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Heiselberg, Per Kvols

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Validation of a numerical model of acoustic ceiling combined with TABS

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

Thermally-Active Building Systems (TABS) have proven to be an energy-efficient and economical cooling and heating solution for commercial buildings. However, acoustic comfort is often jeopardized in such buildings, due to the thermal requirements of the system. More knowledge is required to understand to which extent a layer of hanging sound absorbers will impede the heating and cooling performance of the system, and how this translates on the thermal comfort for the occupants.

In order to address these issues, this study focuses on validation of a new TRNSYS component (Type Ecophon Acoustic Elements) developed to simulate partially covered suspended ceilings such as hanging sound absorbers. The tool is validated by numerically modelling a set of similar experiments carried out in full-scale by a previous study. For this, a total of 12 scenarios from two case studies have been modelled, with varying suspended ceiling coverage ratios, type of suspended ceilings, internal heat gains and TABS water supply temperatures.

The results obtained from the simulations are very close to the experimental results. The first set of measurements analyzed the effect of the above-mentioned parameters in the heat flow from TABS; the difference between the numerical results and measurements is in the range of -6.9% to +5.2%. The second evaluates the impact on TABS cooling capacity coefficient and room temperatures. The simulated cases led to absolute differences +4.3% higher in average for the cooling capacity coefficient. The operative temperature in the room is particularly well estimated, with a maximum relative difference of +0.3°C in total of five scenarios.

Keywords - Thermally-active building systems; Concrete core cooling; Thermal comfort; Acoustic comfort; Cooling capacity coefficient; Sound absorbers; Free-hanging acoustic elements; TRNSYS Type.

1. Introduction

Thermally-Active Building Systems (TABS) are of special importance as they embody a promising solution for energy-efficient heating and cooling of buildings [1]. Several case studies and research emphasize that TABS offer strong opportunities for energy savings in non-residential buildings ([2] [3] [4]).

To provide a comfortable indoor environment to the occupants, TABS rely on activating the thermal mass of the building construction, often using a hydronic system with water-carrying pipes embedded in the slabs. TABS present various advantages including shaving the peaks in cooling power demand, shifting the demand to times of low occupancy, energy efficiency, and so forth [1]. But this widespread solution also features the limitation of requiring large uncovered hard surfaces indoors (typically concrete floor and ceiling). Consequently, acoustic comfort is often a concern in such an environment deprived of sufficient sound absorbing area.

Hanging ceiling absorbers represent 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 number of papers; and a deeper understanding of it is necessary as the number of thermally-activated buildings expand rapidly in Europe. For this, a new Type for the software TRNSYS has been developed (Type Ecophon Acoustic Elements) [5], allowing the modelling of such types of absorbers and the understanding of how their presence will impact the TABS performances and, consequently, the indoor thermal comfort. In this study, the Type is validated by numerically recreating a series of full-scale measurements on the topic [6]. The tool reacts properly and allows an accurate modelling of the actual situation.

2. Numerical model

TRNSYS is a simulation environment widely used to model – among others - the dynamic thermal behaviour of buildings [7]. Until recently, there was no possibility to the authors' knowledge to model a suspended ceiling with a surface area different from the ceiling surface in TRNSYS (i.e. anything else than a classic fully-covering 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 [5]. 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 [8].

The work conducted by Pittarello [6] has been used for the validation of the model, since a clear documentation of the test setups used was available, therefore allowing for an implementation in TRNSYS. Pittarello performed full-scale thermal and acoustic measurements in a TABS test room.

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 can be regulated, and in the present case its temperature has been 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 boundary conditions. A detailed presentation of the simulated building case is available in [8].

12 scenarios of measurements conducted by Pittarello have been modelled in TRNSYS, with varying suspended ceiling coverage ratios, type of material of suspended ceiling, heat loads and TABS water supply temperatures. The measurements are separated into two case studies, for the two types of suspended ceilings investigated: a first set of measurements has been conducted using plywood boards as suspended ceiling, while the second batch made use of rock wool sound absorbers.

Figure 1 illustrates a simulated case study with horizontal absorbers hanging from the active soffit in a two-persons office.

Figure 1 - Render of a simulated case study

3. Measurements with plywood

3.1. Methods

For this series of measurements, a suspended ceiling made of plywood is modelled, and the influence of various internal parameters on the cooling power obtained from the upper deck of the test chamber (W/m^2) is evaluated. For each scenario, the results have been plotted against the temperature difference between the room (considered as the operative temperature) and the fluid in the pipes. Table 1 summarizes the measurements performed.

Table 1 - Summary of the seven measurements used

Layout	Scenario	Coverage ratio [%]	Water supply temperature [°C]	Internal heat sources	Heat load [W/m^2]
Layout 1	1	67	15	Lights, 4P, 2PC	39.6
	2		15	Lights, 2P, 1PC	22.9
	3		17	Lights, 2P, 1PC	22.9
Layout 2	4	67	17	Lights, 2P, 1PC	22.9
	5		15	Lights, 4P, 2PC	39.6
Layout 3	6	83	15	Lights, 4P, 2PC	39.6
	7		17	Lights, 2P, 1PC	22.9

Details of the heat loads used are available in [9]. Three different layouts have been studied by the author, including two different designs at a 67% ceiling coverage ratio. The TRNSYS Type Ecophon Acoustic Elements does not allow simulating different layouts for a given coverage [8] but it is still interesting to compare the results to evaluate the layout influence. Heat loads are varying, using lights, occupants (“P” in Table 1, for “Person”) and computers (“PC” in Table 1). In TRNSYS, panels’ geometry and physical properties have been modelled as described in [7]; in this study, panels are hanging at a distance of 600 mm from the soffit.

In the model, the cooling capacity from the upper deck has been assessed as in [10], using (1).

$$q_{pipe} = \frac{\dot{m} \cdot c_{p,fluid} \cdot (T_{return} - T_{supply})}{A_{room}} \qquad (1)$$

where

- q_{pipe} is the cooling capacity from the upper deck [W/m^2]
- $\dot{m}$ is the water flow rate supplied to the TABS deck [kg/s];
- $c_{p,fluid}$ is the specific heat capacity of 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].

3.2. Results

Figure 2 shows the comparison of the results obtained for each case between Pittarello's measurements and the TRNSYS model. The light lines are illustrating Pittarello's results, whereas the dark lines correspond to the model's results. Each colour corresponds to a different scenario. One point corresponds to one combination of variables (varying heat load and fluid supply temperature), as detailed in Table 1. This allows understanding the model response both in terms of heat flow from the deck and in terms of temperature distribution in the room and pipes.

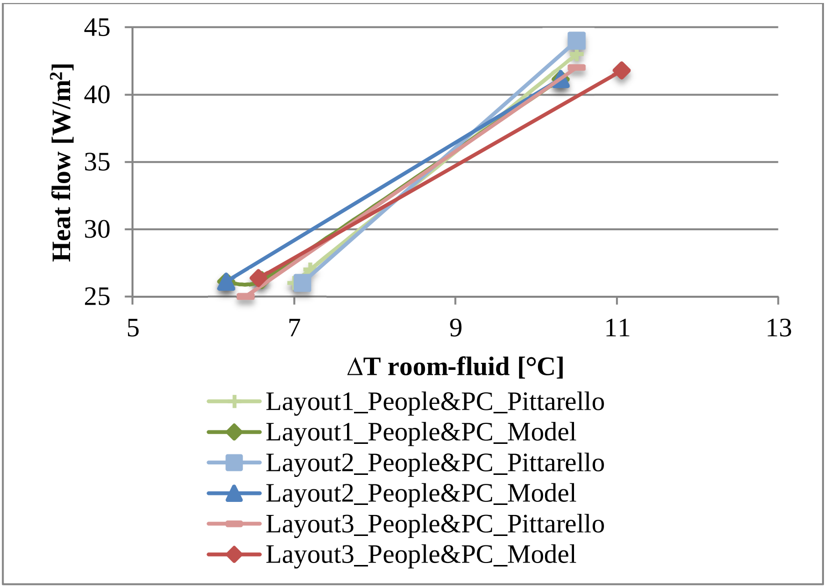


Figure 2 - Results comparison for the first case study

Table 2 - Summary of the results obtained for the first case study

Scenario	TRNSYS Simulation			Measurements [6]		
	Heat flow [W/m^2]	ΔT room-fluid [°C]	U_{cc} [W.m^{-2}.K^{-1}]	Heat flow [W/m^2]	ΔT room-fluid [°C]	U_{cc} [W.m^{-2}.K^{-1}]
1	41.1	10.3	3.98	43	10.5	4.10
2	26.2	6.6	3.98	27	7.2	3.75
3	26.1	6.2	4.24	26	7	3.71
4	26.1	6.2	4.24	26	7.1	3.66
5	41.2	10.3	3.98	44	10.5	4.19
6	41.8	11.1	3.78	42	10.5	4
7	26.4	6.6	4	25	6.4	3.91

Overall, the results are in the same range, both in terms of heat flows and temperatures. The difference between the numerical results and measurements are in the range of -6.9% to +5.2% for the heat flow. Since heat flow, room and water temperature are all susceptible to vary simultaneously, the cooling capacity coefficient of the ceiling has been used as indicator in order to allow a comparison of the results. The cooling capacity coefficient is defined according to (3) [10], where T_{room} is the room operative temperature.

[W.m^{-2}.K^{1}]

$$U_{cc} = \frac{q_{pipe}}{(T_{room} - T_{fluid})} \quad (3)$$

The water temperature has been calculated as the average between supply and return. The room temperature is identified to the room operative temperature, as described in [6]. The cooling capacity coefficient difference lies in the range of 2.7% to -15.8%, with an average value of 0.1% over the seven scenarios considered.

4. Measurements with mineral wool panels

4.1. Methods

In this case, the suspended ceiling is modelled as a layer of rock wool acoustic panels, with different coverage ratios. Five scenarios have been considered, with ceiling coverage ratios of 0, 35 and 70%. The other varying parameters were the water supply temperature to the TABS and its flow rate. In this study, the internal heat gains were the same for all scenarios, simulating two occupants, two computers and lights in the room. This corresponds to a total sensible heat load of 30 W/m^2. Additional details concerning the test methods and assumptions can be found in [6]. Tables 3 and 4 summarize the case study modelled.

Table 3 - Case study modelled for the validation

Heat gains in room	2 Occupants [W]	240
	2 PC with monitors [W each]	140
	Lights [W]	216
	Total heat gains [W/m^2]	34
	Total sensible heat gains [W/m^2]	29
Acoustic panels	Distance from slab [mm]	600
	Thickness [mm]	50
	Thermal conductivity [$W.m^{-1}.K^{-1}$]	0.037
	Density [kg/m^3]	123

Table 4 - Summary of measurement scenarios performed by Pittarello [6]

	Coverage ratio [%]	Water supply temperature [°C]	Water flow rate [L/h]
Scenario 1	0	15	180
Scenario 2	0	17	180
Scenario 3	35	15	180
Scenario 4	70	15	360
Scenario 5	70	15	180

The parameters measured were the temperatures in the room (air and operative) and the cooling capacity coefficient of the ceiling deck as described in (3) [10].

4.2. Results

The results are summarized in the following charts (Figure 3 and 4).

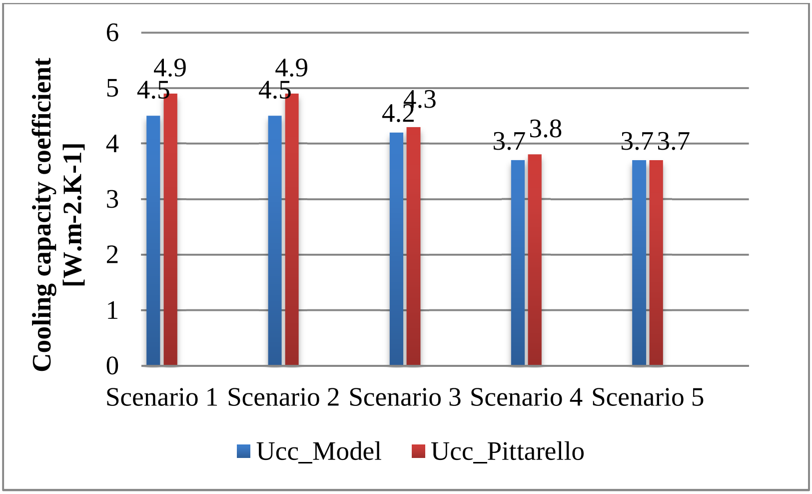
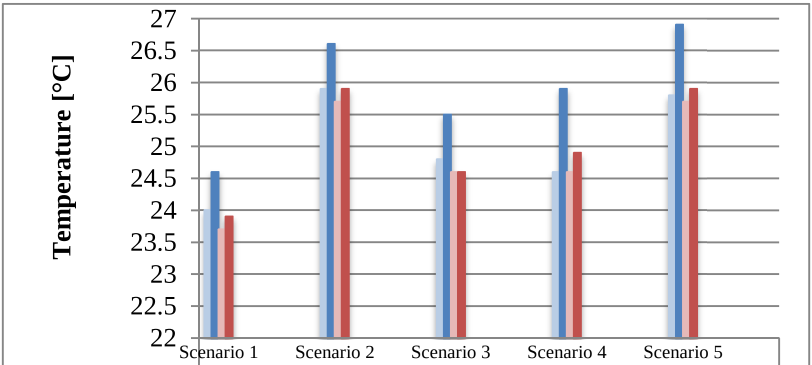


Figure 3 - Results comparison for the cooling capacity coefficient of the upper deck



	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Tair_Pittarello	24	25.9	24.8	24.6	25.8
Tair_Model	24.6	26.6	25.5	25.9	26.9
Top_Pittarello	23.7	25.7	24.6	24.6	25.7
Top_Model	23.9	25.9	24.6	24.9	25.9

Figure 4 - Results comparison for the temperatures in the room

The results show that the cooling capacity coefficient was modelled accurately; the values obtained match closely with the results measured by Pittarello [6]. The difference between the results averages at 4.3%, which is acceptable.

Regarding the modelling of the temperature distribution in the room, the results match closely. The average difference in air and operative temperature is 0.9°C and 0.2°C, respectively. The results show that the operative temperature modelling matches precisely the results obtained in the test room; whereas the air temperature is slightly overestimated in the simulations. Figure 3 shows that the difference increases with the ceiling coverage ratio. Differences could be due to measurement equipment accuracy and position as well as air stratification in the room, which is not taken into account in TRNSYS. In fact, the air temperature was measured at a height of 70mm from the floor in [6], without any ventilation in the test room which induced a stratified air temperature distribution. The numerical software on the other hand assuming a full mixing in the enclosure, a higher overall result can be expected for air temperature in this case. To address latent loads and air quality, buildings in use will be provided with ventilation. The full mixing assumption is valid when considering a space provided with mixing ventilation. Further investigation on the influence of natural and displacement ventilation combined with TABS would be valuable.

5. Conclusion

Adding soffit-hanging sound absorbers to a room conditioned by TABS will affect the heating and cooling performance of TABS, while improving acoustic comfort. In order to help consultants and researchers to evaluate this influence numerically, a new Type for the dynamic simulation software TRNSYS has been developed (Type Ecophon Acoustic Elements) [5]. The reaction and robustness of the Type has been validated in this study, by numerically modelling two sets of experiments carried out in a TABS test facility. The numerical model showed good consistency with the results from the full-scale measurements in terms of heat flow (difference between the numerical results and measurements is in the range of -6.9% to +5.2%), cooling capacity coefficient of the TABS ceiling deck (average difference of 4.3%) and temperature in the enclosure (average differences of 0.9 and 0.2°C for air and operative temperatures, respectively).

The numerical tool is proven to be capable of accurately simulating the effects of hanging acoustic absorbers when installed in a room equipped with TABS. Based on this conclusion, the new Type will be used for future studies to study the impact of the presence of glass wool acoustic panels on the occupants’ thermal comfort. Additionally, the use of this numerical tool can help a better integration of acoustic solutions in the early phases of a building design, when used by consultants and architects.

Acknowledgments

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

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

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

[5] P. Lombard, “Thermal model of Ecophon free-hanging sound absorbers for TRNSYS”, *Technical Report*, Saint-Gobain Recherche, February 8th 2015. [Confidential]

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

[7] Solar Energy Laboratory, *TRNSYS 17 Manual – Volume 1: “Getting started”*. Solar Energy Laboratory, Univ. of Wisconsin-Madison, 2014.

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

[9] 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.

[10] P. Weitzmann, “Modelling building integrated heating and cooling systems”. *PhD dissertation*, Dept. of Civil Engineering, Technical University of Denmark, 2004.