A: Design & technology
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CONCRETE CORE ACTIVATION AND SUSPENDED CEILINGS: DESIGNING FOR COMFORT, ENERGY EFFICIENCY AND GOOD ACOUSTICS

Martijn LS Vercammen[1,*]

[1]Peutz bv, Mook, The Netherlands

*Corresponding email: m.vercammen@peutz.nl

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SUMMARY

Thermally activated concrete slabs (concrete core activation) offer an interesting possibility to control the indoor climate. The important drawback of thermally activated floors is the acoustics. To control sound levels in a space, sufficient sound absorbing material has to be applied. For practical reasons, also cost efficiency, this sound absorbing material is often realized as a sound absorbing suspended ceiling.

Generally sound absorbing material is also thermally insulating, which will have a considerable negative effect on cooling and heating capacity. To show the influence of the configuration of ceiling elements on the sound absorption, a series of measurements have been performed on a mineral wool ceiling. To determine the influence of the free hanging ceiling on thermal capacity of the activated concrete slab, a mock-up has been constructed in a climatic chamber.

From laboratory studies, both regarding acoustic and climatic behaviour, it appears that both reduction of the sound absorption and cooling capacity is less than proportional to the surface of the ceiling elements. The thermal capacity is dominated by the convection air flow between ceiling elements and floor slab. Depending on the type of ceiling material and configuration, an optimum for thermal capacity and sound absorption can be obtained.

INTRODUCTION

Thermally activated concrete slabs (also called concrete core activation or TABS: Thermally Activated Building Systems) offer an interesting possibility to control the indoor climate. Especially the large surface enables low temperature heating and high temperature cooling, thus enabling the use of sustainable energy sources. Transport by water is a space efficient way of transport of energy through the building. The mass of the floor provides stability in the temperature and the use of overnight cooling. As long as no high demands are set to the temperature regulation, the system is sufficiently self-regulating. The cooling capacity is less than the cooling capacity of special cooling ceilings.

The important drawback of thermally activated floors is the acoustics. To control sound levels in a space, sufficient sound absorbing material has to be applied. For practical reasons, also cost efficiency, this sound absorbing material is often realised as a sound absorbing suspended ceiling. Generally sound absorbing material is also thermally insulating, which will have a considerable negative effect on the cooling and heating capacity. When applying this system, both the thermal as well as the acoustic comfort should be considered to find an optimum for each specific situation.

The use of separately suspended sound absorbing elements (horizontal or vertical baffles), allow the air to flow around and transfer the energy from the floor slab to the space. However both conductive as radiated energy flow will be influenced by these baffles. Aim of the current research is to quantify to which extend different suspended ceiling configurations reduce the thermal capacity of the thermally activated concrete slabs, and to relate this to the sound absorption.

We will first discuss the influence of these ceiling types on sound absorption, then on cooling capacity.

SOUND ABSORPTION OF OPEN CEILINGS

Two acoustical effects of free-hanging ceiling elements occur, compared to fully and closed suspended ceilings.

The first effect is that having separate ceiling elements, parts of the sound reflective floor slab will not be covered with absorption material anymore, and locally reflections will appear at the concrete slab above the ceiling. Of course this effect depends on the width of the open area and the location of source and receiver. In practice, no problems have been found in case of open strips with a width of less than 0,5 m. When larger areas of non-covered floor slabs occur, the layout of the interior and the ceiling configuration have to be coordinated.

The second effect is the influence of the reduced ceiling surface on the total absorption. The reduction of surface will inevitably lead to a reduction of sound absorption. To show the influence of the configuration of the ceiling elements on the sound absorption, a series of measurements have been performed on a mineral wool ceiling with a thickness of 25 mm [1]. The ceiling is mounted upside down with a mounting height of 200 mm. The sides are “closed” with a plywood slab. The sound absorption is dependent on the mounting height. The absorption is relatively high at the frequency where the thickness corresponds to $\frac{1}{4}\lambda$, for which maximum particle velocity will occur at the position of the ceiling material.

Figure 1 shows the measurement results according to ISO 354, with the ceiling mounted at 200 mm above the floor of the reverberation room. The number of elements (sized 0.6 x 1.8 m^2) is varied between 1 and 10, in different configurations, and the absorption coefficient shown is the measured absorption (in m^2) related to the ceiling area.

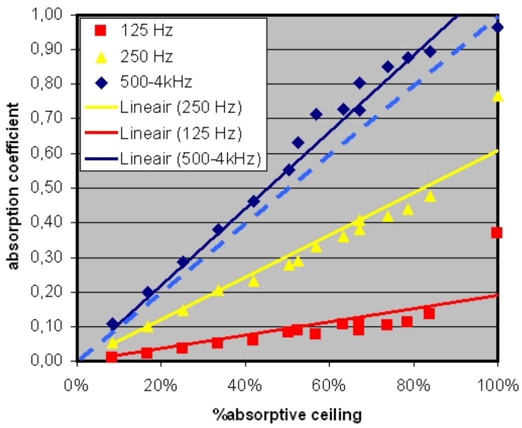

Figure 1. Sound absorption of 25 mm mineral wool ceiling tiles, mounted at 200 mm, for different ceiling elements configurations, expressed in area covered.

The results for the 125 Hz and the 250 Hz octave bands are presented separately. These octave bands show a sudden drop in the sound absorption from a closed (100%) to a free-hanging ceiling (<90%). This drop depends on the material: for mineral wool with considerable thickness, the drop will be less. For low thickness material (e.g. felt on a perforated metal sheet) the drop will be more pronounced.

In case of an open ceiling, the absorption is almost linear to the area of the material for these low frequencies.

As for the average absorption in the 500 Hz to 4 kHz bands it can be seen that reducing the absorptive area from 100 to 80% will hardly reduce the sound absorption. For these higher frequencies the reduction in absorption is less than proportional to the reduction of ceiling surface. This is an important aspect, since most of the energy of speech is in these octave bands. The open areas will also absorb energy since the sound waves will enter the open area between suspended ceiling and floor, where the absorptive backside of the ceiling will remove the sound energy. Although there still is a relation between absorption and the area of the material, the correlation in figure 1 is not perfect. A better correlation [1] can be obtained if we consider the open area between suspended ceiling and floor:

$$A_t = S_{ceiling} \cdot \alpha_s + S_{edge} \cdot \alpha_{edge} \qquad [m^2] \qquad (1)$$

where α_s is the absorption of the closed ceiling in the standard mounting, S_{edge} is the open area at the sides and α_{edge} is the assumed effective sound absorption of the open edge area (see also figure 2).

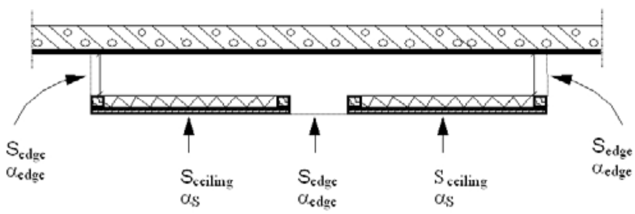

Figure 2. Indication of the open edge area.

COOLING CAPACITY WITH SUSPENDED CEILINGS

To determine the influence of the free hanging ceiling on the thermal capacity of the activated concrete slab, a mock-up has been constructed in a climatic chamber (see figure 3). In this room the cooling of the concrete ceiling was controlled in order to obtain a constant value of the surface temperature. The room temperature was kept constant by using heating elements conform NEN EN 14240 which transfer heat by both radiation and convection. These elements simulate the heat transfer of persons and office equipment in the room.

Figure 3. One of the investigated ceiling configurations in the climatic chamber consisting of 40 mm mineral wool.

Several suspended ceiling configurations have been tested, consisting of 40 mm mineral wool (see figure 4) [2]. Each ceiling configuration with ceiling contained six open lighting fixtures. The height of the gap between the concrete ceiling and the suspended ceiling, as well as the percentage suspended ceiling surface compared to the surface of the concrete ceiling has been varied.

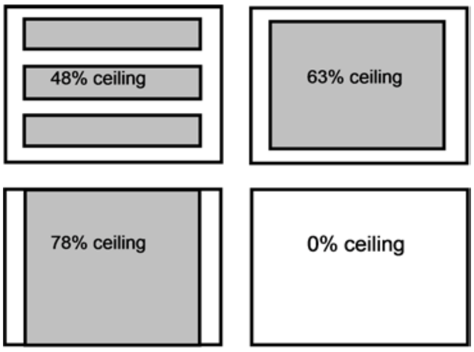

Figure 4. Measured configurations for cooling capacity.

The influence of the suspended ceiling on the cooling capacity of the concrete slab is given in figure 5. Here, 100% capacity represents the capacity of the situation without suspended ceiling.

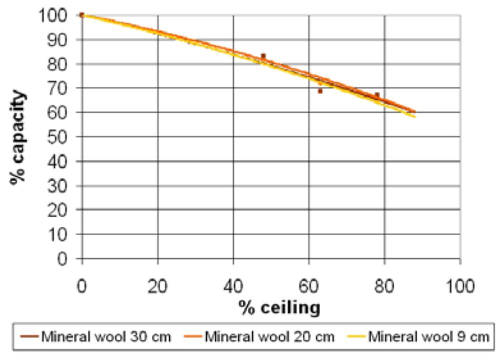

Figure 5. Thermal capacity of 40 mm mineral wool ceiling tiles mounted at different heights and metal baffles, both for different sizes of the ceiling elements.

The graph in figure 5 shows that, as expected, the thermal capacity of the concrete reduces with increasing ceiling area. However, the reduction of the cooling capacity is less than proportional to the coverage of the floor slab. If half of the concrete is covered with a suspended ceiling of 40 mm mineral wool, the thermal capacity reduces with approximately 20%. The height of the cavity between the suspended ceiling and the concrete does seem to affect the reduction of cooling capacity by only a few percent. The position of the light fixtures enables efficient discharge of heat from the space.

In a recent study for Ecophon a similar setup was investigated. The change in cooling capacity was monitored based on constant operative temperature, including the effects of radiation on thermal comfort. In our 3x5 m^2 climatic chamber 6 ceiling panels (Ecophon Solo Square) of 1,2x1,2 m^2 were suspended (effective coverage 58%) with an air gap of 26 cm, in two configurations: A: evenly distributed and B: clustered together, see figure 6.

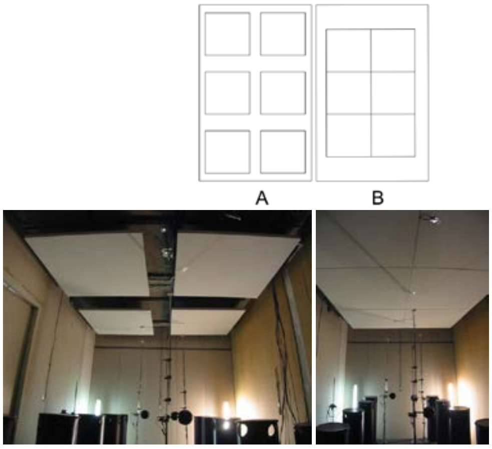

Figure 6. Configurations of ceiling elements tested.

The reduction of cooling capacity with configuration A is 33%, with configuration B it is 37%. This is a slightly larger reduction than obtained from the first study, as indicated in figure 5. The reason for this difference may be the absence of light fixtures in this test. Figure 7 shows the temperature as a function of height. In configuration B the concrete slab is less capable of transferring its energy to the room, resulting in a lower surface temperature. The difference in air temperature above and below the ceiling is smaller with configuration A, indicating a better air exchange. From these results it can be concluded that an equal distribution of elements, with openings in between, is better than large element surfaces.

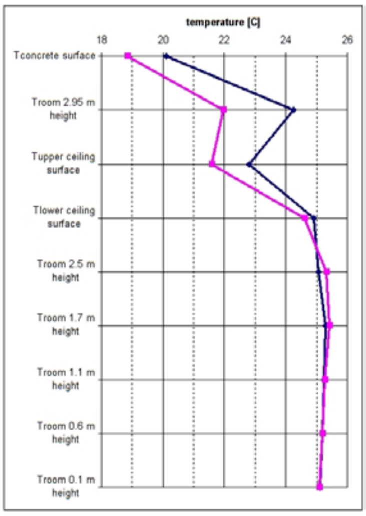

Figure 7. Temperature as a function of height. Blue: A, Purple: B.

In a recent field study [3], the temperature in an office with separate ceiling elements (the Ecophon Solo Square, as in the laboratory study, coverage 58%) was compared to the temperature in an identical office without ceiling elements. The temperature raise was about 0,3 K. A second test with 70% coverage showed an increase in temperature of 0,9 K. Although the influence on cooling capacity was not determined in this case, the results indicate an acceptable change, at least with 58% coverage.

COMBINING ABSORPTION AND COOLING CAPACITY

The sound absorption of the mineral wool ceiling configurations of the first investigation in the climatic chamber have also been measured in the reverberation room according to ISO 354. In figure 8 both the thermal and the acoustic results are presented for different coverage percentages with a cavity of 200 mm.

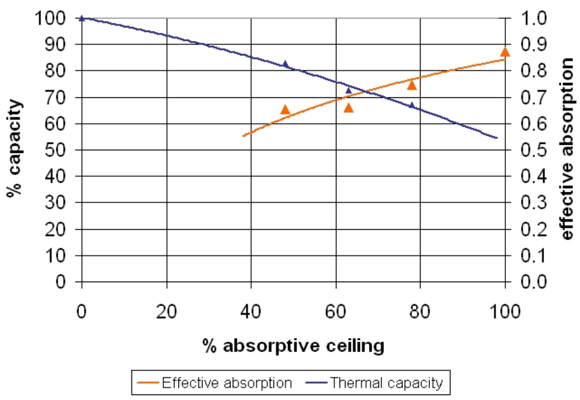

Figure 8. Thermal capacity of 40 mm mineral wool ceiling tiles mounted at 200 mm and effective absorption averaged over octave band from 500 Hz – 4kHz of the same ceiling.

In practice, for a single office an effective sound absorption of 0.65 is required. This means in this case (applying a ceiling type as in figure 8) a percentage absorptive ceiling of 50% to 60%, which reduces the thermal capacity with 20 to 33%. If a higher thermal capacity of the concrete is required, ceiling elements need to be reduced and additional sound absorption has to be applied on vertical surfaces.

For landscaped offices a larger absorption coefficient is required: 0.8 or higher. This implies a suspended ceiling of 85% of the floor area or larger. For the tested ceiling configuration the reduction of the thermal capacity, when applying a suspended ceiling that covers the concrete with 85%, is approximately 40%.

The cooling capacity of the thermally activated floor depends on specific factors such as the air exchange between void between ceiling elements and floor and the space. Driving force for this air exchange will be the influence of façade and may be thus be different for different situations. The thermal insulation of the ceiling tile influences the surface temperature of the underside of the ceiling elements and thus the radiation temperature. Also the way the heat from light fixtures is discharged influences the heat balance.

CONCLUSIONS

The use of thermally activated floor slabs is a cost efficient way to realise sustainable buildings with good climatic conditions.

However, the acoustic consequences should be taken into account. From laboratory studies, both regarding acoustic and climatic behaviour, it appears that both the reduction of the sound absorption and cooling capacity is less than proportional to the surface of the ceiling elements.

At higher frequencies (500 Hz – 4 kHz) the actual absorption of the open edge contributes to the total absorption of the ceiling panels.

The thermal capacity is dominated by the convection air flow between ceiling elements and floor slab. Also the underside of the ceiling elements may contribute to a lower radiation temperature.

Depending on the type of ceiling material and configuration, an optimum for the thermal capacity and sound absorption can be obtained. This optimum depends on several factors such as room type, the room acoustical requirements, the cooling capacity that is required and building characteristic such as façade and solar shading.

Project specific research in a climatic chamber can be used to optimise the design and obtain the correct values regarding cooling capacity.

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