Reverberation Condition Evaluation for Rectangular Rooms with Non-Uniformly Distributed Sound Absorption

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1 Introduction

There are numerous parameters that were developed in order to assess quality of room acoustics (Sabine, 1964), (Beranek, 1992, 1996). It may be said that two main approaches dealing with acoustic quality of a room are based on either objective or subjective evaluation or both. One of the most relevant sensations of the sound field in rooms is the cognition of reverberation (Vorländer, 1998). In addition room acoustical parameters derived from the room impulse response such as clarity, definition or lateral energy fraction are also adequate for assessing a room intended for speech and music (Beranek, 1996), (Vorländer, 1998). On the other hand, it is highly desirable that all calculated parameters are assessed subjectively (Kostek 1999). Therefore one of the most important issues in acoustics is to find relations between objectively measured parameters of rooms and their subjective quality assessed by listeners (preferably experts) (Vorländer, 1998). Moreover, it is most important for the acoustical design of a room to have a tool, which enables prediction of the relevant acoustical properties (Neubauer, 1997).

This paper aim is two-fold. First, a short review on some acoustical principles related to the room acoustic assessment is presented. Then problems related to the acoustical design of rooms in cases most encountered in practice namely rectangular halls where the sound field is not diffuse are discussed. The RT formulae known so far, cannot predict the RT characteristics accurately in halls with non-uniformly distributed absorption. Moreover, the formulae needed in practice ought to be matched to conditions in occupied rather than in empty halls, those being as a rule highly absorptive, i.e. filled with directional sound field, due mainly to audience presence. RT prediction for such cases is highly desirable for acoustic consultants and architectural project engineers. Secondly, it is also important to check in which way and if source- and microphone-directional characteristics influence subjective perception of reverberation. It will be shown that such an influence exists and experts' judgement resulted from subjective tests will be cited. The paper shows selected impulse responses of an auditory room, enabling to assess reverberation subjectively.

2 Room Acoustical Properties

Since Sabine published his results, several different approaches have been adopted to obtain equations that describe the reverberation characteristics. Among others, the best-known researchers who developed theories of reverberation in the last 50 years include: (Fitzroy 1959), (Schroeder, 1965), (Kosten, 1966), (Cremer and Müller, 1978), (Kuttruff, 1976, 1991), (Nilsson, 1992), (Tohyama et al., 1995). Lately, papers by Kuttruff (Kuttruff, 1997), Arau (Arau, 1998), Neubauer (Neubauer, 1999) and Bistafa and Bradley appeared (Bistafa and Bradley, 2000) that dealt with the similar problems. Recently, within the frame work of the standardization process an improvement of the estimation of the reverberation time in rooms with irregular absorption distribution based on Nilsson's model was proposed and discussed (CEN/TC, 1999), (Nilsson, 1992).

There exist also a large number of parameters derived from the hall impulse response. The objective of such measures is to examine the energy distribution within time limits t_1 to t_2 of the impulse response, counted from the time of arrival of the direct sound t_1:

$$E(t_1, t_2) = \int_{t_1}^{t_2} h^2(t)dt \qquad (1)$$

where: h(t) - impulse response of an auditory hall.

The most common cause of reduced diffusion of the acoustical field is extensive sound absorbing applied to the ceiling and the floor, and contrarily walls reflect sound well and they are vertical and poorly subdivided. In such rooms, sound waves propagating in directions close to horizontal attenuate slowly form a horizontal reverberant field. The reverberation time appears to exceed the value calculated using Sabine's equation. Since this is a common situation in real rooms, one of the authors proposed to calculate RT as a sum of two reverberation processes decaying independently along horizontal and vertical main axes of the hall (R. Neubauer, 1999). The model divides the sound field into two parts considering each as a corrected Eyring value and results in a so-called New Formula or Fitzroy-Kuttruff equation (R. Neubauer, 1999), (R. Neubauer, B. Kostek, 2001).

3 Subjective Tests

The impulse response of the auditory room of TUG was measured using both directional and omnidirectional characteristics of microphones. The next step was to convolve these signals with anechoic recordings. For this purpose a number of sound excerpts recorded in an anechoic chamber were used. Experts judged resulted sounds. Their task was to rate all signals from 1 to 5 and to choose the signal that was perceived as the best one. In Fig. 1 a view of the auditory hall is shown with positioning of microphones and place in which a source was placed. Correspondingly in Fig. 2 RT measured in this room is shown. In addition Figures 3 and 4 present impulse responses recorded both by omnidirectional and cardioid microphones. In the last attached Figure (Fig. 5) a convolution of impulse response from Fig. 3 and anechoic recording is shown. This recording was judge by experts as the best one. This means that experts' subjective preference as to modelled reverberation conditions is such as that in case when RT is directional.

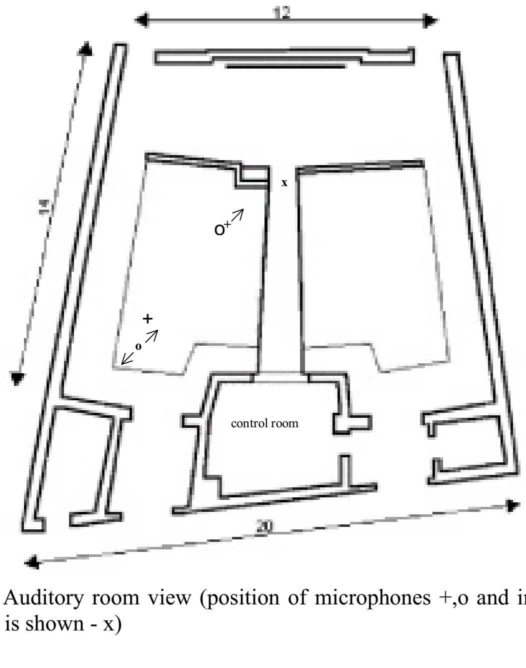

Fig. 1 Auditory room view (position of microphones +,o and impulse source is shown - x)

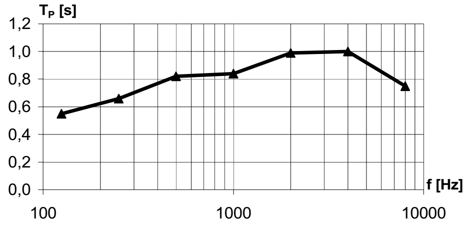

Fig. 2 RT of the measured auditory room

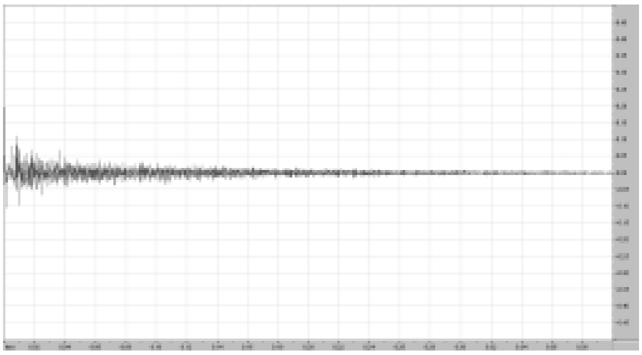

Fig. 3 Impulse response of a room (omnidirectional characteristics of a microphone)

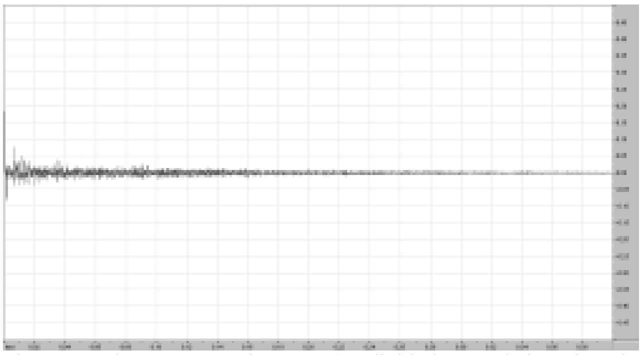

Fig. 4 Impulse response of a room (cardioid characteristics of a microphone)

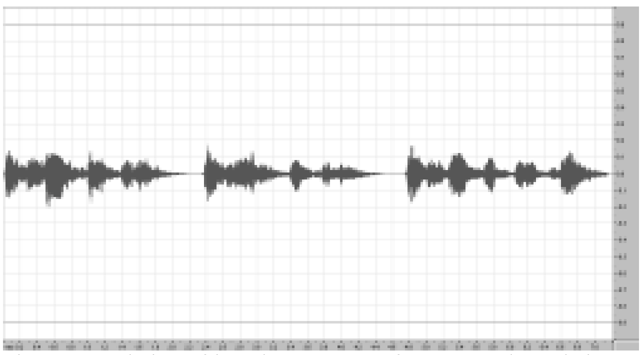

Fig. 5 Convolution of impulse response of a room and anechoic recording of a male voice

4 Conclusion

The differences in reverberation time values measured or predicted according to various methods cause numerous doubts among researchers dealing with room acoustics problems. They "felt" that neither measurements nor predictions based on the classical theories of reverberation do describe it properly. It becomes clear now, that new approaches are necessary to explain the signalled problems.

In contrast to the standard approach to reverberation as to an omnidirectional, statistically defined process, one is compelled to admit that reverberation depends also on particular directions of subsequently reflected waves, i.e. is partly directional and disobeying the statistical law of decay, at least in its early portion.

References

[1] Arau H. (1998). General Theory of the Energy Relations in Halls with Asymmetrical Absorption, J. Building Acoustics. Vol. **5**, No. 3, 163-181.

[2] Beranek L.L. (1996). Concert and Opera Halls. How they Sound, Acoust. Soc. Amer.

[3] Beranek L.L. (1992). Concert Hall Acoustics - 1992, J. Acoust. Soc. Am., Vol. **92**, No. 1, 1-39.

[4] Bistafa S.R., Bradley J.S. (2000). Predicting reverberation times in a simulated classroom, J. Acoust. Soc. Am., Vol. **108**, No. 4, 1721-1731.

[5] CATT-Acoustic program, Mariagatan 16A, SE-41471 Gothenburg, Sweden, 1999.

[6] Cremer L., Müller H.A. (1978). Die wissenschaftlichen Grundlagen der Raumakustik, Band 1, S. Hirzel Verlag, Stuttgart.

[7] Fitzroy D. (1959). Reverberation formulae which seems to be more accurate with non-uniform distribution of absorption, J. Acoust. Soc. Am., Vol. **31**, 893-897.

[8] Kostek B. (1999). Soft Computing in Acoustics, Applications of Neural Networks, Fuzzy Logic and Rough Sets to Musical Acoustics, Studies in Fuzziness and Soft Computing, Physica Verlag, Heidelberg, New York.

[9] Kosten C.W. (1965/66). New Method for the Calculation of the Reverberation Time of Halls for Public Assembly, Acustica, Vol. **16**, No. 6, 325-330.

[10] Kuttruff H. (1976). Nachhall und effektive Absorption in Räumen mit diffuser Wandreflexion, Acustica, Vol. **35**, No. 3, 141-153.

[11] Kuttruff H. (1991). Room Acoustics, 3rd Edition, Elsevier Science Publishers LTD.

[12] Kuttruff H. (1997). Energetic Sound Propagation in Rooms, Acustica – Acta Acustica, Vol. **83**, No. 4, 622-628,

[13] Memorandum to CEN/TC 126/WG2, (1999). Possibilities to improve the estimation of reverberation time in rooms, TNO Institute of Applied Physics, Netherlands, HAG-MEMO-990076, 1-8.

[14] Neubauer R.O. (1997). Berechnung der erforderlichen Schallabsorption für kubische Räume in Abhängigkeit der Raumhöhe. Vereinfachte Berechnungsmethode für die Praxisanwendung, gi – Gesundheits-Ingenieur, Vol. **118**, H. 1, 32-36.

[15] Neubauer R.O. (1999). Prediction of Reverberation Time in Rectangular Rooms with a Modified Fitzroy Equation, ISSEM'99, Proc. 8th International Symposium on Sound Engineering and Mastering, 115 – 122, Gdansk, Poland.

[16] Neubauer R.O., Kostek B. (2000), Prediction of the Reverberation Time in Rectangular Rooms with Non-Uniformly Distributed Sound Absorption, Archives of Acoust., Vol. **26**, No. 3, 183-201.

[17] Nilsson E. (1992). Decay process in rooms with non-diffuse sound fields, Report TVBA-1004, Lund Institute of Technology, Depart. of Eng. Acoustics.

[18] Reichardt W., Alim A.O., Schmidt W. (1975). Definition und Messgrundlage eines objektiven Masses zur Ermittlung der Grenze zwischen brauchbarer und unbrauchbarer Durchsichtigkeit bei Musikdarbietung, Acustica, Vol. **32**, 126-137.

[19] Sabine W.C. (1964). Collected Papers on Acoustics, University Press Harvard, (1922); Reprinted by Dover, New York.

[20] Schroeder M. R. (1965). Some New Results in Reverberation Theory and Measurement Methods, 5e Congres International D'Acoustique LIÉGE 7-14 Sept., G31.

[21] Thiele R. (1953). Richtungsverteilung und Zeitfolge der Schallrückwürfe in Räumen, Acustica, Vol. **3**, 291-302.

[22] Tohyama M., Suzuki H. and Ando Y. (1995). The Nature and Technology of Acoustic Space, Academic Press, London.

[23] Vorländer M. (1998). Objective Characterization of Sound Fields in Small Rooms, Audio Eng. Soc., 15th Int. Conf., Copenhagen, Denmark.