XV ENCAC Encontro Nacional de Conforto no Ambiente Construído
XI ELACAC Encontro Latino-Americano de Conforto no Ambiente Construído
JOÃO PESSOA | 18 a 21 de setembro de 2019

REVERBERATION TIME AND THE SATISFACTION WITH THE CLASSROOMS ACOUSTIC QUALITY

Cristina Y. K. Ikeda (1); Fulvio Vittorino (2); Rosaria Ono (3)

(1) PhD, researcher, cristinak@ipt.br, Institute for Technological Research - IPT, Av. Prof. Almeida Prado, 532 – Prédio 1 – 1º andar – Butantã - 05508-901, São Paulo, SP, Brazil, telephone number: 55 11 3767-4555

(2) PhD, director, fulviov@ipt.br, Institute for Technological Research - IPT, Av. Prof. Almeida Prado, 532 – Prédio 1 – 1º andar – Butantã - 05508-901, São Paulo

(3) PhD, professor, rosaria@usp.br, Faculdade de Arquitetura e Urbanismo da USP – FAU-USP, Rua do Lago, 876 – 05508-080 - SP, Brazil, telephone number: 55 11 3091-9370

(4) , SP, Brazil, telephone number: 55 11 3767-4961

ABSTRACT

With the objective of studying an acceptable reverberation time range from the point of view of the students satisfation with the acoustic quality of classrooms, acoustic measurements were carried out in classrooms of Brazilian schools located in the metropolitan area of Greater São Paulo. Questionnaires were administered to the sudents of those classrooms in which the measurements took place in order to assesss the occupants satisfaction with the rooms. The results determined by the students indicate that the classical limits are more conservative and tend to value "drier" rooms (with lower reverberation times) even when furnished and unoccupied. However, more "lively" rooms (with greater reverberation times) were also considered satisfactory by the users of this research.

Key words: Reverberation time, classroom.

1. INTRODUCTION

In the school building, the performance of the students can be impaired by poor environmental conditions of the building and by the frequent poor acoustical conditions of the speech transmission and perception. Around speech, much of the educational activity within the classroom is revolved. According to DFES (2003), for 80% of all the classroom activities, listening and speaking are required. Therefore, it is important that effective communication of spoken language is allowed by the acoustic characteristic of the classroom.

The design of a classroom should consider not only the external noise, the location of the building and its parts on a site, the acoustic performance of walls, windows and doors; but also the acoustic quality of the classrooms, taking into account the level and reverberation of the sound inside of it.

Post-occupacy evaluations have been performed in Brazilian schools (FRANÇA, 2011; ORNSTEIN, ONO, 2010; MONTEIRO, 2009; FERREIRA et al., 2006; ELALI, 2002) showing that the environmental comfort aspect, along with others, should present optimal performance conditions for a good learning experience. Nevertheless, those post-occupancy evaluations did not consider the aspects of acoustic reverberation inside the classrooms.

There are many acoustic descriptors such as EDT, STI, BR, Ts, and D50 applied to evaluate the acoustic quality of spaces, and some of them are usually more considered when the understanding of the spoken message is fundamental, as discussed by Ikeda (2019). The present research focused on the reverberation time parameter. It is generally considered the most important acoustic parameter that defines the acoustic climate of a room. The reverberation time is the time (in seconds) the sound of a source decreases its level by 60 dB after it has stopped. A decrease of 60 dB represents a reduction of 1/1,000,000 of the original sound intensity (CRANDELL and SMALDINO, 2000).

The limits established by the standard NBR 12179 (1992) range from from 0.4 s to 0.6 s, for 500 Hz. The ones established by France (apud Zannin et al., 2013) range from 0.4 s to 0.8 s (arithmetic mean between 500 Hz, 1000 Hz and 2000 Hz), by Fukuchi and Ueno (2003) the ideal reverberation time is of 0.6 s (arithmetic mean between 500 Hz and 1000 Hz), by ANSI S 12.60 (2010) of 0.6 s (arithmetic mean between 500 Hz, 1000 Hz and 2000 Hz), and by Great Britain Department of Education and Skills (2015) of 0.6 s (arithmetic mean between 500 Hz, 1000 Hz and 2000 Hz). This research intended to review the reverberation time operating range, in which the students were satisfied with the acoustic quality of classrooms, and detail it by frequency band.

The just-noticeable difference (JND) that is the amount that must be changed so that there is a noticeable difference was used to evaluate the differences of values from one octave band to another. For the reverberation time the JND is a relative difference of 5% (Bork, 2000) and (Bradley, 1986) apud ODEON A/S (2018).

2. OBJECTIVE

Study the reverberation time by frequency range in classrooms as well as evaluate if those existing ranges are conservative.

3. METHOD

For this study, 35 schools were contacted and 5 of them allowed the conduction of the research. They are located in the metropolitan area of São Paulo, known as Greater São Paulo. Most of them are private schools with subsidized education. The schools began their operation from 1962 to 2013.The classrooms analyzed in these schools are those used by students in the 8th and 9th years of elementary school and 1st, 2nd and 3rd years of high school, ages ranging from 12 to 19 years old. These classes were chosen, since it was expectated better understanding of the questions of the questionnaires by this age group than the ones by younger students.

As for external noise, there were schools located in quieter areas and schools located in more urbanized areas that suffer more influence of the traffic noise. In these schools, the 32 classrooms considered in this study are either located on both sides of the corridor, as illustrated in Figure 1, or on just one side of the corridor, as illustrated in Figure 2. Classrooms located on both sides of the corridor set the direct path of the sound generated from one room to another and classrooms located on just one side of the corridor are an advantage in acoustic terms, because they make it more difficult the transmission of noise from one room to another, creating longer paths to be covered by the direct sound.

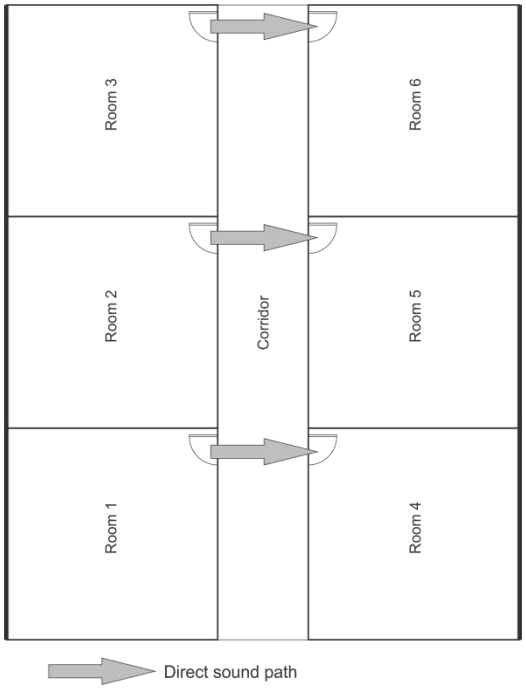


Figure 1 – Classrooms on both sides of the corridor

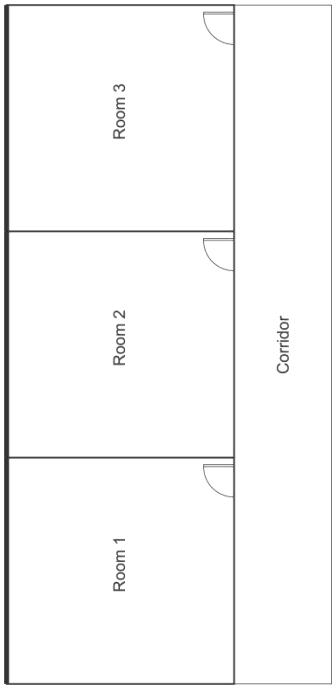


Figure 2 – Classrooms on one side of the corridor

The classrooms considered had glass or wooden doors and windows in metal or wooden frames with float glass. The tables had metal tubular structure and wooden composite top finished with melamine material. The chairs had metal tubular structure and its back and seat with plastic material or wooden composite finished with melamine. The ceiling was composed of painted slabs, plaster or mineral tiles. An example of one of those classrooms is illustrated in Figure 3. The materials that compose these classrooms were generally poorly absorbing: painted mansory walls, glass on windows and doors, stone flooring, furniture in plastic or melamine composite. The most absorbent materials that could be found in these rooms were curtains, and mineral tiles.

Figure 3 – View of one of the classrooms considered in this study

Post-Occupancy Evaluation methods were adopted to obtain qualitative data with the use of questionnaires for the students; and quantitative data with the use of acoustic measurements made in the rooms in which the questionnaires were applied. As the research involved data collection from individuals (high school and middle school students), the research project was submitted to the Research Ethics Committee to ensure the safety and protection of the participants' rights.

3.1. Acoustic measurements

The method chosen for the acoustic measurements was the impulse response technique. Using a known excitation signal, a sine sweep, the behavior of the sound field inside the classroom was analyzed. The signal was produced by the software Dirac. The sine sweep signal passes through all frequencies continuously so that the system is excited sequentially in each of them (BERTOLI and GOMES, 2005). The logarithmic sine

sweep in which the frequency increase is given by the same octave fraction at each fixed time interval, ie, the spectrum declines by 3 dB / octave was used so that every octave contains the same energy (MÜLLER and MASSARANI, 2002).

The acoustic measurements were made in unoccupied furnished rooms, with two configurations: all windows and curtains closed; and all windows closed and curtains open. In each room, there were 9 microphone positions.

The measurement system, illustrated by Figure 4, was composed by:

- ½" pre-polarized diffuse field microphone;
- ½" preamplifier;
- 1-channel power supply with indication of overload and gain adjustment;
- omnidirectional sound source that meets the requirements of ISO 3382-1: 2009;
- power amplifier;
- portable computer with Dirac software installed for the generation of the excitation signal and data acquisition;
- external sound card with 192kHz, 24-bit conversion, with a frequency response of 20Hz to 20kHz.

Figure 4 – Measurement system

3.2. Questionnaires

The questionnaire is a tool used to collect information from a large number of people, about pre-established and well-defined topics, to which the same questions are asked to all members of the group of people, and their answers are statistically treated for analysis (ELLIS, 2014). In the Post-Occupancy Evaluation, its application is a way of collecting data on users' opinions and satisfaction regarding the various aspects of the use and occupation of the built environment.

Based on the response scales of standards ISO 28802 (2012), ISO 10551 (1995) and the questionnaire of the work "Design for educationally appropriate acoustic characteristics in open plan schools" by Charlton Smith Partnership (2005), a new questionnaire was elaborated for the evaluation of the school environment with focus on the acoustic comfort sensation in classrooms for students. The questionnaires did not start directly focusing on the "acoustic" theme. They began with a more general question to make the respondents aware of the topics of their greatest attention, among them, ergonomics, thermal, lighting and acoustic comfort. Then the questions lead the student to evaluate the outdoor spaces of their classrooms, following this sequence: schoolyard, sports court, corridors, classrooms and region next to their desks. For the questionnaire to be considered valid, the student should indicate the position he occupied in the room, making it possible, in this way, to correlate his evaluation with the acoustic parameters measured in the position occupied by him.

The questionnaire was pre-tested in one group of middle school students and two groups of graduate students. Through the feedback received in the pre-test and in the light of scientific articles related to the use of questionnaires in research, a critical analysis was performed to discuss the criteria used to elaborate questions, as well as to make improvements in the developed questionnaire. More details of the questionnaire can be found at Ikeda, Ono and Vittorino (2016).

3.3. Procedure for the definition of limit values

The values were selected from the answers given by respondents who indicated satisfaction with the acoustic quality of the indoor environment. In order to identify the respondents satisfied with the acoustic environment, four questions were made.

- Does noise in this classroom prevent you from hearing the teacher well?
- Does noise in this classroom prevent the teacher from listening to the students?
- Noise generated inside this classroom (people, fans …)
- Noise from outside the classroom (vehicles, sports activities, playground …)

The indication of satisfaction was for those respondents who answered the most favorable alternatives. For the determination of the reverberation time values by frequency range, the ones that comprised 5% of occurrence of the minimum values and 5% of occurrence of the maximum values were discarded so that the values considered were in the range of 90% of occurrence. The intention was to discard values that could have been disturbed by random phenomena that occurred during the measurements.

4. RESULTS

The total number of respondents in these schools was 155 students. It should be emphasized that the type of questionnaire here is the one that the respondent answered autonomously without the support of an interviewer.

The questionnaires were answered by almost the same proportions of boys (44% of the respondents) and girls (46% of the respondents). The remaining 10% did not declare their gender. "Noisy" was one of the most used adjectives to describe the school building as a whole, as illustrated in Figure 5. The students were able to read the main environmental aspects of the school and it is estimated that this process conducted the attention of the students for the following questions focused in acoustics.

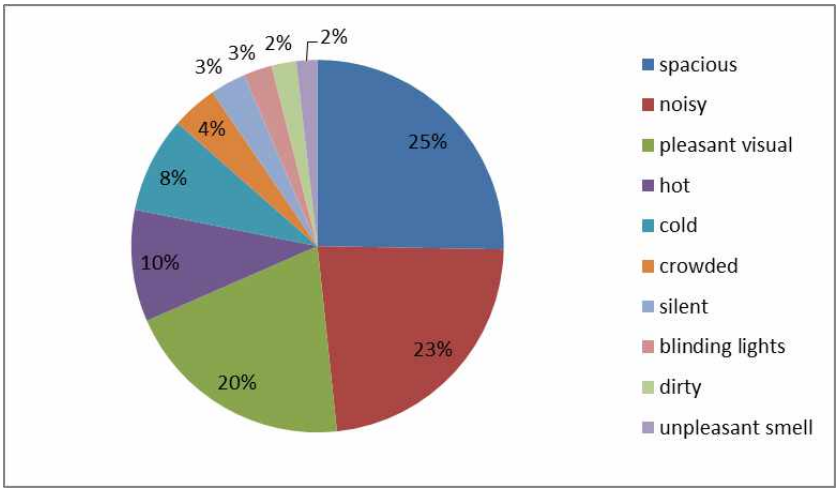


Figure 5 – Words that describe the school building as a whole

The answeres “students would like it to remain unchanged” and “students would like it to be a little quieter” were considered as answers signalling satisfaction. As illustrated in Figures 6, 80% of the students were satisfied with the acoustics of the schoolyard. As for the sports court, according to Figure 7, most of the students (92%) were satisfied with its acoustics. As for the school corridors, as illustrated in Figure 8, almost 2/3 of the students (62%) were satisfied with their acoustics. As for classrooms, according to Figure 9, almost half of the respondents (46%) were satisfied with their acoustics. Regarding the region next to each respondent's desk, 74% of the students were satisfied with its acoustics, as illustrated in Figure 10.

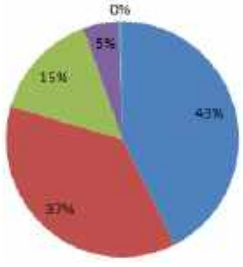


Figure 6 – Schoolyard

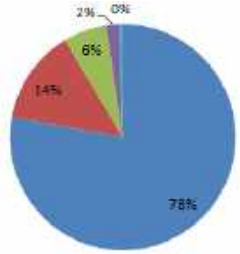


Figure 7 – Sports court

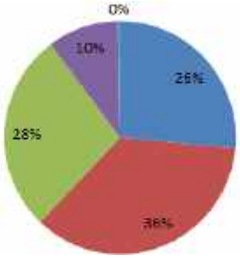


Figure 8 – Corridors

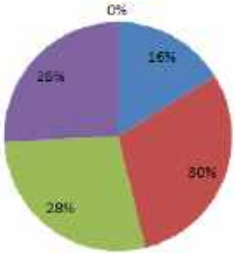


Figure 9 – Classrooms

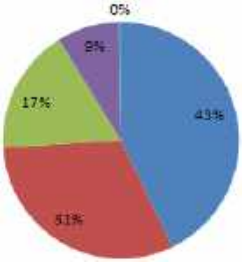


Figure 10 – Near the student’s desks

As illustrated in Figures 11 to 14, for most of the students, noise makes them lose concentration (83% of respondents), it makes activities more difficult to do (76% of the respondents), it does not help to perform activities better (88% of respondents), and it does not help to cover up distractions (79% of respondents). And as illustrated in Figures 15 and 16, for most of the students (58% of the respondents), noise sometimes prevents them from listening to the teacher. The teacher is prevented from listening to the students because of the noise all the time, sometimes to 47% of respondents; and often for 36% of respondents.

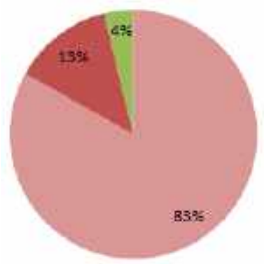


Figure 11 – Noise makes students lose concentration

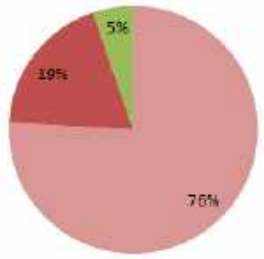


Figure 12 – Noise makes activities more difficult to do

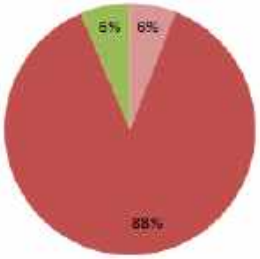


Figure 13 – Noise helps to perform activities better

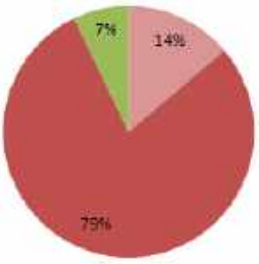
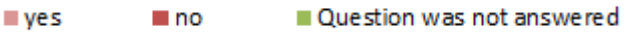


Figure 14 – Noise helps to cover up distractions



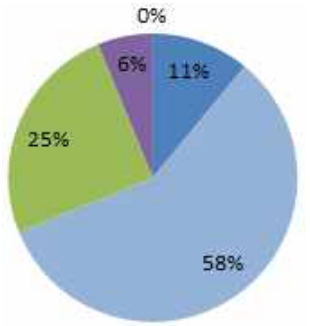


Figure 15 – Noise prevents students from listening to the teacher

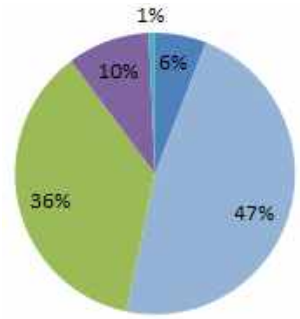
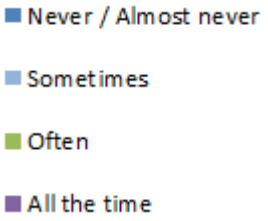


Figure 16 – Noise prevents teachers from listening to the students



The answeres “very disturbing” and “disturbing” were considered as answers signalling dissatisfaction. As illustrated in Figures 17 and 18, 42% of the students are dissatisfied with the noise generated inside their rooms by people. As for the noise coming from outside the classroom, from vehicles, sports activities and recreation, for example, 40% of the respondents were dissatisfied.

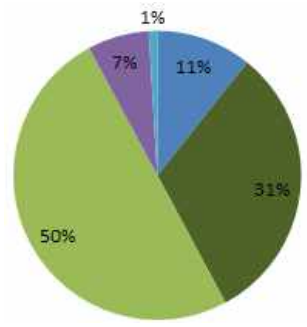


Figure 17 – Noise generated inside the classroom by people and equipment

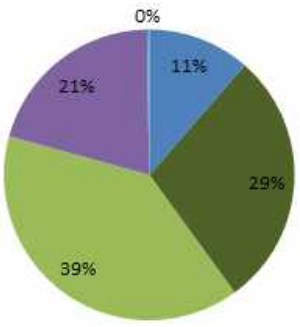
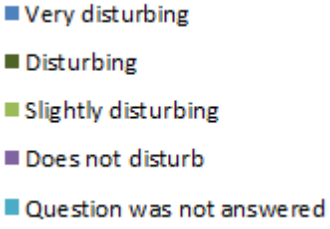


Figure 18 – Noise coming from outside the classroom, from vehicles, sports activities and recreation, for example



The fact that 31% of students are prevented from listening to the teacher because of noise all or most of the time is disturbing, as almost than 1/3 of the respondents did not receive some of the information they were supposed to. For 46% of the students, because of the noise, the teacher is also prevented from listening to them, all the time or often, is also worrying, because for almost half of the students, their questions or comments do not reach the teacher or both sides have to strain to make themselves understood.

Given this universe of the respondents satisfied with the acoustic quality of the classrooms, there was a great deal of answers and among these values, the limits were selected according to item 3.3. The values of Reverberation Time, taking into account the selected points of the classrooms of all the schools, by octave band and by configuration (closed windows and closed curtains, closed windows and curtains open) are in Table 1.

Table 1 – Minimum and maximum values of reverberation time at the positions considered satisfactory by the students.

Frequency (Hz)	**63 Hz**		**125 Hz**		**250 Hz**		**500 Hz**	
Reverberation time (s)	**0.6**	**2.2**	**0.9**	**2.2**	**0.8**	**2.5**	**0.8**	**2.1**
Frequency (Hz)	**1000 Hz**		**2000 Hz**		**4000 Hz**		**8000 Hz**	
Reverberation time (s)	**0.6**	**2.0**	**0.6**	**2.0**	**0.6**	**1.8**	**0.6**	**1.4**

While there were no clear tendency for the minimum values, in general the maximum values decreased, the higher the frequencies were, with the exception for 250 Hz. From one octave band to another, the difference, when existing, was above the JND.

Considering the limits established by the standard NBR 12179 (1992), the range obtained in this study has the minimum limit greater than the maximum limit of this norm. In relation to the limits established by France (apud Zannin et al., 2013), Fukuchi and Ueno (2003), ANSI S 12.60 (2010) and Great Britain Department of Education and Skills (2015), lower and upper limits are higher. These results are presented graphically in Figure 19.

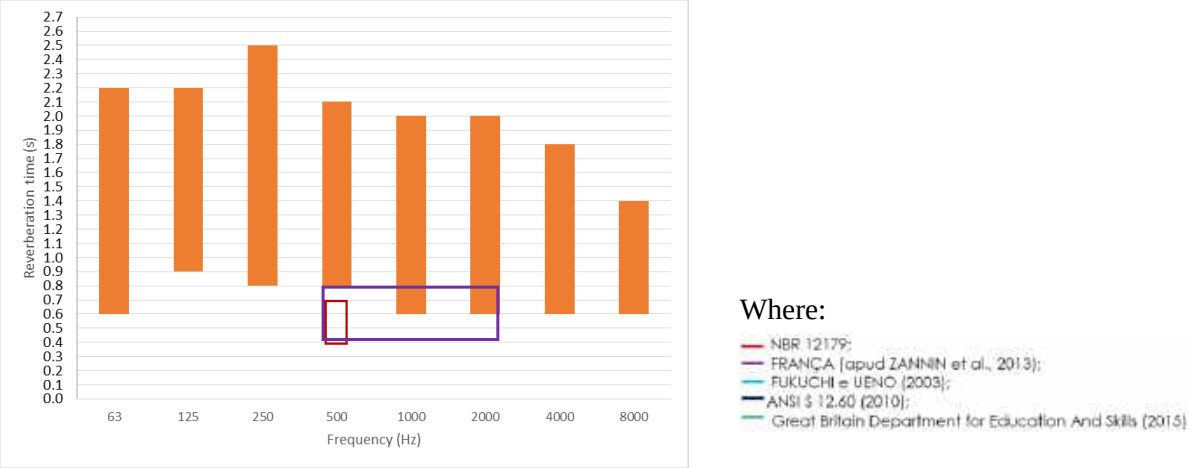


Figure 19 – Reverberation time values obtained in this study and stipulated by other standards and researches.

The ranges obtained in this study were more comprehensive and one reason would be that the answers considering satisfaction for the questions “Does noise in this classroom prevent you from hearing the teacher well” and “Does noise in this classroom prevent the teacher from listening to the students” were not only “never” but also “sometimes”. And the answers considering satisfaction for the questions “Noise generated inside this classroom (people, fans) …” and “Noise from outside the classroom (vehicles, sports activities, playground) …” were “does not disturb” but also “it is slightly disturbing”. There was more tolerance in the options considered.

5. CONCLUSIONS

The results determined by the students’ answers indicate that the classical limits are more conservative and tend to value "drier" rooms (with lower reverberation times) even when furnished and unoccupied. However, more "lively" rooms (with greater reverberation times) were also considered satisfactory by the users of this research.

The acoustic quality depends also on the choices made by the designer. The possibility of using more comprehensive limit ranges grants the designer more freedom in the design process. On the other hand, in order to evaluate the acoustic quality of the project, more refined methods are necessary, such as computer

simulations. It is important to state that accuracy of computer simulations is directly proportional to the quality of overall object modeling process. In particular, the availability of reliable data about material properties is a sensitive subject. There are few libraries with this information, but their increase will just occur in response to the designers demands. The suggested range was based on the concept of performance rather than of prescriptive solutions, such as preset recipes, hence the importance of using computer simulation to test design solutions.

REFERENCES

ACOUSTICAL SOCIETY OF AMERICA - ASA. ANSI S12.60. Acoustical performance criteria, design requirements, and guidelines for schools. Melville, 2010.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS - ABNT. NBR 12179. Tratamento acústico em recintos fechados - Procedimento. Rio de Janeiro, 1992.

BERTOLI, S. R.; GOMES, M. H. A.. Técnicas de Medição para Acústica de Salas. [Material didático para o curso de extensão universitária. Adaptado da apostila do curso Técnicas de Medição em Acústica do professor Michael Vorländer, Alemanha]. Campinas: Universidade Estadual de Campinas – UNICAMP, 2005. 66p.

BORK, I. A Comparison of Room Simulation Software – The 2nd Round Robin on Room Acoustical Computer Simulation. Acta Acustica, 2000; 86, 943-956.

BRADLEY, J.S. Predictors of Speech Intelligibility in Rooms. Journal of the Acoustical Society of America., 80 (3), p.837-845, 1986.

CRANDELL,C.C.; SMALDINO, J.J. Classroom acoustics for children with normal hearing and with hearing impairment. Language, speech, and hearing services in schools 2000; 31: 362–370.

DFE, GREAT BRITAIN DEPARTMENT FOR EDUCATION. Acoustic design of schools: performance standards (Building bulletin 93), 2015.

DFES, GREAT BRITAIN DEPARTMENT FOR EDUCATION AND SKILLS. Acoustic design of schools: a design guide (Building bulletin 93), Stationery Office, 2003.

ELALI, G.A. Ambientes para educação infantil: Um quebra-cabeça? Contribuição metodológica na avaliação pós-ocupação de edificações e na elaboração de diretrizes para projetos arquitetônicos na área. 2002. Tese (Doutorado) – Faculdade de Arquitetura e Urbanismo, Universidade de São Paulo, São Paulo, 2002. Disponível em: <http://www.teses.usp.br/teses/ disponiveis/16/16131/tde-10032010-141853/pt-br.php>. Acesso em: 26 fev. 2013.

ELLIS, J. Writing better questionnaires: getting better data. Charities Evaluation Services. 2014. Disponível em: < http://www.ces-vol.org.uk/Resources/ CharitiesEvaluationServices/Documents/Writing%20better%20questionnaires%20FINAL.pdf>. Acesso em: 17 fev. 2016.

FERREIRA, C.S.C.; SANTOS, C.M.L.; MARQUES, F.M.; AZEVEDO, G.A.N.; CASTRO, I.S.; BECK, L.M. Avaliação pós-ocupação em ambiente destinado à educação infantil: uma abordagem multimétodos. In: ENTAC. 2006, Florianópolis. Anais... Porto Alegre: ANTAC, 2006. p. 1124-1133.

FRANÇA, A.J.G.L. Ambientes contemporâneos para o ensino - aprendizagem: Avaliação Pós-Ocupação aplicada a três edifícios escolares públicos situados na região metropolitana de São Paulo. 2011. Dissertação (Mestrado) - Faculdade de Arquitetura e Urbanismo da USP.

FUKUCHI, T.; UENO, K. Guidelines on acoustic treatments for school buildings proposed by the Architectural Institute of Japan. Proceedings: Proceeding of the International Congress of Acoustics, Kyoto, 2004. Disponível em: <https://www.researchgate.net/publication/268345588_Guidelines_on_acoustic_treatments_for_school_buildings_proposed_by>. Acesso em: 16 set. 2018.

IKEDA, C.Y.K. Determinação de faixas de operação de parâmetros acústicos para avaliação da qualidade sonora de salas de aula. 2018. Tese (Doutorado) – Faculdade de Arquitetura e Urbanismo, Universidade de São Paulo, São Paulo, 2019. Disponível em: <http://www.teses.usp.br/teses/disponiveis/16/16132/tde-15012019-162548/en.php>. Acesso em: 26 jun. 2019.

IKEDA, C.Y.K.; ONO, R.; VITTORINO, F. Elaboração de questionário como ferramenta auxiliar na avaliação de conforto acústico em escolas. In: ENTAC. 2016, São Paulo. Anais... Porto Alegre: ANTAC, 2016. p. 3037-3048.

ISO INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. ISO 28802 Ergonomics of the physical environment – Assessment of environments by means of an environmental survey involving physical measurements of the environment and subjective responses of people. Geneva, 2012.

_____. ISO 10551 Ergonomics of the thermal environment — Assessment of the influence of the thermal environment using subjective judgement scales. Geneva, 1995.

MONTEIRO, B.C. Arquitetura escolar e qualidade ambiental: Avaliação pós-ocupação em duas escolas de Volta Redonda – RJ - Instituto Educacional Professor Manoel Marinho e Centro Integrado de Educação Wladir de Souza Telles . 2009. Dissertação (Mestrado) – Faculdade de Arquitetura e Urbanismo, Universidade Federal do Rio de Janeiro, Rio de Janeiro, 2009. Disponível em: <http://fenix2.ufrj.br:8991/F/YUKPUCSRCUE13JKQ8B27J9IN7 M13RB7NLKLCKXR12E1YV1UX37806?func=fullsetset&set_number=655885&set_entry=000001&format=999#.UfvifpLVAwA >. Acesso em: 20 jul. 2013.

MULLER, S.; MASSARANI, P. Criação de varreduras com ênfase arbitrária. In: Seminário de Engenharia de Áudio, 2002, Belo Horizonte. Anais... Belo Horizonte: SEMEA, 2002. 8p. Disponível em: <https://www.researchgate.net/ publication/268419829_CRIACAO_DE_VARREDURAS_COM_ENFASE_ARBITRARIA >. Acesso em: 28 dez 2018.

ODEON A/S. ODEON Room Acoustics Software. User's Manual. Version 14. Lyngby. 2018.

ORNSTEIN, S.W.; ONO, R. Post-Occupancy Evaluation and Design Quality in Brazil: Concepts, Approaches and an Example of Application. Architectural Engineering And Design Management, Vol. 6, pp. 48-67, 2010.

THE CHARLTON SMITH PARTNERSHIP. Design for Educationally Appropriate Acoustic Characteristics in Open Plan Schools. 2005. Disponível em: <http://www.gov.scot/ Resource/Doc/920/0020505.pdf>. Acesso em: 13 jan. 2015.

ZANNIN, P.H.T.; FIEDLER, P.E.K.; BUNN, F. Reverberation time in classrooms - Case study: When an administrative decision changes acoustic quality. Journal of Scientific and Industrial Research. v.72-8, p. 506 – 510, 2013. Disponível em: <https://www.researchgate.net/publication/288249614_ Reverberation_time_in_classrooms_-_C>. Acesso em: 16 set. 2018.