ZARAGOZA'89
ENVIRONMENTAL ACOUSTICS

B.3.1

8º SYMPOSIUM FASE'89
«ACUSTICA AMBIENTAL»
Zaragoza, Abril 1989

A NEW EMPIRICAL ROOM ACOUSTICS EQUATION FOR SOUND DISTRIBUTION IN IRREGULAR SPACES

Robert E. Jonckheere, Filip Verbandt

Vrije Universiteit Brussel
Faculty of Applied Science, Acoustical Engineering Laboratory.
V.U.B., Pleinlaan 2, B-1050 Brussels, Belgium.

INTRODUCTION.

The classical room acoustics equation (1) is often used to predict a first approximation of the sound field in a enclosed room:

$$L_p = L_w + 10 \log \left(\frac{Q}{4\pi r^2} + \frac{4}{A} \right) \qquad (1)$$

with L_p = sound pressure level at a distance r from the source, L_w = sound power level of the source, r = distance between source and receiver, A = total absorption of the room.

According to this equation L_p becomes a constant in the far field, which is supposedly diffuse. In most practical cases, it is not entirely diffuse [3]: the sound pressure level continues to decrease with increasing distance from the source. This discrepancy is a well known fact [1], [2]. Therefore a research program was launched with the purpose to establish a model based on a large series of measurements performed in a variety of medium sized spaces.

MEASUREMENTS.

We opted for a large number of carefully performed measurements in a rather small number (8) of spaces: 2 sportshalls, 1 festive hall, 4 laboratory halls of different shapes and dimensions, 1 industrial hall, with: volumes between 400 and 14000 m^3, absorption coefficients between 0,07 and 0,21, a complex geometry in some cases.

An omnidirectional sound source (B&K 4205) was placed at 0.25 m above the floor, and sound pressure level measured with the following equipement: B&K 2131 digital frequency analyser, B&K 4615 condensor microphone, every 20 centimeters over 2 straight horizontal lines 1.7 m above the floor, in two perpendicular directions. The measurement campaign in eight different spaces yielded a total of 88000 values of L_p.

DEDUCTION OF THE EQUATION.

In order to develop the new formula following considerations were taken into account: which minimalisation best fit program had to be used; the number of variables on which the regression had to be performed; the general form of the new room acoustics model; the number and choice of parameters in the model.

Out of two very sofisticated least square programs of the MINUIT package from the CERN computerlibrary we opted for the MIGRAD-program which converges quickly if the equation is well chosen.

With trial and error the best number of coefficients of the equation to perform the regression was found to be 26.

The general form of the new model and the number and choice of variables was rather difficult to determine. We started from an expression similar to the classical room acoustics equation and refined it untill the experimental result fitted best with the calculated values. Finally the following model was established:

$$L_p = L_w + A \log \left(\frac{C}{R^2} + \frac{D}{R^B} - \frac{E}{R^F} \right) \quad (2)$$

with L_p	: sound pressure level at a distance r from the source	(dB)
L_w	: sound power level of the source	(dB)
R	: distance between source and receiver	(m)

A = - 5,9407 log H + 5,8267 log S_g - 3,0125 log S_w - 2,5933 log T -1,9651 log L + 8,3711

B = - 0,84669 log H + 0,099740 log S_g - 0,027103 log S_w + 0,14816 log T - 0,025967 log L + 1,0898

C = +0,31944 log H - 0,20796 log S_g + 0,25196 log S_w - 0,025819 log T - 0,12450 log L - 0,14910

D = - 0,72493 log H + 0,071599 log S_g - 0,0504311 log S_w - 0,0035823 log T + 0,0058199 log L + 0,70567

E = + 0,31220 F = + 1,5302

H = room height	L = sound wave length		(m)
S_g = floor area	S_w = total area of all the surfaces		(m^2)
T = reverberation time			(s)

This expression can easily be programmed on a pocket calculator. The input is not very different from the input of the classical equation. Instead of the total absorption coefficient the empirical equation makes use of the reverberation time.

The mean deviation of the measured and the calculated values amounts to 1.24 dB for the 88000 measurements.

COMPARISON BETWEEN THE NEW AND THE CLASSICAL EQUATION.

In order to test the reliability of the new method, it was applied to three very irregular spaces other than the ones used to develop it:

- a laboratory with: 2 coupled spaces, a volume of 846 m^3, α_{sab} = 0.08,
- a workshop with: 5 coupled spaces, a volume of 2926 m^3, α_{sab} = 0.23,
- a corridor with: a stairway (3 coupled spaces), V = 142 m^3, α_{sab} = 0.06,

Figures 1 and 2 show the dimensions and the complexity of two of the three spaces.

FIGURE 1 WORKSHOP.

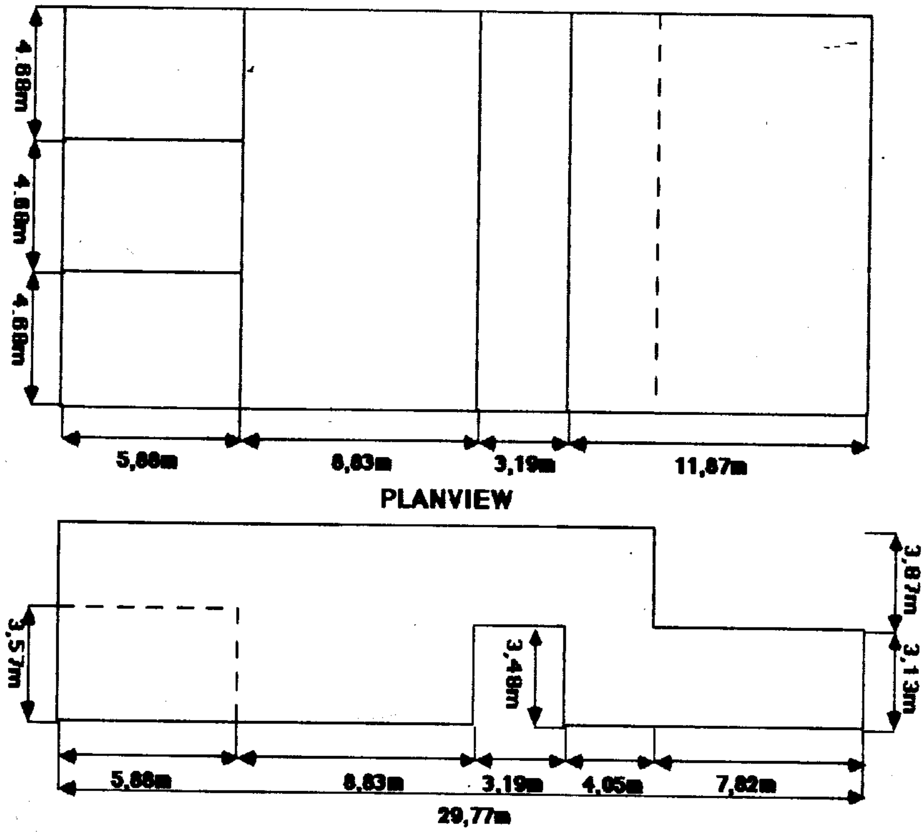
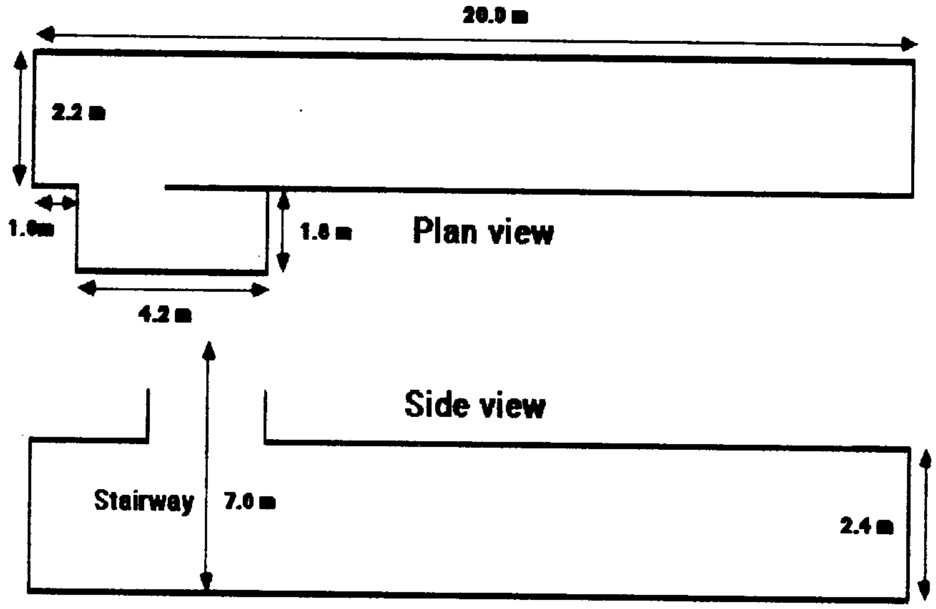


FIGURE 2: CORRIDOR.



The measurements were taken with the same equipement and in the same way as was done in the developing stage. Table 1 lists the mean differences between the measured and predicted values in the spaces for various frequencies.

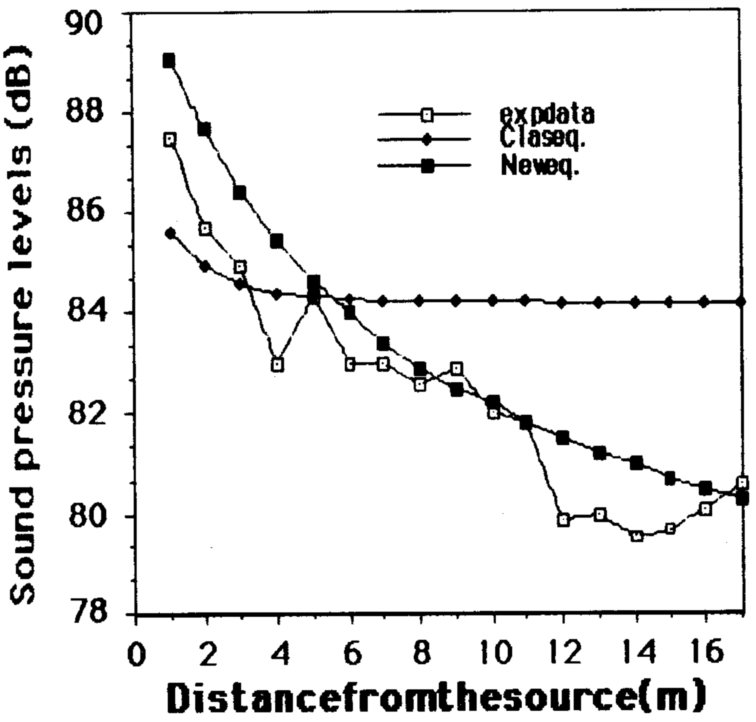
Tabel 1 Mean difference between measured and calculated values (dB).

Room	Model \ Frequency Hz	250	500	1000	2000	4000
1) Laboratory:	Classic equation	1.28	1.18	1.41	1.94	2.88
	New equation	1.16	0.94	1.05	1.41	1.59
2) Workshop:	Classic equation	5.50	6.01	6.00	4.53	6.10
	New equation	4.25	1.72	1.50	1.30	2.35
3) Corridor:	Classic equation	2.85	2.30	2.20	3.85	5.05
	New equation	1.75	1.55	1.15	3.35	3.45

If the experimental data between 500 and 5000 Hz are considered, the arithmetic mean difference between measurement and prediction amounts to **3.6 dB** for the classical equation and **1.8 dB**.for the new equation.

The application to the case of the corridor is shown on figure 4. The new equation allows a closer fit of the experimental data than does the classical equation.

FIG3.COMPARISONOFRESULTS.



CONCLUSION.

The new empirical equation gives the acoustician an accurate tool to predict in a simple way the sound distribution field in a enclosed room.

Within the limits of: a volume between 400 and 14000 m^3, absorption coefficients between 0,07 and 0,21, frequencies between 500 and 5000 Hz, this method allows to make a prediction with a mean accuracy of 1.8 dB.

REFERENCES.

[1] V.M.A. Peutz, "Sound propagation reverberant and semi reverberant halls ", Inter-Noise 85, Munich, september 1985, pp. 425-428

[2] C.J. Hurst and L.D. Mitchell, Computer-Aided Noise Prediction: "Final Report on an Investigation into the Prediction of Noise in Manufacturing Areas", Virginia Polytechnic Institute and State University, Blacksburg Virginia.

[3] K. Beissner, "Acoustic radiation pressure in the near field", Journal of Sound and Vibration 1984, 93 (4), pp. 537-548.