inter noise
2013 | INNSBRUCK | AUSTRIA
15.-18. SEPTEMBER 2013
NOISE CONTROL FOR QUALITY OF LIFE

Combining thermally activated cooling technology (TABS) and high acoustic demand: Acoustic and thermal results from field measurements

Yoan Le Muet[1], Hanneke Peperkamp[2], Rainer Machner[3]

[1] Saint-Gobain Ecophon, Rantigny 60290, France

[2] Peutz, Mook 6585 ZH, The Netherlands

[3] Saint-Gobain Ecophon, Lübeck D-23556, Germany

ABSTRACT

New office buildings use thermal capacity of the structure mass to provide thermal comfort. This technique provides stable thermal conditions and is perceived to be a long-term energy efficient solution. A priori, this kind of technique is not compatible with traditional suspended ceilings, covering a room from wall to wall. This is due to the fact that the ceiling, positioned between the soffit and the users, would then be a mask for radiation and would stop convection. How then can we quantify their acoustic and thermal impact on slab's cooling capacity? In order to investigate the subject we performed dynamic measurements in the summer period of June to August 2012 in the Woopa building located in Lyon, France. The aim of this research was to quantify the reduction of the cooling capacity due to a glass wool suspended ceiling by measuring the temperature increase in the room. The purpose of this paper is to show the acoustic and thermal tests that have been conducted, the set-up used, the measurement methods, as well as to present examples of projects and give data to encourage dialogue and coordination between the acoustician and other building engineering disciplines.

1. INTRODUCTION

1.1 Trend within Europe

Thermal performance is increasingly taken into consideration in the programming and design of European office buildings. With concerns about climate change, stringent legislation and political pressure to meet sustainability targets, the trend to design energy-efficient buildings continues to grow. A popular way to design energy-efficiently is to use a Thermally Activated Building System, also referred to as TABS. In short, TABS creates an effective cooling system using the thermal mass of the building; the concrete keeps the heat out during the day, maintaining a cool interior. It is a system that is increasingly being used for new buildings in France, Germany, UK and the Benelux area.

Many of these offices are using the thermal capacity of the structure mass to provide thermal

[1] yoan.le-muet@saint-gobain.com
[2] h.peperkamp@peutz.nl
[3] rainer.machner@saint-gobain.com

comfort. The thermal issues require the structure (typically concrete) to remain exposed to the room environment. Traditional fitting surfaces, such as wall-to-wall suspended ceilings, are said to be inappropriate. The challenge is to combine this constraint with acoustic requirements for office spaces, described through reverberation (RT) and propagation (D2s). Projects using inertia point out the importance of interaction of acoustic treatments with (prefabricated) concrete elements, lighting, ventilation and cable management. Finally, they emphasize the need for dialogue and coordination between the acoustician and other building engineering disciplines.

As of now, most national regulations on thermal performance for office buildings defines challenging target values around 50 kWhPE/m²/year for the total energy consumption of the building in use. In general, the energy consumption of an office building is shared between 40% for equipment (computers, servers, copy machines, etc.), 40% for lighting and 20% for ventilation and air conditioning. An efficient way to reach this value is to avoid air conditioning, which is a high consumer of energy. The solution is to use the thermal mass of the concrete core: baring walls, soffits, etc. for summer cooling. For physical reasons, the surface that contributes most to comfort is supposed to be the ceiling [1]. Therefore, the slab should be as exposed to the room as possible, in order to facilitate the energy transfer. The principle is that the structure of the building, and particularly the slab contributes to the cooling of the ambient air during summer days. The energy transfer between elements with high thermal mass and the room is made through both convection and radiation.

But while TABS is a proven way to meet energy-efficiency regulations, it creates challenges of its own in terms of sound propagation and acoustic comfort see figure 1. The concrete needed for cooling reflects sound instead of absorbing it, and acts as a sound mirror. Echoes, amplified sounds and even normal speech therefore travel further in open spaces. Concentration is affected and it can be difficult to communicate without disturbing others. Nonetheless, while this has already been shown to be an issue in office TABS-buildings with insufficient acoustical treatment, this may cause even more issues as TABS expands to other segments like education and healthcare.

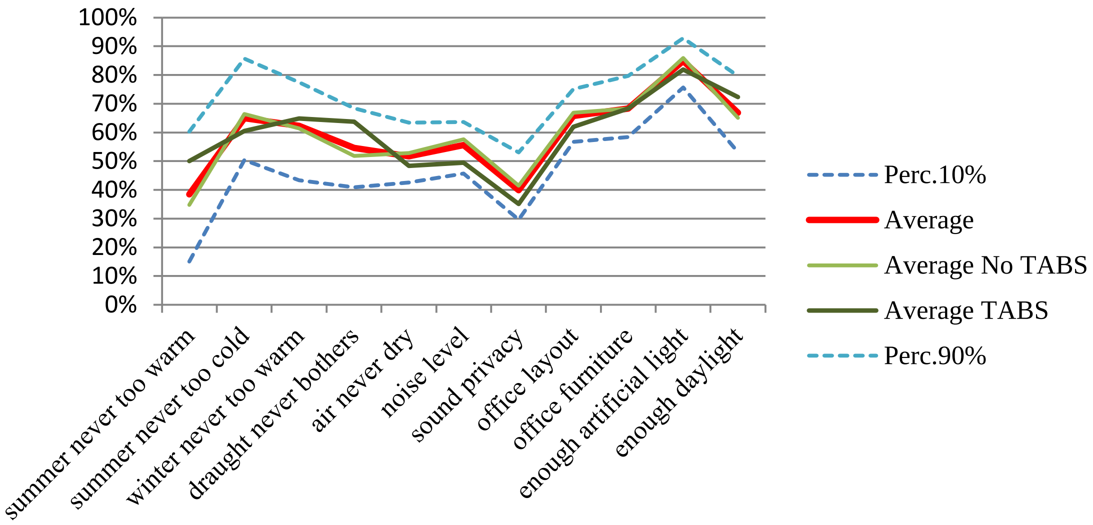

Figure 1 – Results of the comfort survey in 7 TABS buildings and 22 non-TABS buildings. Perc. 10% (Perc. 90%) are the scores below which 10% (90%) of the buildings perform. Average is the score of the sample of the 29 buildings, while Average TABS is the average of the 7 TABS buildings and Average No TABS is the average of the 22 other, non-TABS buildings [2].

There is, however, a growing understanding of the acoustic challenge within the acoustic communities and there are today several examples of projects where a good combination of thermal and acoustic comfort has been created. A list is presented in table 1.

Table 1 – List of office TABS projects

Project Name	Architecture	Location	Surface
Astraturm	KSP Engel und Zimmermann	Hamburg, DE	19000 m²
Green Office	Wilmotte	Reull Malmaison, FR	35000 m²
Duo Belastingdienst	UNStudio	Groningen , NL	47000 m²
Rochdall Council	FaulknerBrowns	Rochdall, UK	15000 m²
Odyssée	Hobo architecture	Niort, FR	8100 m²
TIGF	360°	Pau , FR	1800 m²
Woopa	Rau	Lyon , FR	21000 m²
Nestlé	Graf & MoestArchitekten	Singen, DE	1600 m²
Solaris	Architecture et environement	Clamart, FR	31000 m²

1.2 Previous measurements

In 2008, at SP, the Technical Research Institute of Sweden, we performed tests in order to estimate the influence of acoustic ceiling boards on cooling capacity referring to European Standard EN 14240:2004 - Ventilation for buildings [3]. Measurements were performed in a “room in the room” test set up (see illustration 1). The inside room was fitted with a water chilled ceiling. By mean of the temperature difference between inlet and outlet water as well as the water flow rate, one can calculate the “full regime” cooling effect of the ceiling surface. This “full regime” effect is then more or less degraded by the positioning of horizontal free hanging acoustic elements between the chilled ceiling and the temperature measurement devices located in the room.

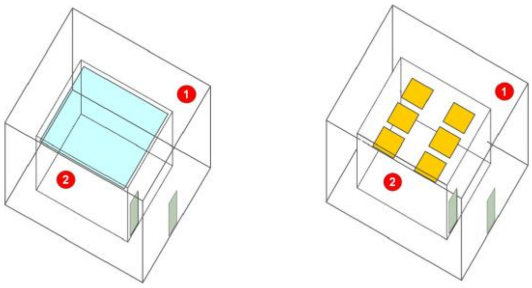

Illustration 1: Axonometric view of test set-up at SP, Technical Research Institute of Sweden. In blue, the water chilled ceiling. In yellow, the glass wool ceiling tiles.1 outside room; 2 inside room.

Test procedure implies that the temperature of room (2) is maintained constant by modulating the temperature in room (1). Since the varying parameter is the outlet temperature from the chilled ceiling, it is possible to calculate the effective cooling effect of the ceiling in the room for each configuration of free hanging horizontal units in the room. The comparison with the full regime situation is expressed in %. For instance, a 20% decrease (with free hanging horizontal units) means that the effective cooling effect in the room is 80% of the full regime effect (empty room) [4]. For a coverage ratio of 45%, the effect drop of the cooling effect of the chilled ceiling should have been close to 45%. On the contrary, the test results tend to indicate that convection is a more important energy transfer mode than radiation is for room cooling via the ceiling. Also, instability of the temperature at the six measuring points in the room further strengthens this hypothesis. Finally, a separate study conducted by the Dutch consultancy firm Peutz [5] concludes in similar terms that “the reduction of the radiation part of the thermal capacity is less than the coverage percentage of the concrete due to the suspended ceiling”. On the other hand the equivalent sound absorption of the suspended ceiling elements is more effective than its coverage percentage for mid and high frequencies. At low frequencies the non-closed ceiling looses quite some absorption. For situations where the speech is dominant the advantage at mid- and high frequencies prevails. [6]

1.3 On site measurements in the office building “Woopa” in Vaulx-en-Velin (France)

The use of TABS represents a real interest over the course of a long period of time. In order to investigate the long-term effect of ceiling coverage on cooling capacity, dynamic measurements were performed in the summer period between June and August 2012. On site thermal and acoustical measurements were performed in the office building “WOOPA” in Vaulx-en-Velin (France), with various coverage ratios of free hanging units suspended from the ceiling. Measurements were performed in a small open-plan office (6 workstations), and in 2 small offices (2 workstations). An overview of the measurements is presented table 2.

Table 2 – List of measurements

Configuration	Thermal	Acoustic	Coverage
Open space	No	Yes	0%;56%
Small office ref.	Yes	No	0%
Small office test.	Yes	Yes	0%;50%;70%

Acoustic measurements were performed in order to investigate the capacity to improve subjective acoustic feelings within TABS buildings in compliance with national and international standards. This was expressed through sound propagation, reverberation, sound pressure levels and comfort distance. Purpose of the onsite thermal measurements was to determine the temperature difference in rooms with thermally activated concrete slabs (thermally activated building systems, TABS) due to the acoustic glass wool suspended ceiling elements. The building has concrete core activation (by means of water pipes embedded in the concrete) combined with ventilation inlets in the concrete ceiling. To improve the acoustics, suspended sound absorbing ceiling elements are installed under the concrete floor. It is expected that this barrier will reduce the cooling capacity of the concrete core activation.
Two rooms called the “test” and the “reference” rooms were used for the measurements; the rooms were similar regarding size and orientation in the building.

Photograph 1 – Outside picture of WOOPA building designed by Thomas Rau.

2. MEASUREMENTS

2.1 Acoustic measurements

The acoustic measurements have been performed in a small open-plan office and in a small office. The small office test room was created through installing a modular partition inside the volume of the open plan office.

2.1.1 Measurements in the Open-plan office:

For the acoustic measurements in the open-plan office, desk screens were covered with absorptive panels (high density glass wool 4 cm thick, height 55 cm), as shown on photograph 2 (top right): The suspended absorptive panels were Ecophon Solo square, 1200 x 1200 mm, thickness 40 mm (photograph 2, bottom right). The height under the panels was 2.52m, the height between suspended panels and concrete ceiling was 22cm. Measurements were made with two different coverage ratios: 56% and 0%. Measurements were made with and without wall treatment at one end of the room (resp. “w” and “wo”). The absorptive panels on the end wall were high-density glass wool and wool panels with fabric facing.

Photograph 2: Top left: Overview of the open-plan office- 0% ceiling coverage ratio; top right: absorptive panels made of high-density glass wool 4cm; bottom left: combination of two absorptive panels against the wall; Bottom right: free hanging units- Ecophon Solo square. Average length 13.7m, average width 4.15m, height under the slab 2.78m. Surface 54m², volume 150m^3.

The following measurements have been carried out with different measurement paths, according to ISO 3382-3: Sound source calibration, sound pressure level in octave band of pink noise, background noise level in octave bands and distance to the sound source.
From those measurements, the following criteria can be derived: Spatial distribution of the A-weighted SPL of speech Lp,S, Spatial decay rate of speech DL2,S , A-weighted SPL of speech at a distance of 4 m Lp,A,S,4m and Distance of comfort rC. Measurements have been done following 2 paths, referenced as “a” and “b” presented in illustration 2 and 3.

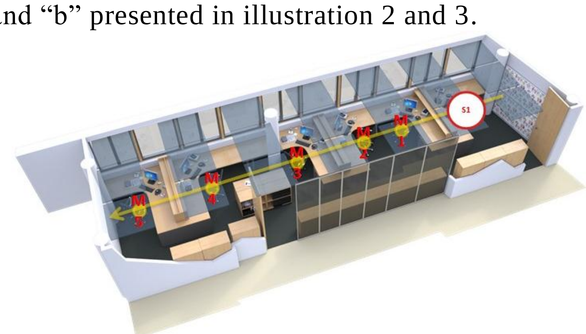

Illustration 2: Path “a”: Source in S1 (workstation located on the right), measurement path from right to left.

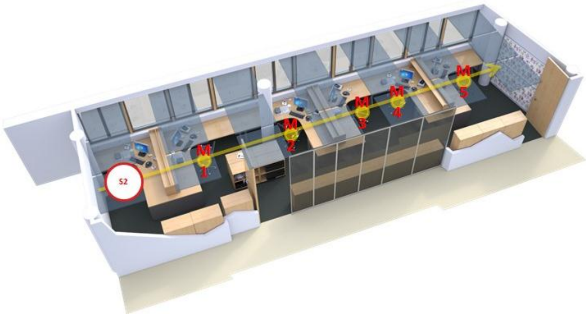

Illustration 3: Path “b”: Source in S2 (workstation located on the left), measurement path from left to right.

Specific considerations regarding the calculation of some of the acoustical criteria are given below:
Spatial decay rate of speech D2s - According to ISO 3382-3, D2s should be made from measurement positions at distance between 4m and 24m from the sound source, and the last measurement position should be ignored if close to a reflecting wall. Considering this, first measurement positions (noted M1) and last measurement positions (noted M5) should have been excluded from the determination of DL2,S. But it has been noted that the results calculated with only three positions (M2 to M4) are inaccurate and inconsistent. It seems that the inhomogeneous ceiling (absorptive panels with large reflective spaces in between) creates strong reflections from the ceiling at some locations, and no reflection from the ceiling at other locations, which leads to strong variations in the measurement results depending on the respective positions of the sound source and the microphone relative to the suspended ceiling panels.
In order to obtain more homogeneous results, it has been decided to include last measurement positions (noted M5) in the determination of D2s, although it does not fully comply with the 3382-3 standard. It has to be noted that the consequence of including M5 in the determination of DL2,S is that the results are influenced by absorptive or reflecting nature of the wall close to M5.
A-weighted SPL of speech at a distance of 4 m Lp,A,S,4m - The determination of the criterion Lp,A,S,4m is derived from the calculation of D2s. Therefore, the same comments about the choice of the measurement positions included in the calculation and their consequences apply.
Distance of comfort rC - A criterion called distance of comfort (in m) is suggested in an article from Canto Leyton & Nilson as an indication of the acoustical comfort provided in offices [7]. The suggested formula is presented bellow (1):

$$r_c = 4 \times 10^{0,3(L_{p,A,S,4m} - L_c)/D_{2,s}} \qquad (1)$$

Where D2s is the spatial decay rate of A-weighted SPL of speech according to ISO3382-3, LP,A,S,4m is the A-weighted SPL of speech at 4 m according to ISO3382-3, and Lc the comfort sound level defined as the acceptable speech level at a certain work station.

Table 3 – List of measurement configurations within the open-plan office

Configuration reference	Ceiling coverage ratio	Path	Wall treatment
56%aw	56%	A	with
56%bw	56%	B	with
56%bwo	56%	B	without
0%aw	0%	A	with
0%bw	0%	B	with
0%bwo	0%	B	without

2.1.2 Measurements in the small office:

The small office has been obtained by installing a modular partition inside the volume of the open plan office (Illustration 4 and 5). The suspended absorptive panels were Ecophon Solo, thickness 40 mm. The height under panels was 2.52 m, and the height between suspended panels and concrete ceiling was 22 cm. The ceiling panels near the façade have been cut to create a small gap in order to facilitate air movements. Measurements were made with tree different coverage ratios: 70%, 50% and 0% .For the acoustic measurements in the small office, there was no absorptive panel added on desk screens or on the walls. Reverberation time measurements have been performed, according to ISO 3382-2.

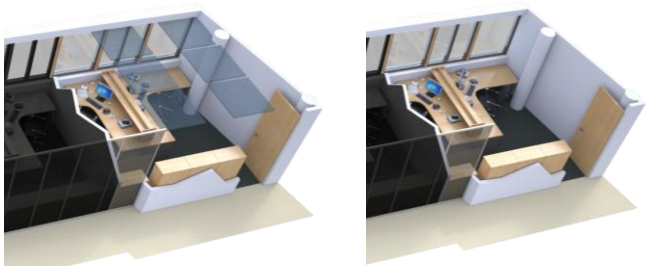

Illustration 4 – Representation of the open plan office (left 50% ceiling coverage & right 0% coverage). Dimensions: Average length 4.3 m, average width 4.20 m, height under slab 2.78 m, surface: about 18 m², volume about 150 m^3.

2.2 Thermal measurements

Two rooms called test and reference room were used for the measurements; the rooms were similar regarding size and orientation of the building (Illustration 5). In the reference room no suspended ceiling was applied during all the measurements. The test room, was used to research the effect of different ceiling configurations. The black globe temperature was initially measured without any acoustic ceiling and these temperatures in the rooms were registered. This initial measurement confirmed that the rooms behaved similar, from a thermal perspective. By means of electric heating elements as described in DIN EN 14240 the internal heat load was simulated.

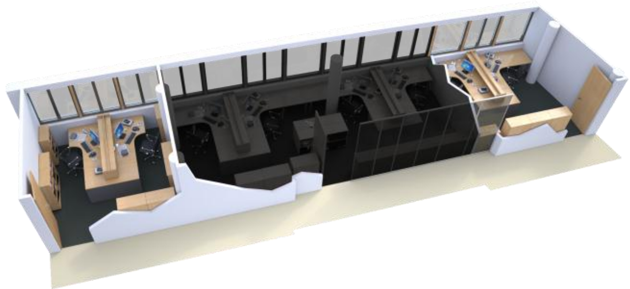

Illustration 5 – Reference room (left) and test room (right).

In the test chamber 40 mm thick glass wool ceiling panels were mounted with a cavity of approximately 22 cm from the concrete ceiling. In the photograph 3, the measured ceiling configurations associated with the covering percentage are given.

Photograph 3 – Ceiling panels covering 50% (left) and appr. 70% (right).

In both rooms, the black globe temperature has been measured at a height of 1.1 m (corresponding to the neck of a sitting person) near the centre of the room. Close to the black globe an air temperature sensor was placed. The surface temperatures of the concrete and surface temperatures of the suspended ceiling were measured by placing thermocouples on the concrete slab or other elements.

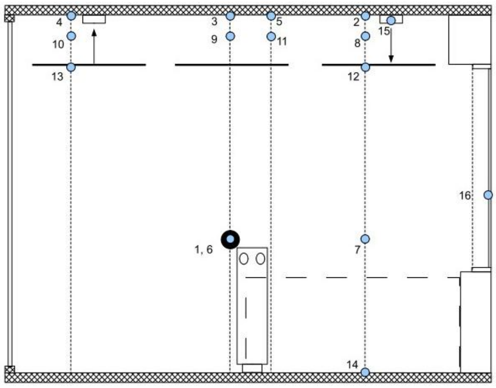

Illustration 6: Section test room facing south-east and have the dimension of appr. l x w x h = 4 x 4 x 2.8. m^3.

Furthermore, air temperature sensors were placed between the suspended ceiling and the concrete ceiling. Simultaneously relevant air, wall and floor temperatures, and installation parameters etc. were recorded. When starting the actual tests, acoustic ceiling elements were installed in the test room and the (black globe) temperatures were measured for both rooms. The difference was calculated and compared with the temperature difference without acoustic ceiling. This was done for the daily maximum black globe temperature, the minimum black globe temperature and the average between 9 am and 5 pm.

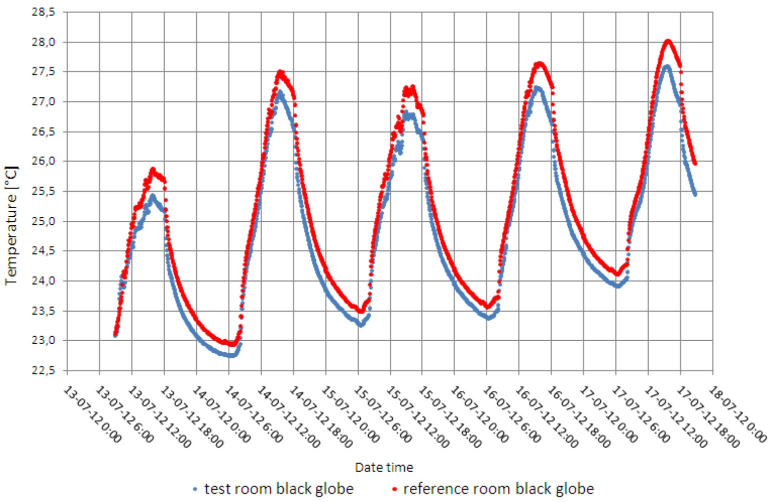

Figure 2: Depicts the graph of black globe temperatures of the test room and the reference room during a measuring period with 50% suspended ceiling in the test room. These values have been compared with the initial measurements without ceiling.

The day type (week/ weekend) and the maximal black globe temperature of the reference room on that day were taken into account to compare the black globe temperature of specific days.
Since the temperature during the measurement period is not identical each day, days with comparable indoor temperature have been paired. For the measurement results the average value as well as the standard deviation (using the n-1 method) is given.

3. RESULTS AND INTERPRETATIONS

3.1 Acoustic measurements

3.1.1 Measurements in the Open-plan office:

The D2s parameter was strongly influenced by the presence/absence of the ceiling. Moreover, the D2s decreased considerably when the acoustic ceiling was removed. In fact the results went from 5,1 up to 2,3db(A) by doubling distance. If we compare those results to the recommendation [8] stipulated within the ISO 3382-3 we have only been able to go over 7dB in the past bw. This can be interpreted by the SPL reduction at the last measurements position that increased the slope of the regression curve.

Table 4 – Spatial decay rate of speech D2s [dB]

Ceiling coverage	path aw	path bw	path bwo
56%	5,1	7,6	5,1
0%	2,3	3,8	2,2

In order to express subjective improvements we decided to derived the measurements using rC instead of rD. In fact within the building the SPL was low, the inlet airflow is reduced as the cooling is integrated within the slab. The value we found was around 35dB(A). Based on the literature, rD is strongly dependent on the SPL [9]. In the calculations of distance of comfort, the comfort sound level Lc has been set to 48 dB, in order to illustrate the distance it takes for the speech to reduce to half in the perception of the listener, as speech level is defined as 57.4 dB(A) at a distance of 1 m in free field considering an omnidirectional sound source in the ISO3382-3, and theory tells us that people experience the sound half as loud at -9 to -10 dB [10].

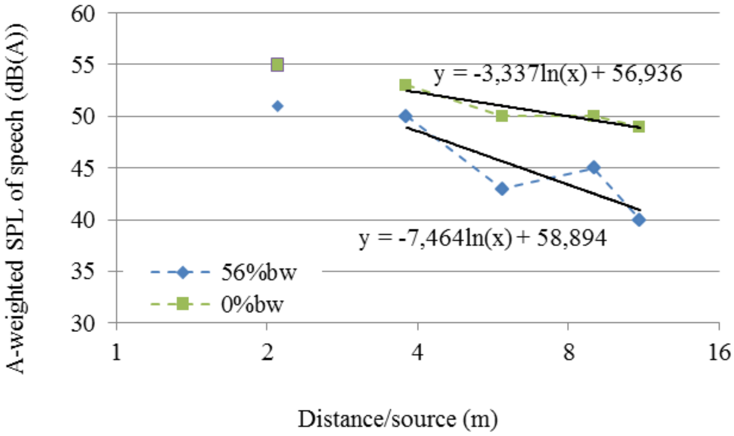

Figure 3 – path bw : Influence of free hanging units on sound propagation. D2s goes from 3.8dB(A) up to 7.6dB(A) per doubling distance.

The value we get for the Lp,A,S,4m were over the ISO 3382-3 recommendation and are presented table 5.

Table 5 – A-weighted SPL of speech at distance of 4m [dB] – Lp,A,S,4m

Ceiling coverage	path aw	path bw	path bwo
56%	50,8	52,1	51,2
0%	52,3	54,1	52,8

From the calculations of distance of comfort with a ceiling coverage of 56%, it appears that the distance of comfort goes from 14.6 m to 5.8 m for the path aw, from 12,1 m to 5.8 m for the path bw and from 18.1 m to 6.2 m for the path bwo (see table 6). The distance it takes for the speech to reduce to half in the perception of the listener has been reduced by two with a ceiling coverage of 56%.

Table 6 – Distance of comfort [m] – rC

Ceiling coverage	path aw	path bw	path bwo
56%	5,8	5,8	6,2

0%	14,6	12,1	18,1

The main objective of the French standards NF S 31-080 is to ensure absence of discomfort between neighboring workstations and also to guarantee a level of comfort for conversations in the vicinity[11]. Within the standard, the highly efficient level recommends a reverberation time under 0,6s (average 500, 1000 and 2000Hz). The results from reverberation measurements are presented in figure 4. The measurements show the reduction of the reverberation under the standard's requirements. It appears that with a ceiling coverage 56%, it is possible to achieve a reverberation time under 0.4s.

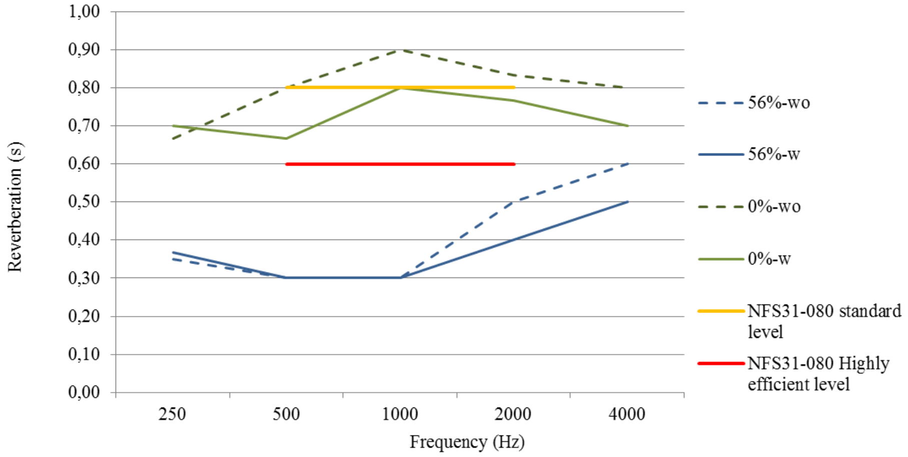

Figure 4 – Reverberation time

3.1.2 Measurements in the small office:

The results from the acoustic measurements within the small office are presented in figure 5. Without suspended ceiling, the reverberation time was over the target value of 0,6s (average 500, 1000 and 2000Hz) from the French standard NF S 31-080. Due to the small volume in the room and low diffusion it appears that the results between 50 and 70% ceiling coverage were not that different. Within this small office, increasing the amount of absorption over 50% does not reduce the reverberation time.

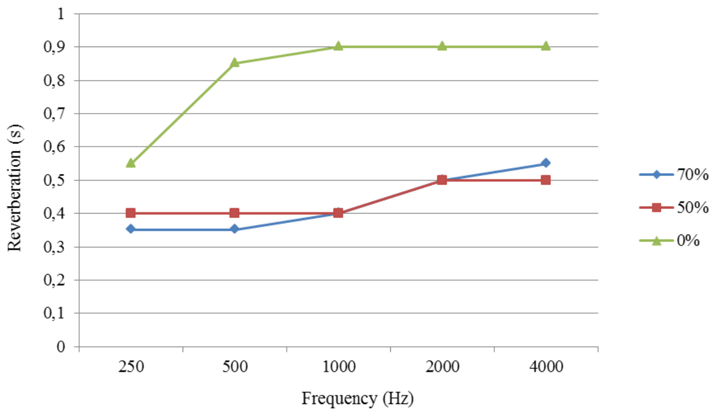

Figure 5 – Reverberation time

3.2 Thermal measurements

Ceiling coverage 50% - The mean difference in temperature of the maximum black globe in the test room – relative to the black globe temperature in the reference room – between the situations with 50% and without suspended ceiling, is approximately 0.30 K with a standard deviation of 0.06 K. The mean temperature difference of the average black globe temperature in the test room between the situations with 50% and without suspended ceiling is approximately 0.29 K, with a standard deviation of 0.05 K. In figure 6, the average black globe temperature increase for different days, due to the suspended ceiling (50% coverage), is indicated.

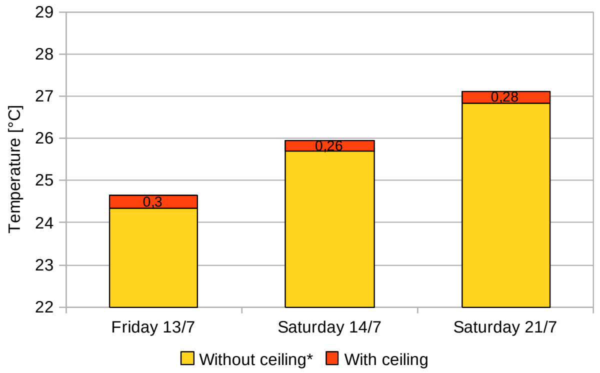

Figure 6: Thermal measurements with 50% suspended ceiling and calculated without.

During the night, the temperature difference due to the suspended ceiling is smaller (approximately 0.1K).

Ceiling coverage 70% **-** For these measurements, 6 additional – smaller – ceiling panels placed. The ceiling panels cover the concrete approximately 70%. On average, the temperature difference of the maximum black globe temperature due to a suspended ceiling, covering appr. 70% of the concrete is 0.96 K with a standard deviation of 0.14 K.The mean temperature difference of the average black globe temperature in the test room between the situations with 70% and without suspended ceiling is approximately 0.82 K with a standard deviation of 0.07K. In figure 7 the average black globe temperature increase for different days, due to the suspended ceiling (70% coverage), is indicated.

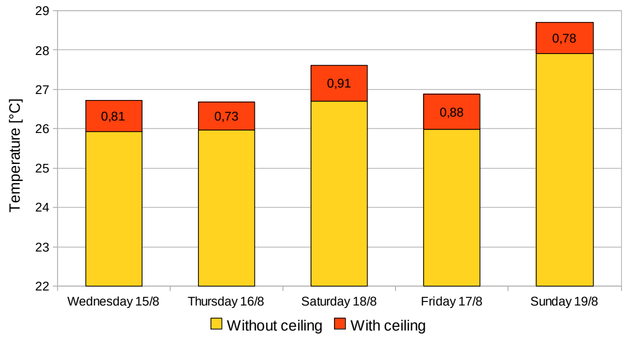

Figure 7: Thermal measurements with appr. 70% suspended ceiling and calculated without
During the nights the minimum black globe temperature difference due to the 70% suspended ceiling coverage is approximately 0.29 K with a standard deviation of 0.03 K.

By applying a glass wool suspended ceiling, an increase of the room centre black globe temperature was observed, depending on the coverage rate of the suspended ceiling. The results are summarized in Figure 8.

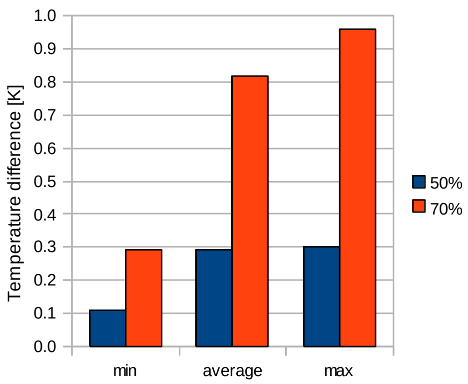

Figure 8 – Black globe temperature increase due to suspended ceiling.

3.3 Impact on thermal comfort

The international standard ISO 7730:2005 [12] defines thermal comfort criteria for heated and cooled buildings. One of them is the Predicted Mean Vote (PMV). For a given thermal environment, the PMV index allows to predict the mean thermal sensation of a large group of building occupants. It is expressed on a thermal sensation scale ranging from “cold” (PMV = -3) to “hot” (PMV = +3). Usually, one consider to be in comfort zone when the PMV is in the [-0.5; 0.5] range.

In a first attempt in this study, we tried to compute the PMV for three different days corresponding to three different ceilings coverage of the test room: 0% (June, 30 th) ; 50% (July, 21st) and 70% (August, 18th). We thus not directly compare test and reference room on the same day. But as explained in section 2.2, these three days are considered here to be equivalent. With the measured air and black globe temperatures we computed the PMV index along these three days. We made several assumptions. First, we assumed for the building occupant a metabolic activity of 1.2 met. This corresponds to the slight activity of an occupant seated and writing. We also considered a vesture of 0.5 clo. This corresponds to classical summer vesture in a working environment. Then we assumed a 0.15 m/s air speed. Last, we assumed a constant relative humidity of 50%. Under all these assumptions, we computed on figure 9, the PMV value as a function of day time for three different days which correspond to three different ceilings coverage.

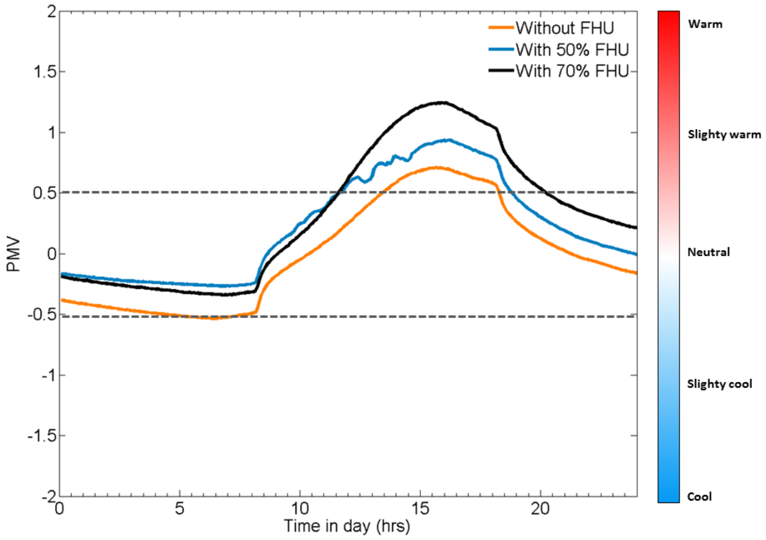

Figure 9 : Predicted Mean Vote (PMV) computed for three different days corresponding to three different ceiling coverage : 0%; 50% 70%.

Between midnight and 8h, the room is unoccupied. Then, as mentioned in section 2.2, between 8h and 18h, the presence of occupant is simulated by two electrical heaters (180 W each). After 18h, the room is once again unoccupied. On figure 9, we observe that at 8h, the PMV is close to -0.5 (end of neutral zone). It increases slowly during the day, reaching a maximum close to 1 (“slighty warm”) around 16h. In the case without FHU and with 50% of FHU, the PMV stays mostly in the comfort zone during the morning and early afternoon. In the 50% case, the afternoon is above 0.5. However, in the case of 70% coverage, we spend more time out of the comfort zone but we still remain close to +1, i.e. close to the “slighty warm” condition. On these three particular days, the presence of FHU seems to lead to a global increase of the PMV value. Because the PMV value is low (PMV ≈ -0.5) in the beginning of the day, we do not spent too much time out of this comfort zone despite this increase. It the day started from a higher value (e.g. PMV = 0.3), we’ll probably spend much more time out of the comfort zone. The present results and the values presented in figure 9 are only a first attempt to determine the effect of free hanging units on thermal comfort in a specific configuration.

4. CONCLUSIONS

The impact of suspended ceiling on thermal and acoustic comfort in a real building was studied. For acoustics, this shows that with a ceiling coverage ratio of around 50% there are no difficulties to reduce the reverberation time. For the little office increasing the ceiling absorption is not a necessity.

For the open space it is clear that the reduction of the distance of comfort by covering only 56% of the ceiling surface is not enough. In fact in order to reach the ISO 3282-3 recommendations the sound propagation need to be optimize. Further measurements needs to be done by adding vertical acoustic solutions: wall solutions or screens.

Regarding thermal comfort, this study showed first that the presence of suspended ceiling has a low impact on thermal comfort. It is thus very difficult to precisely quantify this effect. In the building used, the test and the reference rooms used have a similar but of course not perfectly identical thermal behavior. To overcome this difficulty, we did not directly compare the test room (with different ceiling coverages) to the reference room (without suspended ceiling). Were paired different days which are defined as equivalent. Using this method, we conclude that a coverage of 50% leads to an average increase of black globe temperature of 0.30 K with a standard deviation of 0.06 K. With 70% coverage, it is 0.8-1.0 K. All these results must now be confirmed by a new set of experiments.

5. PERSPECTIVES

This work will be continued first by developing a numerical model of a room with and without FHU. Our objective is, thanks to this model, to determine the configuration (e.g. position between two FHU) and physical properties (e.g. emissivity) which allows the better thermal comfort without losing acoustic properties. Saint-Gobain built a first version of this model under TRNSys. However, as mentioned, thermal comfort of building occupants depends particularly on two phenomena: first the thermal exchanges by radiation between occupant and cooled ceiling and second the thermal exchanges by convection. In the WOOPA tower, the air inside rooms is displaced both by natural convection and by the mechanical ventilation. The presence of suspended ceilings will modify the air movements and thus, the exchanges between air and cooled ceiling. This will modify also the thermal comfort. With TRNSys, the radiative exchanges may be considered thanks to the "detailed radiation model". To the opposite, modeling the air movements requires to define the air flow between air nodes. To overcome this difficulty, Saint-Gobain built under the CFD software Fluent a two dimensional model of the room. Once it will be validated, this model will be used to compute the air speed between each part of the room. These values will be then injected into the TRNSys model. Peutz has experience with CFD software Phoenix and made a 3D model of one of their climatic chambers to validate the thermal measurements that have been performed in their lab [5]. One of the difficulties to overcome was the amount of radiation planes and the simulation of the heat loads. The last step of this work will be to make a new set of experimental measurements to validate the model and the results presented here. With all these results, we'll be able to assess more precisely the impact of suspended ceilings on thermal comfort.

ACKNOWLEDGEMENTS

We would like to thank Saint Gobain Research for believing in our project and for supporting our research financially. We would also like to take this opportunity to thank Sylvain Guitton and Alexis Delajot, whom we have been so privileged to work with. We would like to extend our deepest gratitude to Pierre Lombard and Pierre Chigot for all the invaluable information that they provided us with. It is imperative that we acknowledge Georges Mandica, COGECI Chairman, for allowing us to use his office.

REFERENCES

[1] Prof. B.W. Olesen,"Geotabs –Technology, boundary conditions and comfort", International Centre for Indoor Environment and Energy Department of Civil Engineering & Technical University of Denmark, 2013.

[2] K.U Leuven, Prof. L. Helsen and J. Hoogmartens, "Report comfort survey GeoTabs 2012-09-25 v05" Source: www.comfortmeter.eu, Factor4,(2013).

[3] CEN European Standard 14240:2004 - Ventilation for buildings. Chilled ceilings. Testing.

[4] Y. Le Muet & R. Machner, "Impact of the new French thermal regulation on office indoor environment: combine innovative cooling technology and high acoustic demand" Euronoise Prague 2012.

[5] Peperkamp, H., Vercammen, M., Thermically activated concrete slabs and suspended ceilings, Proceedings of NAG-DAGA International Conference on Acoustics, Rotterdam.

[6] M. Vercammen, T. Scheers, Absorption of open ceilings, proc. ICA Madrid 2007.

[7] R. Canto Leyton, E. Nilson: Acoustic Design of Open Plan Offices – Subjective judgment. Euronoise Prague 2012
[8] ISO 3382-3 Annex A,"Examples of target values for evaluation of measurement data", Acoustics Measurement of room acoustic parameters - Part 3: Open plan spaces.
[9] CRM. Passero, PHT Zannin, "Technical Note - Study of the Acoustic Suitability of an Open Plan Office Based on STI and DL2 Simulations", Laboratory of Environmental and Industrial Acoustics and Acoustic Comfort – LAAICA -Federal University of Parana, Centro Politecnico.
[10] L. Cremer and H.A. Müller, (1982). Vol. 1, Chapter III.1.2. "Principles and Applications of Room Acoustics", Applied Science Publishers.
[11] NF S31-080, Acoustics - Offices and associated areas - Acoustic performance levels and criteria by type of area, janvier 2006 (in English)
[12] ISO 7730:2005, Ergonomics of the thermal environment -- Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria