A Design Tool for Calculating the Sound Insulation Between Buildings Using Statistical Energy Analysis

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1 INTRODUCTION

Design aids are necessary for architects to ensure that there are adequate standards of sound insulation between new buildings or parts of the same building. Current methods are semi-empirical and are not satisfactory because for a reliable estimate of sound insulation complex flanking sound transmission paths have to be considered and a detailed knowledge of the characteristics of these paths is required. To improve the reliability of design procedures a computer model is being developed by BRE. The model calculates sound transmission in building structures using a Statistical Energy Analysis (SEA) approach. This is achieved by describing a building in terms of sub-systems eg. walls, rooms etc. Knowledge of the physical properties and connections (junctions) between the subsystems is used to calculate standardised level differences (D_{nT}) between rooms.

To validate the theoretical work a parallel programme of work is being conducted in BRE's Flanking Laboratory. This facility allows specific design details to be built and investigated. Standardised level differences have been obtained for a number of test configurations.

This paper describes the SEA model and compares theoretical results with those obtained experimentally.

2 THEORY

The technique of statistical energy analysis has ben used to predict acoustic and vibrational energy flow in structures for a number of years[1,2,3]. However, cavity walls which are common in the UK have not been investigated adequately. SEA relies on the principal of conservation of energy i.e. energy entering a system is equal to the sum of the energy leaving and the energy dissipated internally. In any system of connected elements (eg. a building), power flows between the elements. A set of simultaneous equations can be written which describe this flow in terms of power W, energy E and energy loss factors η. Loss factors can be split into two types, (i) Total loss factor (TLF) which is the fraction of energy lost by a subsystem per cycle and (ii) coupling loss factor (CLF) which is the fraction of energy lost from one subsystem to another per cycle.

Total loss factors for walls are obtained from the expression given by Craik[4] and for rooms from the reverberation time. Coupling loss factors from walls to rooms are obtained from the radiation efficiency, whilst wall to wall CLFs are obtained from the bending wave transmission loss across the junction.[3]

2.1 Power Balance Equations

The power lost from a subsystem *m* is given by;

$$W_{mloss} = E_m \omega \eta_m$$

where E_m is the energy levels in subsystems *m*
ω is the angular frequency
η_m is the total loss factor of subsystem *m*

The power flow between subsystems *m* and *n* is given by;

$$W_{mn} = E_m \omega \eta_{mn}$$

where η_{mn} is the coupling loss factor between subsystems *m* and *n*

For a building with *m* subsystems a set of generalised equations can be written in matrix form;

$$\begin{vmatrix} -\eta_1 & \eta_{21} & \eta_{31} & \cdots & \eta_{m1} \\ \eta_{12} & -\eta_2 & \eta_{32} & \cdots & \eta_{m2} \\ \eta_{13} & \eta_{23} & -\eta_3 & \cdots & \eta_{m3} \\ . & . & . & \cdots & . \\ . & . & . & \cdots & . \\ \eta_{1m} & \eta_{2m} & \eta_{3m} & \cdots & -\eta_m \end{vmatrix} \begin{vmatrix} E_1 \\ E_2 \\ E_3 \\ . \\ . \\ E_m \end{vmatrix} = \begin{vmatrix} W_1/\omega \\ W_2/\omega \\ W_3/\omega \\ . \\ . \\ W_m/\omega \end{vmatrix}$$

The energy matrix |E| can be obtained for a particular input power by solution of the above matrix for each frequency value of interest. Energy level differences, E, between two subsystems *m* and *n* can be obtained from the ratio of two energy levels, A Design Tool for Calculating Sound Insulation using S.E.A.

$$E = 10Log\frac{E_n}{E_m}$$

where E_m and E_n are the energy levels in subsystems m and n

The standardised sound pressure level difference between two rooms m and n is then calculated from a simple ratio of the energy levels,

$$D_{nT} = 10Log\frac{E_n}{E_m} + 10Log\frac{V_m}{V_n} + 10Log\frac{T_m}{0.5}$$

where E_m and E_n are the energy levels in rooms m and n
V_m and V_n are the volumes
T_m is the reverberation time in room m

2.2 Building elements and properties

Three subsystems are used to describe a building construction - rooms, walls and cavities. Ceilings and floors are treated as special cases of the wall type. In general, easily available physical data is used to characterise these elements e.g. length, density. A model can thus be constructed using architects drawings with a minimum of supplementary information. Connections between subsystems are described by six types of junctions eg. cross joint, tee joint.

3 THE FLANKING TRANSMISSION SUITE

The flanking transmission suite was designed by BRE and built in 1991 to provide the experimental data needed to validate the SEA prediction method for sound insulation between dwellings. The laboratory is a 'U' shaped, two storey structure consisting of three solid 560mm brick walls, a concrete floor and a plasterboard ceiling with a tiled roof on trussed rafters. It is split into two unequal parts by layers of resilient insulating material running vertically through the rear wall which is otherwise common to the two parts. Additionally the concrete floor is split by a cavity to reduce unwanted transmission across the two parts of the building. A front elevation of the facility is shown in Figure 1.

The first of the test constructions to be built within this shell is illustrated in Figures 2 and 3. They show a two storey, four room construction of brick and blockwork. The cavity separating wall is of medium weight aggregate blockwork without ties, the leaves being built on either side of the floor cavity. The external flanking wall is a cavity wall, with an inner leaf of lightweight blockwork and an outer leaf of brickwork connected with butterfly ties. The ceiling/floor was made of plasterboard and flooring grade chipboard. Joists were built into the separating wall. Physical data is given in Table 1.

4 RESULTS

A 30 subsystem model was created using the architects drawings. The subsystem numbers are on Figures 2 and 3. In this paper attention will be directed towards the structural level differences. Predictions of D_{nT} will be presented at the conference.

Vibration level differences were measured for the separating wall and the flanking wall. The data was obtained by hitting the source subsystem with a soft headed hammer for sixteen seconds. Acceleration levels were measured on source wall (subsystem 6 or 10) and receiving wall (subsystem 5 or 13).

Figures 4 and 5 each compare measured and predicted structural energy level differences. The upper line on each graph shows the predicted values for the direct path only ie. a three subsystem model with two walls separated by a cavity. When all the paths are included in the model, predicted values show good agreement with measured values.

Figure 6 shows the measured airborne level difference, D_{nT}, between pairs of rooms on the ground and first floors. These were measured according to BS 2750[1]. Up to 500Hz there is good agreement between the airborne insulation performance. However, above this value airborne transmission through the first floor ceiling and roof void becomes dominant. Thus, the coincidence dip at 2500Hz of the plasterboard ceiling is clearly visible in the first floor insulation curve. This effect is responsible for the differences in the ground floor and first floor $D_{nT,w}$ values which are 56 and 53 respectively. Initial predictions do not compare well with these measured values, because certain junctions do not behave as expected. The latest results will be presented at the conference.

5 CONCLUSIONS

This paper described a computer model being developed at BRE to predict airborne sound insulation within building using Statistical Energy Analysis. Results from a new flanking transmission test laboratory were discussed and initial predictions from the theoretical model presented. Structure energy level differences predictions showed good agreement with those measured.

6 REFERENCES

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3. GERRETSEN E, 1979, Calculation of the Sound Transmission Between Dwellings by Partitions and Flanking Structures, Applied Acoustics, Vol. 12(6), pp. 413-433

4. R.J. CRAIK, 1981, Damping of Building Structures, Applied Acoustics, Vol. 14(5), pp. 347-359

5. BS 2750 Measurement of Sound Insulation in Buildings and of Building Elements: Part 4 Field Measurements of Airborne Sound Insulation Between Rooms 1980 (Equivalent to ISO 140 part 4 1978)

Wall	Material	Surface Density (kgm^{-2})	Thickness (mm)
Separating	Medium block	166*	100*
Flanking (inner)	Light block	70	100
Flanking (outer)	Brick	154	100
End/rear	Brick	861	560
Floor	Concrete	275	125

Table 1 Wall materials of test construction (* each leaf)

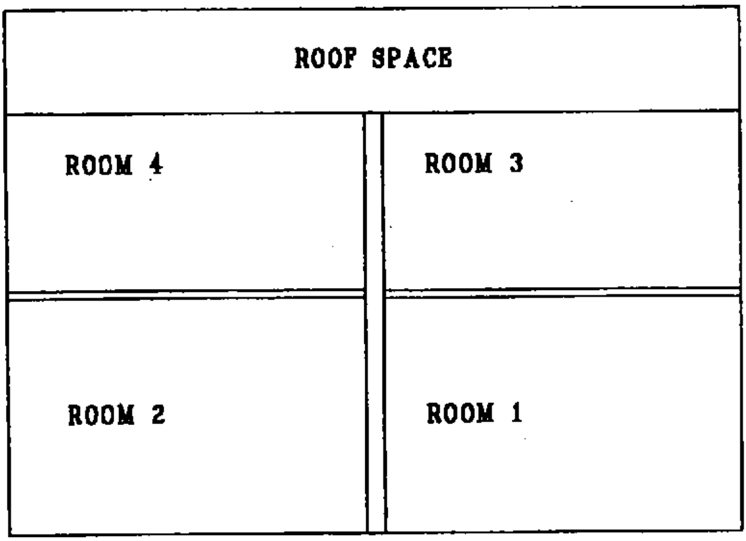

Figure 1 Front elevation of BRE flanking transmission suite
(Not to scale)

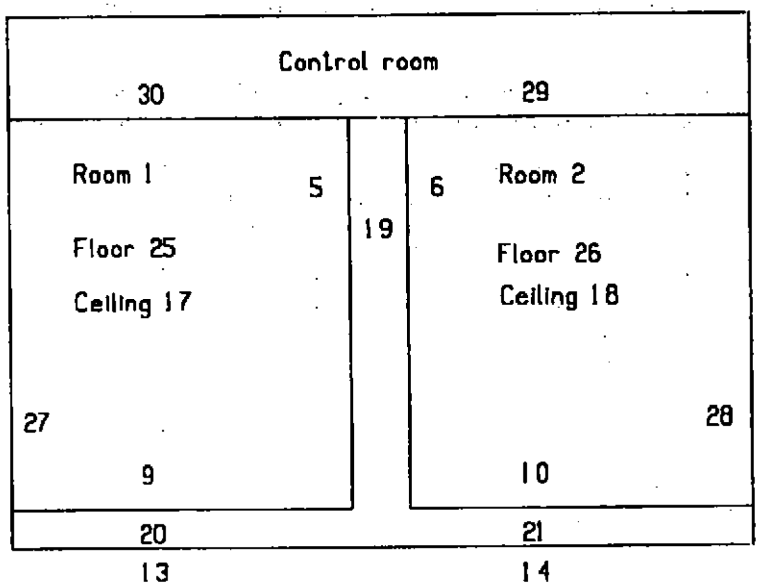

Figure 2 Plan view - ground floor

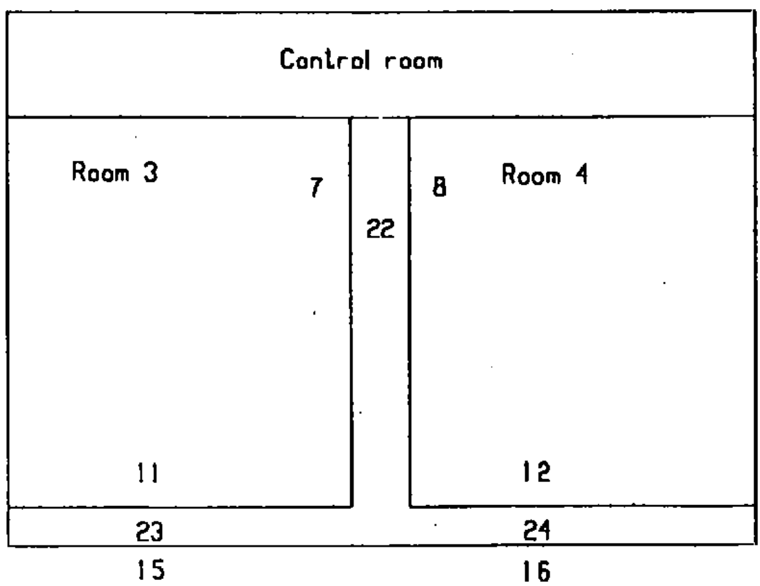

Figure 3 Plan view - first floor

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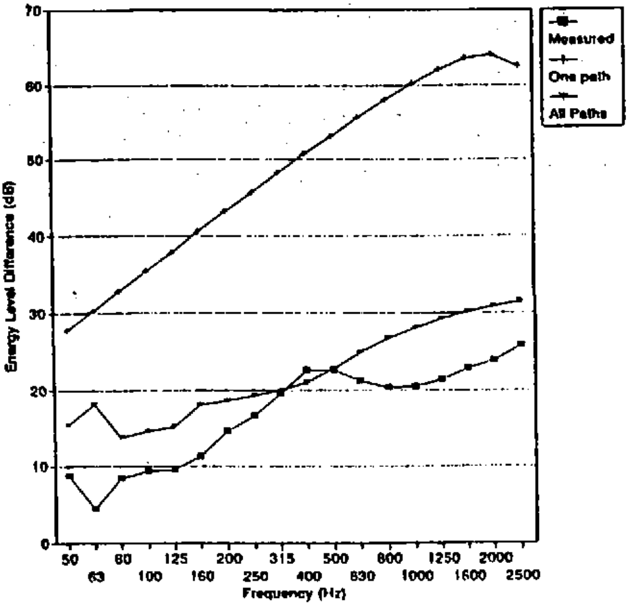

Figure 4 Level difference for separating wall

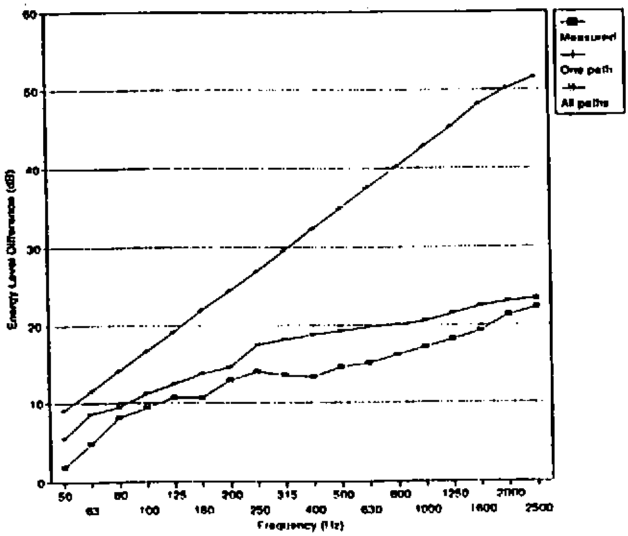

Figure 5 Level difference for flanking wall

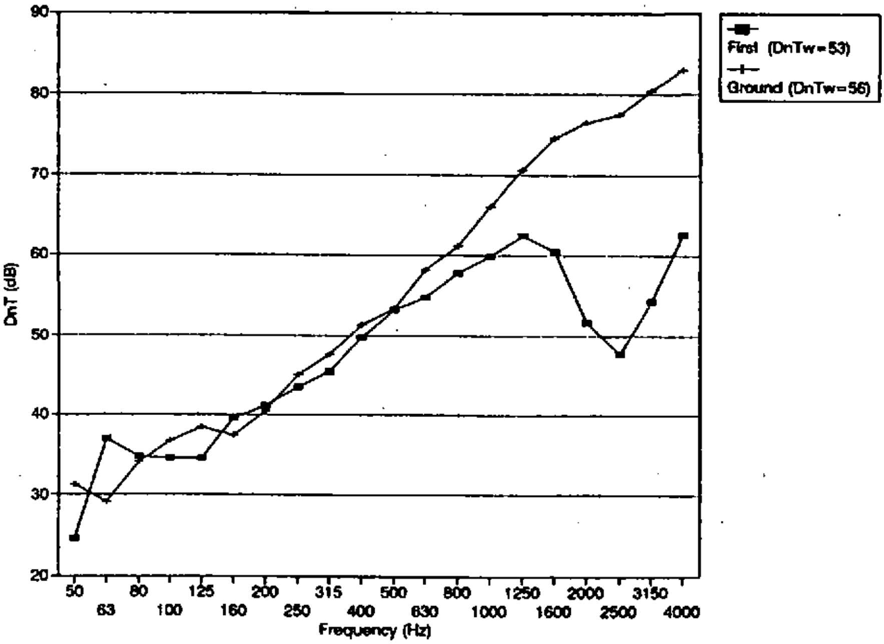

Figure 6 Standardised level difference