DTU Library

Numerical simulation of the effects of hanging sound absorbers on TABS cooling performance

Rage, Nils; Kazanci, Ongun Berk; Olesen, Bjarne W.

Published in:
CLIMA 2016 - Proceedings of the 12th REHVA World Congress

Publication date:
2016

Document Version
Peer reviewed version

Numerical simulation of the effects of hanging sound absorbers on TABS cooling performance

Nils Rage, Ongun B. Kazanci*, Bjarne W. Olesen

International Centre for Indoor Environment and Energy, Department of Civil Engineering, Technical University of Denmark, Nils Koppels Allé, Building 402, 2800 Kgs. Lyngby, Denmark

*onka@byg.dtu.dk

Abstract

Recently there has been a considerable increase in the use of Thermally-Active Building Systems (TABS) in Europe as an energy-efficient and economical cooling and heating solution for buildings. However, this widespread solution requires large uncovered hard surfaces indoors, which can lead to a degradation of the room acoustic comfort. Therefore, challenges arise when this system has to be combined with acoustic requirements.

Soffit-hanging sound absorbers embody a promising solution. This study focuses on quantifying their impact on the cooling performance of TABS, assessed by means of the cooling capacity coefficient of the ceiling deck. The influence of different ceiling coverage ratios (0-30-45-60 and 80%) as well as the influence of the distance at which the absorbers are placed is studied by numerical simulations using a new, specially-developed TRNSYS Type. Tests were performed in a test room simulating a two-person office of 20 m^2, with a typical cooling load of 42 W/m^2.

The results show that covering 60% of the ceiling surface with sound absorbers hanging at 300 mm from the ceiling active deck is expected to reduce the cooling capacity coefficient of TABS by 15.8%. This drops to 25.4% with a coverage of 80%. The presence of acoustic panels also affects the thermal comfort: the operative temperature in the room increases by 0.9°C in the former case and up to 1.6°C in the latter. Results also show that comfort ventilation supplied to the enclosure has a considerable influence on the thermal conditions in the room; if the ventilation is removed, then the operative temperature increases by 1.8°C for a 60%-covered ceiling.

Keywords - Thermally-active building systems; TRNSYS Type; Thermal comfort; Acoustic comfort.

1. Introduction

Today, Thermally-Active Building Systems (TABS) are of special importance as a solution for energy-efficient heating and cooling of buildings [1]. Several case studies and research works emphasize that TABS offer strong potential for energy savings in commercial buildings ([2] [3] [4]).

Activating the thermal mass of the building structure – typically by means of embedded water-carrying pipes, but air-based alternatives also exist [5] –ensures a comfortable indoor environment to the occupants, while making it possible to integrate renewable energy sources into heating and cooling systems [1]. However, to ensure optimal thermal conditions, this solution requires large uncovered hard surfaces indoors (typically concrete floor and ceiling). Acoustic comfort is consequently often a concern in such an environment deprived of sufficient sound absorbing area.

Hanging ceiling absorbers present a viable solution to the acoustic issue, but their presence will interfere with the heat transfer performance of an active deck system. Hanging at a certain distance from the soffit, these units present the advantage of enabling convective air movements both between their upper surface and the soffit, as well as between this layer and the room. They also allow some radiation from the soffit to reach the room, and hot air from the room to reach the soffit.

This influence has only been studied in a limited amount of papers; and a deeper understanding of it is necessary as the number of thermally-activated buildings expand rapidly in Europe. The present study focuses on quantifying the influence of the presence of hanging sound absorbers on the steady-state heat exchange in a room conditioned with TABS. For this purpose, computer simulations are carried-out, using a specially-developed new Type for the simulation software TRNSYS (Type Ecophon Acoustic Elements) [6]. Results assess the impact of different ceiling coverage ratios (0-30-45-60-80%) on the cooling capacity coefficient of the TABS ceiling deck and the thermal indoor environment.

2. Numerical model

TRNSYS is a simulation environment widely used to model – among others - the dynamic thermal behaviour of buildings [6]. Until recently, there was no possibility, to the authors' knowledge, of modelling a suspended ceiling with a surface area different from the ceiling surface in TRNSYS (i.e. anything else than a conventional fully-covered suspended ceiling). To answer this problem, Ecophon supervised the development of a new Type allowing simulating hanging sound absorbers with a certain coverage defined by the user [7]. The new Type (Ecophon Acoustic Elements) considers convective heat exchange of the sound absorbers with the room air, and radiative heat exchange with the room inner surfaces. Linked to the Type 56's room model, the component allows evaluating the impact of sound absorbers on operative temperature in the room and on the cooled ceiling efficiency, as a function of the ceiling coverage ratio [7].

This new Type has been used in the present work to account for variations in the ceiling coverage ratio and to investigate its influence on TABS efficiency and indoor environment. This tool has first been validated based on the comparison with full-scale measurements [8] [9], which showed consistent results.

The case study has been set up in order to be then tested out in full scale in a TABS test facility located at the Technical University of Denmark. The numerical model therefore reproduces the same geometrical and thermal properties as the facility. The construction consists of two thermo-active concrete decks (floor and ceiling) surrounding an office room. The dimensions of the room are 6.0 x 3.6 x 3.6 m (L x W x H), i.e. a floor surface area of 21.6 m^2. The test room is designed as a room in a room: a thermal guard surrounds the chamber. The temperature of the guard is kept equal to the room temperature in order to limit any disturbing heat transfer across the room walls. As a consequence, vertical walls in the numerical building model are simulated as adiabatic. A detailed description of the simulated building case is available in [8].

The building model simulates a two-person office room. The following heat gains have been implemented in the building model (Table 1). The details of the room geometry are given in [9].

Table 1 – Inputs used for the numerical simulation

Water TABS	Supply temperature [°C]	15
	Flow rate [kg/h]	300
Heat gains in room	2 Occupants [W]	240
	2 PC with monitors [W]	280
	Lights [W]	216
	Simulated solar gain [W]	175
	Total heat gains [W/m^2]	42.2
Acoustic panels	Thickness [mm]	40
	Thermal conductivity [$W.m^{-1}.K^{-1}$]	0.03
	Density [kg/m^3]	123

A constant ventilation rate of 1.35 ACH is set in the model for mechanical ventilation, with a supply temperature of 20°C. This air change rate has been calculated according to the requirements in EN 15251:2007 [10] for comfort ventilation.

3. Influence of the distance between soffit and acoustic panels

The first parameter investigated is the distance at which the acoustic panels' layer is placed from the soffit. According to literature [6] [8], this parameter can vary greatly from one study to another, thus making it difficult to compare the results. Therefore, this paragraph will present a comparative evaluation of the influence of this parameter on the cooling capacity coefficient to be expected from the active ceiling.

For this, a case study has been modelled in TRNSYS, with the parameters listed in Table 1. For a given coverage ratio, the cooling capacity coefficient of the active ceiling has been assessed for six different heights of acoustic ceilings, and compared to the value obtained without any suspended ceiling. A constant ceiling coverage ratio of 60% has been chosen, as it corresponds to the recommended coverage for TABS buildings according to acousticians [11]. Using hanging horizontal acoustic units at this coverage creates acoustic conditions comparable to that of the same room with a continuous fully-covering ceiling of the same material [12]. The distances studied are 50, 150, 300, 450, 600 and 750 mm from the soffit to the top surface of the acoustic panel.

In the model, the cooling capacity coefficient from the upper deck (U_{cc}, [$W.m^{-2}.K^{-1}$]) has been assessed as in [13] and [14], using Eq. (1).

$$U_{cc} = \frac{q_{TABS}}{\Delta T_{room-fluid}} \tag{1}$$

where

- $\Delta T_{room-fluid}$ is the temperature difference between the room operative temperature and the average water of the TABS [°C];
- q_{TABS} is the heat flow from the active ceiling deck, calculated using Eq. (2) [$W.m^{-2}$].

$$q_{TABS} = \frac{\dot{m} \cdot c_{p,water} \cdot (T_{return} - T_{supply})}{A_{room}} \tag{2}$$

In (2),

- $\dot{m}$ is the water flow rate supplied to the TABS deck [kg/s];
- $c_{p,water}$ is the specific heat capacity of the water [J/(kg.K)];
- T_{supply} is the water supply temperature [°C];
- T_{return} is the water return temperature [°C];
- A_{room} is the floor area of the room [m^2].

The water temperature is calculated as the average between supply and return.

3.1. Cooling capacity coefficient results

Figure 1 summarizes the results. The cooling capacity coefficient reduction has been assessed and it corresponds to the absolute difference between the cooling capacity coefficient obtained for a given scenario and the value for an uncovered ceiling.

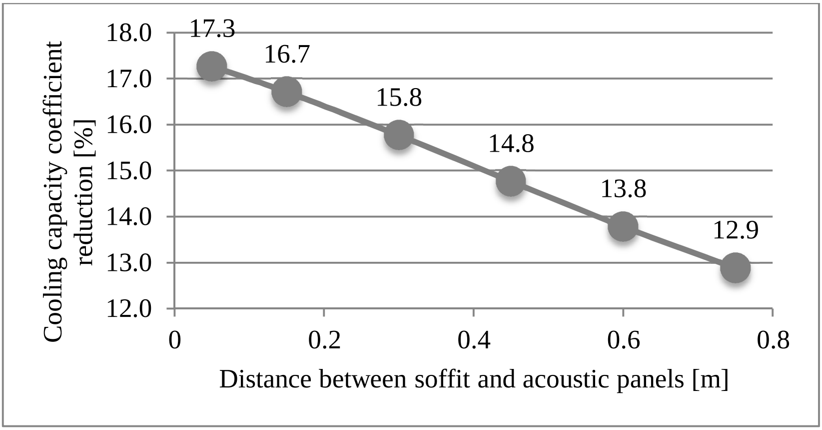

Figure 1 - Cooling capacity reduction as a function of the distance between soffit and acoustic panels for a coverage ratio of 60%.

The results show that the further away from the soffit the acoustic panels are placed, the smaller the cooling capacity coefficient reduction is. This could be explained by a higher accessibility of the TABS to the room air. This will ease convection movements in the air layer above the panels, and reduce the masking effect of the radiation from the TABS. The reduction is nonetheless limited, with a difference under 5%.

3.2. Thermal comfort results

Figure 2 summarizes the results obtained for air and operative temperatures in the room. Covering 60% of the active ceiling with sound absorbers has a clear effect on the temperature levels in the room, with an average operative temperature increase of 0.8°C over the six scenarios investigated. However, the influence of the distance at which the sound absorbers layer is placed from the ceiling does not have a significant impact on the temperature increase (under 0.2°C).

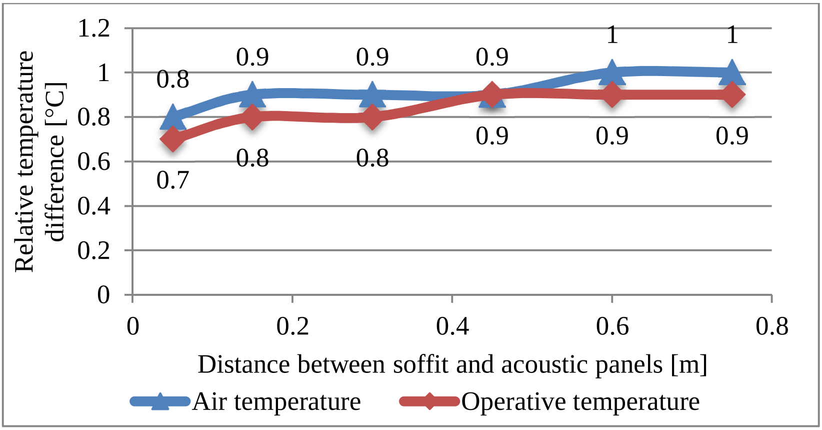

Figure 2 - Temperature increase as function of the distance between soffit and acoustic panels for a coverage ratio of 60%.

In order to limit the shading effect of acoustic panels on TABS cooling performance, it appears that it is beneficial to place them as far as realistically possible from the slab surface. This is however limited in actual situations by practical considerations such as costs and building height. To study the influence of the coverage ratio, a distance of 300 mm has been simulated, as it is a typical realistic case encountered in office buildings by ceiling manufacturers [11].

4. Influence of the ceiling coverage ratio

Using the inputs and methodology previously described, simulations have been carried out to assess the cooling capacity coefficient of the room's ceiling TABS for different scenarios. Each scenario features a different ratio of the ceiling covered by hanging glass wool sound absorbers: 0, 30, 45, 60 and 80%.

Results showing the evolution of the cooling capacity coefficient and the operative temperature with the ceiling coverage ratio are plotted in Figure 3. As expected, a decrease in cooling capacity coefficient with the increase of ceiling coverage ratio can be noted. The cooling performance of TABS is reduced when large portions of the slab are covered by hanging sound absorbers. This reduction is 15.8% for 60% coverage and 25.4% at 80%, compared to a bare active deck. Consequently, one can note an increase in the room's operative temperature, due to reduced cooling. Under the present conditions, this increase has been registered to be 0.9°C for 60% coverage and 1.6°C at 80%.

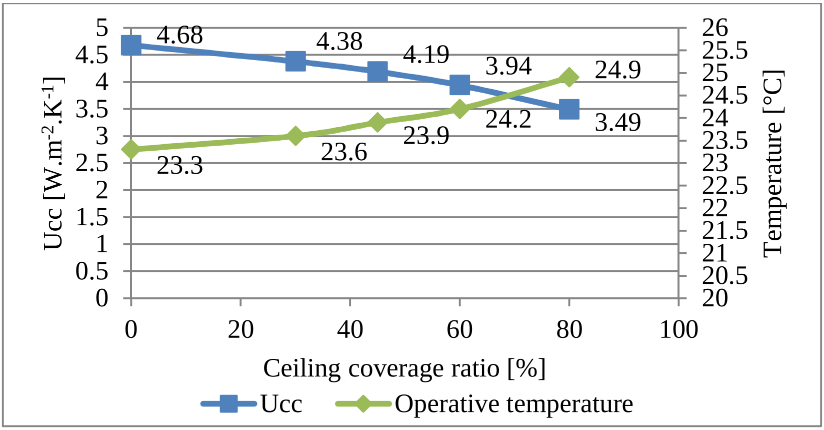

Figure 3 - Evolution of TABS cooling capacity coefficient and room temperatures with the ratio of ceiling surface covered by acoustic hanging elements

The main results are summarized in Table 2. The table also includes other physical parameters that have been monitored to understand the evolution of the active slab properties.

Table 2 - Numerical simulations results

Parameter	Unit	Coverage [%]				
		0	30	45	60	80
$Ucc_{ceiling}$	$W.m^{-2}.K^{-1}$	4.68	4.38	4.19	3.94	3.49
T_{air}	°C	23.9	24.3	24.5	24.9	25.6
T_{op}	°C	23.3	23.6	23.9	24.2	24.9
$\Delta T_{room-fluid}$	°C	7.3	7.6	7.9	8.2	8.9
$T_{ceiling\_surface}$	°C	21.1	21.0	20.9	20.7	20.5
PMV	-	0.36	0.42	0.47	0.53	0.66
PPD	%	7.76	8.73	9.60	10.90	14.00

5. Sensitivity analysis

Additional simulations have been performed in order to provide a holistic meaning out of these results. They feature the same varying criterion – the part of the TABS active ceiling covered by acoustic panels – with different inputs. This sensitivity analysis will allow understanding the weight of each parameter on the results. The varied parameters are as follows.

- The absence of comfort ventilation in the room: ACH=0.
- Smaller internal heat gains: the simulated solar gain has been removed from the model, leading to an internal heat gain of 34 W/m^2.
- Increased TABS supply water temperature from 17°C to 19°C.
- Higher and lower air supply temperature to the room: 22°C and 18°C.

The parameter investigated is the operative temperature increase between an uncovered and a 60%-covered deck, as shown in Figure 4.

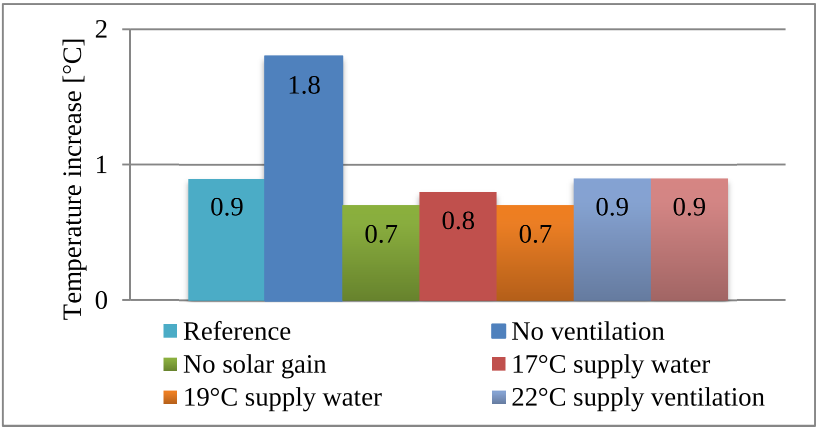

Figure 4 - Relative operative temperature increase between a bare TABS ceiling and a 60%-covered ceiling for different cases

The increase in operative temperature to be expected when covering 60% of the active ceiling area is similar in each case when mechanical ventilation is supplied to the enclosure. As soon as the fresh air supply is removed, the effect of the panels will be much more contrasted. Indeed, the temperature rise in this case is twice as big as the reference case, reaching 1.8°C. This value matches with previous results measured in laboratory reporting an operative temperature increase of 2°C in a TABS test facility without ventilation for a coverage ratio of 70% [14]. This emphasizes the supportive cooling effect of mechanical ventilation. Future investigations could focus on the combination of displacement ventilation in such situation, as this principle relies on a stratified air distribution that could be perturbed by the presence of hanging elements from the active slab.

6. Discussion

The impact of sound absorbers hanging from an active deck on the performance of this latter has only been studied in a limited amount of works. The numerical results obtained in this paper corroborate previous results from Pittarello [14]. The author performed two different series of tests, using different types of panels and layouts. The author reports cooling capacity coefficient reductions of 29% for 67% coverage in one case, and 22% for coverage of 70% in the other case. Besides, the conclusions drawn in this study in cooling mode are still viable when TABS are used in a heating mode. As Álvarez [15] concludes from her experimental study, the heating capacity coefficient of a TABS ceiling deck is reduced by 30% when 70% of the active surface is covered with suspended mineral wool panels.

Based on the simulation results, thermal comfort can still be achieved with TABS, while covering part of their surface, with an operative temperature increase under 1°C. This corresponds to an ideal case modelled using computer simulation; but a reduced effect on comfort is expected to be registered in an actual building. Measurements in a building equipped with TABS show that the occupants' behaviour's influence on indoor environment is at least as big as the effect of the actual change in ceiling geometry [16].

7. Conclusion

Thermally-Activate Building Systems (TABS) present an energy-efficient solution to provide comfortable thermal conditions indoors [4]. Buildings designed with this technology, where the ceiling cannot be fully covered for thermal reasons, can still benefit from room acoustic optimization. Such buildings can be equipped with free hanging acoustic units or baffles to control the acoustics of the room, combined with wall absorbers.

Adding such sound absorbers in a room conditioned by TABS will impact the performance of this latter, as the sound absorbers will shield some of the radiation from the chilled surface, as well as prevent some of the hot air plume generated by the internal heat sources to reach the soffit. Consequently, the temperature in the enclosure will increase.

The simulations allowed quantifying a reduction of the TABS performance – represented by the ceiling deck cooling capacity coefficient – of 15.8% when 60% of the ceiling area was covered with floating acoustic panels; and of 25.4% when this coverage increased to 80%. In terms of indoor comfort, this effect translates into an increase in operative temperature of 0.9°C in the former case, and up to 1.6°C in the latter. The sensitivity analysis underlined the major peak-reduction impact of mechanical ventilation on the temperature increase. The distance at which panels are placed from the slab has a moderate impact on the results, but it is beneficial to place them as far from the slab as possible, both for acoustic and thermal reasons.

Hanging sound absorbers make it possible to combine high levels of thermal and acoustic comfort in buildings equipped with TABS. Additionally, the numerical tool developed can help a better integration of acoustic solutions in the early design phases of a building, when used by consultants and architects.

Acknowledgments

The authors would like to express their gratitude to Pierre Lombard from Saint-Gobain Recherche for his work developing the Type Ecophon Acoustic Elements.

References

[1] J. Babiak, B.W. Olesen, D. Petrás, "Low temperature heating and high temperature cooling", *Rehva Guidebook*, vol. 7, 2009.

[2] D.E. Kalz and J. Pfafferott, *Thermal Comfort and Energy-Efficient Cooling of Nonresidential Buildings*, Springer, 2014.

[3] D.E. Kalz, J. Pfafferott and S. Herkel, *Monitoring and Data Analysis of two Low Energy Office Buildings with a Thermo-Active Building System (TABS)*, 2006.

[4] B. Lehmann, V. Dorer, and M. Koschenz, "Application range of thermally activated building systems tabs". *Energy and Buildings*, vol. 39, pp. 593–598, 2007.

[5] O.B. Kazanci, B.W. Olesen, IEA EBC Annex 59 - Possibilities, limitations and capacities of indoor terminal units. 6th International Building Physics Conference, IBPC 2015. *Accepted, to be published in Energy Procedia.* Pages: 6. doi: 10.1016/j.egypro.2015.11.213, 2015.

[6] P. Lombard, "Thermal model of Ecophon free-hanging sound absorbers for TRNSYS", Note Technique, Saint-Gobain Recherche, February 8th 2015. [Confidential]

[7] Ecophon, *Type Ecophon Acoustic Elements User Guide*, 2015.

[8] N. Rage, "Experimental and theoretical study of the influence of acoustic panels on the heat exchange between Thermo-Active Building Systems (TABS), the occupants and the room". *MSc thesis*, Technical University of Denmark, 2015.

[9] N. Rage, O.B. Kazanci, B.W. Olesen, "Validation of a numerical model of acoustic ceiling combined with TABS", *Submitted to 12th REHVA World Congress CLIMA 2016*, 2015.

[10] EN 15251, *Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.* European Comittee for Standardization, 2007.

[11] Ecophon, *Knowledge Guide, Thermally Activated Building Systems*, 2014.

[12] P. Chigot, *Office buildings and natural cooling:room acoustic demands and influence of acoustic treatment on thermal performance*. Proceedings of Inter-Noise, 39th International Congress and Exposition on Noise Control Engineering. Lisbon, 13-16 June 2010.

[13] P. Weitzmann, "Modelling building integrated heating and cooling systems". PhD dissertation, Dept. of Civil Engineering, Technical University of Denmark, Lyngby, 2004.

[14] E. Pittarello, "Influence of acoustical panels on cooling of Thermo-Active Building Systems (TABS)". MSc thesis, Technical University of Denmark, 2006.

[15] M.A. Álvarez, "Experimental and Numerical Investigations of Heat Transfer in Thermo Active Building Systems in combination with suspended ceilings". MSc thesis, Dept. of Civil Engineering, Technical University of Denmark, 2013.

[16] Y. Le Muet, P. Lombard, "Combining thermally activated cooling technology and high acoustic demand: Acoustic and thermal results from field measurements part II". *EuroNoise 2015*, 2015.