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SINTEF Building and Infrastructure Sigurd Hveem

Design for improvement of acoustic properties

COIN Project report 19 - 2009

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COIN P 5 Energy efficiency comfort

Sub P 5.2 Comfortable buildings and constructions

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Address: Forskningsveien 3 B
POBox 124 Blindern
N-0314 OSLO
Tel: +47 22 96 55 55
Fax: +47 22 69 94 38 and 22 96 55 08

www.sintef.no/byggforsk
www.coinweb.no

Cooperation partners / Consortium Concrete Innovation Centre (COIN)

Aker Solutions
Contact: Jan-Diederik Advocaat
Email: jan-diederik.advocaat@akersolutions.com
Tel: +47 67595050

Borregaard Ligno Tech
Contact: Kåre Reknes
Email: kare.reknes@borregaard.com
Tel: +47 69118000

maxit Group AB
Contact: Geir Norden
Email: geir.norden@maxit.no
Tel: +47 22887700

Norcem AS
Contact: Terje Rønning
Email: terje.ronning@norcem.no
Tel: +47 35572000

NTNU
Contact: Terje Kanstad
Email: terje.kanstad@ntnu.no
Tel: +47 73594700

Rescon Mapei AS
Contact: Trond Hagerud
Email: trond.hagerud@resconmapei.no
Tel: +47 69972000

SINTEF Building and Infrastructure
Contact: Tor Arne Hammer
Email: tor.hammer@sintef.no
Tel: +47 73596856

Skanska Norge AS
Contact: Sverre Smeplass
Email: sverre.smeplass@skanska.no
Tel: +47 40013660

Spenncon AS
Contact: Ingrid Dahl Hovland
Email: ingrid.dahl.hovland@spenncon.no
Tel: +47 67573900

Norwegian Public Roads Administration
Contact: Kjersti K. Dunham
Email: kjersti.kvalheim.dunham@vegvesen.no
Tel: +47 22073940

Unicon AS
Contact: Stein Tosterud
Email: stto@unicon.no
Tel: +47 22309035

Veidekke Entreprenør ASA
Contact: Christine Hauck
Email: christine.hauck@veidekke.no
Tel: +47 21055000

Preface

This study 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 5 projects:

- Advanced cementing materials and admixtures
- Improved construction techniques
- Innovative construction concepts
- Operational service life design
- Energy efficiency and comfort of concrete structures

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 %).

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Summary

The result of activity 1 Acoustic element design studies. Assessment and analyzes of different possible design" in the subproject 5.2 is reported here. The main goal of the subproject 5.2 is to find possible acoustic solutions for effective use of passive thermal mass (ptm). The acoustic element design studies have been coordinated closely with the activities in subproject 5.1. "Room design and ventilation system design for efficient utilization of thermal mass in office buildings"

This study has assessed the following types of absorbers as positive or possible positive:

- Retracted parts by formwork of concrete surfaces combined with different integrated sound absorbers, especially the micro perforated technology (from DeAmp or other possible producers) opens for a possible efficient system. The possible use of traditional absorbers in combination with 10 -20 % perforated metallic front panel in direct contact with metallic formwork should also be considered.
- Absorbers based on the micro perforated technology (from DeAmp or other possible producers) mounted beneath the concrete surfaces with good metallic contact to the concrete surface, the possible use of traditional absorbers in combination with 10 -20 % perforated metallic front panel in direct contact with the metallic frame should also be considered also for this type.
- Vertical sound absorber pads or baffles based on traditionally sound absorption materials

On this basis we will start the process for prototype development of new solutions and element design in collaboration with manufacturer and contractors. Further, the plan is to make verification tests of prototypes of the acoustic properties at our laboratory.

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1 Background

1.1 STAR report and project proposal

The STAR report (State of The Art Review) of the sub-project 5.2 "*Comfortable buildings and constructions*" (Hveem, 2007) was the first delivery to the subproject and dealt with the consequences for the indoor environment when concrete is chosen as the main building material in buildings and especially when large exposed concrete surfaces are used to take advantage of concrete's thermal mass. The Summarized need for future research concerning acoustic in this STAR report was as follows: "Sound and acoustics is a challenge related to free exposed concrete surfaces. Further studies are needed for mapping out different acoustic solutions for effective use of passive thermal mass (PTM)"

1.2 Brief account on "acoustics"

From the START report on acoustics we summarized the following:

- Ordinary concrete surface is highly reflective (has very low absorption coefficient)
- Utilization of PTM implies free exposed concrete surfaces that may cause problem for the sound properties (long reverberation time and low damping) of the room.
- The needed amount of free exposed surfaces is not totally clarified for the thermal mass interaction (to be further investigated in the thermal mass project).
- The needed amount of sound absorptive surfaces for acoustic purpose is known, but varies a lot depending of type of room and area of utilization:
  - For relatively small rooms for dwellings, offices etc have no need for additional room damping (sufficient absorption contribution from furniture etc.)
  - In the other end, large room like open plan offices, open plan schools etc have a large need for additional room damping, i.e. most of the ceiling and possible also part of the walls must be highly absorptive.
- Suspended absorptive ceilings are not an alternative as a starting point for two reasons:
  - In the project meeting 08.10.2007, mechanical assisted air distribution for interaction with concrete surfaces over the ceiling is not desirable for energy consumption reasons.
  - The thermal mass effect will be reduced (must be verified)

From this, we can conclude that it would be of great interest to make further investigations on what possible different design of the concrete surface that may have a considerable impact on bettering the sound absorptive properties.

This must be seen in connection with the thermal mass project, concerning how large amount of the surface that need to be active, i.e. how large amount of the surface is possible available for sound absorption. It will also be of great interest to study the possibility to combine the thermal active mass of concrete with partly or totally absorptive surfaces. Here we must look into possible use of new absorptive materials or solutions, e.g. micro perforated panels.
After the discussions of the START report in the project meeting in Oslo 08.10.2007 we were asked to prepare a short project description related to different possible acoustic solutions for effective use of PTM. This was later approved as the project "Design for improvement of acoustic properties"

1.3 Work description for "Design for improvement of acoustic properties"

The main goal of this subproject proposal is to find possible acoustic solutions for effective use of PTM. Further, the objective is to use these findings to start the process for development of new solutions and element design in collaboration with manufacturer and contractors. Finally, we will make verification tests of prototypes of the acoustic properties at our laboratory. This work will be coordinated closely with the activities in sub-project 5.1. "Room design and ventilation system design for efficient utilization of thermal mass in office buildings"

Activity 1: Acoustic element design studies

Assessment and analyzes of different possible design

Perform calculations and analyses to assess different types with respect to sound absorption:

- Concept study of retracted parts by formwork of concrete surfaces combined with different integrated sound absorbers:
  - using permanent formwork of metal as an integrated part of the reinforcement
  - mapping alternative absorption materials with focus on no possible negative effect on the indoor climate as to fibres in the air, maintenance (cleaning) etc.
  - assessment of the needed area for thermal mass interaction / possible area for sound absorption
  - assessment of the best geometry of the retracted parts (width, length and depth)
  - a special focus on a new type of micro perforated absorbers in collaboration of the Norwegian company DeAmp AS.

- Assessment of porous/open concrete surface:
  The sound absorption may be increased by making the surface less reflective:
  - using porous rendering
  - using openings to hollow structure (resonator absorbers) or similar

Assessment and analyzes of ventilated sound absorbers

- This design principle should, in spite of negative reactions be further assessed since such solutions can solve the sound absorption problem without any direct modifications of the concrete surface:
  - When the sound absorbers are divided into separate elements with limited dimensions with free openings on all four sides, the air exchange should be secured without mechanical air devices. Such a principle should be possible to use for the purpose of using thermal mass of a concrete structure as a stabilizer. However, there are challenges attached to dust, cleaning etc.

Different acoustic element designs will be analysed, in cooperation with sub-project 5.1.

Activity 2: Prototype development

- From the design study (activity 1) we will open a cooperation with manufacturer to make prototypes of integrated acoustic elements:
  - cooperation with producers of sound absorption materials (technique and design)
  - cooperation with the precast concrete industry (formwork, design, reinforcement)
  - preliminary testing of the acoustic properties (different design)

Activity 3: Verification tests in laboratory

- Perform verification measurements (sound absorption coefficient) of final solutions

2 Activity 1. Acoustic element design studies. Assessment and analyzes of different possible design

2.1 Concrete elements with sound absorbers of stiff mineral wool cast to the element

There already exist systems where mineral wool is an integrated part of the concrete element. The mineral wool can be put directly into the formwork. This type of products is already on the market, first of all meant for industrial buildings (factory halls). All the same, the surface of the mineral wool must be covered by a fibre cloth to prevent the mineral wool fibres to spread to the room. Mineral wool products for sound absorption are normally produced with such fibre cloths, often ready painted with a smooth surface. In principle, such product may also be suitable in all types of buildings, also for open plan offices and open plan schools.

However, this kind of absorbers will probably not be suitable for the type of buildings we are looking into, first of all due to the fact that the mineral wool will highly insulate large parts of the surfaces. On the other hand, if it is possible to find alternative materials and solutions for integrated sound absorbers as retracted parts of the concrete elements that has a moderate negative influence for effective use of passive thermal mass, i.e. has a low heat insulating effect, it opens for this type of construction, see 2.2.

2.2 Concept study of retracted parts by formwork of concrete surfaces combined with different integrated sound absorbers:

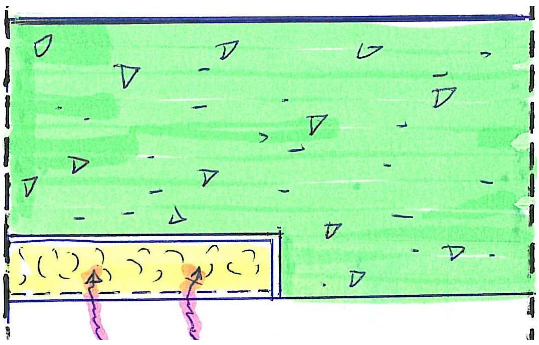


Figure 2.2.1. Integrated sound absorbers in retracted parts of the fomwork

2.2.1 Using permanent formwork of metal as an integrated part of the reinforcement

This idea came up early in a project-meeting when we discussed the possible use of a new technology using laser cut micro slot panels developed by the Norwegian company DeAmp, see 2.2.5. This technology is based on the well known Helmholz resonator principle and implies that the panels must have a fixed distance to the wall or ceiling behind. Therefore it seems like a good idea to look into the possibility of combining retracted parts or boxes to form such geometry to be e.g. a part of the reinforcement of the elements. Perforated front panel in general and especially micro perforated front panel with good metallic contact to the concrete structure through the metallic retracted formwork are positive for the heat interaction

In 2.2.5 we look more closely to the Micro perforated technology (from DeAmp or other possible producers) where the cavity behind the panels only consists of air. One of the large advantages is that this eliminates the use of porous materials, like mineral fibres, traditionally used in acoustic absorbers.

However, at this stage we must also assess other possible materials that can be used as an integrated, retracted part of concrete elements in respect to possible negative effects on the indoor climate and to fitness for effective use of PTM among other things, see 2.2.2 – 2.2.3.

2.2.2 Mapping alternative absorption materials with focus on no possible negative effect on the indoor climate as to fibres in the air, maintenance (cleaning) etc.

Diagram 2.2.2 shows the typical frequency characteristic for different main types of sound absorbers (Sintef Building and Infrastructure, 1996).

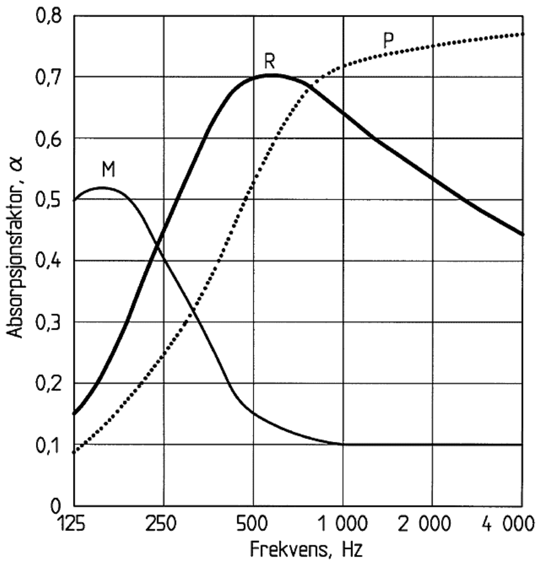


Diagram 2.2.1. Typical frequency characteristic for the different main types of sound absorbers (M = membrane absorbers. R = resonator absorbers. P= porous absorbers)

The most effective type is porous absorbers, and the most common type is mineral wool. In principle, all porous material with an open pore structure can be used for this purpose. They can not be covered by materials that hinder the free propagation of sound wave to penetrate into the porous structure where the sound energy is transformed to heat. We have made a list over possible materials:

- mineral wool
- wood shavings
- textiles

To avoid the problems with fibres in the air, this kind of absorbers are often covered by fibre cloth or similar by the manufacturer. The resistance for mechanical strain is low and porous materials often need to be covered by perforated panels, panels with open slits etc when used in vulnerable areas. In this context the main problem with porous absorbers is that they have a high heat insulating effect and is therefore difficult to combine with effective use of PTM. However, we cannot totally reject the possibility of using porous absorbers if it is acceptable to cover parts of the surfaces, see 21.2.3

The resonator absorbers may have a reasonable good sound absorption characteristic. A special type of interest is micro perforated panels, see 2.2.5.

2.2.3 Assessment of the needed area for thermal mass interaction / possible area for sound absorption

The conflict between the need for sound absorptive materials (that often is highly heat insulating) and the need for free exposed concrete surfaces for effective use of PTM is obvious. In some types of building / areas the need for sound absorption is so large that almost 100 % of the ceiling (or equivalent areas) should be highly absorptive. Other area of utilization has a lower need for absorption.
Calculations or assessment of the needed area for thermal mass interaction should be performed by the specialist on this field to clarify if there is any possibility at all to utilize parts of the surface to sound absorption that at the same time is highly heat insulating. The answer to this should be estimation on a rather rough level, for instance 0 %, 20 %, 50 %.

In January 2009 such calculations have been made (Sartori, 2009). The main conclusion concerning partially covered concrete surface by absorbers (in direct contact with the concrete) is that the effect on heat interaction is linear. However one may obtain some improvement due to two-dimensional effects if the absorbers are mounted in stripes (diffusion of heat “behind” the sound absorber stripe).

This linear effect was as expected, and it is not possible to draw any direct conclusions on how much of the area (in percentage) that must be reserved for direct heat interaction and how much that can be reserved for sound absorbers. However, it is reasonable to conclude any degree of covering is clearly negative for effective use of PTM, at least for highly heat insulation materials. Vice versa the reduction of the area reserved for sound absorbers is clearly negative for the sound environment.

2.2.4 Assessment of the best geometry of the retracted parts (width, length and depth)

The geometry is first of all connected to the thickness of the absorber. Mineral wool absorbers that are an integrated part of the element should have a thickness of at least 50 mm to get reasonable high absorption factor at low frequencies. It is also possible to use thinner products (25 mm) combined with an airspace of 25 – 75 mm behind. This means that a retracted part should at least be 50 – 100 mm. The width and length is a matter of design and standard deliveries from the manufacturer (for instance length x width typically 1200 mm x 600 mm). If we look at the products offered by DeAmp (see 1.2.5) the thickness varies between 40 – 200 mm, typically 100 mm.

2.2.5 A special focus on a new type of micro perforated absorbers made by the Norwegian company Deamp AS or other possible producers.

The products from the Norwegian company DeAmp AS (or other possible producers) are of special interest because this system has an expected lower negative effect on the heat interaction (compared to absorbers of mineral wool etc) when used in front of, or as an integrated part of a concrete structure. In addition the use of materials with no possible negative effect on the indoor climate (no fibres used, only air in the cavity) is a positive factor. DeAmp AS has been contacted to discuss the possibilities for further collaboration. See also 2.3 for the same concept, but as a separate box-absorber mounted beneath the concrete surface.

Micro perforated absorbers are a special type of resonator absorbers with extreme small hole or slot dimensions. A good absorption characteristic is depending of interaction with a cavity behind and often two panels and two cavities are used to get good properties in a broad frequency range. The absorbers may be produced of metal boards / panels or by transparent polycarbonate, see figure 2.2.2.

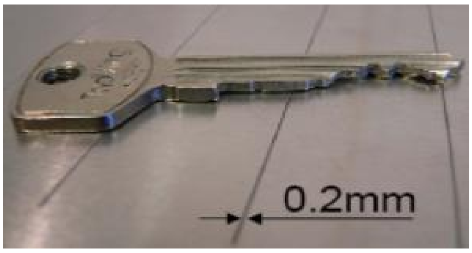


Figure 2.2.2. Micro perforated materials

The home site for DeAmp AS (www.deamp.no) describes the technology and an extract is given in appendix 1.
According to the description concerning "Sound Absorption" (appendix 1) one can achieve very good results in spite of that the high frequency absorption are poorer than for the best porous absorbers. This is confirmed by the results from laboratory tests of sound absorption coefficients that are given at the home site (extracts also given appendix 1). In figure 2.2.3 we have also given test results for single and double panels with a cavity of 100 mm (reference: from power points presentation by Tor Erik Vigran given to the author of this report).

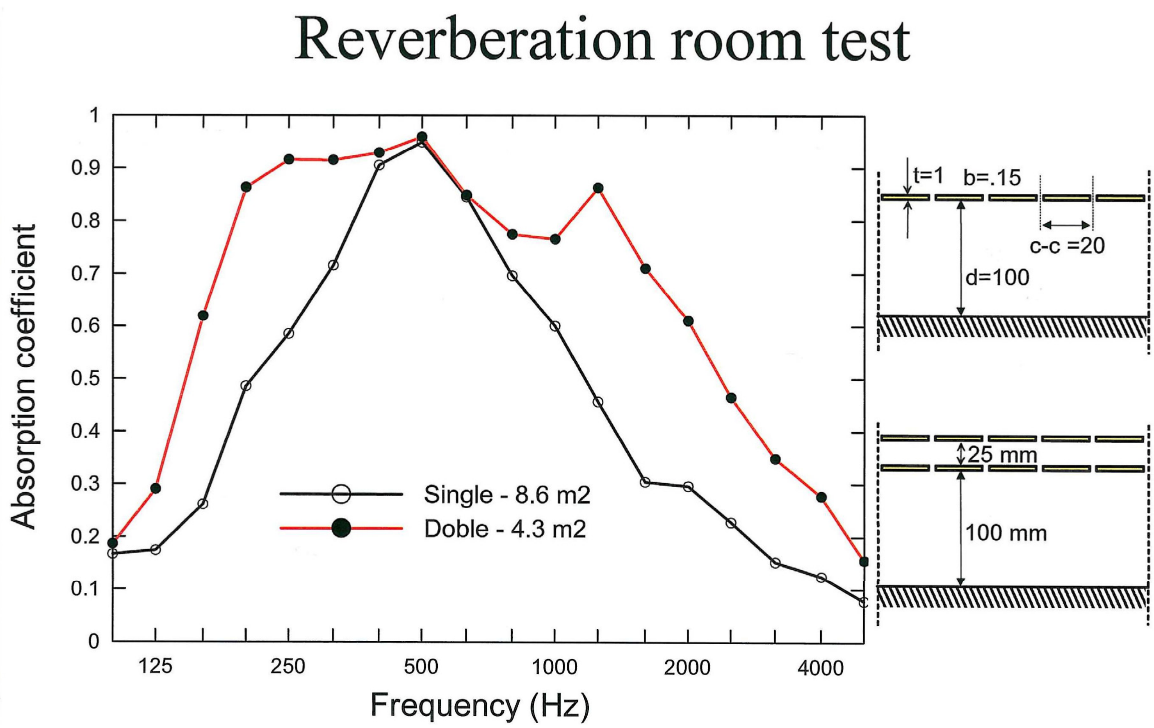


Diagram 2.2.2. Absorption coefficient for single and double panels with a cavity of 100 mm (reference: power points presentation by Tor Erik Vigran).

DeAmp delivers panels both in aluminium and steel (metal series) and in cast acrylic (acrylic series). In appendix 2 we have shown products and technical specifications taken from the product catalogue (www.deamp.no) of both series.

Cooperation with producers of sound absorption materials (technique and design)

We invited DeAmp AS / Pål Ove Henden to the project meeting 06.10.2008 to participate in the discussion of our preliminary report on element design studies and the way further. Pål Ove Henden also presented what they already have done in respect of absorption and PTM and their proposals.

Further collaboration will depend on what design that is suitable based on a total evaluation of the relevant properties.

Cooperation with the precast concrete industry (formwork, design, reinforcement)

We had a preliminary meeting 19.09.2008 with Magne Pedersen from the company Spenncon AS, Hønefoss (Manufacturer of concrete precast elements). The purpose of this meeting is to discuss different possible solutions for integrated acoustic elements (formwork, design, reinforcement, etc). This is a first step in the process of making possible prototypes for further testing.

Another meeting between Magne Pedersen (Spenncon AS, Norway) and Jouni Punkki (Consolis, Finland) was held 02.02.2009 where they planned to discuss the possibilities for “Absorbers as retracted parts by formwork integrated in concrete elements”. We have also asked for possible input to alternative design, absorbers connected or hung underneath the concrete surface. The actual discussion was a little postponed and their response is as described below and was sent over 05.02.2009.
The concrete element industry is sceptical but not negative to integrated absorbers in general. Today they cannot see any obvious advantages by retracted parts on the underside of floor elements, but there may be advantages to the total system that they have overlooked at this stage. Some supplemented comments are given below:

- retracted parts will complicate the production process and increase the cost of the slab, but the slip form technique for casting may reduce the complications
- retracted parts will increase the thickness of the slab by the same thickness as the DeAmp boxes (hinder an efficient placing of the strand reinforcement)
- it is probably difficult to utilize retracted steel formwork as an effective part of the reinforcement.
- retracted parts will affect transport, storage and erection (more vulnerable for damages under handling process)
- the absorbers must probably be completed at the building site (extra operations and scaffolding not avoided)

Part conclusion 2.2

From this, we may conclude that the design “Retracted parts by formwork of concrete surfaces combined with different integrated sound absorbers” shown in fig.2.2.1, based on a total evaluation of the relevant properties, cannot yet be confirmed or rejected as a suitable design. In general the acoustic properties may be good if the covered area in percentage is large. The thermal effect is negative if the covered area in percentage is large. The micro perforated technology (from DeAmp or other possible producers) opens for a possible efficient system both thermal and acoustical. Perforated front panel in general and especially micro perforated front panel with good metallic contact to the concrete structure through the metallic retracted formwork are positive for the heat interaction. If this thermal effect of metallic contact is large and dominating, it may perhaps be possible to also use traditional 10-15 % perforated or slit panel with mineral wool in the cavity and still obtain good heat interaction.

Be aware of the fact that the thermal calculations (Sartori, 2009) for the DeAmp system assumed a system of extra metal profiles in the boxes connecting the micro perforated front and the back panel to improve the heat transfer (connected to the concrete not only through the metal frame) and this technique may also be utilized for traditional absorbers with mineral wool and ordinary perforated metallic panels.

The complication of the production process may be a negative factor for this design, but the advantages being a part of the concrete element are possibly a positive factor if additional operations on the building site can be avoided. To use the metallic retracted formwork (along the whole length of the element) as a part of the reinforcement was originally pointed out as a possible advantage, but this must probably be rejected due to high temperature under fire.

From this we recommend, in agreement with the concrete element industry that this design based on the micro perforated technology (from DeAmp or other possible producers) should be investigated further by casting prototypes with hollow core elements before concluding. The possible use of traditional absorbers in combination with 10 -20 % perforated metallic front panel in direct contact with metallic formwork should also be considered.

2.3 Concept study of box-absorbers based on the micro perforated technology (from DeAmp or other possible producers) mounted beneath the concrete surfaces with good metallic contact to the concrete surface:

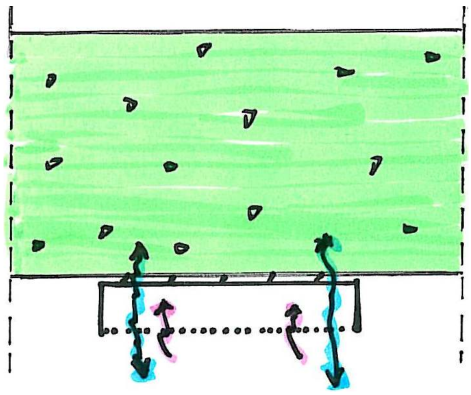


Figure 2.3.1. Box-sound absorbers based on the micro perforated technology (from DeAmp or other possible producers) mounted beneath the concrete surfaces with good metallic contact to the concrete surface.

Since the concept with integrated absorbers in retracted parts by formwork of concrete surfaces (see 2.2) does not have any large thermal advantages and have a large number of negative effects from a production view, we therefore suggest that the thermal effect should be studied for absorbers mounted beneath the concrete surface, but with good metallic contact to the concrete.

In the “Technology description” from www.deamp.no (see 2.2.5) concerning “Energy efficiency” it is referred to reports on “Active cooling on concrete ceiling” and “Thermal inertia of the building materials”. This means that the thermal PTM effect has been evaluated earlier. Corresponding simulations for the technology of the DeAmp products have recently been carried out (Sartori, 2009). Both these and earlier calculations and assessments for the same type of product show better performance than traditional (thermally insulating) absorbers.

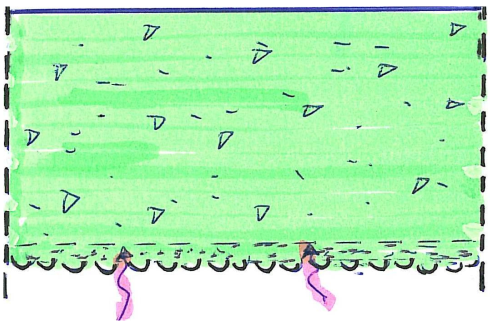
Sound absorbers with a good metallic contact with the concrete will transmit heat to the concrete, and so the thermal mass is not strongly de-coupled from the room air. Much depends, of course, on the goodness of the thermal contact between metal and concrete. Simulations (Sartori, 2009) have been done supposing no extra-thermal resistance at the junctions, which is of course an ideal case. Be aware of the fact that the thermal calculations also for this DeAmp system assumes of extra metal profiles in the boxes connecting the micro perforated front and the back panel to improve the heat transfer (connected to the concrete not only through the metal frame) and this technique may also be utilized for traditional absorbers with mineral wool and ordinary perforated metallic panels.

Part conclusion 2.3

From this, we may conclude that the design “Absorbers based on the Micro perforated technology (from DeAmp or other possible producers) mounted beneath the concrete surfaces with good metallic contact to the concrete surface” shown in fig.2.3.1, based on a total evaluation of the relevant properties, opens for a possible good combination of sound absorption and thermal PTM interaction. One large challenge is that compared with traditional sound absorbers of mineral wool, the DeAmp absorbers have a cost (according to information from DeAmp AS by Pål Ove Henden given in COIN-

meeting 06.10.2008) of the order of 5 times higher. This type is not integrated in the concrete element and must be mounted on site.
If the thermal effect of metallic contact is large and dominating, the possible use of traditional absorbers in combination with 10 -20 % perforated metallic front panel in direct contact with the metallic frame should also be considered also for this type.

2.4 Assessment of porous/open concrete surface



Figur 2.4.1. Porous / open concrete surface

2.4.1 General

The sound absorption may be increased by making the surface more open to a hollow structure or with a porous surface. In practice this means that there must be an open structure for air transportation by narrow slits/small holes or between the cement grain and the aggregate into voids in the structure. In the STAR-report we found some references to the effect of open structure (openings to voids or a hollow structure) or adding porous rendering to the concrete surface that we have evaluated.

2.4.2 Small openings to voids/hollow structure

At this stage we believe that using techniques to establish a more open structure with voids in the structure has not the potential that makes it interesting to follow up. It seems to be a complicated production process. It will probably reduce the load bearing capacity of floor elements and the porous structure will reduce the heat exchange. By using element types like “Bubble deck”, it may be of interest to utilize the cavity of the bubbles. However, the conclusion of not following this track must be assessed and verified by the concrete element industry.

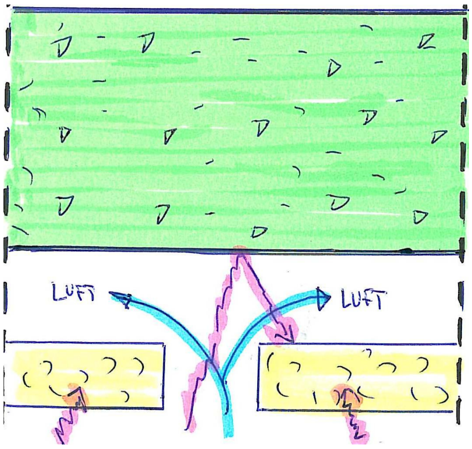
2.4.3 Acoustic, porous rendering

The sound absorption coefficient can be increased by adding a porous rendering directly to the concrete surface. This is a well known technique. However, the rendering must be both relatively thick and extremely porous to get good results. At this stage we believe that use of porous rendering will not give sufficiently high sound absorption for the use we have in mind. At the same time thick rendering will lead to other problems, for instance rough surfaces hard to clean and an insulating effect that is negative in our context.

Part conclusion 2.4

From this, we may conclude that the design “Porous/open concrete surface” shown in fig.2.4.1, based on a total evaluation of the relevant properties, is not suitable. The concrete element industry states that the rendering would have to be applied on site (or in a second operation), and this is not a favourable system in proportion neither to technique nor to cost.

2.5 Assessment and analyzes of ventilated sound absorbers (horisontally suspended ceiling)

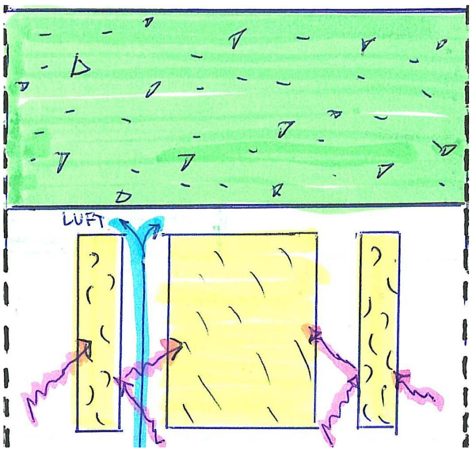


Figur 2.5.1. Ventilated sound absorbers (horisontally suspended ceiling)

The design principle for ventilated sound absorbers is to direct the indoor air behind the sound absorbing elements to get in direct contact with the surface of the main construction (for instance over suspended ceilings). The sound absorption of the ceiling may be quite good. Even if the sound absorbers are divided into separate elements with limited dimensions and free openings at all four edges, the air circulation will probably be hampered and the convective heat exchange will be reduced. From a thermal view proper ceiling ventilation must be provided (fans or ceiling diffusers). However, such a concept has severe challenges attached to dust, cleaning etc. Possible additional need for mechanical air moving devices is another negative factor.

Part conclusion 2.5
From this, we may conclude that the design "Assessment and analyzes of ventilated sound absorbers (horisontally suspended ceiling)" shown in fig.2.5.1, based on a total evaluation of the relevant properties, is not suitable.

21.6 Vertical sound absorber pads or baffles



Figur 2.6.1. Vertically sound absorber pads or baffles

An alternative to ventilated sound absorbers (suspended absorptive ceiling divided into smaller elements) is to use discrete sound absorbers like rectangular unit sound absorber pads or baffles. The baffles will then hang vertically from the ceiling and may be arranged in rows or groups. The vertical mounting normally gives a large surface area compared to a horizontal absorber. Consequently it opens for a very good sound absorption when using porous materials inside covered with free choice among a large number of materials having a free opening of about 20 % (perforation, slits etc.). The mounting allows free passage of air exchange to the main ceiling of the concrete structure and the utilization of PTM is little affected (what about thermal radiation? This must be verified). Just a small area of the absorbers will be horizontal, and the danger of dust depots on these parts is little. The use of materials, the height, the thickness and the mounting closeness of the baffles will decide the sound absorption properties. Dust on small horizontal parts may be reduced by letting the surface be curved or sharp pointed. The challenge with such a product is to find a good design that opens for good light distribution and at the same time gives space and covering for technical installations (ventilation pipes and outlets.).   The principle may also be used in front of walls etc.

This is perhaps the most obvious and relevant way to solve the challenge for effective use of passive thermal mass when you at the same time must add a large amount of absorption to the room. The geometry and the pattern of the sound absorber pads or baffles can vary. Such a system opens for highly absorptive elements with a large surface area relative to the area of the ceiling. However it must be verified that this type of sound absorber pads will not cause problems obtaining an effective thermal interaction with the main concrete structure above. Such a study should include some limits for typical recommended geometry (distance between baffles, heights, orientations etc.) that will effect the thermal interaction at a low and acceptable degree.

In January 2009 such simulations for sound absorber pads or baffles have been made (Sartori, 2009). These simulations show that sound absorber pads or baffles has negligible negative effect on thermal PTM interaction, but we have to be careful about one thing. Vertical baffler will affect the ceiling heat exchange both in terms of radiation exchange with the other surfaces and in terms of convective exchange with the room air. The simulations show that altering the path of radiation heat exchange has a negligible effect. On the other hand, convection heat exchange may be compromised, and this would be equivalent more or less to a half covered ceiling with horizontal sound absorbers. So, displacement and distance from ceiling surface should be such to not hamper significantly the otherwise free air motion. In combination, ceiling diffusers that would increase convective transfer on the ceiling surface would help.

Sound absorber pads or baffles may be designed with front material and design adapted to the choice of materials in the room. The inner materials may be of traditionally porous materials. Such sound absorber pads may also be made two sided according to micro perforated principle from DeAmp or other possible producers.

Those sound absorption elements will be totally separate from the concrete structure and will never be a product to be integrated in concrete elements. On the other hand it may be a product that can be a part of a product selection to solve the acoustical problem.

Part conclusion 2.6
From this, we may conclude that the design “Vertically sound absorber pads or baffles” shown in fig.2.6.1, based on a total evaluation of the relevant properties, is highly suitable. The acoustic properties may be very good and has a low influence on the thermal PTM effect. However, it is not integrated in the concrete element and must be mounted on site.

This design is in principle on the market already and it is not likely that the concrete industry will profit directly of a possible further development.

3 Design evaluation and further work

3.1 General

According to original project plan we shall, from the results of the design study open for cooperation with manufacturer to make prototypes of integrated acoustic elements or separate acoustic elements adapted for use combined with PTM including preliminary testing of the acoustic properties (activity 2). The next step in the project plan was to perform verification test in laboratory of the sound absorption of final solutions (activity 3).

3.2 Proposal for prototypes for further testing of acoustic properties

From activity 1 concerning acoustic element design studies, we have assessed the following types of absorbers as positive or possible positive:

3.2.1 Retracted parts by formwork of concrete surfaces combined with different integrated sound absorbers

In general the acoustic properties may be good. The thermal effect is in general negative, but the micro perforated technology (from DeAmp or other possible producers) opens for a possible efficient system both thermal and acoustical. However, the price for the DeAmp technology and the complication of the production process may be negative factors for this design. The slip form technique for casting may reduce the complications. The fact that the absorber will be an integrated part of the concrete element is on the other hand a possibly positive factor, especially if additional operations on the building site can be avoided. Jouni Punkki (Consolis, Finland) and Magne Pedersen (Spenncon, Norway) is prepared to join in discussions for cast prototype elements for testing of the production process and the finished product. This also implies further collaboration with Pål Ove Henden (DeAmp AS). If the thermal effect of metallic contact is large and dominating, the possible use of traditional absorbers in combination with 10 -20 % perforated metallic front panel in direct contact with metallic formwork should also be considered. Extra metal profiles connecting the front and the back panel to improve the heat transfer (not only through the metal frame) is assumed for both types.

3.2.2 Box-absorbers based on the Micro perforated technology (from DeAmp or other possible producers) mounted beneath the concrete surfaces with good metallic contact to the concrete surface.

The design is basically similar to the design described in 3.2.1, but the absorber is not integrated in the concrete element. The absorber must be mounted on site implying additional operations and scaffolding, but does not affect the production of the concrete elements. The price for the DeAmp technology may still be a negative factor. If the thermal effect of metallic contact is large and dominating, the possible use of traditional absorbers in combination with 10 -20 % perforated metallic front panel in direct contact with the metallic frame should also be considered also for this type. Extra metal profiles connecting the front and the back panel to improve the heat transfer (not only through the metal frame) is assumed for both types.

3.2.3 Vertical sound absorber pads or baffles.

Based on a total evaluation of the relevant properties, this design is highly suitable. The acoustic properties may be very good and the absorbers have a low influence on the thermal effect. However, it is not an integrated part of the concrete element and must be mounted on site implying additional operations and scaffolding. The heights of vertical absorbers must be relatively high. The absorbers may be produced of traditional sound absorption materials, but the use of Micro perforated technology (from DeAmp or other possible producers) is also possible. However, this design is in principle on the market already and it is not likely that the concrete industry will profit directly of a possible further development.

Oslo, 06.03.2009

Sigurd Hveem

References

1) Hveem,Sigurd. COIN project report. STAR report (State of The Art Review) of the sub-project 5.2 "*Comfortable buildings and constructions*" Oslo, 17.09.2007

2) SINTEF Building and Infrastructure. Building Research Design Sheet no: 543.414. Sound absorbing properties for materials and constructions. Oslo, 1996

3) Sartori, Igor. COIN project report. Simulations of thermal effect. SINTEF Building and Infrastructure, Report on COIN sp 5.1 available march 2009", Oslo, 2009

From www.deamp.no (product catalogue): Appendix 1

Technology

DeAmp is developing and marketing acoustical ceilings and walls, utilizing a revolutionary technology; laser cut acoustic micro slots. Sound absorption by micro slotting makes it possible to exploit new indoor areas with smooth surfaces and excellent finish. The technology also eliminates use of mineral fibers, traditionally used in acoustic absorbers.

Unique Patented Technology

DeAmp's technology is developed during 10 years of research at SINTEF and The Norwegian University of Science and Technology. The technology is based on the well-known acoustic principle Helmholtz resonator. DeAmp's unique technology utilizes laser cut micro slits to perforate the surface. When sound waves, defined as compressed air, hit the perforated surface an overpressure arises on the front of the panel. To equalize the pressure, the compressed air is forced through the micro slits, and viscous forces between the very narrow slit and the air causes friction. Hence the sound waves are absorbed and transformed into heat without use of any porous fiber-materials. The technology is internationally patented by DeAmp.

Excellent Esthetical Properties

Our sound absorbers offer excellent esthetical properties treasured by architects. We offer clean and smooth surfaces and a wide variety of colors and surface finishes. DeAmp's absorbers can be anodized, painted, engraved or printed on, and because they are fiber free they can be transparent, translucent or colored. Panels can be mounted in traditional ceiling suspensions, directly on walls, as panel elements in office furniture systems or stand alone partition walls.

The Safe and Healthy Alternative

Fiber free sound absorbers ensure a better indoor environment, especially for children and people with respiratory disorders. The products do not emit fiber particles, nor do they collect dust in the slits. They do not absorb moisture, which can lead to fungi and rot, and they are easy to clean with water based products. These benefits reduce costs related to sick leave, loss of productivity and maintenance of facilities.

Dust from porous materials can be inflammable and create life-threatening hazards because of limited visibility and breathing difficulties in a fire emergency. DeAmp metal absorbers are made from 100% solid aluminum or steel without the use of porous layers or fiber membranes.

High Light Reflection

The laser cut micro perforated slits are less than 0.2mm wide and therefore barely visible at a normal distance from the ceiling. They cover less than 1% of the panel surface and consequently over 99% of the material is left as a reflecting area. By utilization of the reflecting or transparent surfaces, DeAmp panels can lead the light into the room, something which has been difficult with traditional sound absorbers. Exploitation of daylight reduces lighting costs, and improves the users' well-being.

Energy Efficiency

Traditional suspended fiber based ceiling systems, in combination with active cooling in a concrete ceiling, will reduce the performance of the cooling system. The fibers will work as an insulating layer, and hence increase the energy consumption of the cooling system. Scientific reports on the energy efficiency of DeAmp products, states that this increase can be reduced with 50% by using DeAmp's aluminum absorbers compared to traditional fiber absorbers. The effect will also be considerable when utilizing the thermal inertia of the building materials to keep the temperature at a comfortable and more stable level during the shifting day and night conditions.

Sound Absorption

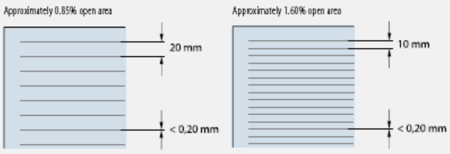
Compared to the best porous absorbers, micro perforated products perform somewhat poorer in higher frequencies. However, higher frequencies are more easily absorbed by furniture, people and surface elements in the room. Therefore excellent acoustic conditions can still be achieved based on the high absorption at low and middle frequencies. Scientific measurements from our reference projects show that values are below the required reverberation time for the whole frequency band.

From www.deamp.no (product catalogue): *Appendix 2*

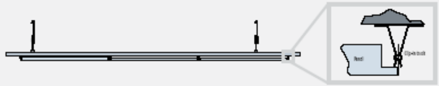
Metal series

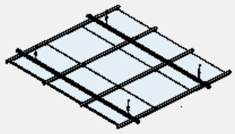
Metal Ceiling

Perforations

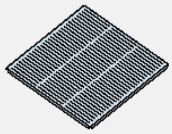


Clip-in Ceiling Panel



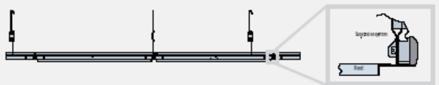


Typical suspension system for clip-in ceiling panels



Clip-in panel, module 600x600 mm

Lay-in Ceiling Panel

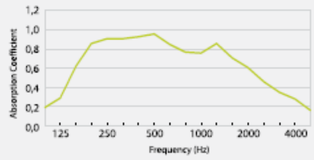


Technical Data

Material	aluminum or steel
Thickness	from 0.7 mm to 1 mm
Size	standard 600 x 600 mm / 600 x 1200 mm customizations available
Color	standard RAL 9010 all NCS- and RAL coded colors available
Sound absorption	NRC 0.50 to 0.80
Fire standards	UK, BS 476 Part 7 – Class 1

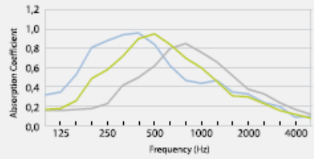
Sound Absorption

The absorption coefficient is adjustable to the desired frequency area.



Suspension height, H (mm):
Layer 1: 100 mm [1]
Layer 2: 125 mm

This figure shows the absorption coeffecient using double layers mounted 100 mm and 125 mm from the noise reflecting surface.



Suspension height, H (mm):
200mm [2]
100mm [1]
40mm [2]

This figure illustrates the absorption coefficient when the absorbing panel is placed respectively 200, 100 and 40 mm from the noise reflecting surface behind.

H (mm)	125	250	500	1000	2000	4000	NRC
100 / 125 [1]	0.29	0.91	0.96	0.76	0.61	0.28	0.80
40 [2]	0.16	0.23	0.62	0.76	0.38	0.17	0.50
100 [1]	0.18	0.58	0.95	0.60	0.30	0.12	0.60
200 [2]	0.35	0.88	0.84	0.44	0.33	0.09	0.60

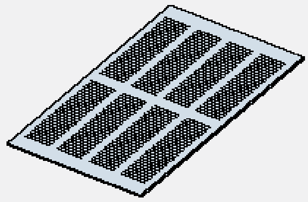
[1] Measured results from SINTEF/NTNU acoustic laboratory. All tests are performed by Professor Tor Erik Vigran.

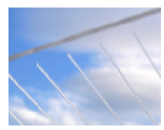
[2] Calculated results.

Panel Absorber

DeAmp panel absorbers are perfect for use in facilities with extensive use of glass, concrete and other hard surfaces. Our panels can be mounted directly on the wall, or in front of windows, pictures or light sources. It is also possible to print directly on the panels. DeAmp corner absorbers can be installed towards ceilings or walls and deliver excellent absorption performance compared to its limited size.

Product Options



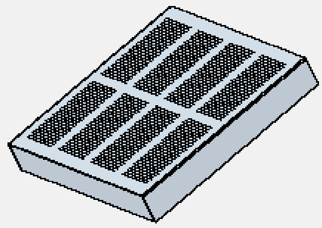


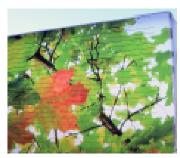
Size	standard 600 x 600 mm customizations avaible
Maximum size	2000 x 3000 mm
Tickness	from 4 mm to 15 mm

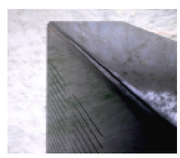
Box Absorber

DeAmp box absorbers are very easy to install without the need for any additional suspension or mounting system. They are suitable in small installations or as building blocks in larger installations. In addition they can be customized with printing and fitted for home theater use.

Product Options







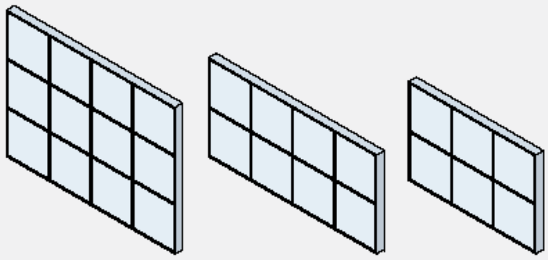
Height	700 mm
Width	700 mm
Depth	100 mm

From www.deamp.no (product catalogue): *Appendix 2 cont.*
Acrylic series

Framed Wall Absorber

DeAmp framed wall absorbers are perfect for small renovation projects or as supplementary product to acoustical ceiling tiles. It is also suitable in buildings where acoustical ceiling tiles can not be used. DeAmp framed wall absorbers can be mounted directly on the wall or used in front of windows or light sources to create a stylish effect. The product is compounded of our standard 600 x 600 mm acrylic panels and prefabricated MDF frameworks. Panels and frameworks are available in various colors and customized sizes.

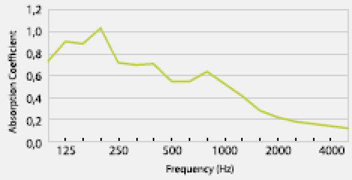
Product Options



Height	1816 mm	1217 mm	1217 mm
Width	2415 mm	2415 mm	1816 mm
Depth	110 mm	110 mm	110 mm

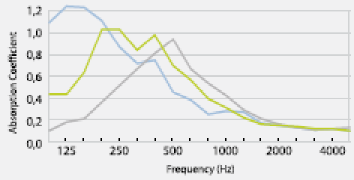
Sound Absorption

The absorption coefficient is adjustable to the desired frequency area.



Suspension height, H (mm):
Layer 1: 110 mm [2)]
Layer 2: 130 mm

This figure shows the absorption coeffecient using double layers mounted 110 mm and 130 mm from the noise reflecting surface.



Suspension height, H (mm):
197 mm [2)]
97 mm [2)]
54 mm [2)]

This figure shows the absorption coefficient when the absorbing panel is placed respectively 197, 97 and 54 mm from the noise reflecting surface behind.

H (mm)	125	250	500	1000	2000	4000	NRC
110 / 130 [2)]	0.90	0.71	0.54	0.52	0.22	0.14	0.50
54 [2)]	0.19	0.52	0.94	0.43	0.17	0.13	0.50
97 [2)]	0.44	1.03	0.70	0.32	0.16	0.13	0.55
197 [2)]	1.24	0.87	0.46	0.29	0.16	0.13	0.45

[2)] Measured results from tests performed by SINTEF ICT according to ISO 354 and ISO 11654.

Acrylic series. From www.deamp.no (product catalogue)

Technical Data

Material		cast acrylic (PMMA) [1)]
Thickness		from 4 mm to 15 mm
Size		customizations available
Color		colored, transparent or translucent
Sound absorption		NRC 0.45 to 0.55
Flammability	UK, BS 476 Part 7 - Class 3 DIN 4102 - B2 [1)] NFP 92-507 - M4	UL94 - HB ISO 11925-2 - E

[1)] Also available in PETG with flammability class B1 (DIN 4102) / class 1Y (UK, BS 476 Part 7)

Summary

The result of activity 1 Acoustic element design studies. Assessment and analyzes of different possible design” in the subproject 5.2 is reported here. The main goal of the subproject 5.2 is to find possible acoustic solutions for effective use of passive thermal mass (ptm). The acoustic element design studies have been coordinated closely with the activities in subproject 5.1. “Room design and ventilation system design for efficient utilization of thermal mass in office buildings”

This study has assessed the following types of absorbers as positive or possible positive:

- Retracted parts by formwork of concrete surfaces combined with different integrated sound absorbers, especially the micro perforated technology (from DeAmp or other possible producers) opens for a possible efficient system. The possible use of traditional absorbers in combination with 10 -20 % perforated metallic front panel in direct contact with metallic formwork should also be considered.
- Absorbers based on the micro perforated technology (from DeAmp or other possible producers) mounted beneath the concrete surfaces with good metallic contact to the concrete surface, the possible use of traditional absorbers in combination with 10 -20 % perforated metallic front panel in direct contact with the metallic frame should also be considered also for this type.
- Vertical sound absorber pads or baffles based on traditionally sound absorption materials

On this basis we will start the process for prototype development of new solutions and element design in collaboration with manufacturer and contractors. Further, the plan is to make verification tests of prototypes of the acoustic properties at our laboratory.

Table of content

0 Background

01 STAR report and project proposal

The STAR report (State of The Art Review) of the sub-project 5.2 "*Comfortable buildings and constructions*" (Hveem, 2007) was the first delivery to the subproject and dealt with the consequences for the indoor environment when concrete is chosen as the main building material in buildings and especially when large exposed concrete surfaces are used to take advantage of concrete's thermal mass. The Summarized need for future research concerning acoustic in this STAR report was as follows: "Sound and acoustics is a challenge related to free exposed concrete surfaces. Further studies are needed for mapping out different acoustic solutions for effective use of passive thermal mass (PTM)"

02 Brief account on "acoustics"

From the START report on acoustics we summarized the following:

- Ordinary concrete surface is highly reflective (has very low absorption coefficient)
- Utilization of PTM implies free exposed concrete surfaces that may cause problem for the sound properties (long reverberation time and low damping) of the room.
- The needed amount of free exposed surfaces is not totally clarified for the thermal mass interaction (to be further investigated in the thermal mass project).
- The needed amount of sound absorptive surfaces for acoustic purpose is known, but varies a lot depending of type of room and area of utilization:
    - For relatively small rooms for dwellings, offices etc have no need for additional room damping (sufficient absorption contribution from furniture etc.)
    - In the other end, large room like open plan offices, open plan schools etc have a large need for additional room damping, i.e. most of the ceiling and possible also part of the walls must be highly absorptive.
- Suspended absorptive ceilings are not an alternative as a starting point for two reasons:
    - In the project meeting 08.10.2007, mechanical assisted air distribution for interaction with concrete surfaces over the ceiling is not desirable for energy consumption reasons.
    - The thermal mass effect will be reduced (must be verified)

From this, we can conclude that it would be of great interest to make further investigations on what possible different design of the concrete surface that may have a considerable impact on bettering the sound absorptive properties.

This must be seen in connection with the thermal mass project, concerning how large amount of the surface that need to be active, i.e. how large amount of the surface is possible available for sound absorption. It will also be of great interest to study the possibility to combine the thermal active mass of concrete with partly or totally absorptive surfaces. Here we must look into possible use of new absorptive materials or solutions, e.g. micro perforated panels.
After the discussions of the START report in the project meeting in Oslo 08.10.2007 we were asked to prepare a short project description related to different possible acoustic solutions for effective use of PTM. This was later approved as the project "Design for improvement of acoustic properties"

03 Work description for “Design for improvement of acoustic properties”

The main goal of this subproject proposal is to find possible acoustic solutions for effective use of PTM. Further, the objective is to use these findings to start the process for development of new solutions and element design in collaboration with manufacturer and contractors. Finally, we will make verification tests of prototypes of the acoustic properties at our laboratory. This work will be coordinated closely with the activities in sub-project 5.1. “Room design and ventilation system design for efficient utilization of thermal mass in office buildings”

Activity 1: Acoustic element design studies

Assessment and analyzes of different possible design

Perform calculations and analyses to assess different types with respect to sound absorption:

- Concept study of retracted parts by formwork of concrete surfaces combined with different integrated sound absorbers:
  - using permanent formwork of metal as an integrated part of the reinforcement
  - mapping alternative absorption materials with focus on no possible negative effect on the indoor climate as to fibres in the air, maintenance (cleaning) etc.
  - assessment of the needed area for thermal mass interaction / possible area for sound absorption
  - assessment of the best geometry of the retracted parts (width, length and depth)
  - a special focus on a new type of micro perforated absorbers in collaboration of the Norwegian company DeAmp AS.

- Assessment of porous/open concrete surface:
  The sound absorption may be increased by making the surface less reflective:
  - using porous rendering
  - using openings to hollow structure (resonator absorbers) or similar

Assessment and analyzes of ventilated sound absorbers

- This design principle should, in spite of negative reactions be further assessed since such solutions can solve the sound absorption problem without any direct modifications of the concrete surface:
  - When the sound absorbers are divided into separate elements with limited dimensions with free openings on all four sides, the air exchange should be secured without mechanical air devices. Such a principle should be possible to use for the purpose of using thermal mass of a concrete structure as a stabilizer. However, there are challenges attached to dust, cleaning etc.

Different acoustic element designs will be analysed, in cooperation with sub-project 5.1.

Activity 2: Prototype development

- From the design study (activity 1) we will open a cooperation with manufacturer to make prototypes of integrated acoustic elements:
  - cooperation with producers of sound absorption materials (technique and design)
  - cooperation with the precast concrete industry (formwork, design, reinforcement)
  - preliminary testing of the acoustic properties (different design)

Activity 3: Verification tests in laboratory

- Perform verification measurements (sound absorption coefficient) of final solutions

1 Activity 1. Acoustic element design studies. Assessment and analyzes of different possible design

1.1 Concrete elements with sound absorbers of stiff mineral wool cast to the element

There already exist systems where mineral wool is an integrated part of the concrete element. The mineral wool can be put directly into the formwork. This type of products is already on the market, first of all meant for industrial buildings (factory halls). All the same, the surface of the mineral wool must be covered by a fibre cloth to prevent the mineral wool fibres to spread to the room. Mineral wool products for sound absorption are normally produced with such fibre cloths, often ready painted with a smooth surface. In principle, such product may also be suitable in all types of buildings, also for open plan offices and open plan schools.

However, this kind of absorbers will probably not be suitable for the type of buildings we are looking into, first of all due to the fact that the mineral wool will highly insulate large parts of the surfaces. On the other hand, if it is possible to find alternative materials and solutions for integrated sound absorbers as retracted parts of the concrete elements that has a moderate negative influence for effective use of passive thermal mass, i.e. has a low heat insulating effect, it opens for this type of construction, see 1.2.

1.2 Concept study of retracted parts by formwork of concrete surfaces combined with different integrated sound absorbers:

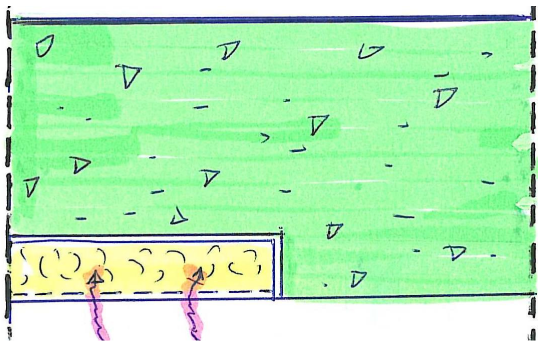


Figure 1.2.1. Integrated sound absorbers in retracted parts of the fomwork

1.2.1 Using permanent formwork of metal as an integrated part of the reinforcement

This idea came up early in a project-meeting when we discussed the possible use of a new technology using laser cut micro slot panels developed by the Norwegian company DeAmp, see 1.2.5. This technology is based on the well known Helmholz resonator principle and implies that the panels must have a fixed distance to the wall or ceiling behind. Therefore it seems like a good idea to look into the possibility of combining retracted parts or boxes to form such geometry to be e.g. a part of the reinforcement of the elements. Perforated front panel in general and especially micro perforated front panel with good metallic contact to the concrete structure through the metallic retracted formwork are positive for the heat interaction

In 1.2.5 we look more closely to the Micro perforated technology (from DeAmp or other possible producers) where the cavity behind the panels only consists of air. One of the large advantages is that this eliminates the use of porous materials, like mineral fibres, traditionally used in acoustic absorbers.

However, at this stage we must also assess other possible materials that can be used as an integrated, retracted part of concrete elements in respect to possible negative effects on the indoor climate and to fitness for effective use of PTM among other things, see 1.2.2 – 1.2.3.

1.2.2 Mapping alternative absorption materials with focus on no possible negative effect on the indoor climate as to fibres in the air, maintenance (cleaning) etc.

Diagram 1.2.2 shows the typical frequency characteristic for different main types of sound absorbers (Sintef Building and Infrastructure, 1996).

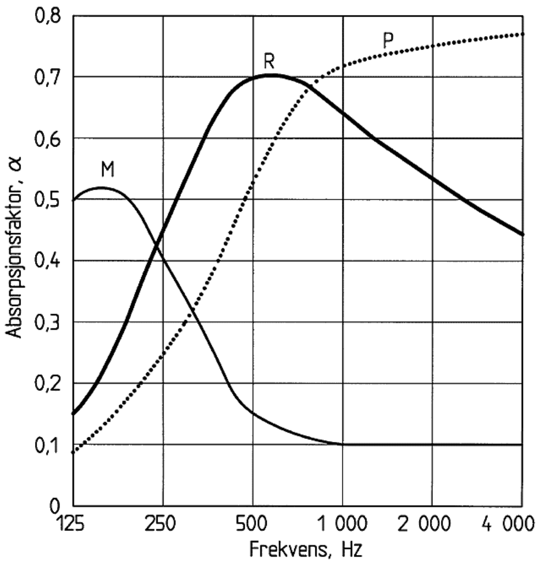


Diagram 1.2.1. Typical frequency characteristic for the different main types of sound absorbers (M = membrane absorbers. R = resonator absorbers. P= porous absorbers)

The most effective type is porous absorbers, and the most common type is mineral wool. In principle, all porous material with an open pore structure can be used for this purpose. They can not be covered by materials that hinder the free propagation of sound wave to penetrate into the porous structure where the sound energy is transformed to heat. We have made a list over possible materials:

- mineral wool
- wood shavings
- textiles

To avoid the problems with fibres in the air, this kind of absorbers are often covered by fibre cloth or similar by the manufacturer. The resistance for mechanical strain is low and porous materials often need to be covered by perforated panels, panels with open slits etc when used in vulnerable areas. In this context the main problem with porous absorbers is that they have a high heat insulating effect and is therefore difficult to combine with effective use of PTM. However, we cannot totally reject the possibility of using porous absorbers if it is acceptable to cover parts of the surfaces, see 1.2.3

The resonator absorbers may have a reasonable good sound absorption characteristic. A special type of interest is micro perforated panels, see 1.2.5.

1.2.3 Assessment of the needed area for thermal mass interaction / possible area for sound absorption

The conflict between the need for sound absorptive materials (that often is highly heat insulating) and the need for free exposed concrete surfaces for effective use of PTM is obvious. In some types of building / areas the need for sound absorption is so large that almost 100 % of the ceiling (or equivalent areas) should be highly absorptive. Other area of utilization has a lower need for absorption.
Calculations or assessment of the needed area for thermal mass interaction should be performed by the specialist on this field to clarify if there is any possibility at all to utilize parts of the surface to sound absorption that at the same time is highly heat insulating. The answer to this should be estimation on a rather rough level, for instance 0 %, 20 %, 50 %.

In January 2009 such calculations have been made (Sartori, 2009). The main conclusion concerning partially covered concrete surface by absorbers (in direct contact with the concrete) is that the effect on heat interaction is linear. However one may obtain some improvement due to two-dimensional effects if the absorbers are mounted in stripes (diffusion of heat "behind" the sound absorber stripe).

This linear effect was as expected, and it is not possible to draw any direct conclusions on how much of the area (in percentage) that must be reserved for direct heat interaction and how much that can be reserved for sound absorbers. However, it is reasonable to conclude any degree of covering is clearly negative for effective use of PTM, at least for highly heat insulation materials. Vice versa the reduction of the area reserved for sound absorbers is clearly negative for the sound environment.

1.2.4 Assessment of the best geometry of the retracted parts (width, length and depth)

The geometry is first of all connected to the thickness of the absorber. Mineral wool absorbers that are an integrated part of the element should have a thickness of at least 50 mm to get reasonable high absorption factor at low frequencies. It is also possible to use thinner products (25 mm) combined with an airspace of 25 – 75 mm behind. This means that a retracted part should at least be 50 – 100 mm. The width and length is a matter of design and standard deliveries from the manufacturer (for instance length x width typically 1200 mm x 600 mm). If we look at the products offered by DeAmp (see 1.2.5) the thickness varies between 40 – 200 mm, typically 100 mm.

1.2.5 A special focus on a new type of micro perforated absorbers made by the Norwegian company Deamp AS or other possible producers.

The products from the Norwegian company DeAmp AS (or other possible producers) are of special interest because this system has an expected lower negative effect on the heat interaction (compared to absorbers of mineral wool etc) when used in front of, or as an integrated part of a concrete structure. In addition the use of materials with no possible negative effect on the indoor climate (no fibres used, only air in the cavity) is a positive factor. DeAmp AS has been contacted to discuss the possibilities for further collaboration. See also 1.3 for the same concept, but as a separate box-absorber mounted beneath the concrete surface.

Micro perforated absorbers are a special type of resonator absorbers with extreme small hole or slot dimensions. A good absorption characteristic is depending of interaction with a cavity behind and often two panels and two cavities are used to get good properties in a broad frequency range. The absorbers may be produced of metal boards / panels or by transparent polycarbonate, see figure 1.2.2.

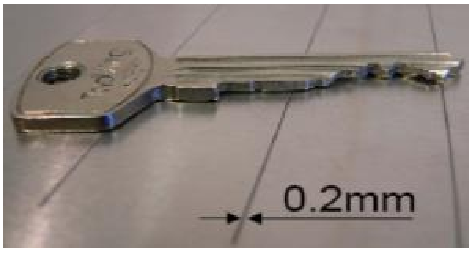


Figure 1.2.2. Micro perforated materials

The home site for DeAmp AS (www.deamp.no) describes the technology and an extract is given in appendix 1.
According to the description concerning "Sound Absorption" (appendix 1) one can achieve very good results in spite of that the high frequency absorption are poorer than for the best porous absorbers. This is confirmed by the results from laboratory tests of sound absorption coefficients that are given at the home site (extracts also given appendix 1). In figure 1.2.3 we have also given test results for single and double panels with a cavity of 100 mm (reference: from power points presentation by Tor Erik Vigran given to the author of this report).

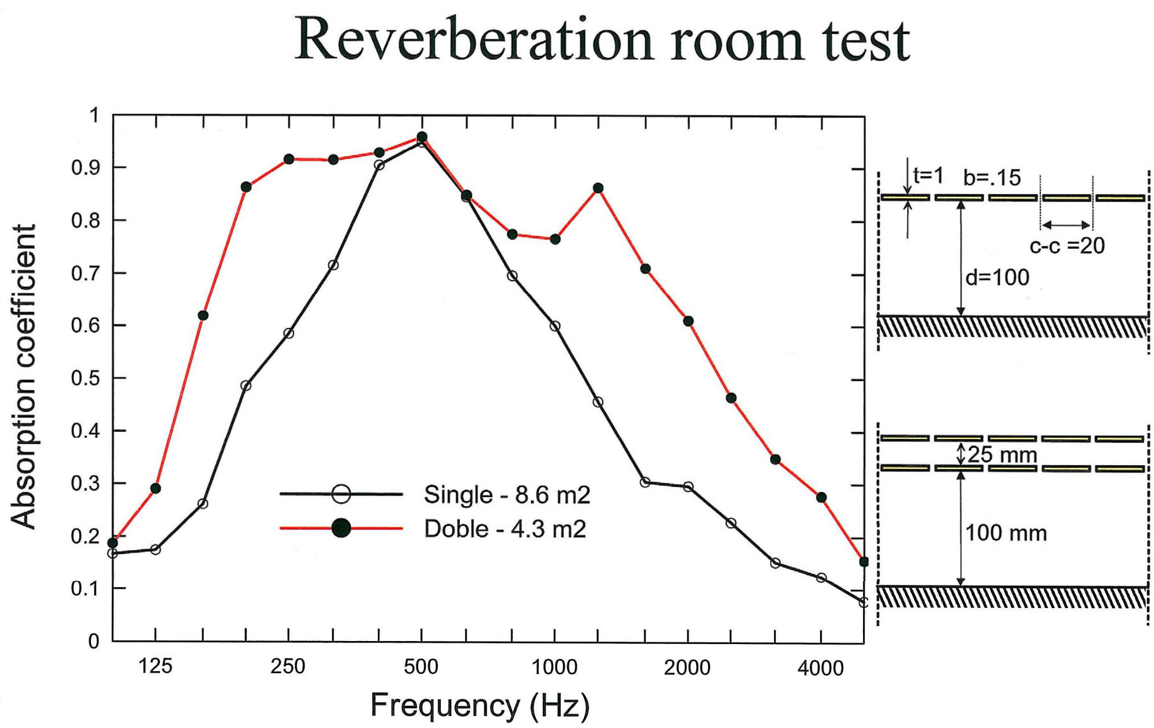


Diagram 1.2.2. Absorption coefficient for single and double panels with a cavity of 100 mm (reference: power points presentation by Tor Erik Vigran).

DeAmp delivers panels both in aluminium and steel (metal series) and in cast acrylic (acrylic series). In appendix 2 we have shown products and technical specifications taken from the product catalogue (www.deamp.no) of both series.

Cooperation with producers of sound absorption materials (technique and design)

We invited DeAmp AS / Pål Ove Henden to the project meeting 06.10.2008 to participate in the discussion of our preliminary report on element design studies and the way further. Pål Ove Henden also presented what they already have done in respect of absorption and PTM and their proposals.

Further collaboration will depend on what design that is suitable based on a total evaluation of the relevant properties.

Cooperation with the precast concrete industry (formwork, design, reinforcement)

We had a preliminary meeting 19.09.2008 with Magne Pedersen from the company Spenncon AS, Hønefoss (Manufacturer of concrete precast elements). The purpose of this meeting is to discuss different possible solutions for integrated acoustic elements (formwork, design, reinforcement, etc). This is a first step in the process of making possible prototypes for further testing.

Another meeting between Magne Pedersen (Spenncon AS, Norway) and Jouni Punkki (Consolis, Finland) was held 02.02.2009 where they planned to discuss the possibilities for "Absorbers as retracted parts by formwork integrated in concrete elements". We have also asked for possible input to alternative design, absorbers connected or hung underneath the concrete surface. The actual discussion was a little postponed and their response is as described below and was sent over 05.02.2009.
The concrete element industry is sceptical but not negative to integrated absorbers in general. Today they cannot see any obvious advantages by retracted parts on the underside of floor elements, but there may be advantages to the total system that they have overlooked at this stage. Some supplemented comments are given below:

- retracted parts will complicate the production process and increase the cost of the slab, but the slip form technique for casting may reduce the complications
- retracted parts will increase the thickness of the slab by the same thickness as the DeAmp boxes (hinder an efficient placing of the strand reinforcement)
- it is probably difficult to utilize retracted steel formwork as an effective part of the reinforcement.
- retracted parts will affect transport, storage and erection (more vulnerable for damages under handling process)
- the absorbers must probably be completed at the building site (extra operations and scaffolding not avoided)

Part conclusion 1.2

From this, we may conclude that the design "Retracted parts by formwork of concrete surfaces combined with different integrated sound absorbers" shown in fig.1.2.1, based on a total evaluation of the relevant properties, cannot yet be confirmed or rejected as a suitable design. In general the acoustic properties may be good if the covered area in percentage is large. The thermal effect is negative if the covered area in percentage is large. The micro perforated technology (from DeAmp or other possible producers) opens for a possible efficient system both thermal and acoustical. Perforated front panel in general and especially micro perforated front panel with good metallic contact to the concrete structure through the metallic retracted formwork are positive for the heat interaction. If this thermal effect of metallic contact is large and dominating, it may perhaps be possible to also use traditional 10-15 % perforated or slit panel with mineral wool in the cavity and still obtain good heat interaction.

Be aware of the fact that the thermal calculations (Sartori, 2009) for the DeAmp system assumed a system of extra metal profiles in the boxes connecting the micro perforated front and the back panel to improve the heat transfer (connected to the concrete not only through the metal frame) and this technique may also be utilized for traditional absorbers with mineral wool and ordinary perforated metallic panels.

The complication of the production process may be a negative factor for this design, but the advantages being a part of the concrete element are possibly a positive factor if additional operations on the building site can be avoided. To use the metallic retracted formwork (along the whole length of the element) as a part of the reinforcement was originally pointed out as a possible advantage, but this must probably be rejected due to high temperature under fire.

From this we recommend, in agreement with the concrete element industry that this design based on the micro perforated technology (from DeAmp or other possible producers) should be investigated further by casting prototypes with hollow core elements before concluding. The possible use of traditional absorbers in combination with 10 -20 % perforated metallic front panel in direct contact with metallic formwork should also be considered.

1.3 Concept study of box-absorbers based on the micro perforated technology (from DeAmp or other possible producers) mounted beneath the concrete surfaces with good metallic contact to the concrete surface:

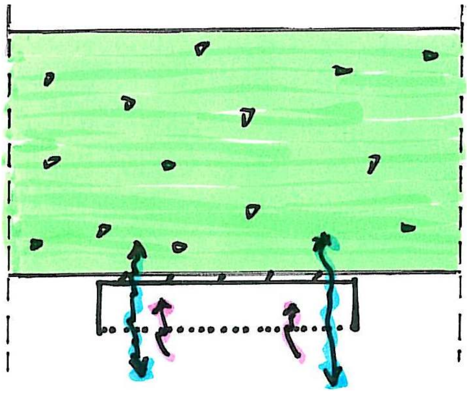


Figure 1.3.1. Box-sound absorbers based on the micro perforated technology (from DeAmp or other possible producers) mounted beneath the concrete surfaces with good metallic contact to the concrete surface.

Since the concept with integrated absorbers in retracted parts by formwork of concrete surfaces (see 1.2) does not have any large thermal advantages and have a large number of negative effects from a production view, we therefore suggest that the thermal effect should be studied for absorbers mounted beneath the concrete surface, but with good metallic contact to the concrete.

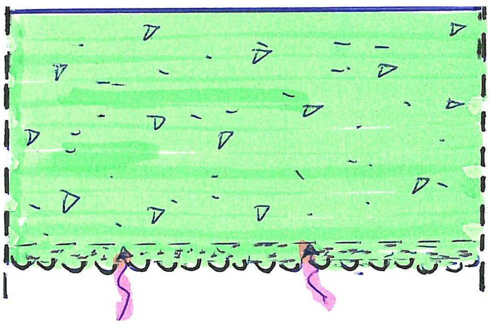
In the "Technology description" from www.deamp.no (see 1.2.5) concerning "Energy efficiency" it is referred to reports on "Active cooling on concrete ceiling" and "Thermal inertia of the building materials". This means that the thermal PTM effect has been evaluated earlier. Corresponding simulations for the technology of the DeAmp products have recently been carried out (Sartori, 2009). Both these and earlier calculations and assessments for the same type of product show better performance than traditional (thermally insulating) absorbers.

Sound absorbers with a good metallic contact with the concrete will transmit heat to the concrete, and so the thermal mass is not strongly de-coupled from the room air. Much depends, of course, on the goodness of the thermal contact between metal and concrete. Simulations (Sartori, 2009) have been done supposing no extra-thermal resistance at the junctions, which is of course an ideal case. Be aware of the fact that the thermal calculations also for this DeAmp system assumes of extra metal profiles in the boxes connecting the micro perforated front and the back panel to improve the heat transfer (connected to the concrete not only through the metal frame) and this technique may also be utilized for traditional absorbers with mineral wool and ordinary perforated metallic panels.

Part conclusion 1.3
From this, we may conclude that the design "Absorbers based on the Micro perforated technology (from DeAmp or other possible producers) mounted beneath the concrete surfaces with good metallic contact to the concrete surface" shown in fig.1.3.1, based on a total evaluation of the relevant properties, opens for a possible good combination of sound absorption and thermal PTM interaction. One large challenge is that compared with traditional sound absorbers of mineral wool, the DeAmp absorbers have a cost (according to information from DeAmp AS by Pål Ove Henden given in COIN-

meeting 06.10.2008) of the order of 5 times higher. This type is not integrated in the concrete element and must be mounted on site.
If the thermal effect of metallic contact is large and dominating, the possible use of traditional absorbers in combination with 10 -20 % perforated metallic front panel in direct contact with the metallic frame should also be considered also for this type.

1.4 Assessment of porous/open concrete surface



Figur 1.4.1. Porous / open concrete surface

1.4.1 General

The sound absorption may be increased by making the surface more open to a hollow structure or with a porous surface. In practice this means that there must be an open structure for air transportation by narrow slits/small holes or between the cement grain and the aggregate into voids in the structure. In the STAR-report we found some references to the effect of open structure (openings to voids or a hollow structure) or adding porous rendering to the concrete surface that we have evaluated.

1.4.2 Small openings to voids/hollow structure

At this stage we believe that using techniques to establish a more open structure with voids in the structure has not the potential that makes it interesting to follow up. It seems to be a complicated production process. It will probably reduce the load bearing capacity of floor elements and the porous structure will reduce the heat exchange. By using element types like “Bubble deck”, it may be of interest to utilize the cavity of the bubbles. However, the conclusion of not following this track must be assessed and verified by the concrete element industry.

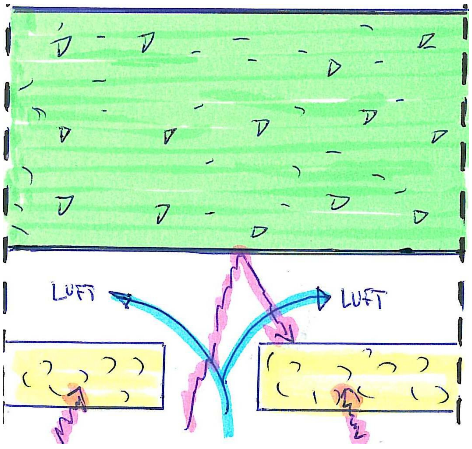
1.4.3 Acoustic, porous rendering

The sound absorption coefficient can be increased by adding a porous rendering directly to the concrete surface. This is a well known technique. However, the rendering must be both relatively thick and extremely porous to get good results. At this stage we believe that use of porous rendering will not give sufficiently high sound absorption for the use we have in mind. At the same time thick rendering will lead to other problems, for instance rough surfaces hard to clean and an insulating effect that is negative in our context.

Part conclusion 1.4

From this, we may conclude that the design “Porous/open concrete surface” shown in fig.1.4.1, based on a total evaluation of the relevant properties, is not suitable. The concrete element industry states that the rendering would have to be applied on site (or in a second operation), and this is not a favourable system in proportion neither to technique nor to cost.

1.5 Assessment and analyzes of ventilated sound absorbers (horisontally suspended ceiling)

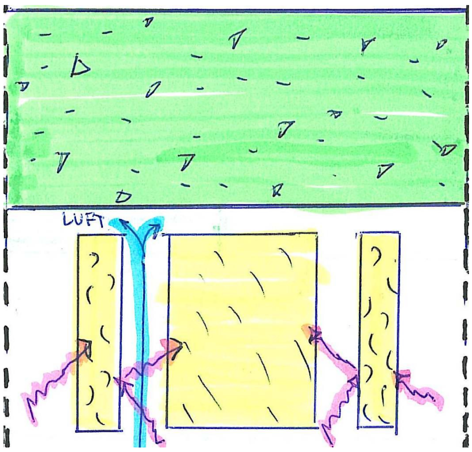


Figur 1.5.1. Ventilated sound absorbers (horisontally suspended ceiling)

The design principle for ventilated sound absorbers is to direct the indoor air behind the sound absorbing elements to get in direct contact with the surface of the main construction (for instance over suspended ceilings). The sound absorption of the ceiling may be quite good. Even if the sound absorbers are divided into separate elements with limited dimensions and free openings at all four edges, the air circulation will probably be hampered and the convective heat exchange will be reduced. From a thermal view proper ceiling ventilation must be provided (fans or ceiling diffusers). However, such a concept has severe challenges attached to dust, cleaning etc. Possible additional need for mechanical air moving devices is another negative factor.

Part conclusion 1.5
From this, we may conclude that the design “Assessment and analyzes of ventilated sound absorbers (horisontally suspended ceiling)” shown in fig.1.5.1, based on a total evaluation of the relevant properties, is not suitable.

1.6 Vertical sound absorber pads or baffles



Figur 1.6.1. Vertically sound absorber pads or baffles

An alternative to ventilated sound absorbers (suspended absorptive ceiling divided into smaller elements) is to use discrete sound absorbers like rectangular unit sound absorber pads or baffles. The baffles will then hang vertically from the ceiling and may be arranged in rows or groups. The vertical mounting normally gives a large surface area compared to a horizontal absorber. Consequently it opens for a very good sound absorption when using porous materials inside covered with free choice among a large number of materials having a free opening of about 20 % (perforation, slits etc.). The mounting allows free passage of air exchange to the main ceiling of the concrete structure and the utilization of PTM is little affected (what about thermal radiation? This must be verified). Just a small area of the absorbers will be horizontal, and the danger of dust depots on these parts is little. The use of materials, the height, the thickness and the mounting closeness of the baffles will decide the sound absorption properties. Dust on small horizontal parts may be reduced by letting the surface be curved or sharp pointed. The challenge with such a product is to find a good design that opens for good light distribution and at the same time gives space and covering for technical installations (ventilation pipes and outlets.).   The principle may also be used in front of walls etc.

This is perhaps the most obvious and relevant way to solve the challenge for effective use of passive thermal mass when you at the same time must add a large amount of absorption to the room. The geometry and the pattern of the sound absorber pads or baffles can vary. Such a system opens for highly absorptive elements with a large surface area relative to the area of the ceiling. However it must be verified that this type of sound absorber pads will not cause problems obtaining an effective thermal interaction with the main concrete structure above. Such a study should include some limits for typical recommended geometry (distance between baffles, heights, orientations etc.) that will effect the thermal interaction at a low and acceptable degree.

In January 2009 such simulations for sound absorber pads or baffles have been made (Sartori, 2009). These simulations show that sound absorber pads or baffles has negligible negative effect on thermal PTM interaction, but we have to be careful about one thing. Vertical baffler will affect the ceiling heat exchange both in terms of radiation exchange with the other surfaces and in terms of convective exchange with the room air. The simulations show that altering the path of radiation heat exchange has a negligible effect. On the other hand, convection heat exchange may be compromised, and this would be equivalent more or less to a half covered ceiling with horizontal sound absorbers. So, displacement and distance from ceiling surface should be such to not hamper significantly the otherwise free air motion. In combination, ceiling diffusers that would increase convective transfer on the ceiling surface would help.

Sound absorber pads or baffles may be designed with front material and design adapted to the choice of materials in the room. The inner materials may be of traditionally porous materials. Such sound absorber pads may also be made two sided according to micro perforated principle from DeAmp or other possible producers.

Those sound absorption elements will be totally separate from the concrete structure and will never be a product to be integrated in concrete elements. On the other hand it may be a product that can be a part of a product selection to solve the acoustical problem.

Part conclusion 1.6
From this, we may conclude that the design “Vertically sound absorber pads or baffles” shown in fig.1.6.1, based on a total evaluation of the relevant properties, is highly suitable. The acoustic properties may be very good and has a low influence on the thermal PTM effect. However, it is not integrated in the concrete element and must be mounted on site.

This design is in principle on the market already and it is not likely that the concrete industry will profit directly of a possible further development.

2 Design evaluation and further work

2.1 General

According to original project plan we shall, from the results of the design study open for cooperation with manufacturer to make prototypes of integrated acoustic elements or separate acoustic elements adapted for use combined with PTM including preliminary testing of the acoustic properties (activity 2). The next step in the project plan was to perform verification test in laboratory of the sound absorption of final solutions (activity 3).

2.2 Proposal for prototypes for further testing of acoustic properties

From activity 1 concerning acoustic element design studies, we have assessed the following types of absorbers as positive or possible positive:

2.2.1 Retracted parts by formwork of concrete surfaces combined with different integrated sound absorbers

In general the acoustic properties may be good. The thermal effect is in general negative, but the micro perforated technology (from DeAmp or other possible producers) opens for a possible efficient system both thermal and acoustical. However, the price for the DeAmp technology and the complication of the production process may be negative factors for this design. The slip form technique for casting may reduce the complications. The fact that the absorber will be an integrated part of the concrete element is on the other hand a possibly positive factor, especially if additional operations on the building site can be avoided. Jouni Punkki (Consolis, Finland) and Magne Pedersen (Spenncon, Norway) is prepared to join in discussions for cast prototype elements for testing of the production process and the finished product. This also implies further collaboration with Pål Ove Henden (DeAmp AS). If the thermal effect of metallic contact is large and dominating, the possible use of traditional absorbers in combination with 10 -20 % perforated metallic front panel in direct contact with metallic formwork should also be considered. Extra metal profiles connecting the front and the back panel to improve the heat transfer (not only through the metal frame) is assumed for both types.

2.2.2 Box-absorbers based on the Micro perforated technology (from DeAmp or other possible producers) mounted beneath the concrete surfaces with good metallic contact to the concrete surface.

The design is basically similar to the design described in 2.2.1, but the absorber is not integrated in the concrete element. The absorber must be mounted on site implying additional operations and scaffolding, but does not affect the production of the concrete elements. The price for the DeAmp technology may still be a negative factor. If the thermal effect of metallic contact is large and dominating, the possible use of traditional absorbers in combination with 10 -20 % perforated metallic front panel in direct contact with the metallic frame should also be considered also for this type. Extra metal profiles connecting the front and the back panel to improve the heat transfer (not only through the metal frame) is assumed for both types.

2.2.3 Vertical sound absorber pads or baffles.

Based on a total evaluation of the relevant properties, this design is highly suitable. The acoustic properties may be very good and the absorbers have a low influence on the thermal effect. However, it is not an integrated part of the concrete element and must be mounted on site implying additional operations and scaffolding. The heights of vertical absorbers must be relatively high. The absorbers may be produced of traditional sound absorption materials, but the use of Micro perforated technology (from DeAmp or other possible producers) is also possible. However, this design is in principle on the market already and it is not likely that the concrete industry will profit directly of a possible further development.

Oslo, 06.03.2009

Sigurd Hveem

References

1) Hveem,Sigurd. COIN project report. STAR report (State of The Art Review) of the sub-project 5.2 "*Comfortable buildings and constructions*" Oslo, 17.09.2007

2) SINTEF Building and Infrastructure. Building Research Design Sheet no: 543.414. Sound absorbing properties for materials and constructions. Oslo, 1996.

3) Sartori, Igor. COIN project report. Simulations of thermal effect. SINTEF Building and Infrastructure, Report on COIN sp 5.1 available march 2009", Oslo, 2009

From www.deamp.no (product catalogue): Appendix 1

Technology

DeAmp is developing and marketing acoustical ceilings and walls, utilizing a revolutionary technology; laser cut acoustic micro slots. Sound absorption by micro slotting makes it possible to exploit new indoor areas with smooth surfaces and excellent finish. The technology also eliminates use of mineral fibers, traditionally used in acoustic absorbers.

Unique Patented Technology

DeAmp's technology is developed during 10 years of research at SINTEF and The Norwegian University of Science and Technology. The technology is based on the well-known acoustic principle Helmholtz resonator. DeAmp's unique technology utilizes laser cut micro slits to perforate the surface. When sound waves, defined as compressed air, hit the perforated surface an overpressure arises on the front of the panel. To equalize the pressure, the compressed air is forced through the micro slits, and viscous forces between the very narrow slit and the air causes friction. Hence the sound waves are absorbed and transformed into heat without use of any porous fiber-materials. The technology is internationally patented by DeAmp.

Excellent Esthetical Properties

Our sound absorbers offer excellent esthetical properties treasured by architects. We offer clean and smooth surfaces and a wide variety of colors and surface finishes. DeAmp's absorbers can be anodized, painted, engraved or printed on, and because they are fiber free they can be transparent, translucent or colored. Panels can be mounted in traditional ceiling suspensions, directly on walls, as panel elements in office furniture systems or stand alone partition walls.

The Safe and Healthy Alternative

Fiber free sound absorbers ensure a better indoor environment, especially for children and people with respiratory disorders. The products do not emit fiber particles, nor do they collect dust in the slits. They do not absorb moisture, which can lead to fungi and rot, and they are easy to clean with water based products. These benefits reduce costs related to sick leave, loss of productivity and maintenance of facilities.

Dust from porous materials can be inflammable and create life-threatening hazards because of limited visibility and breathing difficulties in a fire emergency. DeAmp metal absorbers are made from 100% solid aluminum or steel without the use of porous layers or fiber membranes.

High Light Reflection

The laser cut micro perforated slits are less than 0.2mm wide and therefore barely visible at a normal distance from the ceiling. They cover less than 1% of the panel surface and consequently over 99% of the material is left as a reflecting area. By utilization of the reflecting or transparent surfaces, DeAmp panels can lead the light into the room, something which has been difficult with traditional sound absorbers. Exploitation of daylight reduces lighting costs, and improves the users' well-being.

Energy Efficiency

Traditional suspended fiber based ceiling systems, in combination with active cooling in a concrete ceiling, will reduce the performance of the cooling system. The fibers will work as an insulating layer, and hence increase the energy consumption of the cooling system. Scientific reports on the energy efficiency of DeAmp products, states that this increase can be reduced with 50% by using DeAmp's aluminum absorbers compared to traditional fiber absorbers. The effect will also be considerable when utilizing the thermal inertia of the building materials to keep the temperature at a comfortable and more stable level during the shifting day and night conditions.

Sound Absorption

Compared to the best porous absorbers, micro perforated products perform somewhat poorer in higher frequencies. However, higher frequencies are more easily absorbed by furniture, people and surface elements in the room. Therefore excellent acoustic conditions can still be achieved based on the high absorption at low and middle frequencies. Scientific measurements from our reference projects show that values are below the required reverberation time for the whole frequency band.

From www.deamp.no (product catalogue): ***Appendix 2***

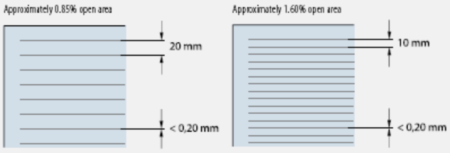
Metal series

Metal Ceiling

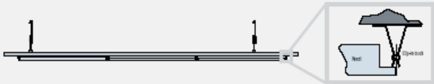
Perforations

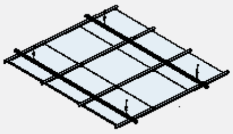
Approximately 0.85% open area

Approximately 1.60% open area

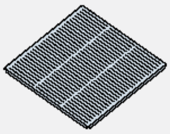


Clip-in Ceiling Panel



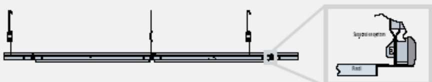


Typical suspension system for clip-in ceiling panels



Clip-in panel, module 600x600 mm

Lay-in Ceiling Panel

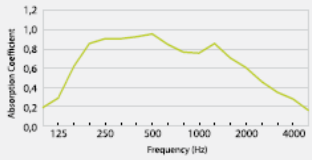


Technical Data

Material	aluminum or steel
Thickness	from 0.7 mm to 1 mm
Size	standard 600x 600 mm / 600 x 1200 mm customizations available
Color	standard RAL 9010 all NCS- and RAL coded colors available
Sound absorption	NRC 0.50 to 0.80
Fire standards	UK, BS 476 Part 7 - Class 1

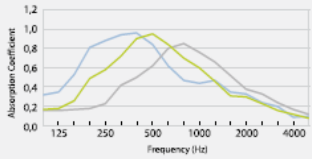
Sound Absorption

The absorption coefficient is adjustable to the desired frequency area.



Suspension height, H (mm):
Layer 1: 100 mm 1)
Layer 2: 125 mm

This figure shows the absorption coeffecient using double layers mounted 100 mm and 125 mm from the noise reflecting surface.



Suspension height, H (mm):
200mm 2)
100mm 1)
40mm 2)

This figure illustrates the absorption coefficient when the absorbing panel is placed respectively 200, 100 and 40 mm from the noise reflecting surface behind.

H (mm)	125	250	500	1000	2000	4000	NRC
100 / 125 [1]	0.29	0.91	0.96	0.76	0.61	0.28	0.80
40 [2]	0.16	0.23	0.62	0.76	0.38	0.17	0.50
100 [1]	0.18	0.58	0.95	0.60	0.30	0.12	0.60
200 [2]	0.35	0.88	0.84	0.44	0.33	0.09	0.60

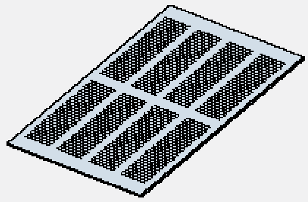
1) Measured results from SINTEF/NTNU acoustic laboratory. All tests are performed by Professor Tor Erik Vigran.

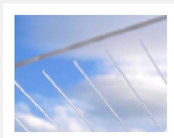
2) Calculated results.

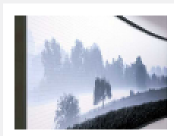
Panel Absorber

DeAmp panel absorbers are perfect for use in facilities with extensive use of glass, concrete and other hard surfaces. Our panels can be mounted directly on the wall, or in front of windows, pictures or light sources. It is also possible to print directly on the panels. DeAmp corner absorbers can be installed towards ceilings or walls and deliver excellent absorption performance compared to its limited size.

Product Options





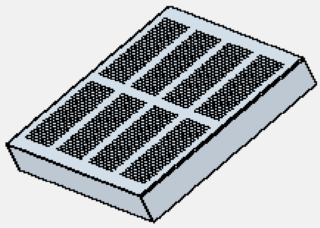


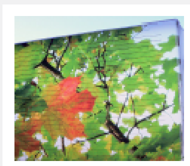
Size	standard 600 x 600 mm customizations avaiable
Maximum size	2000 x 3000 mm
Tickness	from 4 mm to 15 mm

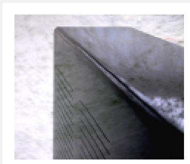
Box Absorber

DeAmp box absorbers are very easy to install without the need for any additional suspension or mounting system. They are suitable in small installations or as building blocks in larger installations. In addition they can be customized with printing and fitted for home theater use.

Product Options







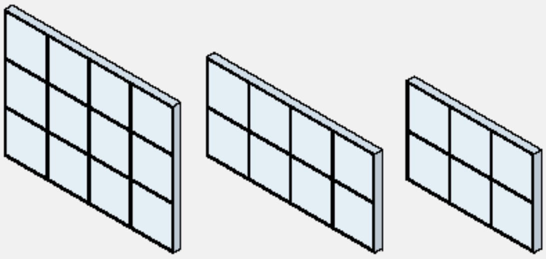
Height	700 mm
Width	700 mm
Depth	100 mm

From www.deamp.no (product catalogue): *Appendix 2 cont.*
Acrylic series

Framed Wall Absorber

DeAmp framed wall absorbers are perfect for small renovation projects or as supplementary product to acoustical ceiling tiles. It is also suitable in buildings where acoustical ceiling tiles can not be used. DeAmp framed wall absorbers can be mounted directly on the wall or used in front of windows or light sources to create a stylish effect. The product is compounded of our standard 600 x 600 mm acrylic panels and prefabricated MDF frameworks. Panels and frameworks are available in various colors and customized sizes.

Product Options



Height	1816 mm	1217 mm	1217 mm
Width	2415 mm	2415 mm	1816 mm
Depth	110 mm	110 mm	110 mm

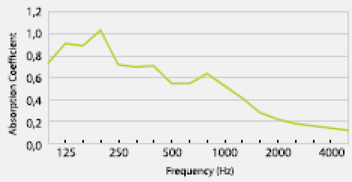
Technical Data

Material		cast acrylic (PMMA) ¹⁾
Thickness		from 4 mm to 15 mm
Size		customizations available
Color		colored, transparent or translucent
Sound absorption		NRC 0.45 to 0.55
Flammability	UK, BS 476 Part 7 - Class 3	UL94 - HB
	DIN 4102 - B2 ¹⁾	ISO 11925-2 - E
	NFP 92-507 - M4	

¹⁾ *Also available in PETG with flammability class B1 (DIN 4102) / class 1Y (UK, BS 476 Part 7)*

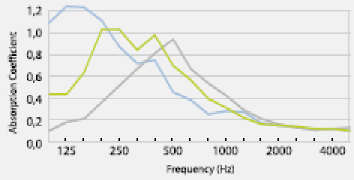
Sound Absorption

The absorption coefficient is adjustable to the desired frequency area.



Suspension height, H (mm):
Layer 1: 110 mm ²⁾
Layer 2: 130 mm

This figure shows the absorption coeffecient using double layers mounted 110 mm and 130 mm from the noise reflecting surface.



Suspension height, H (mm):
197 mm ²⁾
97 mm ²⁾
54 mm ²⁾

This figure shows the absorption coefficient when the absorbing panel is placed respectively 197, 97 and 54 mm from the noise reflecting surface behind.

H (mm)	125	250	500	1000	2000	4000	NRC
110 / 130 ²⁾	0.90	0.71	0.54	0.52	0.22	0.14	0.50
54 ²⁾	0.19	0.52	0.94	0.43	0.17	0.13	0.50
97 ²⁾	0.44	1.03	0.70	0.32	0.16	0.13	0.55
197 ²⁾	1.24	0.87	0.46	0.29	0.16	0.13	0.45

²⁾ *Measured results from tests performed by SINTEF ICT according to ISO 354 and ISO 11654.*

Acrylic series. From www.deamp.no (product catalogue)

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.