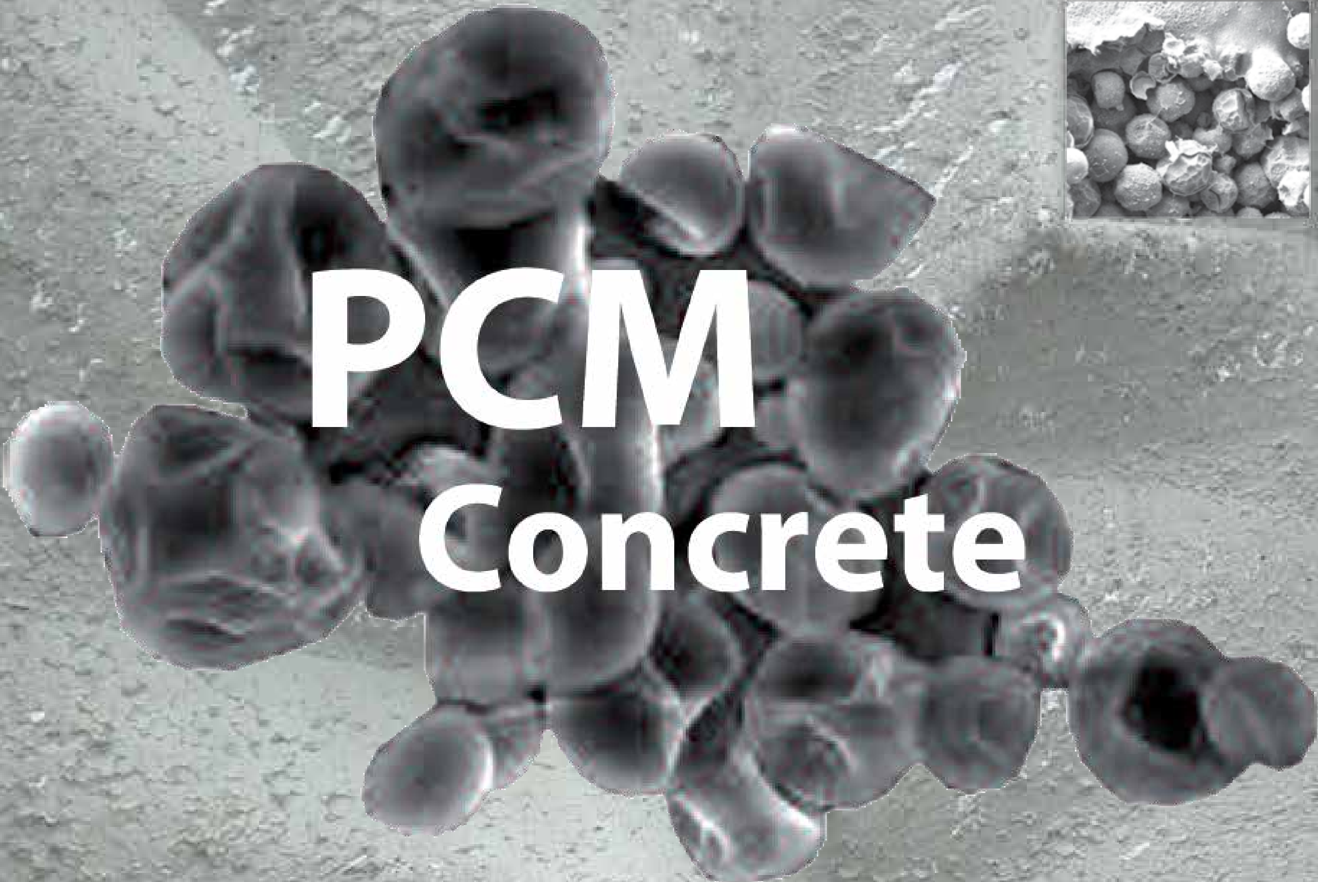
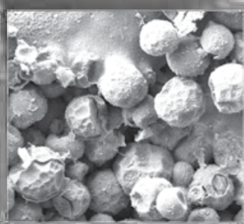
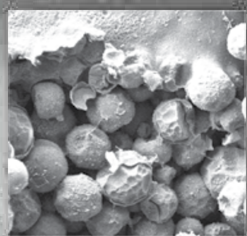
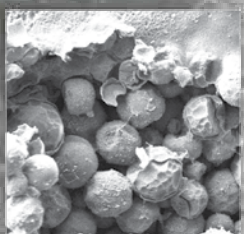
PCM Concrete









Selected activities and results from the project:
PCM-Concrete – New Energy Efficient Concrete Prepared for Industrialized Production

INTRODUCTION

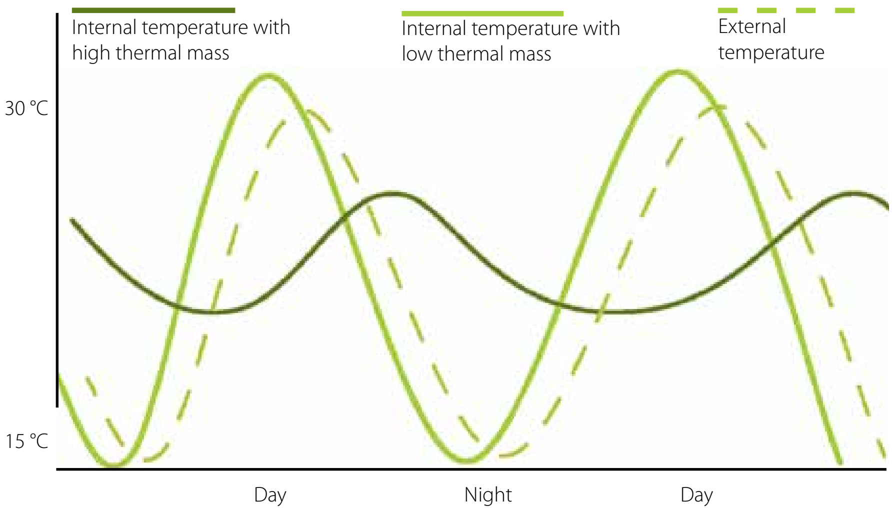
PCM-Concrete was a research and development project launched in 2009 and finished in 2012. The project, which was funded by The Danish National Advanced Technology Foundation, had a total budget of 1.7 million Euros and included 4 partners: Danish Technological Institute (project manager), Aalborg University, BASF A/S and Spæncom A/S. The overall vision of the project was to reduce energy consumption for heating and cooling in buildings by developing high-performance concrete structures micro-encapsulated Phase Change Materials (PCM). This brochure presents selected activities and results from the research project.

PCMs are able to absorb, store and release heat at almost a constant temperature. This active temperature compensation mechanism enables construction materials, which have been modified by means of PCM, to contribute to perfect room conditions by reducing the peak temperatures in a room and thus resulting in a better indoor climate and less energy consumption for cooling and heating. The PCM used in the project was Micronal® produced by BASF A/S. Micronal® is small capsules with an acrylic shell and inside a wax with a melting point at approx. 23°C equal to a comfortable indoor temperature. During the melting process thermal energy is transferred to chemical reaction (melting/solidification) depending on PCM being heated up or cooled down.

Adding Micronal® to concrete would theoretically increase the thermal mass of the concrete and improve the diurnal heat capacity which is the amount of energy that can be stored and released during 24 hours. Nevertheless, it is a relatively new technology that has not received much attention, yet. In the PCM-Concrete project 5 main investigations were carried out:

- Development of concrete mix design with PCM
- Investigation of thermal properties of the PCM concrete: thermal conductivity, specific heat capacity, density
- Up-scaling the research to industrial production of PCM-concrete structures
- Testing energy efficiency in full scale
- Confronting aesthetic and acoustic barriers to full exploitation of the potential of PCM-concrete structures.

Adding Micronal® - a type of Phase Changing Materials consisting of small capsules with paraffin - to concrete would theoretically increase the thermal mass.



Stabilising effect of thermal mass on internal temperature.

PCM-Concrete facts:

Funded by:
The Danish National Advanced Technology Foundation

Total budget:
1,7 million €

Partners:
Danish Technological Institute
Aalborg University
BASF A/S
Spæncom A/S

ADDING PCM TO CONCRETE

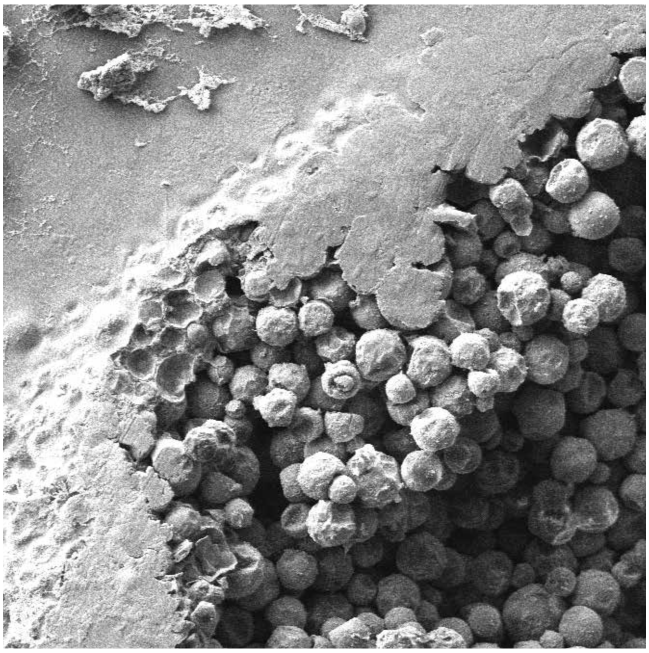
Adding small Micronal® PCM-capsules to the concrete affects the workability significantly. Without the use of dispersants the concrete is stiff and "sticky" and hardly workable. Thus in the PCM-concrete project development of a suitable concrete mix design has been carried out. Special focus has been on finding the optimum amount and most suitable type of:

- Cement
- PCM
- Aggregate
- Superplastisizer - to ensure acceptable workability
- Defoamer - to reduce the air content of the concrete
- Water

This has led to a final mix design of PCM-mortar – which was found to give an acceptable fresh state workability – with 7,5% Micronal® (in powdered form, on weight basis), corresponding to approx. 15% (on volume basis). With higher levels of added PCM the mortar loose workability despite of the high level of added super plasticizer.

The concrete gets "sticky" and loose workability when PCM is added. This puts a limit on the amount of PCM which can be added.

In order to ensure that the PCM-capsules are suitable for concrete production tests on both mechanical and chemical resistance have been carried out. SEM investigations indicated that the PCM-capsules were not affected by the alkaline environment in concrete. Shear forces from the concrete mixing process mostly deform the PCM-capsules instead of breaking them.



Cryo-SEM picture of PCM-capsules in mortar. Section size approx. 75x75 µm.

The following constituents for PCM-mortar is found to give an acceptable fresh state workability when adding up to 7,5 weight% Micronal® (figures in kg/m3):

- 330 kg CEM I 52.5 (cement)
- 142 kg Micronal® (PCM)
- 1190 kg Nørhalne 0/2 pit sand (aggregate)
- 38 kg Glenium (superplasticizer)
- 1 kg Tego Foamex 1488 (defoamer)
- 200 kg water

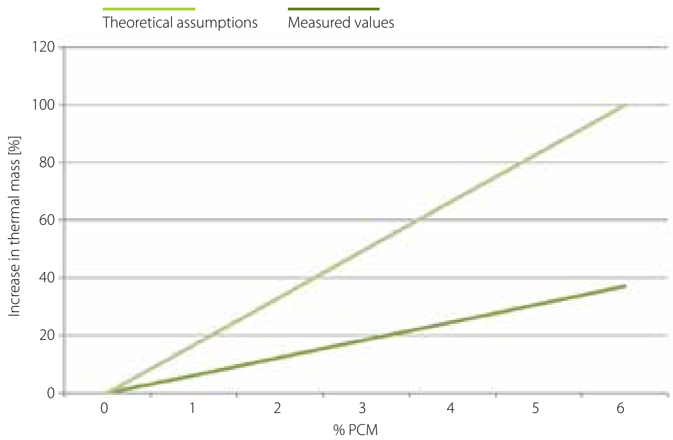
TECHNICAL PROPERTIES - THEORY CHALLENGING THE RESULTS

In order to investigate whether the theoretical energy performance of pcm-concrete corresponds to the actual performance, thermal properties of the PCM-concrete have been experimentally investigated. The performance is determined by the diurnal heat storage capacity, which is affected by:

- Specific heat capacity – how much heat can be stored per kg. of the material
- Density – weight of the material per m3
- Thermal conductivity – how well heat can be conducted in the material
- Surface heat transfer – how well heat can be transferred from air to material.

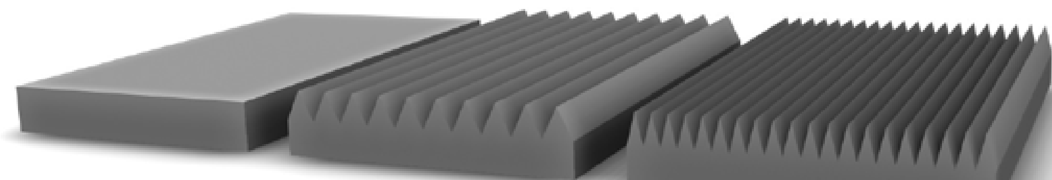
In order to determine the actual thermal properties for typical indoor temperature diurnal cycle of PCM-concrete, several measurements on PCM-concrete samples using advanced hot-plate apparatus have been performed. Based on initial assumptions regarding thermal properties of PCM-concrete, the increase of thermal mass was expected about 67% when adding 4% PCM to the concrete, and 100% with 6% PCM. However, with corrected values from the hot-plate measurements of specific heat capacity, the increase in thermal mass using 4% PCM was calculated to 30%, and for 6% PCM to 37% increase when taking temperature intervals from 20 to 26°C into account. The reason why the actual energy performance does not correspond to the theoretical calculations is due to detected higher content of air (which decreases the density of PCM-concrete composite) and not as high as expected latent heat capacity of PCM-concrete.

Periodic steady-state simulations have indicated that the surface heat transfer has a great influence on the diurnal heat storage capacity. If the surface heat transfer coefficient is doubled, the improvement of the diurnal heat storage capacity is also doubled. Initial numerical simulations have shown that increasing the surface area of concrete also increases the surface heat transfer coefficient. Thus it was chosen to work further with PCM-concrete samples with increased surface area for the industrial production development and full scale testing.



Simulated increase in thermal mass based on hot-plate measurements compared to theoretical assumptions.

Hot-plate apparatus used for precise measurements of heat transfer of PCM-concrete.



Previous simulations have shown that increasing the concrete surface area with a factor 2 (middle) or even factor 3 (right) will theoretically increase the surface heat transfer and thus possibly improve the diurnal heat storage capacity.

INDUSTRIAL PRODUCTION OF PCM-CONCRETE STRUCTURES

In order to ensure that the technological developments could be industrially produced in large scale, methods based on the Spæncom A/S factory production were developed. For the development concrete hollow core decks were chosen as the structural concrete element. The downside of hollow core decks in buildings often gives possibilities to expose large areas of concrete and thus benefit from the thermal properties. In order to ensure a cost-effective, industrial production, 2 main challenges were detected:

- Development of a PCM-concrete hollow core deck with the required properties
- Achieving sufficient strength development.

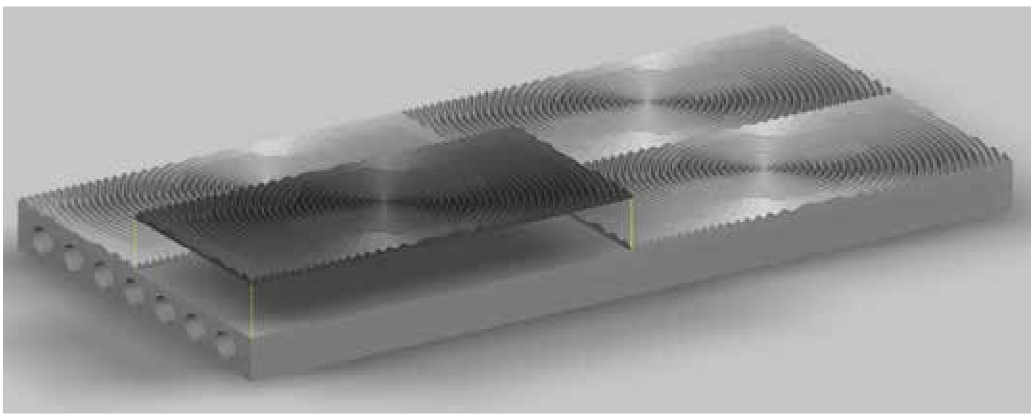
For the PCM-concrete hollow core decks a special tile solution was developed. This resulted in a production where thin PCM-mortar tiles (when the maximum sizes of aggregate in the mixture is below 4 mm. It is classified as mortar) were cast, demoulded and afterwards the hollow core decks were cast on top of the PCM-mortar tiles. In this way the tiles substituted the bottom layer of the traditional deck. This solution ensured:

- A minimum usage of Micronal which is more expensive than the other constituents of concrete
- That the PCM is only used in the structure where it can be activated. It is only the outer 3-4 cm. of the structure which are being activated most efficiently
- That the PCM-mortar with lower strength is not a part of the load bearing structure
- Design freedom in the exposed concrete layer which gives more aesthetic possibilities in the process of increasing the surface area.

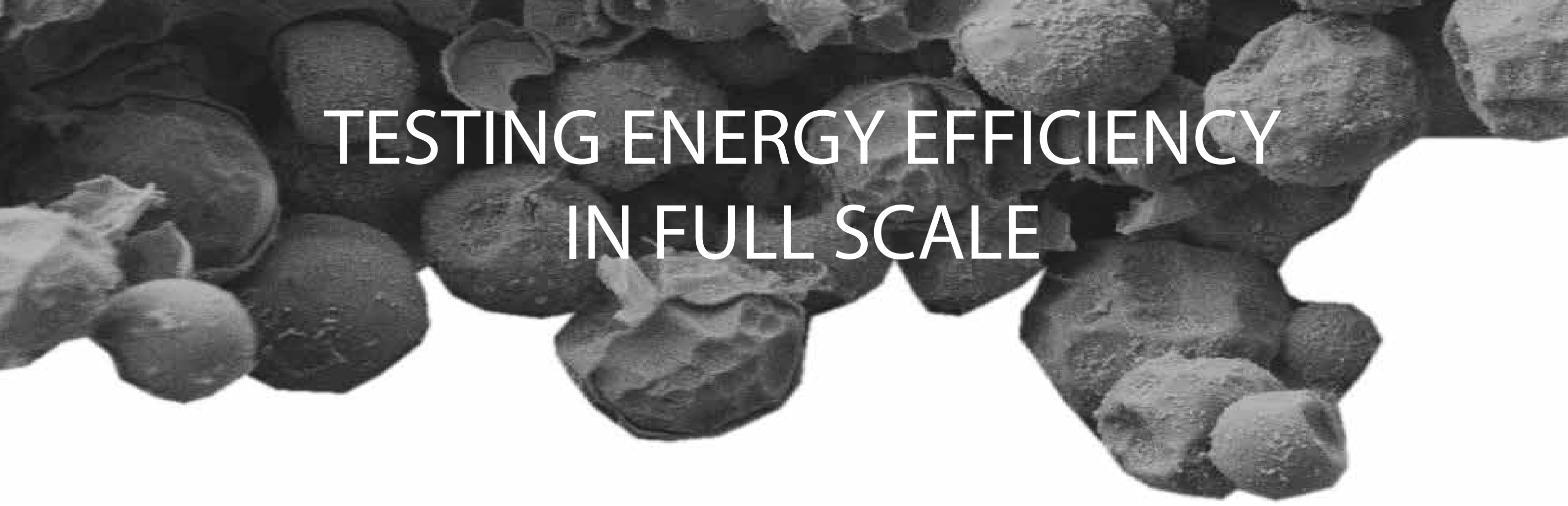
The PCM-mortar has proven to have lower strength than traditional mortar. But with the final up-scaled mix design, it was possible to achieve two-day strengths of approximately 10 MPa without the use of heat curing, and thus it is possible to perform normal demoulding of samples after two days.

With the developed mix design it was possible to achieve two-day strengths of the concrete of approximately 10 MPa.

Hollow core decks were cast on top of the PCM-mortar tiles at the Spæncom A/S factory resulting in the final PCM-hollow core decks.



The solution with PCM-mortar tiles attached to traditional hollow core decks. The decks produced for measurement of thermal properties had linear surface patterns on the PCM-mortar tiles.



TESTING ENERGY EFFICIENCY IN FULL SCALE

In order to investigate whether the technological developments and results correspond to up-scale environments the energy efficiency has been tested in full scale. Two test environments were chosen:

- Energy Flex House at Danish Technological Institute
- Large size hot-box at Aalborg University.

Energy Flex House – situated at Danish Technological Institute in Taastrup – is a flexible house where the building envelope and installations can be adjusted or changed. Experiments with PCM-concrete floors have shown that the positive effect of PCM in concrete is reduced in buildings with an already high thermal mass. The added PCM is best utilized in buildings where the thermal mass of surrounding constructions is low compared to a PCM-concrete hollow core deck in a room where floor and walls have a high thermal mass compared to the use of a standard hollow core deck.

During the project a large sized "hot-box" was built at Aalborg University. In the hot-box it is possible to test for instance U-value and lambda-values of constructions as well as the diurnal heat storage capacity. In the hot-box a number of hollow core decks – produced at the Spæncom A/S factory using the up-scaled, industrial production method – have been measured. The objective of the measurements was to investigate the diurnal heat storage capacity of the full scale decks. In order to test both the effect of PCM and profiled surfaces (270 % increased surface area) a specific test program was conducted, including:

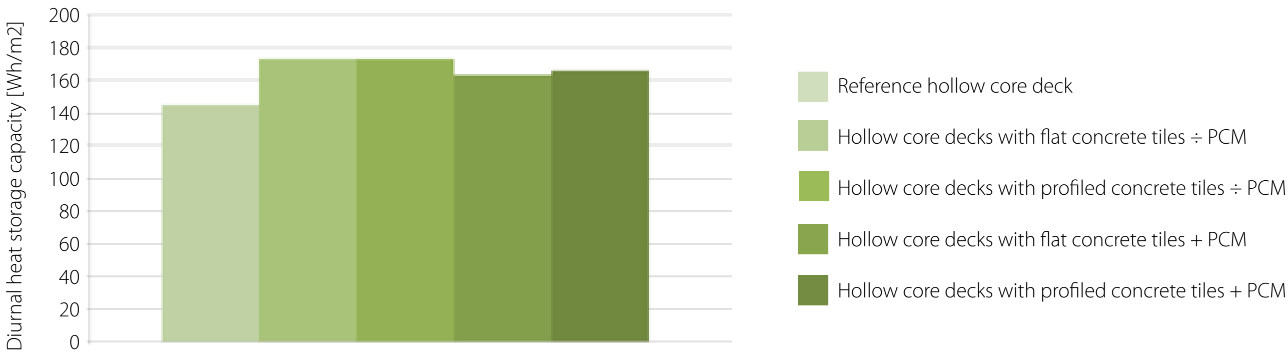
- Traditional hollow core decks (reference)
- Hollow core decks with flat concrete tiles ÷ PCM
- Hollow core decks with profiled concrete tiles ÷ PCM
- Hollow core decks with flat tiles + PCM
- Hollow core decks with profiled concrete tiles + PCM.

The results from the test program – which can be seen in the figure below – showed:

- That the diurnal heat storage capacity is higher for all 4 hollow core decks with tiles attached compared to the reference hollow core deck.
- The hollow core decks with concrete tiles without PCM performs slightly better than the tiles with PCM
- That is was impossible to measure a significant difference between decks with flat and profiled tiles.

Based on these results it can be concluded that it was impossible to increase the diurnal heat storage capacity by adding PCM to the concrete. Further, it was impossible to increase the diurnal heat storage capacity by increasing the surface area. Nevertheless, attaching concrete tiles on traditional hollow core decks seems to increase the diurnal heat storage capacity. The reason for this might be explained in the added reinforcement used to ensure a solid attachment between the tiles and hollow core deck.

Hot-box for thermal measurements of hollow core decks at Aalborg University.



Results from hot-box measurements showing measurement of diurnal heat storage capacity.

AESTHETICS AND ACOUSTICS

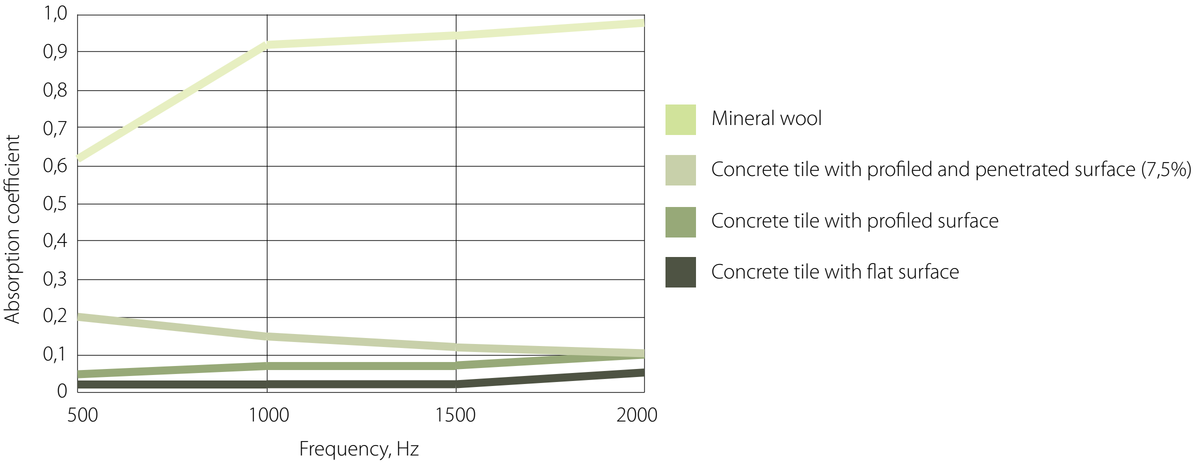
Utilization of the thermal properties of exposed indoor concrete surfaces often meets two obstacles: Aesthetics and Acoustics. It was decided to investigate whether the work with profiled surfaces also could be a part of removing these to obstacles.

Designing concrete surfaces with increased surface areas give new aesthetic possibilities to create both interesting and thermally optimized concrete surfaces. Using digital fabrication methods – e.g. robot milling – it is possible to create these surfaces with a realistic economy.

In order to obtain a comfortable indoor climate, it is important also to ensure acceptable acoustic properties. Exposed indoor concrete is known to contribute negatively to the acoustics and thus often covered in other, softer materials, among these the often used suspended ceilings with acoustic regulation. Thus, it was decided to investigate how the profiled concrete surfaces could be exploited to improve the acoustic properties of the concrete.

A number of concrete samples was produced using robot milling technology. The samples were designed both to show aesthetic possibilities with profiled concrete surfaces and to test acoustic properties. The results showed that profiling only has a small increase of the absorption properties in relation to the increase of the surface area. Concrete with holes leading to absorbing materials gives better absorption properties – but in order to improve the absorbing properties, the holes should be relatively small and the area of perforation bigger – up to approx. 20%. In this case the concrete should be able to achieve acceptable acoustic properties.

Concrete samples designed both to show aesthetic possibilities with profiled concrete surfaces and to test for acoustic properties.



Results from acoustic measurements of concrete tiles show that profiled tiles only give small improvement of the acoustic properties compared to flat tiles. Penetrating the surface leading into an absorbing material improves the acoustic properties, but 7,5% penetrated surface area is insufficient.

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This brochure was prepared by the partners of PCM-Concrete.
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