A comparison study between prediction models and in situ measurements of acoustic clouds in open plan offices

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Summary

Open plan offices are now one of the most common form of workspaces and in order to establish acoustic performance criteria and field measurements procedures for these spaces, new standards and many researches are being developed.

When considering open plan offices acoustic design, there is a lack of specific methods to predict the precise influence of acoustic clouds and baffles since the characterization of these products by ISO 354 does not represent the real-life setups.

In this paper, several prediction models are compared to in situ measurements aiming to evaluate its suitability, by means of Reverberation Time evaluation. The main objective of this study is to identify which existent prediction model can be used on the development of more precise acoustic design for open plan offices.

PACS no. 43.55.Br, 43.55.Dt, 43.55.Nd.

1. Introduction

In the past decade, the extensive use of the open plan solution in offices has increased all over the world[1]. This organization concept has emerged in the 1950's, when a German design group, created the Quickborner, an office landscape idea[2]. The transition from the conventional format to a new one, changed the default office layouts from single cubicles, to an organic layout that organizes the workstations in an open area. This concept became more massive in the offices scenario, which highlighted the acoustic problems, though.

This change happened thanks to a new mentality about the workspace environment and the need to reduce expenses. Instead of a capsule office to each employee, the open plan layout provides one large space for all the workers with more usable area and higher occupancy density [3]. This type of configuration facilitates, not just the communication between co-workers but also the interaction between teams.

Although, this layout promotes workplace satisfaction and teamwork effectiveness, the presence of noise in theses spaces can cause distractions and productivity loss [4]. Thus, to guarantee a proper acoustic quality for those workspaces, a specific study is needed.

According to Hongisto [5], room acoustic can be technically controlled by three main factors in open plan offices.

- Room absorption, which prevents reverberation and early reflections.
- Screens, which cut the direct sound, and;
- Masking sound, which gives a stable sound environment and masks the speech from nearby workstations.

In order to deal with this organizational layout, many researches are being improved and standards are being carried out recently, all of them aim to measure parameters and some of them propose to establish design requirements [3]. ISO 3382-3 instructs how to measure other parameters, but, on the other hand it does not present design requirements, as $D_{2,S}$, D_n, L_{Aeq}, L_{bkg}, $L_{p,A,S,4m}$ and r_D, used to establish criteria in RIL 243-3, VDI 2569 and NFS 31 199. Moreover, recently, the ISO/ TC 43/SC 1 was proposed by France as an international standard based on the NFS 31 199, which indicates different requirements for different office activities.

In Brazil, there are no regulations or standards which indicate acoustic criteria or appropriated parameter to design open plan offices. Yet the international standard ISO 3382-3 was adopted in Brazil as ABNT NBR ISO 3382-3. However, this standard does not present acoustic criteria to design an acoustic environment that would increase the workspace satisfaction.
In many countries, as Australia and Germany, national building codes still indicates Reverberation Time (RT) requirements as a design parameter. Despite consistent researches show that RT is not sufficient to characterize acoustic quality in open plan offices spaces[6], it is referenced in AS/NZS 2107:2016, DIN 18041. One of the reasons, is that reverberation time, despite its limitations [7], can be easily incorporated to the office design process, as it can be predicted by statistical and raytracing methods in specific software to obtain designed results or simply have its measurements verified *in situ*.
There are many reasons to use the Reverberation Time of a room as a predominant indicator of its acoustical properties[6]. RT is an objective parameter which gives numerical aspects to a nonobjective parameter. Therefore, it is possible to comprehend that it relates with many others subject aspects connected to the room experience [7] and in most cases this parameter will be evaluated to determine acoustic insulation results.
Also considering the office acoustic design, clouds and baffles are commonly specified by architects as a solution for open plan offices sound quality. This type of solution can be easily incorporated during the building process and allows different configurations in the ceiling design. It is also more sustainable as it uses less material for the same performance as a regular acoustic ceiling system and enables the access to the mechanical electrical plumbing systems (MEP) in the ceiling areas.
The ISO 354 establishes the measurement procedure to characterize the sound absorption coefficient of clouds and baffles, but as observed by Plötzner[8], those standard procedures and results are not suitable for real life cloud and baffles setups. In field, acoustics clouds are frequently placed distant from other surfaces, with different heights and distances between each other. The absorption coefficient obtained in laboratory, only consider positions close to the floor or close to each other.[8] Consequently, using these sound absorption coefficients to predict the acoustics conditions of an open plan office reduces the correlation between the predicted and measured parameters.
Some researchers had already investigated this issue, *e.g.* the study made by Plötzner[8], where it is possible to notice many differences between the results achieved in laboratory measurements and *in situ* measurements.
Yet, in the draft standard DIS 2189, a more realistic approach, incorporates several positions for laboratory measurements.
Since there is no precise method to predict the performance of clouds in the acoustic of open plan offices, the aim of this paper is to accomplish a specific study between different RT prediction methods and *in situ* measurements to examine which prediction method better correlates.
As explained in this section, even though RT evaluation does not comprise a complete acoustic characterization of the space to provide workplace satisfaction, it still is one of the main criteria adopted in international building codes. It is also a useful parameter for architects when designing and evaluating open plan offices in field.
Furthermore, this study intends to stimulate other researchers to develop methods to characterize sound absorption of objects, *e.g.* acoustic clouds and baffles, in order to assist acoustic consultants when it comes to design an efficient and comfortable place to work.

2. Objectives

This study aims to compare the RT results of prediction models and software simulation with real life setups, analyzing, which one is more related to reality.
According to the concept previously explained, this paper will compare three different reverberation time study cases:

- using statistical prediction models (Sabine, Eyring, Fitzroy and EN 12354-6[10])
- using software calculation (EASE® and Cadna R®); and
- Measurements *in situ*.

These results were compared with three field measurements study cases.

3. Methodology

Even though there is no RT criteria in Brazil regulations for the design of room acoustics, it is common to reference the Australian [11] and the German [12] RT target values for open plan offices.

In this current paper, different prediction methods will be compared with field measurement results of four open plan study cases.

3.1. Statistical models

The statistical models chosen to compare the results are:

- Sabine:

$$T_{60,S} = \frac{0{,}161\,V}{S\,\bar{\alpha}} \tag{1}$$

- Eyring:

$$T_{60,E} = \frac{0{,}161\,V}{-S\ln(1-\bar{\alpha})+4mV} \tag{2}$$

- Fitzroy:

$$T_{60,F} = \frac{0{,}161V}{S\alpha_F+4mV} \tag{3}$$

- EN 12354-6:

$$T_{60} = \frac{16V\,(1-\Psi)}{A} \tag{4}$$

3.2. Software

Besides applying statistical models, these study cases were also modeled in the Room Acoustics commercial *software* AFMG EASE® v. 4.4 with aura module and DataKustik Cadna R®. In both software models several assumptions were considered: current furniture, different lining materials and HVAC system.

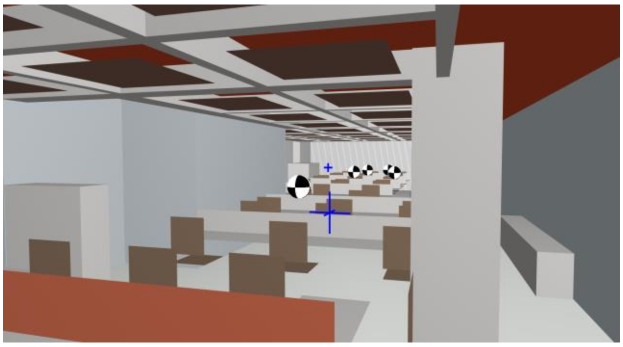

Figure 1. Figure from Cadna R® for Case 2.

Figure 2. Figure from EASE® for Case 1.

3.3. Field Measurements

The four cases were measured according to ABNT NBR ISO 3382-3. All the equipments used in the *in-situ* measurements are certificated and calibrated every year according to IEC 61672 and IEC 61260 standards.

4. Results

The result tables will present the correlation between each case with all the relevant predictions. A description of the four study cases are defined in tables I to IV.

Table I. Description of case 1.

Case 1			
Volume:	1.093,4 m³		
Number of workstations	10	**Number of employees per station**	6
Type of work	Collaborative	Non-collaborative	Call Center
	x		
Absorbent Ceiling	Acoustic Clouds	Regular Absorbent Ceiling	Baffles
	x		
Absorbent Surfaces	Wall Covering	Carpet	Screen
	x	x	

Table II. Description of case 2.

Case 2			
Volume:	778,8 m³		
Number of workstations	7	**Number of employees per station**	6
Type of work	Collaborative	Non-collaborative	Call Center
	x		
Absorbent Ceiling	Acoustic Clouds	Regular Absorbent Ceiling	Baffles
	x	x	
Absorbent Surfaces	Wall Covering	Carpet	Screen
			x

Table III. Description of case 3.

Case 3			
Volume:	99,96 m³		
Number of workstations	2	**Number of employees per station**	8
Type of work	Collaborative	Non-collaborative	Call Center
	x		
Absorbent Ceiling	Acoustic Clouds	Regular Absorbent Ceiling	Baffles
	x		
Absorbent Surfaces	Wall Covering	Carpet	Screen
	x		

Table IV. Description of case 4.

Case 4			
Volume:	759,65 m³		
Number of workstations	22	**Number of employees per station**	6
Type of work	Collaborative	Non-collaborative	Call Center
			x
Absorbent Ceiling	Acoustic Clouds	Regular Absorbent Ceiling	Baffles
	x		
Absorbent Surfaces	Wall Covering	Carpet	Screen

4.1. Reverberation time results

In this section, the calculated result of each model and the measurement will be presented from tables V to XII and in the figures 1 to 4.

Table V. Case 1: Relation between prediction models in different band frequencies.

		Reverberation Time (s)					
		125Hz	*250Hz*	*500Hz*	*1000Hz*	*2000Hz*	*4000Hz*
Method	Sabine	0,44	0,48	0,5	0,47	0,47	0,47
	Eyring	0,39	0,43	0,45	0,42	0,42	0,42
	Fitzroy	0,96	1,04	0,99	0,94	1,11	1,46
	EN 12354-6	1,24	1,05	1,07	0,99	0,99	1,00
	EASE®	0,64	0,74	0,84	0,86	0,83	0,78
	Cadna R®	0,58	0,68	0,72	0,84	0,75	0,63
	Measurements	0,47	0,51	0,57	0,58	0,56	0,54

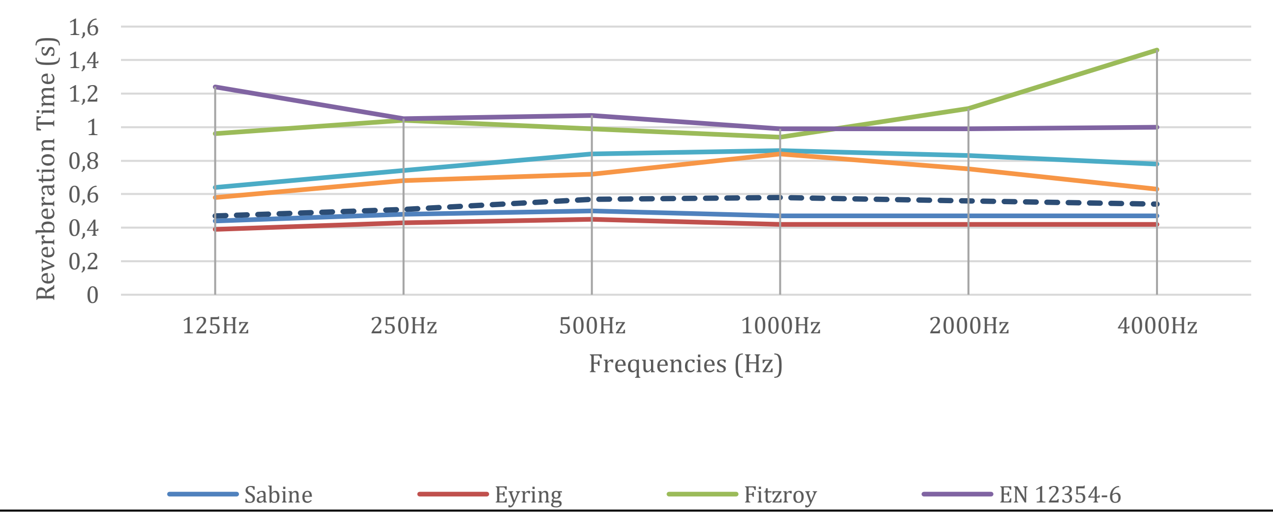

Figure 1: Reverberation Times from case 1

Table VI. Case 2: Relation between prediction models in different band frequencies.

		Reverberation Time (s)					
		125Hz	*250Hz*	*500Hz*	*1000Hz*	*2000Hz*	*4000Hz*
Method	Sabine	0,74	0,57	0,44	0,36	0,33	0,33
	Eyring	0,69	0,52	0,38	0,31	0,28	0,28
	Fitzroy	1,05	0,69	0,74	0,91	1,13	1,53
	EN 12354-6	1,48	0,89	0,56	0,5	0,49	0,49
	EASE®	0,99	1,05	1,03	0,90	0,95	0,81
	Cadna R®	0,70	0,72	0,88	0,82	0,73	0,59
	Measurements	0,77	0,60	0,57	0,52	0,55	-

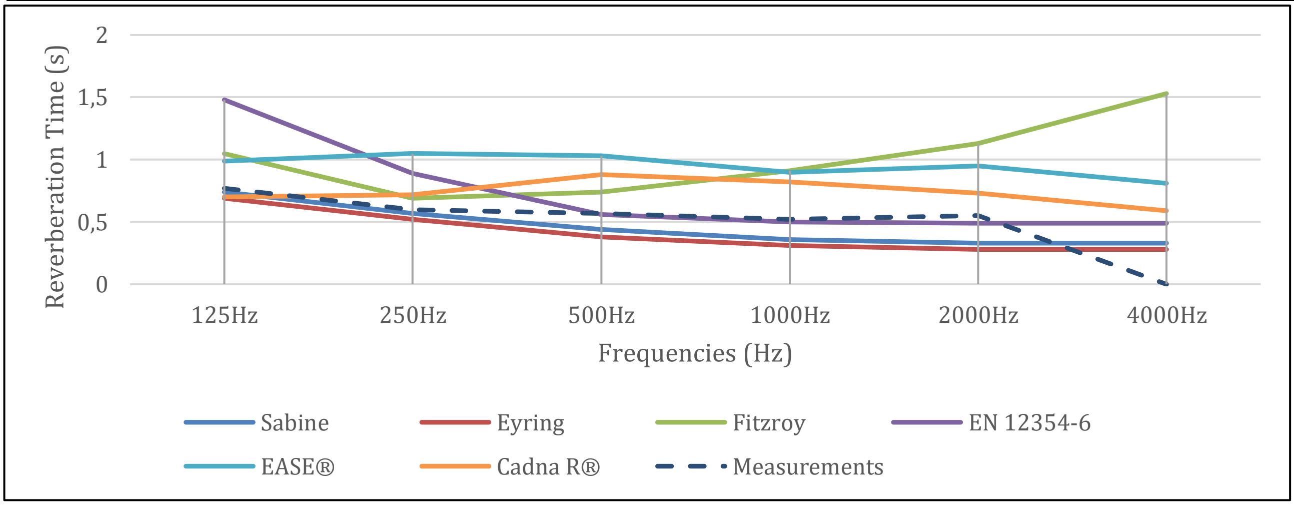

Figure 2: Reverberation Time from case 2

Table VII. Case 3: Relation between prediction models in different band frequencies.

		Reverberation Time (s)					
		125Hz	*250Hz*	*500Hz*	*1000Hz*	*2000Hz*	*4000Hz*
Method	Sabine	0,66	0,65	0,57	0,54	0,55	0,52
	Eyring	0,62	0,61	0,53	0,50	0,51	0,48
	Fitzroy	0,97	0,74	0,82	0,82	1,07	1,35
	EN 12354-6	1,32	1,01	0,92	0,76	0,82	0,81
	EASE®	0,69	0,78	0,86	0,86	0,82	0,75
	Cadna R®	1,03	0,84	0,94	0,84	0,84	0,71
	Measurements	1,11	1,12	0,84	0,75	0,67	0,62

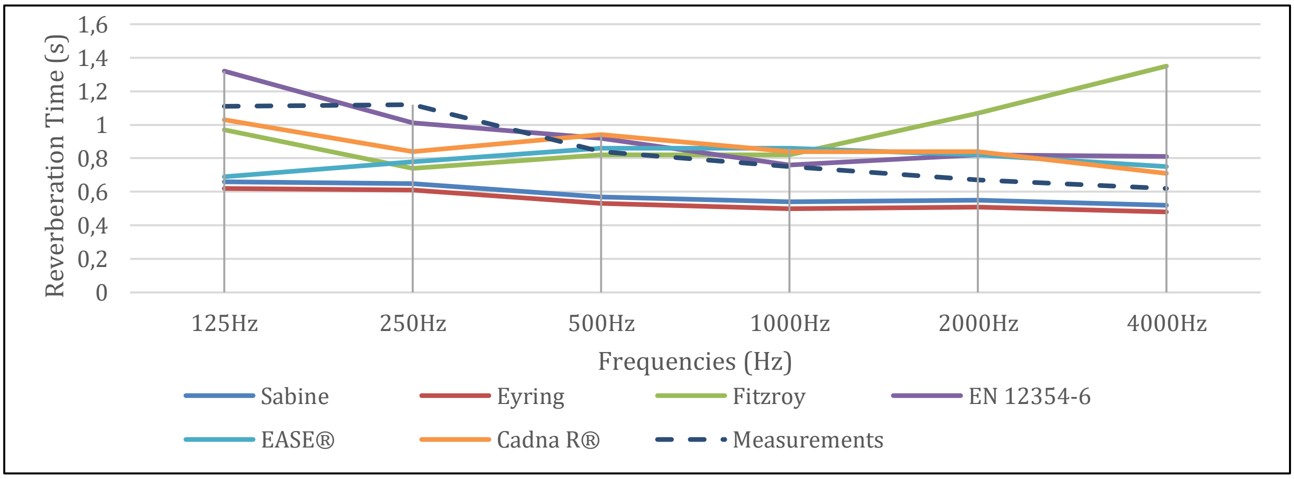

Figure 3: Reverberation Time from case 3

Table VIII. Case 4: Relation between prediction models in different band frequencies.

		Reverberation Time (s)					
		125Hz	*250Hz*	*500Hz*	*1000Hz*	*2000Hz*	*4000Hz*
Method	Sabine	0,29	0,20	0,21	0,19	0,22	0,21
	Eyring	0,25	0,16	0,16	0,15	0,18	0,16
	Fitzroy	0,43	0,41	0,52	0,67	1,05	1,46
	EN 12354-6	0,37	0,27	0,28	0,25	0,31	0,28
	EASE®	0,71	0,75	0,75	0,82	0,81	0,75
	Cadna R®	0,36	0,35	0,38	0,46	0,44	0,40
	Measurements	0,46	0,42	0,46	0,50	0,70	0,79

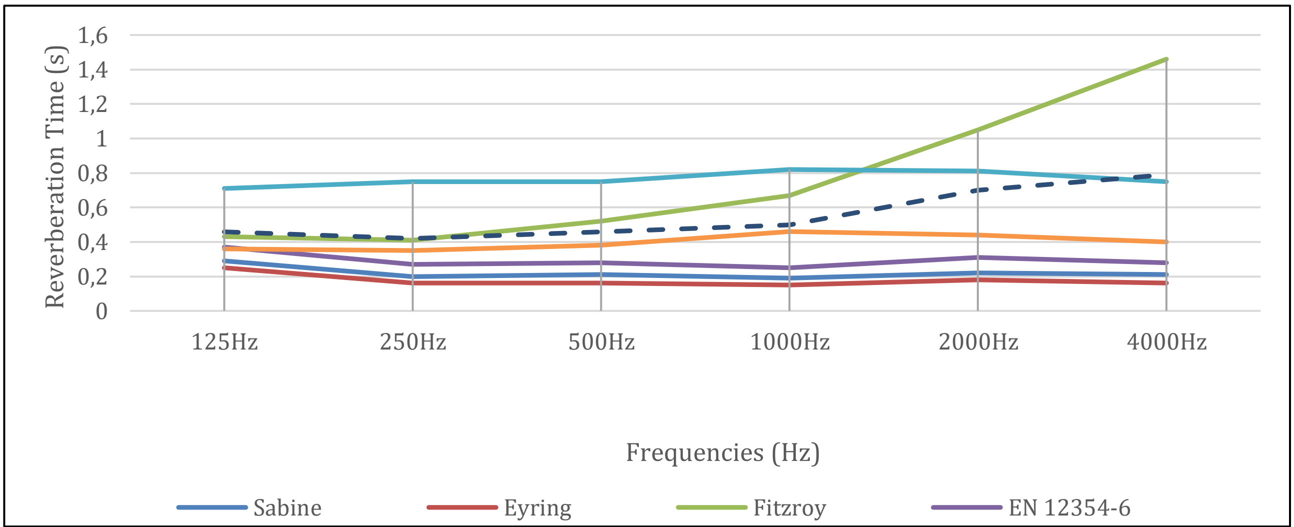

Figure 4: Reverberation Time from case 2

5. Correlation

In this section, the difference between the measurement and each model will be presented from tables IX to XII.

Table IX: Correlation between measurements and each method per frequency from case 1.

	Reverberation Time (s)					
Method	*125Hz*	*250Hz*	*500Hz*	*1000Hz*	*2000Hz*	*4000Hz*
Measurements	0,47	0,51	0,57	0,58	0,56	0,54
Sabine	0,08	0,03	0,07	0,11	0,09	0,07
Eyring	0,08	0,08	0,12	0,16	0,14	0,12
Fitzroy	-0,49	-0,53	-0,42	-0,36	-0,55	-0,92
EN 12354-6	-0,77	-0,5	-0,50	-0,41	-0,43	-0,46
EASE Aura®	-0,17	-0,23	-0,27	-0,28	-0,27	-0,24
Cadna R®	-0,11	-0,17	-0,15	-0,26	-0,19	-0,09

Table X: Correlation between measurements and each method per frequency from case 2.

	Reverberation Time (s)					
Method	*125Hz*	*250Hz*	*500Hz*	*1000Hz*	*2000Hz*	*4000Hz*
Measurements	0,77	0,6	0,57	0,52	0,55	-
Sabine	0,03	0,03	0,13	0,16	0,22	-
Eyring	0,08	0,08	0,19	0,21	0,27	-
Fitzroy	-0,28	-0,09	-0,17	-0,39	-0,58	-
EN 12354-6	-0,71	-0,29	0,01	0,02	0,06	-
EASE Aura®	-0,22	-0,45	-0,46	-0,38	-0,40	-
Cadna R®	0,07	-0,12	-0,31	-0,30	-0,18	-

Table XI: Correlation between measurements and each method per frequency from case 3.

	Reverberation Time (s)					
Method	*125Hz*	*250Hz*	*500Hz*	*1000Hz*	*2000Hz*	*4000Hz*
Measurements	1,11	1,12	0,84	0,75	0,67	0,62
Sabine	0,45	0,47	0,27	0,21	0,12	0,10
Eyring	0,49	0,51	0,31	0,25	0,16	0,14
Fitzroy	0,14	0,38	0,02	-0,07	-0,40	-0,73
EN 12354-6	-0,21	0,11	-0,08	-0,01	-0,15	-0,19
EASE Aura®	0,42	0,34	-0,02	-0,11	-0,15	-0,13
Cadna R®	0,08	0,28	-0,1	-0,09	-0,17	-0,09

Table XII: Correlation between measurements and each method per frequency from case 4.

	Reverberation Time (s)					
Method	*125Hz*	*250Hz*	*500Hz*	*1000Hz*	*2000Hz*	*4000Hz*
Measurements	0,46	0,42	0,46	0,5	0,7	0,79
Sabine	0,17	0,22	0,25	0,31	0,48	0,58
Eyring	0,21	0,26	0,3	0,35	0,52	0,63
Fitzroy	0,03	0,01	-0,06	-0,17	-0,35	-0,67
EN 12354-6	0,09	0,15	0,18	0,25	0,39	0,51
EASE Aura®	-0,25	-0,33	-0,29	-0,32	-0,11	0,04
Cadna R®	0,1	0,07	0,08	0,04	0,26	0,39

6. Conclusion

The Reverberation Time was chosen in this study as the only parameter to evaluate those cases due to the difficulty in applying other parameters in Brazilian office projects. RT is an important objective parameter when it takes into consideration the volume and absorption distribution in a room.

According to the obtained results, it could not be concluded which statistical method would be the closest to reality. In case 1 the method that presents the closer results is Sabine's method in all frequency bands. Case 2 shows a proximity to Sabine's method in the lower frequencies and a proximity to EN 12354-6's method in the higher frequencies. The third case, having the smallest room volume, shows that the methods have different relation to *in situ* measurements in each frequency band. And, in the last case, Fitzroy's method is closer to *in situ* measurements in lower frequency bands and the virtual source/ray tracing methods in higher frequencies.

At the conference presentation, more results will be presented.

The point of this research was to reduce an obstacle that architects face when it comes to designing open plan spaces with acoustic clouds. Thus, encouraging acoustic clouds manufacturers to develop an absorption calculator for acoustic clouds, or, an absorption coefficient that consider the clouds diffractions. With such apparatus, the use of clouds would be more applicable, and the projects would have a more precise calculation.

7. Further work

As it could not be concluded which reverberation time statistical method corresponds better with *in situ* measurements, the next phase of this research will measure acoustic clouds in a controlled environment, *i.e.* in a reverberant chamber, observing the RT response when clouds are set in different positions, heights, numbers and characterized by several products.

Acknowledgement

The authors would like to thank DataKustik represented by ACOEM - 01dB Brasil, for providing Cadna R® *software.*

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