger AS)

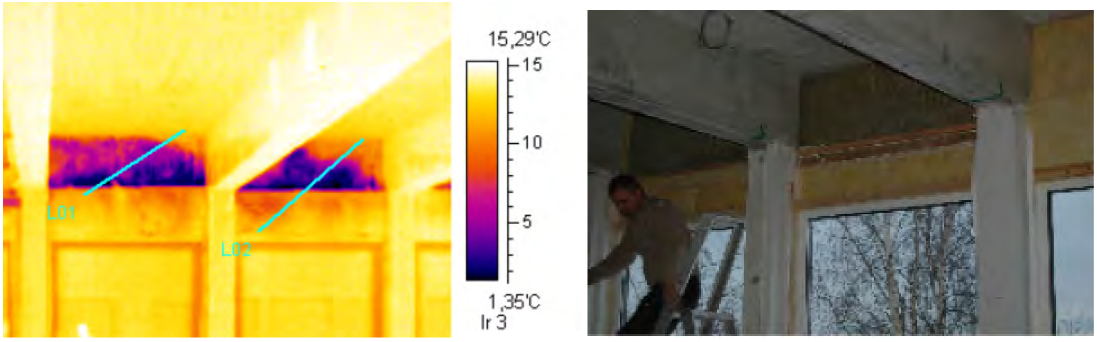


Figure 15 - thermal camera image showing are leakage between the concrete elements and surrounding constructions

The air-tightening of these details will cause a yearly reduction of approx. 103.000 kWh/m^2/yr for the first phase of the project (which involves rehabilitation of 2 stories of the building). The existing joints (butyl) between the concrete elements did not show any errors and maintained a good air-tightness even after 50 years. The air-tightening of the details around the existing concrete elements is twice as more energy effective than to add 50 mm of insulation on the inside of all walls, as well as replacing the windows with triple glazing. Calculations executed according to NS 3031 [Standard Norge, 2007].
All details were tightened with a 2 phase silicone joint and expandable insulation between the sills and windows. After completion of the project a new air-pressure test was executed, showing a remarkable reduction of the buildings air-tightness to 0.9 (h^{-1}).

5 Conclusion

Our main objective with the above mentioned projects has not been to investigate the air tightness of concrete building envelop, but during our testing have we noticed typical errors and measured results which indicate that there is a good potential in the usage of concrete in the building envelop to reduce air-leakage.
During the testing we have not located any errors regarding the connection between the concrete elements itself, but rather between the concrete elements and other building constructions. Most of the precast concrete elements like slabs and roofs are very tight. The main focus must be on the connection with the surrounding building parts in the buildings envelop.
A concrete element used in the building envelop will have a good air tightness. Together with the design and execution of good details we will be able to design high efficient air-tight buildings.
There have at this moment not yet been established any standard details or good practice details which can be used by architects, contractors and engineers, to secure that these future solutions can comply with today's demands regarding air-tightness. Also more air-pressure tests of several buildings are necessary to secure and verify any new solutions. It might also be relevant to test good practice solutions from other countries as well; this could be part of a future research project.

References

[NS 3031 2007], Pronorm, NS 3031 Beregning av bygningers energiytelse - Metode og data, appendix A (2007)
[NS-EN ISO 13829 2000], Pronorm, NS EN ISO 13829 Bestemmelse av bygningers luftlekkasje– differansetrykkmetode (2001)
[NS-EN ISO 13187, 1998], Pronorm, NS EN ISO 13187 kvalitativ metode for å oppdage termiskeuregelmessigheter i bygningers klimaskjermer – infrarød metode (1998)
[TEK, 2007]; Bygningsteknisk Etat, Teknisk forskrift 1997 4. Utgave (2007)
[SINTEF Byggforsk, 1999], Byggforsk, Byggdetaljblad 421.501 Temperaturforhold og lufthastighet. Betingelser for termisk komfort (1999)

FERRY SMITS
CONCRETE CONSTRUCTIONS AND AIR TIGHTNESS OF THE BUILDING ENVELOP

ABOUT ME AND RAMBØLL

- Teknisk høyskole Zwolle
- Eindhoven University of technology
- DTU, Lyngby
- Working as an Architect until 2006
- Rambøll Norge, Building Physics Technical Manager 2006 -

- Rambøll Group
- Approx. 9000 employees
- Main areas Nordic countries, UK and Middle East
- Working within all types of fields

ENOVA CONSULTING TEAM FOR EXAMPLE PROJECTS

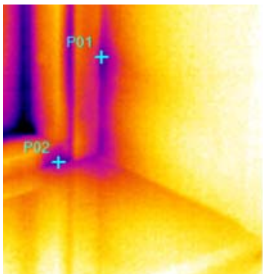
- Main objective passiv houses
- Example projects
- Consultancy
- Workshops / courses
- Approx. 100 projects per year

CONTROL OBJECTS

1. Stiklestadveien (2008), approx 10.000 sqm
2. Professor Brochsgate 2 (2009), approx 12.500 sqm
3. Sluppen Eiendom (1960), approx. 2.500 sqm

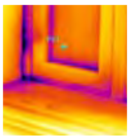
EXECUTION OF TESTS

- Air pressure testing according to NS EN-ISO 13829
- Infrared investigation according to NS-EN ISO 13187
- Tests by using of “blower door”
- Tests by using the building its own ventilationsystem

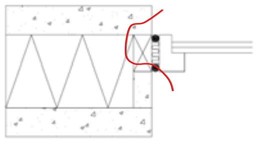


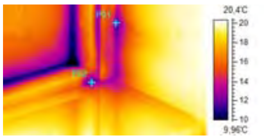
CASE 1 – OFFICE BUILDING AT STIKLESTADVEIEN

- Concrete sandwich construction
- Complains about draft from the windows
- No previous test executed
- Air-leakage approx 1.0 (h-1)
- Local air velocity between 1.5 – 3.0 (m/s)


CASE 1 - OFFICE BUILDING AT STIKLESTADVEIEN



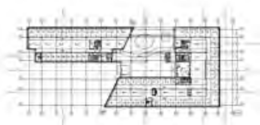


CASE 2 – OFFICE BUILDING AT PROFESSOR BROCHSGATE 2 (2009)

CASE 2 – OFFICE BUILDING AT PROFESSOR BROCHSGATE 2 (2009)

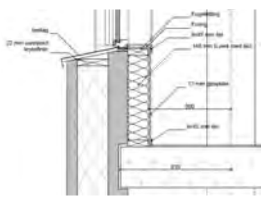
- concrete sandwich construction
- Timber insulated walls

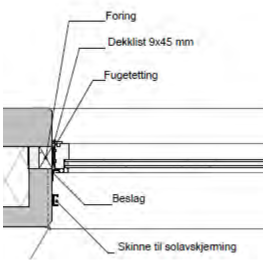
- Control to verify the quality
- 2 minor tests / 1 large test of the entire building
- Air-leakage 0.6 / 0.4 (h-1)



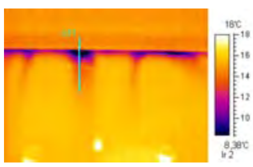
CASE 2 – OFFICE BUILDING AT PROFESSOR BROCHSGATE 2 (2009)

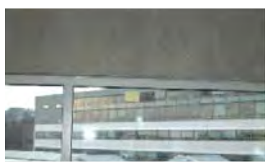
CASE 2 – OFFICE BUILDING AT PROFESSOR BROCHSGATE 2 (2009)





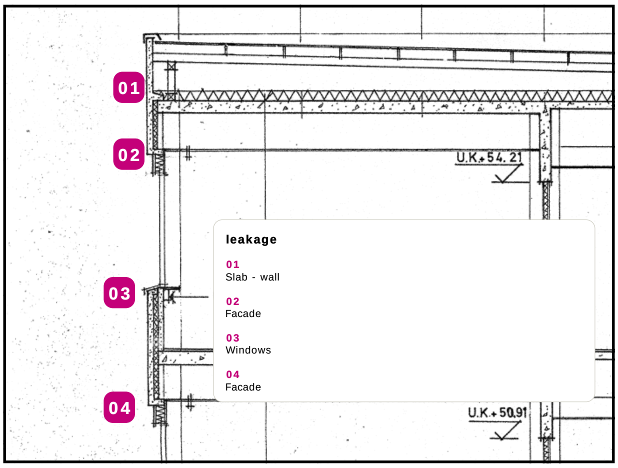
CASE 2 – OFFICE BUILDING AT PROFESSOR BROCHSGATE 2 (2009)



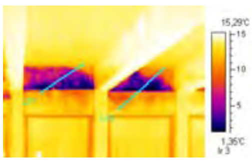


CASE 3 – SLUPPEN EIENDOM (1960)

- Concrete sandwich construction
- Complains about draft from the windows, cold air
- No previous tests executed
- Air-leakage reduced from 5.0 – 0.9 (h-1)
- Reduced yearly heattransmission with approx. 103.000 kWh/yr (1st. Phase)



CASE 3 - SLUPPEN EIENDOM (1960)



CONCLUSION

- Tests have shown a good air-tightness of the buildings envelop of concrete constructions
- Minor errors of air-leakage in the concrete elements
- More focus on the connections and details to the surrounding elements
- There is need to develop good details which can be used by architects, engineers and contractors.

THANK YOU

13 Thermo Active Building Systems (TABS) in Concrete Slabs

Thermo Active Building Systems (TABS) in Concrete Slabs

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THERMO ACTIVE BUILDING SYSTEMS (TABS) IN CONCRETE SLABS

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1 Introduction

Both new and existing buildings to be retrofitted can use Thermo Active Buildings Systems (TABS), which basically is structures with embedded plastic pipes used for heating in and cooling purposes.

The difference between passive and active building systems is that in TABS the heat is transferred in and out of the structure through the surface but also internally by the embedded tubes as an active system also called core activation. The activation can be used at times of the day where it fits the supply system, which can be off-set of the load profile of the room served.

The temperature difference between the room temperature and the temperature in the TABS is only a few degrees.

It must be noted that TABS are regulation slowly in respect to fast changes in the room loads. To compensate, it is normal to supplement with additional convectors or coils to cover for fast changes and individual demands in some zones.

In new buildings, prefab concrete elements with plastic hoses embedded in the ceiling side of the element, can be used (e.g. Spæncom - Consolis hollow core slabs type TermoMax). In-situ solutions such as Stramax systems can be used in existing buildings, where the embedded pipes are mounted and covered by plaster on the existing ceiling of the participation slab.

As the concrete core is activated, the full thermal capacity of the thermal mass can be utilized, which is optimal to ensure a stable indoor climate. At the same time the peak load demand is reduced as the structure it self is a heating and cooling storage.

TABS will in principle work as radiant heating during winter and as a cooling ceiling during summer. The typical design temperatures of the working fluids are the following:

- Low temperature heating: 30-25ºC with design temperature difference of 4^{o}C
- Cooling: 15-20ºC with a design temperature difference of 3^{o}C

With these small temperature differences between the water in the hoses of the ceiling and the room air, the heating and cooling flux will be nearly self controlled. For example if the temperature difference is 5 degrees during normal cooling and the room temperature rises with one degree, then the cooling capacity increases with 16%.

At the same time a stable indoor climate can be ensured even if heating or cooling is supplied offset e.g. at times of the day where the energy is cheaper.

A pre-condition for optimal use of thermal storage is that a slight temperature drift of the room temperature is allowed over the day. This drift will normally not exceed the 0.6^{o}C per hour which research has shown is generally accepted.

The standard for categorisation og indoor climate DS/EN 15 251, allows the following temperature drift during operation time from 9-17 hours in the summer season at 0.5 clo and 1.2 met:

Class I: PPD 6%; 23.5 - 25.5^{o}C
Class II: PPD 10%; 23 - 26^{o}C
Class III: PPD 15%; 22 - 27^{o}C

TABS can full fill Class I most of the time and Class II during peak periods. Class II is general accepted for office buildings.
The low operating temperatures enables optimal utilization of heat pumps (high COP) for heating. Similarly the operating temperatures allows for free cooling i.e. with out use of cooling compressors.
TABS with the given fluid temperatures will typically be able to cover a heating and cooling load of 30-40 W/m^2 active area, which is sufficient for most new and energy renovated refurbished buildings.
Prefab TABS are used several places e.g. in the Netherlands. In Denmark it is used e.g. in the new head quarters of the bank Middelfart Sparekasse in Middelfart and in TT slabs of Habour house.
In-situ cast TABS are widely used in central Europe over the last decade e.g. in Germany. An interesting Danish reference building for in-situ TABS is the new Royal Playhouse Theatre in Copenhagen.
The presentation will give examples from these buildings.

2 Benefits and Barriers

Thermo Active Buildings Slabs have the following benefits and barriers:

<u>Benefits:</u>

- Stabilize the indoor thermal environment.
- Function as an active heating-/ cold storage which reduce the peak load demand by about 30%.
- Simple and partly self controlling system.
- Enable heating at low temperatures i.e. 22-30^oC and cooling at high temperatures 15-20^oC - which is optimal for the supply system (high COP on heat-pump/cooling machines, possibilities for free cooling, use of low temperature waste heat and integration of renewable energy such as solar energy).
- Can basically cover the heating and cooling needs in office areas and can easily be combined with cooling baffles to cover peak loads in meeting rooms.
- Reduce demand for ventilation air changes (as ventilation only has to ensure the atmospheric indoor climate).
- TABS function well together with hybrid ventilation concepts (e.g. in Green Lighhouse passive house office building in Copenhagen).
- Reduce need for mechanical cooling compressors.
- Reduce energy consumption and thereby CO_2-emissions.

<u>Barriers to be considered:</u>

- Slow response on changed heating loads due to the thermal inertia, i.e. must be combined with supplementary heating sources for fast fine control.
- TABS must to a certain level be in open connection with the room that it serves, i.e. suspended acoustic ceilings must have openings to ensure the air movement.
- Less acoustic ceiling area must be compensated e.g. by corner absorbents or use of wall surfaces.
- Possibilities to overcome these barriers will be discussed at the COIN workshop in Oslo 26-27 Jan 2010.

3 Total economy

It is COWI's experience that use of TABS will result in reductions in construction cost for ventilation and cooling, which is equal or above the extra cost of the TABS.
Besides saving in construction costs, the use of TABS will result in savings in operation and maintenance compared with traditional systems. The savings depend on the total energy supply concept and the reference compared with. Under Danish condition the energy used

for cooling can be reduced by typically 80% compared with mechanical cooling in a traditional 6/12^{o}C cooling system re: Danish reference year, as free cooling is possible during night using TABS.

4 Conclusions

Ideally cooling need should be avoided, but in practice increasing loads from persons and IT together with climate change and better insulation of buildings in-force a need for cooling; which should be provided as far as possible by natural sources, e.g. as by using free cooling with air, geo-exchange or groundwater. As TABS work at temperatures close to the room temperature, they are well suited for utilization of these natural cooling sources.

It is therefore recommended to use TABS in office buildings and institutions which have a cooling need. For more than a decade TABS are now widely used in Europe from Spain to Sweden with most references in Switzerland, Austria, Germany, Holland, Denmark. Several buildings report good results e.g. the Festo building in Germany and Bregenz Art Museum in Austria to mention a few.

In Denmark prefab concrete elements called TermoMax have been developed and tested in full-scale. This is well suited for new commercial buildings. For retrofit solutions, capillary tubes mats embedded in surface plaster is another TABS variant, which is known from several installations abroad especially in Germany (where floor carpets frequently are used in stead acoustic ceilings).

Use of TABS is a starting point for development of many interesting energy concepts with integration of natural and renewable energy sources.

TABS reduce the construction costs, ensure a good thermal environment, function as an efficient thermal buffer and reduce the operation costs.

COIN workshop

Thermo Active Building Systems (TABS) in concrete slabs

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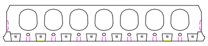
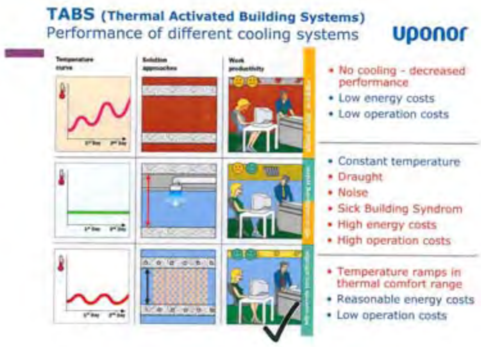
COWI - see www.cowi.com
6000 employees working world wide

Thermal Activated Building Systems

PSO ELFOR project 335-20
Indoor comfort and load levelling with energy efficient cooling with TABS

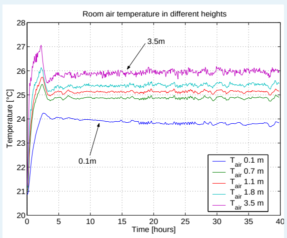


- TABS are building structures with cast in tubes for heating and cooling
- Heating at 25-30ºC warm water
- Cooling with 15-20ºC chilled water
- TABS is a key to efficient use of heat pumps, free cooling and heat recovery e.g. from server rooms
- More room height => better daylight utilisation
- Functions well with hybrid ventilation
- Savings in electricity consumption in relation to ventilation and cooling

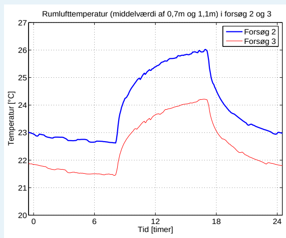


Full scale mock-up of 22 m² for test and verification of modelling

Examples of measured conditions

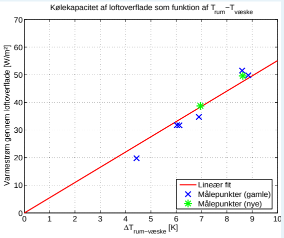


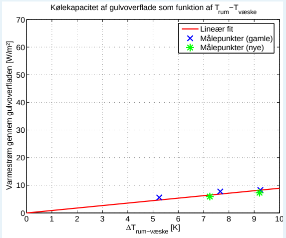
Stationary at 60 W/m² flow temp 15ºC



Dynamic 40/5 W/m² flow 20ºC only upper slap

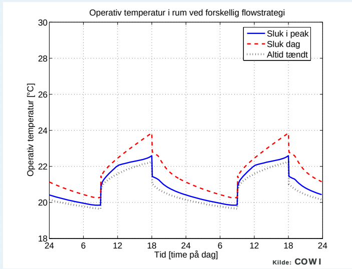
Results of stationary tests





Total capacity 6,4 W/m²K

TABS => good comfort and new possibilities for energy storage and new operation strategies



DS/EN 15 251 Standard for categorisation of indoor climate

Class I: PPD 6% 23,5 - 25,5ºC

Class II: PPD 10% 23 - 26ºC

Class III: PPD 15% 22 - 27ºC

Occupation time 9-17

0,5 clo

1,2 met

0,6ºC/h temperature drift

DS 474 specification of indoor climate

100 h > 26ºC

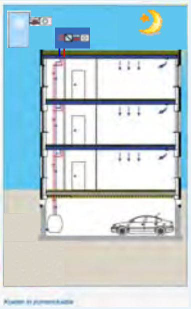
25 h > 27ºC

Free cooling during night possibly supplemented with a heat pump / cooling machine

Hverdage 23-08

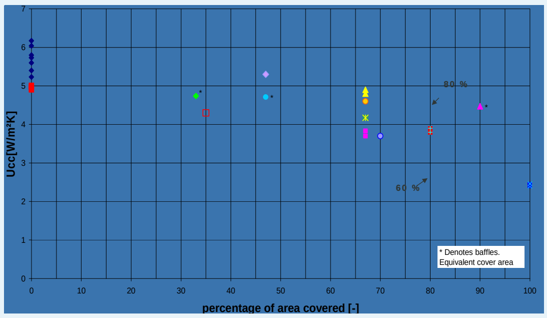
	Timer over 20°	19°	18°	17°	16°	15°	Timer i alt
Jan	0	0	0	0	0	0	207
Feb	0	0	0	0	0	0	180
Mar	0	0	0	0	0	0	189
Apr	0	0	0	0	0	0	198
Maj	0	0	0	0	0	5	207
Jun	0	1	5	6	19	30	180
Jul	1	3	7	20	36	50	207
Aug	0	5	12	23	28	54	198
Sep	0	0	0	2	3	10	189
Okt	0	0	0	0	0	0	207
Nov	0	0	0	0	0	0	189
Dec	0	0	0	0	0	0	198

Source: Danish Thermal reference year

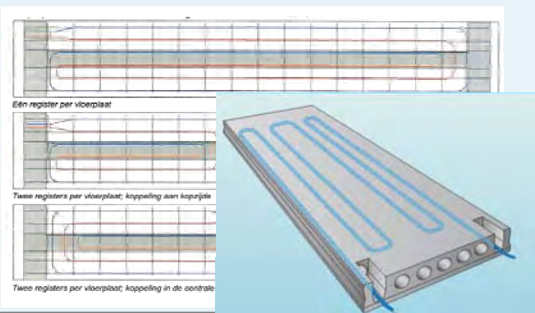


Mechanical cooling first used if room temperature at the end of the reaches > 25,5 C

Effect of suspended ceilings of various designs



PSO project led to TermoMax product which is available with different pipe lay-outs



Many references

- **References**
  - Many buildings e.g. in Germany, Austria, Switzerland, since 1998 e.g.
  - D: FESTO building, in situ
  - S: Kv. Katsan Stockholm, TT
  - DK: Habour house, TT
  - DK: DR Segm. 4, Stramax
  - DK: New playhouse , floor slabs
  - DK: Middelfart Bank, TermoMax
  - DK: House of Science, Bjerringbro
  - DK:Viborg Townhall, floor slabs
  - DK: Green Lighthouse, floor slabs

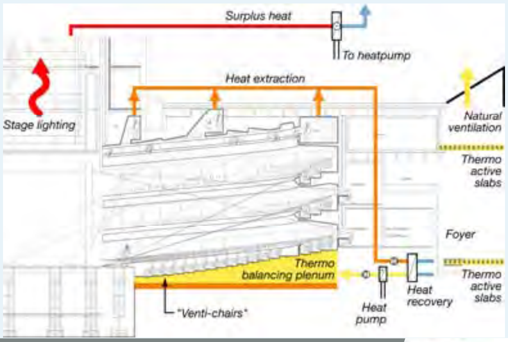
Other references

- Informations Center, Winthertur, Schweiz, 3300 m²
- PAGO fabrik i Grabs, Schweiz
- Ivoclar AG, Schan-Liechtenstein 2430 m²
- Bregenz Arts Centre, Austria, 3750 m²
- Allianz-Kai, Frankfurt, 40.000 m²
- ABC-Bogen, Hamburg, 7.500 m²
- DVG Data, Hanover, 24.000 m²
- Europa centrale, München 15.500 m²
- Berliner Bogen, 18.000 m²
- Mercedes-Welt, Berlin 7.000 m²
- Norddeutsche Landesbank, Hannover, 72.000 m²
- Geiger 2000, Oberstdorf, 1200 m²
- Cenifer Training Centre; Pamplona
- Daimler-Chrysler Building, Brussels
- Gardermoen Airport, Oslo
- Bangkok Airport
- Muscat airport, Oman
- Canal Museum, Beijing

Some Danish examples
New playhouse theatre in Copenhagen

Lundgaard & Tranberg architects Foto: Jens Lindhe

Utilisation of surplus heat from audience and stage lighting



Energy storage in TABS

Extra investment for energy concept 9,6 mio. kr.

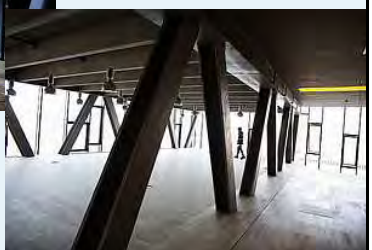
~ 2 %

PB 8.7 years

Distribution pipes in floor of corridors

TABS at playhouse theatre

Foto: Jens Lindhe



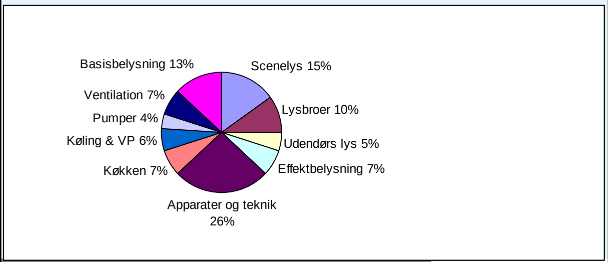
Supported by 85 m cantilever beam

Heat consumption, playhouse theatre 1/5 2008 - 1/5 2009

- Space heating 51 kWh/m² p.a.
- Hot water and pipe losses 7 kWh/m² p.a.
- Total 58 kWh/m² p.a.
- Goal was 75 kWh/m² p.a., i.e. OK
- (Oslo opera 113 kWh/m² p.a. also part of the EC ECO-Culture project)

Power consumption, playhouse theatre 2009

- Power consumption 105 kWh/m² hereof 30% for building operation (Oslo opera 159 kWh/m²)
- Further optimisation ongoing

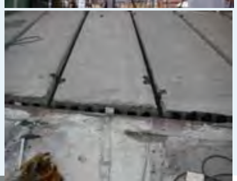


Full scale demonstration, evaluation of TABS at Middelfart Sparekasse PSO project 338-041

- Test of capacity and control strategies (40 W/m² cooling and 30 W/m² heating)
- Subjective evaluation of comfort by user groups in old and new building.

3XN architects

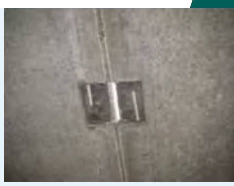
Construction



Jorton A/S

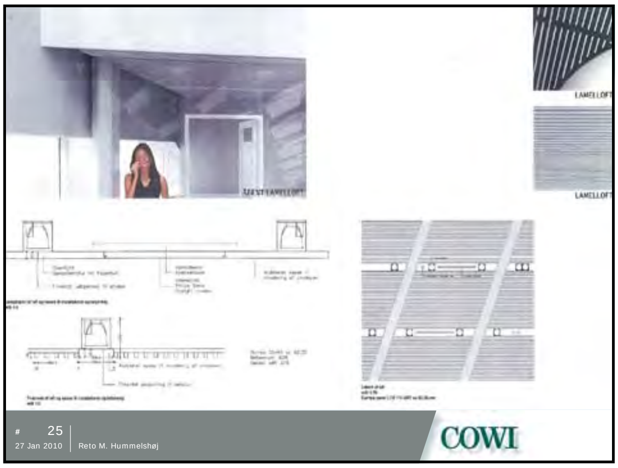
TermoMax as normal construction with SpanMax hollow core elements.

Installation



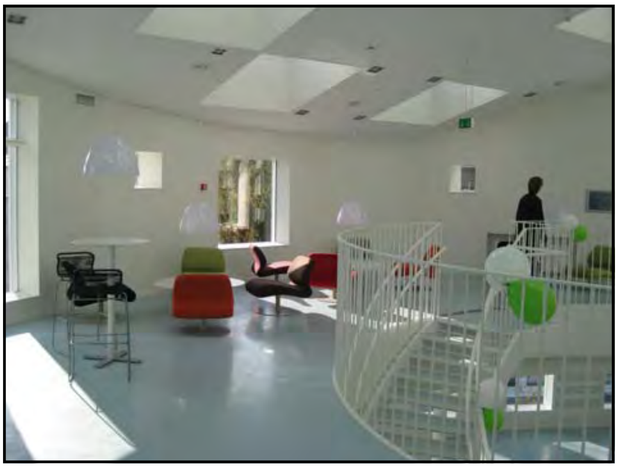
Mikkelsen og Andersen VVS

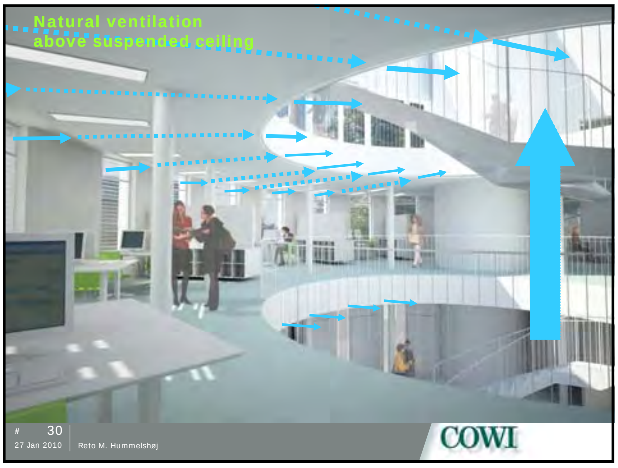
Easy solution with flex hoses gave no problems


25
27 Jan 2010
Reto M. Hummelshøj
COWI


Other designs
26
27 Jan 2010
Reto M. Hummelshøj
COWI


Green Lighthouse - office to Passive House standard
23 kWh/m2 primary energy consumption (heat and power)
27
27 Jan 2010
CCO Architects
Reto M. Hummelshøj
COWI

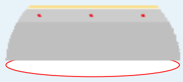



Natural ventilation
above suspended ceiling
30
27 Jan 2010
Reto M. Hummelshøj
COWI

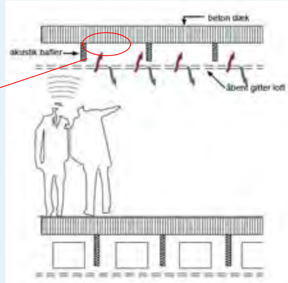
Viborg Townhall 12000 m² now under construction

TABS at Viborg Townhall

Exposed concrete combined with acoustic control



- Floor
- Cladding with cast-in tubes
- PX22 element
- Grid ceiling



Challenges

- Uncertainties / conservatism in the building sector
- Building methods - in-situ / elements – suspended ceilings
- Slow control – best together with small additional heaters
- Energy savings depends on allowable temperature drift
- Precautions necessary when drilling

Concrete Low Energy Buildings in Cold Climate

Clara Good[1]*, Tobias Boström*[1]*, Ove-H Lorentzen*[2]*, Bård Arntsen*[1]

[1]*Norut Narvik AS, Norway*
[2]*Betong & Entreprenørsenteret, Norway*

Concrete Low Energy Buildings in Cold Climate

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Introduction

The interest in passive and low energy buildings in Norway has increased significantly in the last years and there has been an increasing number of building projects started throughout the country. However, few of these are being built in cold climates. Building in colder regions increases the demands on the design, choice of materials, control systems and other technological solutions. However, since the energy use in these regions is high there is also much to gain from building energy efficiently.

Presented here is a research project with the objective of developing technologies for concrete low energy buildings in cold climate. The work is done is close cooperation with industry, and also with institutions in other Nordic countries. One of the results of the project will be a pilot building in the Lofoten-Ofoten region.

Narvik – a center for cold climate research

Norut Narvik and Narvik University College (NUC) have over 20 years of experience in working with cold climate technology, and it is a special focus area for Norut Narvik. Together the two institutions are joined in the Cold Climate Technology Research Center (CCTRC). The objective of the center is to work close to industry in developing solutions for structures, infrastructure and operations in cold climate.

Both the competence and the facilities at Norut and NUC will be of importance to the project work. The resources in the cold climate laboratory includes insulated and connectable climate chambers with regulated temperatures, thermography equipment as well as various snow, ice and frost sensors.

Cross-border cooperation

An important feature of the project is the connection between research and industry. The project was started as regional cooperation between Betong & Entreprenørsenteret (B&E) in Kabelvåg, Lofoten, and Norut Narvik research institute in Narvik. The project group was soon extended internationally, and now involves Luleå University of Technology, Umeå University in Sweden and Oulu University of applied Sciences in Finland. As the Swedish partners are concerned with wooden houses, it will be a useful arena for exchange of ideas and experiences. Industry partners in all three countries are also involved, which gives an opportunity to test and develop new products in practice. In Norway, Norcem is a partner in the project.

Precast concrete – ideal for energy efficiency

Concrete has several well-known qualities that make it an ideal material for energy efficient houses.

- The thermal qualities make it possible to use concrete structures at heat storage and temperature leveler.
- Concrete is an effective air and moisture barrier. An air tight building envelope with effective heat recovery minimizes the need to supply energy to the building.
- The long lifetime of concrete structures makes it a good choice since the major part of the energy use of a building is during its occupancy.

B&E-senteret is specialized in precast concrete element construction, using insulated sandwich elements. This method has some additional qualities beneficial for energy efficiency. The prefabricated concrete elements are cast together on the building site which gives very good air tightness. As the wall and floor elements and insulation are overlapping it also results in a minimum of thermal bridges. On-site casting also gives large freedom in building design and possibilities for adjustments during the construction phase. Additionally, concrete gives protection from fire and mould.

Project structure

The project is divided into four parts, from theory to practice.

1. Measurements of air tightness and heat distribution

These measurements will be performed on existing buildings, as well as in laboratory setups. In the international cooperation, the measured buildings will be distributed over the whole project area and will thus cover both the coastal and inland regions in the three countries.

2. Simulation and design proposals

The results from the measurements will be used in development of prototypes and test designs. The energy performance will be simulated in for example EnergyPlus/Designbuilder.

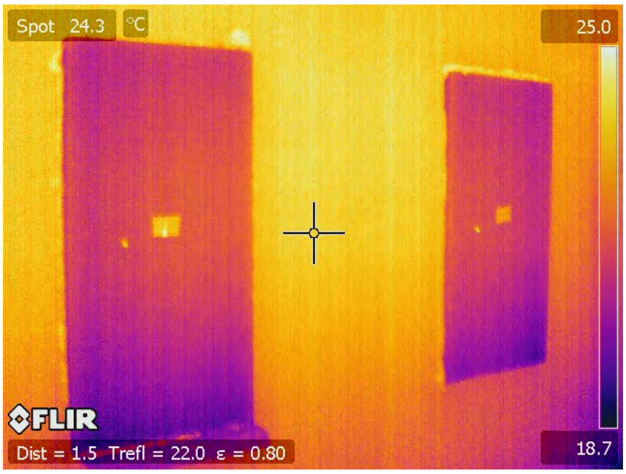
3. Construction

A project team with representatives from research, construction, HVAC and architecture will work together in the development of a pilot building. The focus will be on optimal use of concrete, control of ventilation and heat recovery and the use of local energy sources.

4. Monitoring and verification

The pilot building will be equipped with sensors for follow-up monitoring and verification of the results. This will be an important source of information for coming projects.

Preparatory test are being performed in the climate labs. Different concrete element configurations have been tested evaluate the performance in cold climate. The image shows a setup to study how the lattice girders in sandwich elements influence the heat conduction through the elements. The results from the study will be used in the work to minimize thermal bridges.



Two elements studied by IR thermography to investigate the influence of lattice girders on heat conduction.

Energy for a cold climate

The sun is an important source of heat and energy for low energy and passive houses. For locations far north the available energy from the sun will vary significantly over the year, making the use of solar energy more complicated.

Solar heating can be used for domestic hot water and heating of the building mass. Additionally, photovoltaic modules can be mounted on the roof to yield electricity. Narvik is situated north of the Arctic Circle and has approximately six weeks of polar night and six weeks of midnight sun and this makes the use of solar heating for hot water more challenging. Solar heating can supply domestic hot water in the summer, but in the wintertime other methods will have to be used. Heat storage in the ground in combination with an earth-to-air heat pump is one method that will be investigated. If several buildings are connected, more solar collectors can be installed and shared inter-seasonal heat storage in the ground is an alternative.

The use of renewable energy sources and their adaptation to the local conditions will be studied in the project. Aside from solar energy for example biomass, wind, and seawater heating will be of interest to the project. The regulation and control of these different energy sources, including heat emitted from people and equipment is another challenge. It is an area that will be further studied during the work.

15 Conclusion

Group discussions

The group discussions focused on the possibilities and challenges for the different materials and constructions to contribute to the construction of Passive House or Zero Emission Building. The discussions resulted in commentaries and questions. Those are summed up by topic below.

PCM

- Vulnerable with respect to design (temperature, user behaviour)
- Useful in office buildings etc, that requires cooling, and do not have enough exposed concrete surfaces
- Avoid breakage of micronal PCM – effect the strength of concrete + indoor environment
- Challenge? Emissions from PCM or from the combination of PCM and concrete? Indoor environmental classification?
- Control of indoor environment according to the Norwegian requirements (minimum allowed airflow is partly depending on the emissions from the materials / surfaces / furniture)
- The combination of concrete and PCM could be disadvantageous for the utilisation of the concrete's thermal mass. The PCM will first start to store heat from the room and it is not certain that the concrete's thermal mass will have time to be useful.
- If both concrete and PCM manage to react, it will be necessary to "purge" the stored heat by night. Is it possible to do so without using ventilation or cooling energy (much higher energy demand than the one required when using concrete alone)?
- Possibility to combine PCM with metal to compensate for the low thermal conductivity of organic PCM?
- Possibility to combine PCM with porous concrete to obtain a material with good acoustical and thermal qualities?
- PCM may be able to reduce subsequently the peak load for heating, and then the size of the heating installation(s).
- Do the combination PCM + concrete has a lower or higher surface temperature than fair-faced concrete? Is it possible to obtain lower surface temperature, which means lower operative temperature (better thermal comfort summertime)?
- PCM from paraffin (oil-based). This is not a sustainable material?

VIP

- Vulnerability: Check if foil is concrete resistance (alkali resistant?)
- Sandwich element: protected but not easy to disassemble and replace
- Renovation of concrete buildings: Exterior insulation keeping exposed concrete on the inside.
- Short term: Improve stability + vulnerability + possibility of replacement
- Long term: improve workability on site: VIM
- Potential study to investigate use in renovation of concrete buildings + special applications in new buildings (terraces, thermal bridges)
- Sandwich element: will primary be used for walls, analyse the possibility of prefabrication and industrialization of the production, seems doable in the near future
- Refurbishment: Possibility to insulate thermal bridges

NIM + concrete mixture

- Conform element with porous concrete
- Follow what is happening in Zeb

- Seems far away (to far away for COIN?)

Polybetong

- + Light weight
- +/- In the middle on thermal capacity and thermal insulation – need better performance on both
- Strength?
- The production is not homogenous (depending on the expanded polystyrene that is collected)
- The material is homogenous. Possibility to use only one material for the façade? Thermal bridges are then reduced.
- Thermal conductivity is too high to reach Passive House standard without an enormous thickness. Possibility to make a sculpture out of the façade?
- Polybetong: will primary be used for ground floors, perhaps for horizontal roofs, in combination with mineral wool?

Small houses – concrete vs wood

- Concrete and wood, use concrete where it is gives special advantages (strength, thermal mass, fire, etc)
- Challenge: how to combine concrete with other materials? Detailing
- Small buildings in concrete? Where thermal mass is needed. Systemhus – passive house with concrete wall.
- Future competitor: wood with PCM?
- Visual comfort and ”feeling” of concrete versus wood? Cultural thing in Norway
- Traditional wood architecture in Norway for small buildings
- Concrete is an expensive material for small buildings, if it is used it should have at least 2 functions (bearing + thermal mass)
- Concrete should preferably be used for the inner construction, not in the façade
- Possibility to combine concrete and passive solar design

Large buildings

- Concrete most useful to reduce cooling demand, need good control systems.
- How to treat flexibility, change of use. Combine with dynamic PCM to get changes when needed. *DynaCon*!
- TABs – cost effectiveness when you have very small heating and cooling needs? May then be more cost-efficient to heat/cool just by ventilation air?
- TABs can stop when they are not needed (ventilation air has to be carried to the room when it is occupied)
- Need good (easy to use, user friendly) performance prediction tools that can predict comfort conditions with varying exterior and internal gains.
- Need good control systems
- Dynamic concrete surface – control the emissivity of the surface.
- Contact between concrete and insulation: achieved with metal nowadays, possibility to use composite materials instead of metal?

Conclusion - Research Agenda

The group discussions concluded with a research agenda that COIN should pursue. The research agenda is described below, first as a complete list of topics of interest, with questions and commentaries. The research activities are then sorted out by theme and by research need (short-term or long-term research).

- Atlas of good construction details (how to minimize thermal bridges? How to obtain low air tightness? How to reach low energy / Passive House standard?)
- Control system for thermal mass
- Embodied energy: more environmental friendly cement/concrete production, first reduce/eliminate CO2-emission, secondary capture/store carbon
- High insulating concrete with good thermal mass properties
- PCM: COIN cooperate with DTI project, calculation of potential energy reduction in buildings, compare with measurements in pilot buildings.
- COIN cooperate with ZEB, development of new materials
- Possibility to reduce the ventilation airflows? Comparison of fair-faced concrete + night ventilation with thermal active building system?
- Survey on air-tightness in buildings with concrete façade (prefabricated façade elements)/ concrete modules (bathroom). Is it sure that a building will achieve a better air-tightness with concrete façade elements (what about the joints and transitions)? Is it easier to predict the final air-tightness of the building? SBI has published a report on this topic.
- Dissemination of our knowledge (details, thermal bridges, failures)
- Emissions to the indoor air. Comparison of to concepts: concrete (one material) + gypsum boards versus wood + glue + paint + gypsum board.
- Ground heat exchangers in concrete: how should they be built to ensure a long service time without fungi and moisture problems?
- Compare wood+pcm houses to ”concrete” houses with respect to life cycle environmental impacts (calculation tool)
- compare air tightness details of wood versus concrete constructions
- Improve insulation properties without too thick walls

<u>Research Agenda by theme</u>

Theme that influences the energy balance	**Research activity**
Thermal insulation of the materials	• High insulating concrete with good thermal mass properties “NanoCon”, start a cooperation with ZEB
Thermal insulation of the constructions	• Test the alkali resistivity of VIP’s foil • Sandwich element concrete + VIP: analysis of the possibility of prefabrication and industrialization of the production
Minimize thermal bridges	• Atlas of good construction details
Ensure low air tightness of the building envelope	• Atlas of good construction details • Survey on air-tightness in buildings with concrete façade
Reduction of ventilation airflows	• Control systems for thermal mass utilisation • Comparison fair-faced concrete versus TABS • Emissions to the indoor air from fair-faced concrete, fair-faced concrete + lim+

	linoleum
Reduction of cooling demand	• Control systems for thermal mass utilisation • PCM, cooperation with DTI • Guidelines for the design of ground heat exchangers in concrete
Zero Emission Building	• Calculation of embodied energy • Calculation tool for comparison of wood houses versus concrete houses with respect to life cycle environmental impacts, cooperation with Consensus

<u>Research Agenda by research need</u>

Term	Short term	Near future	Long term
Activity	• Atlas of good construction details • Guidelines for control systems for thermal mass utilisation • Guidelines for the design of TABS • Guidelines for the design of ground heat exchangers in concrete • Calculation of embodied energy in concrete buildings • Survey on air-tightness in buildings with concrete façade • Measurement of emissions to the indoor air from fair-faced concrete and the combination fair-faced concrete + glue + linoleum	• PCM, cooperation with DTI • Test the alkali resistivity of VIP's foil • Sandwich element concrete + VIP: analysis of the possibility of prefabrication and industrialization of the production • Calculation tool for comparison of wood buildings versus concrete buildings with respect to life cycle environmental impacts, cooperation with Consensus	• High insulating concrete with good thermal mass properties "NanoCon", start a cooperation with ZEB

SINTEF Building and Infrastructure is the third largest building research institute in Europe. Our objective is to promote environmentally friendly, cost-effective products and solutions within the built environment. SINTEF Building and Infrastructure is Norway's leading provider of research-based knowledge to the construction sector. Through our activity in research and development, we have established a unique platform for disseminating knowledge throughout a large part of the construction industry.

COIN – Concrete Innovation Center is a Center for Research based Innovation (CRI) initiated by the Research Council of Norway. The vision of COIN is creation of more attractive concrete buildings and constructions. The primary goal is to fulfill this vision by bringing the development a major leap forward by long-term research in close alliances with the industry regarding advanced materials, efficient construction techniques and new design concepts combined with more environmentally friendly material production.