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

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Summary
New office buildings use thermal capacity of the structure mass to provide thermal comfort. Thermo-active building systems (TABS) have become established as innovative systems for surface heating and cooling with significant economic and ecological potential. A challenge arises when this system is combined with a requirement for good acoustics: traditional class A 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. In order to investigate the subject we performed acoustic and thermal measurements under the summer 2014 in an office building located in Freiburg, Germany. The aim of this research was not only to quantify the reduction of the cooling capacity due to a glass wool suspended ceiling by measuring the temperature increase in the room but also to describe and evaluate thermal and acoustic comfort in office rooms under real operation. Therefore, monitoring data of energy consumption, thermal and acoustic conditions in the rooms as well as ambient conditions have been gathered and monitored. The purpose of this paper is to show the acoustic and thermal tests that have been conducted (6 rooms – Free hanging units and baffle), the set-up used (3 periods combining 4 scenarios 30% -45% and 60% coverage with FHU & baffles), the measurement methods and give data to encourage dialogue and coordination between the acoustician and other building engineering disciplines.

1. Introduction

1.1 Previews on-site measurements

In order to investigate the long-term effect of ceiling coverage on cooling capacity, a first campaign of dynamic measurements were performed in the summer period between June and August 2012[1]. 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. 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. For acoustics, this shows that with a ceiling coverage ratio of around 50% there are no difficulties to reduce the reverberation time. For smaller offices 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 optimized. Regarding thermal comfort, this first study showed first that the presence of suspended ceiling has a low impact on thermal comfort. We paired different days which are defined as equivalent. 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 needed to be confirmed by a new set of experiments. In fact the test and the reference rooms used did not have perfectly identical thermal behavior, the values were difficult to analyze and the scope of the study had a limited set of coverage ratios. As a result, we decided to perform new tests in an office building in Freiburg.

1.2 On site measurements in the office building "T" in Freiburg (Germany)

From June 30th to September 18th 2014 the influence of free hanging sound absorbers on the thermal comfort and acoustic conditions in office rooms was monitored and analyzed. Four office rooms (two 3-persons and two 4-persons offices) were equipped with sound absorbers and two rooms (one 3- and one 4-persons office) were monitored as reference rooms. All offices were in the same building with the same orientation (facing northwest).The arrangement and in two rooms also the kind of sound absorbers were changed 3 times during the testing period in order to compare different ceiling coverage ratios in the rooms equipped with the Master Matrix of Ecophon and to compare the Master Matrix with the Solo Baffles. The acoustic measurements for all configurations were carried out during two days in August, while the acoustic measurements (activity and background noise level) were carried out during several weeks in August and September. Thermal comfort and cooling energy demand in all six rooms have been assessed. For this, operative temperature, dry bulb temperature, occupancy, relative humidity and CO2-concentration have been monitored in every room, as well as window and door openings. Additionally, cooling power and energy, supply air velocity and temperature, air velocity in the room, electricity consumption (plug loads) and the use of solar shading was monitored in the three 4-persons offices. Furthermore, outdoor weather conditions were monitored with a weather station.

2. Building description

The building "T" in Freiburg is cooled during summer by a water-driven thermo-active cooling system where the pipe system is integrated in the concrete ceiling. The building was established in 2010 and is oriented from South-West to North-East. All monitored rooms are located at the North-East façade. The three-person rooms have a size of 21 m² (5.5 m x 5.4 m) and the four-person rooms of 29 m² (7.7 m x 5.4 m). All rooms are used as office rooms and are usually occupied between 8 a.m. and 8 p.m. The building has a mechanical ventilation system with heat recovery and the air exchange rate is 1 h-1. Additionally, windows can be opened manually by the occupants. The rooms are equipped with exterior solar shading (Venetian blinds), which can be manually controlled. The building is cooled actively by thermo-active building systems (TABS) (here: concrete core conditioning system), where pipes are integrated into the core of the concrete ceiling of the office rooms (20 mm pipe diameter, 150 mm spacing between pipes, approximately 40 mm deep). The system is designed for a supply temperature of 16 °C and a temperature difference of 2K. Each office has an individual room temperature control (set-point controller in 2K increments), resulting in 263 hydronic circuits in the entire building controlled by electronic actuators. The control units are only enabled during the heating period; therefore the room temperature cannot be changed or adjusted during the cooling period in summer. The cooling energy is generated either by the direct use of a groundwater system (temperature level in summer between 14 and 19 °C, capacity about 200 kWtherm) or recooling to the outside air via a wet cooling tower (200 kWtherm). If the demand is higher, cooling energy can also be provided by two compression chillers cooling to the outside air.

3. Description of the scenarios

Four scenarios were carried out (see table 1) within three monitoring campaigns, each over a period of three to four weeks (see Table 2). Therefore, six office rooms were monitored in parallel per monitoring campaign. The rooms were monitored continuously, i.e. not only during occupancy, but also during weekends and outside the occupancy. The configuration of the rooms and the scenarios monitored during the different campaigns are as follows:

- Campaign 1: 2 reference rooms without absorbers, 2 rooms with absorbers according to scenario 1 (30 % coverage) and 2 rooms with absorbers according to scenario 3 (60 % coverage).
- Campaign 2: 2 reference rooms without absorbers, 2 rooms with absorbers according to scenario 1 (30 % coverage) and 2 rooms with absorbers according to scenario 2 (45 % coverage).
- Campaign 3: 2 reference rooms without absorbers, 2 rooms with absorbers according to scenario 3 (60 % coverage) and 2 rooms with

absorbers according to scenario 4 (Ecophon Solo Baffle, 1200x300, spacing 300 mm, direct mounted).

Table 1: 4 scenarios

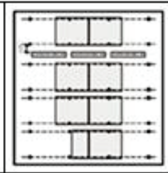
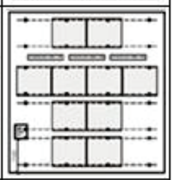
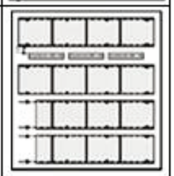
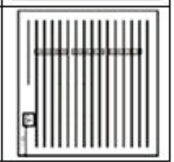
1 - 30% Master Matrix		
2 - 45% Master Matrix		
3 - 60% Master Matrix		
4 - Baffle 1200x300, spacing 300mm		

Table 2: campaigns

Cases	Room numbers and ceiling coverage		
Campaigns	room 5 & 6	room 1 & 3	Room 4 & 2
1	0%	30%	60%
2	0%	30%	45%
3	0%	60%	baffles

4. Thermal results

4.1 Thermal comfort

Thermal comfort is evaluated according to the Predicted Mean Vote (PMV) comfort model of the European standard EN 15251 [3]. Measurements of the operative room temperature are evaluated according to the defined comfort classes I to III (class I – high level of expectation, class II - normal level of expectation, class III – acceptable, moderate level of expectation, and class IV – values outside the criteria for the above categories). PMV comfort model of EN 15251: The criterion for thermal comfort is determined as an average operative room temperature during summer of 24.5°C. The tolerance range of the operative room temperature is respectively +/- 1, +/- 1.5 and +/- 2.5 K (comfort categories I, II and III) depending on the predicted percentage of unsatisfied occupants (Kalz & Pfafferott, 2014) [2]. These values are defined for summer/ cooling days with a running mean of the ambient air temperature of 15 °C. The PMV-model and with it the constant comfort boundaries of categories I – III is applied for comfort analysis in buildings with mechanical cooling.

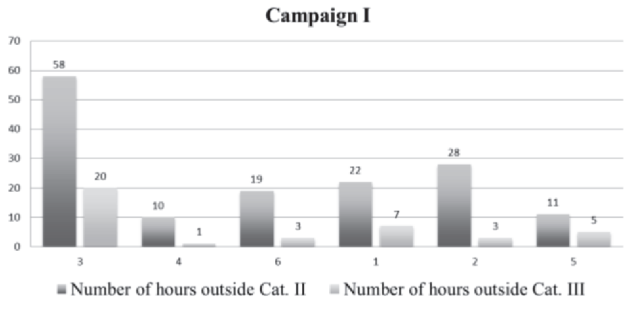
4.2 Results of thermal comfort:

4.2.1 Campaign I

In the following the thermal comfort during occupancy in campaign 1 is analyzed according to EN 15251 for the 3- and 4-persons offices.

The main results of the 3-persons offices are (Figure 2): the boundary of category II is violated several times during occupancy (58 hours in room 3, 10 hours in room 4 and 19 hours in room 6) and in a few hours during occupancy, also the boundary of comfort category III is violated with the highest peak in room 4 (20 hours in room 3, 1 hour in room 4 and 3 hours in room 6). The high amount of hours above 26 °C in room 6 is mainly due to the position of the monitoring equipment during the first week of the campaign. The comfort footprint of the 3-persons offices shows that room 4 achieves comfort category II in approximately 98% of the occupancy hours, which is above the acceptable value of 95% during occupancy according to EN 15151. In room 4 the thermal comfort is three percentage points better than in the reference room (thermal comfort with respect to category II during approx. 95% of occupancy) and 23 percentage points better than in room 3 (thermal comfort with respect to category II during approx. 75% of occupancy). A possible reason for the minor thermal comfort in room 3 is the user behavior, especially with respect to window opening and the use of solar shading (not monitored in 3-persons offices).

Figure 2: Evaluation of the thermal comfort in the 3 & 4 persons offices during occupancy according to the PMV-model on EN 15251

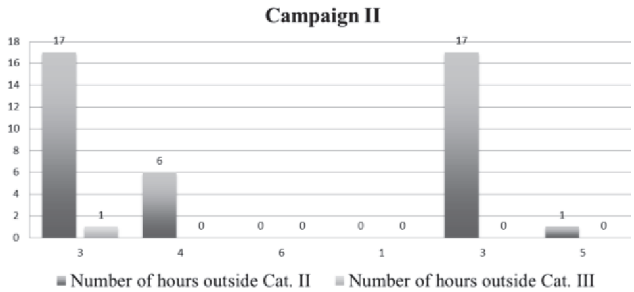


The main results of the 4-persons offices are : the boundary of category II is violated several times during occupancy (22 hours in room 1, 28 hours in room 2 and 11 hours in room 5) and in a few hours during occupancy, also the boundary of comfort category III is violated with the highest temperature peak in room 5 (29 °C) (7 hours in room 1, 3hours in room 2 and 5 hours in room 5). Similar to the 3-persons offices, the highest variation of the ORT is between the running mean of the ambient air temperature of 18.5 and 20 °C, with a decreasing variation for an increasing running mean of the ambient temperature. The main findings of the comfort footprint of the 4-persons offices are: Category II is achieved in room 1: approx. 93% during occupancy, in room 2: approx. 86% during occupancy and in room 5: approx. 96% during occupancy.

4.2.2 Campaign II

The main results of the 3-persons offices are (see Figure 3): the boundary of category II is violated several times during occupancy in the rooms equipped with sound absorbers (17 hours in room 3, 6 hours in room 4 and 0 hour in room 6) and in one room the boundary of category III is violated during one hour (Room 3). The comfort footprint of the 3-persons offices in campaign 2 shows the percentage of hours in which category II is achieved (Room 3: 92%, Room 4: 99% and Room 6: 100%). Like in campaign 1, in room 4 with a higher ceiling coverage ratio than in room 3, a better thermal comfort is achieved.

Figure 3: Evaluation of the thermal comfort in the 3 & 4 persons offices during occupancy according to the PMV-model on EN 15251

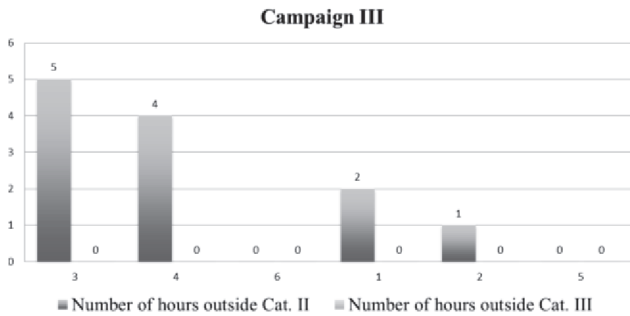


The main results of the 4-persons offices are The boundary of category II is violated several times during occupancy (0 hour in room 1, 17hours in room 3 and 1 hour in room 5) and comfort category III is not violated in the 4-persons offices. The main findings of the comfort footprint of the 4-persons offices are : Category II is achieved in room 1: approx. 100% during occupancy, in room 2: approx. 93% during occupancy and in room 5: approx. 100% during occupancy. As expected, most of the time the ORT in the reference rooms was below the one in rooms equipped with acoustic panels. In rooms with 30% coverage, the ORT in the 3 persons office was almost always above the ORT in the 4 persons office. There is no clear effect of the ceiling coverage ratio (45% and 60%) on the 3 and 4 person offices.

4.2.3 Campaign III

The main results of the 3-persons offices are (see Figure 4): the upper boundary of category II is violated during a few hours (5 hours in room 3, 4 hours in room 4 and 0 hour in room 6)and category III is not violated. The ORT-levels are lower than in campaigns 1 and 2. The comfort footprint of the 3-persons offices in campaign 3 shows the percentage of hours in which each comfort category is achieved category II is achieved in room 3: approx. 97% during occupancy, in room 4: approx. 99% during occupancy and in room 6: approx. 100% during occupancy. In the 3-persons offices during campaign 3, the lowest thermal comfort is in room 3 and the best thermal comfort in room 6. According to EN 15251 category II should be achieved during 95% of the occupancy hours, which is achieved in all rooms.

Figure 4: Evaluation of the thermal comfort in the 3 & 4 persons offices during occupancy according to the PMV-model on EN 15251



The main results of the 4-persons offices are : the boundary of category II is almost never violated during occupancy (2 hours in room 1, 1 hour in room 2 and 0 hour in room 5) and comfort category III is not violated. The ORTs do not have a large variation. The main findings of the comfort footprint of the 4-persons offices are category II is achieved in room 1: approx. 99% during occupancy, in room 2: approx. 100% during occupancy and in room 5: approx. 100% during occupancy. The best thermal comfort is achieved in reference room, the lowest in room 1.Requirement of EN 15251 that category II is achieved during at least 95% of occupancy hours is fulfilled in all 4-persons offices. In room with 30% coverage, the ORT in the 3 persons office is above the ORT in the 4 persons office. There is only a small difference of ORT between the reference rooms and the rooms equipped with solo baffles. This 3nd campaign show no clear effect of the acoustic absorber type (FHU & Baffles)

4.2.4 Synthesis of the 3 campaigns

Table 3 displays the approximate percentage of occupied hours during which Category II is achieved according to the standard EN 15251. According to 15251 the thermal comfort, a minimum of 95% of occupied hours among Category II should be achieved.

Table 3: synthesis all 3 campaigns

	3 persons offices		4 persons offices	
30%	75%	92%	93%	100%
45%	99%		93%	
60%	98%	97%	86%	99%
Baffles	99%		100%	

5. Acoustic Results

Room acoustic requirements are taken from the applicable standard DIN 18041 [4]. Following the room classification scheme of that standard, office rooms fall in category B (acoustic quality over small distances). The recommendation for office rooms is the installation of an equivalent absorption area of 60% to 85% of the room´s ground floor area, where equivalent absorption area refers to a notional sound absorber with an absorption coefficient of 1. No requirements in terms of room acoustic parameters are given in the German standards. Room acoustic measurements have been performed in small office rooms (room 2 and 4) for 3 and 4 persons. The rooms were fully furnished, and a varying amount of sound absorbers was suspended from the ceiling (same scenarios presented in annex 2). Stepwise increasing the amount of absorbers leads to the expected effect - lower reverberation times (Figure 5 and 6) and higher clarity.

Figure 5: Early Decay Time EDT vs. ceiling coverage in room IV, 3 persons office

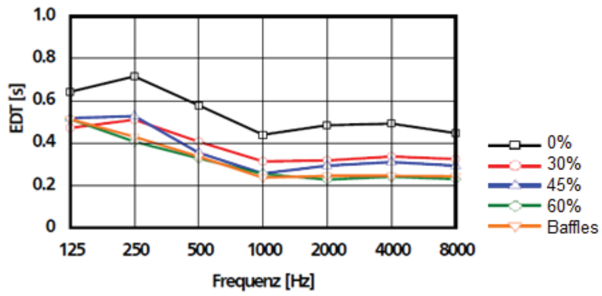
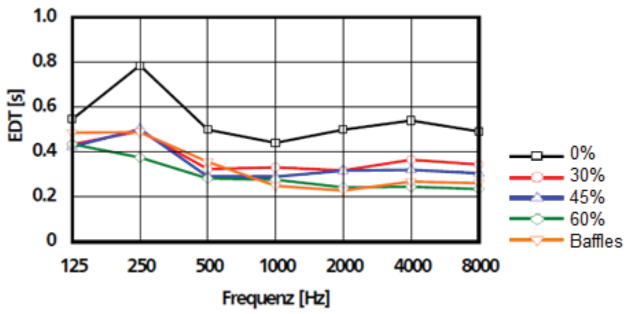


Figure 6: Early Decay Time EDT vs. ceiling coverage in room II, 4 persons office



6. Conclusion

Sound absorbers in office buildings influence the acoustic and thermal comfort. While the acoustic comfort can be increased with an increasing ceiling coverage ratio up to a certain limit, this measure can lead to a decrease of the thermal comfort. Overall, this intuitive idea for TABS building should be nuanced. The results of the measurements performed in the 3 persons offices present the counter-intuitive conclusion that a smaller coverage ratio does not lead to a better thermal comfort – the opposite is actually true. Even though this could partly derivate from user behavior, the fact that this situation happened in all of the 3 campaigns shows that this issue should not be underestimated. Hence, it is important to highlight the fact that in these offices higher coverage ratios (45%, up to 60%) can still meet the requirements for thermal comfort. In the 4 persons offices, the results match better with intuition. Nonetheless, here again interesting tracks exist. Based on The third campaign, even 60% coverage was able to meet the requirements for a category II indoor environment. The 45% coverage is maybe the more promising in this study, with results almost high enough to meet the requirements of a category II thermal comfort according to the standard EN 15251. In the 4 persons office with this coverage, the operative temperature remains in the comfort range approximately 93% of the time. Even if, on a strict application based on the measurements, this does not exactly comply with the 95% required by the standard, this solution worth remembering. With some minor updates, it could fairly be able to reach the expected level of comfort. And the 45% coverage was also the solution with the best results in terms of thermal comfort for the 3 persons office, even higher than the reference room. On the acoustic comfort point of view, even with a 30% coverage the comfort drastically improves compared to a reference room. However, in practice this coverage remains very low in terms of what could be done to improve the rooms acoustic quality. This is especially true given the size of the rooms in the present study (the room surface is always under 30m²). Fairly small compared to the European recommendations, they present the advantage of a better stability of measurements and reducing potential deviations. But on the other hand, the smaller the room the smaller the demand for acoustic absorbers. And in larger rooms, more representative of the actual office building demand would be greater than in the present rooms. The intuitive conclusion according to which the lowest coverage ratio the better the thermal comfort should be dealt with care. The monitoring has also shown that the short term influence of the occupants on the thermal comfort is least as high as the influence of sound absorbers. The thermal and acoustic conditions in an office room not only depend on the heat- and cold supply system and installed sound absorbers. Occupant behavior and the surrounding conditions as well as the interactions of relevant parameters (window opening, use of solar shading, occupancy, kind of work etc.) have a significant influence on the thermal and acoustic conditions in office buildings and specific rooms. In practice, a good thermal comfort in TABS buildings can be achieved with free hanging absorbers. The baffle system leads to good acoustic conditions and a low decrease in thermal comfort; and high levels of thermal comfort can still be achieved with a coverage ratio of at least 45%, and even higher in some cases.

Perspectives

This work will be pursued by further validating the effect of sound absorbers in rooms, both through field and laboratory measurements. A model has been created to numerically estimate the impact of discrete sound absorbers (Free Hanging Units) on the Operative Room Temperature. Our objective is, thanks to this model, to determine the configuration (e.g. position between two FHU) and physical properties (e.g. size, proportions, surface properties, etc.) which allows the better thermal comfort without losing acoustic properties. This model has been implemented into a plug-in for the thermal simulation software TRNsys. The TRNSys "type" and the user guide can be shared on simple request by emailing: yoan.le-muet@saint-gobain.com for France or rainer.machner@ecophon.de for Germany.

Acknowledgements

We would like to thank Saint Gobain Research its support before, under and after the study. We lso want to thank Fraunhofer Institute ISE for performing the measurements. We also thank personally Pierre Chigot for requesting that this project be carried out and Heiner Grewsmuehl for the logistic support and installation. Finally, we would like to thank Nils Rage, from DTU for his help writing portions of this document.

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