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PRACTICAL EXPERIENCE OF FACTORY NOISE PROPAGATION MODELLING.

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INTRODUCTION

It has been known for many years that continuous exposure to high noise levels can permanently damage hearing. Following the publication of quantitative data in 1970 the UK government issued its Code of Practice specifying the maximum permissible noise level to which people in industry should be exposed. Non-compliance with this Code can be seen as a breach of Section 2 of the UK Health and Safety at Work Act.

In December 1985 the content of the EEC directive on noise at work was agreed, setting an action level at operator exposure levels of 85 dBA Leq (8 hr) and a limit level of 90 dBA Leq (8 hr). In the future it is anticipated that a limit level of 85 dBA could be enforced. It is Unilever policy that associate companies comply with current recommendations/ legislation and sets a target exposure limit of 85 dBA Leq 8 hour.

In this paper two case studies are presented, the objectives of which were to model the noise fields inside factory buildings and evaluate the cost effectiveness of noise control measures to achieve operator exposure levels of <85 dBA Leq. The first example concerned a site where noise survey had shown exposure levels were up to 89 dBA Leq 8 hr. The second was a design stage study for a new production building.

Case I

The main production/packing hall at this factory is a large open building 140m long by 40m wide with a suspended ceiling at 6m. Twenty two production lines are situated in the building arranged parallel to each other across the width. For each line there is a production module comprising a cubic steel frame onto which various motors, gearboxes and pumps are mounted. Product is fed from this unit to the filling/packing line and then is conveyed to the cold store situated alongside the production building. Figure 1.

Noise Measurements

A survey of the production hall gave levels of 85-90 dB at operator position (Figure 1). Assuming an attendance time of 10.5 hrs out of a 12 hour shift, an estimated Leq 8 hr of 89-90 dBA could result. As this was very close to recommended limits it was decided to implement a noise control program. A target level of 83 dBA at operator position was set to ensure compliance with an 85 dBA Leq 8 hr.

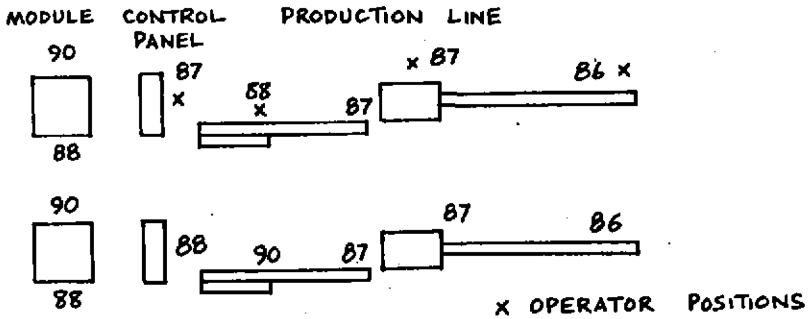

Figure 1.

Shutdown Tests

During a weekend shutdown a detailed investigation of noise sources was undertaken which confirmed that the production modules were the dominant noise sources and that all components contributed to the radiated noise. In addition sound power measurements on all machines comprising one line, and sound propagation tests, were conducted using a Bruel & Kjaer 4205 sound power source. The reverberation time of the building was measured using an impulsive noise source.

The important results of these measurements were:-

that the rate of decrease of sound/doubling of distance was ~3.5 dBA and

the reverberation time was 4.5 seconds (linear).

Computer Model

In order to assess the requirements for noise control the x, y coordinates of all the machines in the building, their sound power levels and the rate of decrease of sound with distance were entered into a computer program. The combined effect of all the sources was then computed for positions 2m apart throughout the building. The modelled results were found to agree with data measured under production conditions to within ~1 dBA.

Two other computer models based on the work of Friberg[1] and H J Sabine[2] were also used to repredict the noise levels in the hall from the same source data. The Friberg approach was found to be the more accurate and this was used to simulate the effects of various control options. These were:-

Change of source sound power
Change of ceiling height
Change of ceiling absorption

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Interpretation of Results

From the computer printouts several conclusions could be made:-

a) To achieve a noise level of 83 dBA, noise control at source on the production modules together with acoustic ceiling treatment would be required.

b) Increasing the NRC of the ceiling to $\sim$0.5 would reduce noise levels close to the production module by 1-2 dBA and up to 10 dBA at large distances. The results were independent of ceiling height.

c) Increasing the ceiling height by removing the existing suspended ceiling would reduce noise levels by 1-2 dBA.

Remedial Measures

Following discussions between the writer, the factory and the acoustic contractor it was decided that three approaches to noise control would be adopted:-

i) A suspended acoustic absorber system. [1/m^2 of 600 x 900 x 80 m pads encased in 0.4mm plastic.]

ii) An acoustic screen along the line of the control panels between the production modules and packing line. [4m high x 50mm thick comprising 22mm steel skins with mineral fibre infill].

iii) Acoustic enclosure of dominant sources on the production module.

Initially a trial phase covering 5 lines was implemented (excluding the enclosure of production module) and the effects evaluated. The results agreed well with the modelled data and the treatment was therefore extended to the whole building.

Evaluation of Completed Project

After installation of the screen and suspended absorber system a noticeable, subjective improvement in noise levels was reported. Since the initial survey in 1980 some changes in production hall layout had taken place making direct comparison of noise levels difficult. During the re-survey a similar number of production modules and packing lines were operating.

Measured Noise Levels

A comparison of measured noise levels is illustrated for 2 lines near the centre of the hall in Figure 2. An overall summary of noise levels is given in Table 1.

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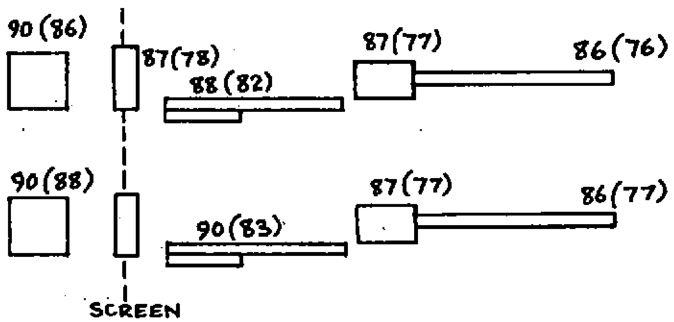

Figure 2.

Table 1

	Production Modules	Control Panel	Operator Posn.	Lifts to Cold Store
Before Treatment	88 - 91	87 - 90	87 - 90	85 - 86
After Treatment	85 - 89	77 - 82	80 - 83	75 - 77
Reduction	3 dBA	9 dBA	7 dBA	9 dBA

Predicted Noise Levels

Although a computer prediction of noise levels was not made for the specific case of a screen and acoustic treatment a simulation was made for reducing the noise level of the production modules by 5 dBA and acoustically treating the ceiling. This therefore is a similar effect to that which would be achieved by a screen if only positions on the packing line side of the screen are considered. A comparison between measured and predicted levels is given in Table 2.

Table 2

	Control Panel	Operator Posn.	Lifts to Cold Store
Measured	77 - 82	80 - 83	75 - 77
Predicted	77 - 81	80 - 84	73 - 77

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CASE STUDY II

At the design stage of a new project for a food processing/packaging building it was required to estimate the noise levels to be expected inside the building. The building was to be essentially one large open hall, approximately 100m long by 45m wide by 8m high. Noisy comminution equipment (SWL 100 dBA) was to be positioned at one end feeding forming machines and packing lines running the length of the building. To meet hygienic requirements the building was to have a ceramic tiled floor, walls with glazed tiles to 3m and the remaining walls and suspended ceiling to be of PVC faced metal, polystyrene, metal sandwich panels.

Assesement of Source Sound Power

Accurate source sound power data on process/packing machinery is generally not available from suppliers. In order to estimate sound power levels measurements were made on similar plant already in use on other Unilever sites.

Measurements were made approximately in line with ISO 3746 both with machines under normal production conditions and with machines operating individually. Sound pressure levels were measured at 1m from machine surfaces, being corrected for background and then integrated over the measurement surface.

Computer Model

A modelling technique similar to that used in Case I was used to calculate noise levels at 2m intervals throughout the building. The equation of propagation for the sources was represented as a sound reduction per doubling of distance and was initially computed using the Friberg[1] approach. The figures used were however adjusted taking into account propagation rates established in other geometrically similar buildings[3]. Single and double slopes were used to check the effects on computed noise levels. Calculations were made solely in dBA as in almost all cases the octave band spectra of the noise sources peaked in the 500-2K Octave band. In addition the computation time to calculate the combined effect of ~100 noise sources at 1200 points for each octave band would have been prohibitive.

During the building design period many alternative options were computed:

e.g.	Estimated Sound Reduction per Doubling of Distance
All lines running - no acoustic treatment	L = 3.5 dB
All lines running - acoustic ceiling (NRC 0.8)	L = 5.1 dB
All lines running - partial acoustic ceiling (Average NRC 0.4)	L = 4.3 dB
All lines running - acoustic ceiling over comminution equipment only	L = 5.1/3.5
As above but with various machines turned off.	

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Design Considerations

The acoustic design criterion was essentially to ensure that the maximum number of operators had exposure levels <85 dBA (leq 8hr). From the computer simulation it was clear that, with all lines running noise levels would exceed 85 dBA at all operator positions. Experience has shown that effective and acceptable retrofitted source control measures are difficult to realise in food factories. The requirements for hygiene sanitation and ease of access for maintenance conflict with those for noise control.

Approaches were made to suppliers of the noisier machines suggesting a collaborative effort to investigate viable noise control options. They did not however wish to pursue this approach.

The computer simulation showed that, with a full or partial acoustic ceiling treatment, noise levels would generally be reduced to 85 dBA or below at most operator stations. It was therefore decided to investigate the alternatives for acoustically absorptive ceilings.

Acoustic Ceiling Options

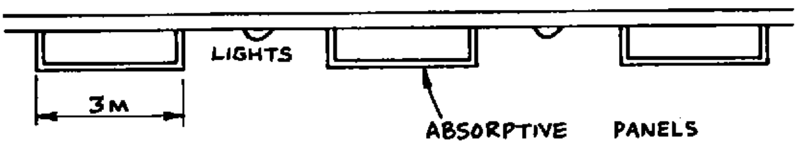
The building design concept required that the ceiling of the building could support the heating and ventilating plant. A system comprising a secondary suspended system below the 'walk-on' ceiling was chosen, with 3m sections of absorptive panels being installed between the rows of lighting and ventilation services. See Figure 3.

The absorptive material chosen was a dense 25mm glass fibre panel with a glass tissue facing on the front and rear sides. All surfaces including the edges were spray painted. A reverberant field sound absorption test was conducted at the University of Salford in order to confirm the absorption coefficients with different air spacings behind the panels. The measured absorption coefficients are tabulated.

	OCTAVE BAND CENTRE FREQUENCY					
	125	250	500	1K	2K	4K
Absorption Coefficient (50mm Airspace)	.29	.68	.85	.89	.88	.85

A spacing of 200mm was chosen as a compromise giving the optimum low frequency absorption without adversely affecting lighting or ventilation.

Figure 3.



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Propagation Measurements

At various stages of the project measurements of sound propagation were made inside the building using calibrated sound power sources. Two loudspeaker arrangements were used through which octave band white noise was played. The first was a dodecahedron comprising 12 KEF B200 mid range units for the range 125 - 1kHz and a cube comprising 4 high frequency tweaters for the 2kHz and 4kHz octave bands. These were each mounted on a 1.5m stand. Sound pressure levels were measured along the length and width of the hall in octave bands each reading being integrated over a 12 second period. The results in terms of best fit sound propagation per doubling of distance are tabulated below.

Table 3 Best fit slopes 2-90 metres

	OCTAVE BAND CENTRE FREQUENCY						
	125	250	500	1K	2K	4K	dBA
Length Empty	2.3	2.4	2.5	2.3	2.5	3.7	3.6
Empty + ABS	2.9	3.1	3.2	3.4	3.6	3.6	3.4
½ Fitted	3.3	4.3	4.2	4.6	4.6	5.2	4.4
Empty	2.2	2.5	2.5	2.4	2.6	3.0	2.5
Empty + ABS	2.5	2.5	2.4	2.7	2.9	3.1	2.7
½ Fitted	2.5	2.6	2.6	2.9	2.5	3.3	2.7

The results for the 250-2kHz octave bands are presented graphically in Figure 4.

In addition the reverberation times were also measured and analysed in third octaves and octaves. These are presented in Table 4.

Table 4

	OCTAVE BAND CENTRE FREQUENCY					
	125	250	500	1K	2K	4K
Empty	5.7	6.7	6.0	6.6	6.2	3.6
Empty + ABS	3.8	3.0	3.4	4.5	4.4	2.5
½ Fitted		2.8	2.9	3.9	4.1	

Discussion

The measurements of sound propagation in the empty, partially treated and half furnished factory leads to the following general conclusions:-

1) When empty noise levels initially decreased at a rate of 2.8 dBA/doubling of distance. The rate decreased to 2.6dBA/dd between 20 and 100m from the source.

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2) After installation of partial acoustic treatment noise levels at short distances dropped by ~2 dBA. The short distance SP curve increased in slope from 2.6 to 3.4 dBA/doubling of distance while the SP curve beyond 20m increased from 2.8 to 3.8 dBA/dd.

3) Across the building sound propagation was only marginally affected by acoustic treatment. Noise levels at all distances across the building were reduced slightly at most frequencies when the source was under an untreated section of ceiling and by 1.5-2 dBA when under a treated section.

4) After installation of machines noise levels within ~10m of the source increased slightly, probably due to back scattering effects from adjacent machinery. The slope of the SP curve increased at all distances particularly beyond 20m. This is in line with the general findings of Hodgeson and Orlowski[4,5].

5) Measured noise levels in the building are in line with those predicted.

6) Sound propagation for the furnished building agrees well with the estimates at the design stage. Friberg estimates of SP in the empty building over estimates propagation losses. This is understandable as some scattering is always assumed in this method.

7) The Friberg approach greatly under-estimates the RT.

Conclusions

In the geometrically simple buildings discussed the empirical modelling techniques used to estimate the effects of various noise control measures have been found to be accurate to within ~2 dBA. For engineering design studies and for cost benefit analysis this technique has been found invaluable. Care must be taken in estimating source sound power and further work is required in refining the modelling of complex machinery noise sources.

In more complex buildings having mezzanine floors and none regular shapes a more generalised approach allowing for differing SP in different directions may be required.

A more detailed discussion of this work with particular reference to comparisons with mathematical image predictions will be presented by Dr M Hodgeson at Inter Noise 1986.

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Acknowledgements

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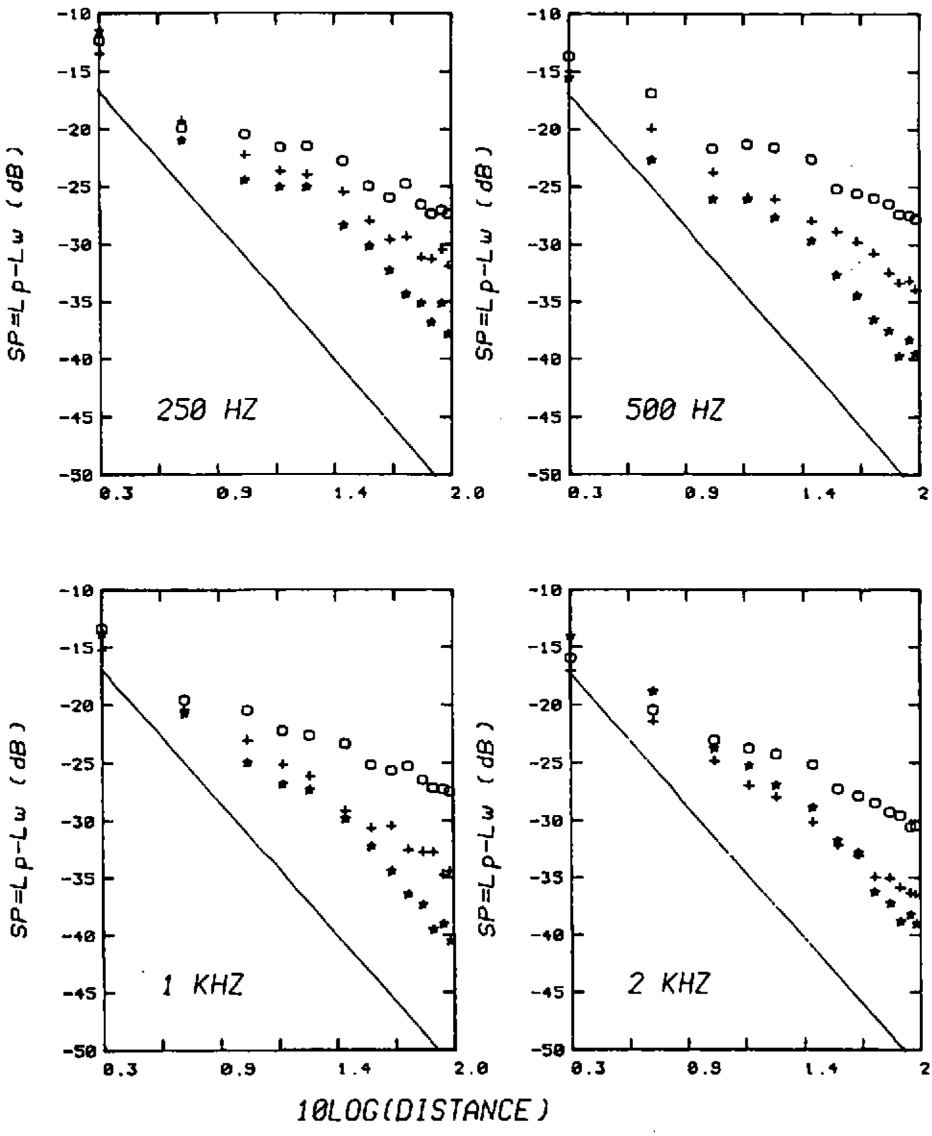
FIGURE 4 - RELATIVE SOUND PRESSURE VS DISTANCE



Lw = SOUND POWER LEVEL   O - ROOM EMPTY, * - ½ FITTED

Lp = SOUND PRESSURE LEVEL   + - EMPTY + ABSORBERS