AN EASY TO USE MODEL TO AID IN THE ACOUSTIC DESIGN OF CLASSROOMS.

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1 Introduction

Evolving classroom codes and standards require the design professional to limit the background noise level, and target the reverberation time to a specified time. In order to do this, estimates of design parameters need to be calculated. To facilitate this process, a model based on classical acoustics has been developed which allows the designer to select component performance characteristics from menus of measured data. These data are entered into an energy balance, which predicts the overall classroom diffuse field sound pressure level. The direct fields from sound sources inside the room are added to predict overall sound pressure level as a function of position in the classroom. Reverberation time is also calculated. In this paper, the formulation of the model is described. Validation experiments and comparisons with another analysis tool are shown, and a design example is included.

2 Formulation

Sound travels to and from a classroom space by structural and airborne paths. This model addresses airborne paths only. Care should be taken isolate structure borne sources such as roof mounted central HVAC components, but these effects are not included in this model. Sound energy enters the space by dispersion from the adjacent spaces through walls, windows, doors, ceilings, and floors. Sound energy is generated in the space by noise sources such as HVAC units and terminals, lighting fixtures, plumbing, computer equipment, occupants, and etc. (background noise does not include occupant generated noise). Sound energy is dissipated within the space by absorption of the rooms' surfaces, furnishings, and occupants. Figure 1 shows the classroom energy balance. Note that the dispersive energy can travel either way depending on the relative strength of the driving potential between the classroom and the adjacent space.

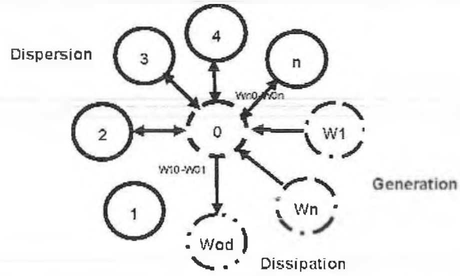

Figure 1. Classroom energy balance.

The relationship between energy and sound pressure, Eq. 1, is

$$\overline{E} = \frac{\overline{p}_{sp}^2}{\rho_0 c_0^2} V$$

where

$\overline{E}$ – Space Averaged Energy

$\overline{p}_{sp}$ = Space Averaged Sound Pressure

V = Room Volume

ρ_0 = Density of Air

c_0 = Air Speed of Sound

The relationship between power dispersed and transmission loss factor's (TL's), Eq. 2, is

$$\Delta P_{n\to 0} = \tau_{n\to 0} \frac{A_{wn}}{4\rho_0 c_0}\left(p_n^2 - p_0^2\right) = C_n\left(p_n^2 - p_0^2\right)$$

where

$$TL_{n\to 0} = 10\text{Log}\left(\frac{1}{\tau_{n\to 0}}\right)$$

The relationship between power dissipated and absorption coefficients, Eq. 3, is

$$P_{od} = \frac{A}{4\rho_0 c_0}\overline{\alpha} p_0^2 = D p_0^2$$

where

$$\overline{\alpha} = \frac{\sum \alpha_i A_i}{\sum A_i}$$

Summing these terms results in the following simplified power balance equation. Eq. 4,

$$p_0^2 = \frac{\sum C_i p_i^2 + \sum W_i}{\sum C_i + D}$$

where

$$C_n = \tau_{n,m} \frac{A_{nm}}{4 \rho_0 c_0}$$

Wi = Internal power

$$D = \frac{A}{4 \rho_0 c_0} \overline{\alpha}$$

The direct field is added to the diffuse field to get the total local pressure. The direct field model, Eq. 5, is

General Case : n sources of W_i & Q_i

where

W_i = power, watts

$$Q_i = \text{Directivity} = \frac{4 \pi r^2 c p_r^2}{\rho_0 c^2 W_i},$$

$$L_n = 10 Log \left(\frac{W_r \rho_0 c}{4 \pi p_r^2} \sum \frac{Q_i \, W_i / W_r}{r_i^2} \right)$$

Ref ASHRAE Handbook of Fund. Chap. 6

3 Validation

The diffuse field portion of this simplified model was compared to predictions made by a commercially available statistical energy analysis program. Predictions were also compared to measurements made in a suit of reverberation rooms. The case shown in Figure 2 includes the combined effects of generation and a dispersive path .

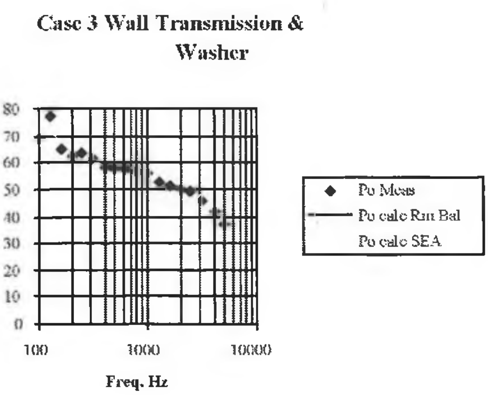

Figure 2. Combination of generation and dispersion.

Figure 3 shows the combined effects of a window and a wall.

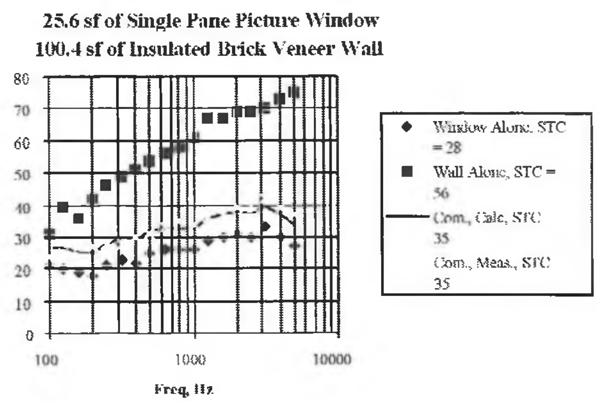

Figure 3. Combination of window and wall.

4 Design Example

The maximum sound power level emitted by two alternate HVAC designs were calculated which meet a 35 dBA background noise design criteria. One is a unit ventilator under a window along a side wall. The other is a central system with energy exchange in the hall way, and air ducted to a diffuser in the center of the ceiling.

Table 1. Maximum HVAC sound power level.

Case	Unit Ventilator Under Window	Ceiling Outlet
Child Seated	31	34
Adult Seated	32	33
Seated Middle of Room	34	
Adult Standing		33

5 Observations

- There is no significant difference between the SEA program and simplified energy balance model for this simple case.
- Direct field effects can be significant especially in the HVAC under window case.
- Ceiling HVAC outlets result in lower levels at the student's ear than under window HVAC unit of equal strength.

References

- Auto SEA Training Course, Vibro-Acoustic Sciences Limited, 1996
- ASHRAE Handbook of Fundamentals Chapter 6, 1972.