Canadian Acoustics / Acoustique Canadienne 19(1) 15-23 (1991) **Review paper / Article de revue**

REVIEW AND CRITIQUE OF EXISTING SIMPLIFIED MODELS FOR PREDICTING FACTORY NOISE LEVELS

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ABSTRACT

This article is based on a report to the CSA Industrial Noise sub-committee in response to its request to study the need for and feasibilty of revising the existing CSA standard procedure for predicting noise levels in factories[1]. It reviews and attempts a preliminary evalution of existing models for predicting noise levels in factories. The important factory-acoustic parameters and factory-noise characteristics are discussed. Six models are described, along with the extent to which they have been validated. The models are then evaluated with respect to what extent they take the various parameters into account, and predict the various characteristics. It is concluded that the models have significant merits and short-comings, and that they have not been adequately validated in comparison with reliable experimental results. It is further suggested that there may be scope for a new, more comprehensive simplified model.

SOMMAIRE

Le présent article est fondé sur un rapport présenté au sous-comité sur le bruit industriel de l'ACNOR, qui avait demandé à l'auteur d'examiner le besoin et la faisabilité d'une révision de la méthode normative de l'ACNOR visant à prédire les niveaux de bruit dans les usines[1]. Il passe en revue les modèles existants de prédiction des niveaux de bruit dans les usines et tente de les évaluer de façon préliminaire. Les plus importants paramètres acoustiques et caractéristiques de bruit des usines y sont discutés. Six modèles sont décrits de même que leur dégré de validation. Ces modèles sont ensuite évalués en fonction de l'importance qu'ils accordent aux divers paramètres et de la justesse de la prédiction des différentes caractéristiques. Selon les conclusions du rapport, les modèles présentent des avantages certains mais aussi des faiblesses, et ils n'ont pas été validés adéquatement en comparison de résultats d'essais fiables. Il serait peut-être justifié d'élaborer un nouveau modèle simplifié, plus exhaustif.

1. INTRODUCTION

Recent years have seen a considerable increase in awareness of occupational hearing loss due to elevated noise levels in industrial work environments. This has naturally lead to an increased interest in industrial noise control. An important aspect of the noise-control process concerns the prediction of factory noise levels. Prediction models allow factory noise levels to be estimated, and noise-control measures planned, before construction at considerable potential cost savings. In existing factories they allow retro-fit noise-control measures to be evaluated for cost-effectiveness. The measures may consist of changes to the factory layout, construction and/or equipment, as well as the introduction of acoustic barriers and absorptive treatments.

Many models for predicting factory noise levels have been proposed over the last thirty or so years. Many of these are complex, computer-based models based on method-of-image or ray-tracing approaches. While potentially quite flexible and accurate, their implementation requires knowledge, computer facilities and an expenditure of time that many practitioners do not possess. There is considerable need for more simplified prediction models which, while being less accurate and generally applicable, would allow reasonable estimates to be made with little effort in typical cases. Several simplified models have in fact been developed, but are not well known. One simplified model, not developed for but often applied to factories, is the well-known Sabine diffuse-field model. Let it be said from the beginning that this model is not generally applicable to factories and provides very inaccurate predictions (examples are shown in Figures 1 and 2). It is not considered further here.

It is the aim of this report to review the existing models and to draw preliminary conclusions regarding their usefulness. In order to help in this task, we first discuss the factory-acoustic parameters that influence factory noise and that, in principle, a comprehensive prediction model must take into account. Next, using experimental and prediction results, we discuss some general characteristics of factory sound propagation that a model should be able to predict. The existing simplified models known to the author are then described, along with the extent to which their authors validated them experimentally. Finally, a preliminary attempt is made to evaluate the various models.

It must be stated immediately that this report discusses models which take an energy-based approach, ignoring wave, and therefore modal and diffraction, effects. Since we are dealing with large rooms and octave-band results, this should not represent a serious limitation except perhaps at low frequencies and when predicting levels in the presence of acoustic barriers. Further, all models predict the sound pressure level at some distance from an omni-directional point source, which radiates broad-band noise. We define the Sound Propagation Function (SPF) as the variation with distance, r, from an omni-directional point source of the sound pressure level, $L_p(r)$, minus the source sound power level, L_w: that is, $SPF(r) = L_p(r) - L_w$. The sound propagation function describes the variation of noise levels normalized for the source power. Both parameters are necessary to determine noise levels.

2. PARAMETERS

Factories are buildings of highly variable shape, construction and contents. Many factories are essentially of rectangular plan and section shapes (that is, parallelepipedic). Others are of more complex shape, with non-rectangular plan and section shapes, or with the space sub-divided by barriers such as mezzanine floors, internal enclosures and internal partitions. The composition of the various surfaces may vary from building to building and from surface to surface within a given building, especially if the factory contains acoustic treatment. Thus, the magnitude of the acoustic absorption of the surfaces may be highly variable and its distribution non-uniform. Factories contain furnishings (equipment, stockpiles, benches, roof trusswork, etc.) that scatter and absorb propagating sound, resulting in noise levels which are very different from those in the empty factory. The furnishing density and absorption usually vary throughout the factory. Finally, factories contain many noise sources and noise-sensitive positions, located throughout the building. Receiver positions may be operator positions, for which the average source/receiver distance is small. In the other extreme, a long factory may have noise sources at one end and noise-sensitive receivers at the other; in this case, the average source/receiver distance may be large. The surface absorption and the noise radiated by sources may vary with frequency as, of course, do factory noise levels.

The main factory-acoustic parameters that have a significant influence on factory noise levels, are as follows:

- geometry - the geometry (size and shape) of the building envelope, and the positions of internal barriers;
- surface absorption -the absorption coefficients of the various surfaces;
- furnishings - their density, absorption and distribution;
- source power and position;
- receiver position.

The frequency variation of the parameters and of noise levels is conventionally described by their values in octave bands.

3. CHARACTERISTICS

The main characteristics of factory sound propagation will be illustrated using two examples. The first illustrates the influence of sound absorption and of furnishing density. The second illustrates the influence of factory geometry.

Figure 1 shows the 1000 Hz octave-band sound propagation function measured in an empty, untreated factory with average dimensions 45 m x 42.5 m x 4 m high and a double-panel roof. As is often the case, the sound propagation function at most source/receiver distances is found to be highest at mid-frequencies. It decreases at low and high frequencies due, respectively, to increased surface and air absorption. The effect of furnishings is also illustrated in Figure 1, showing the sound propagation functions in the factory after first 25 and then an additional 25 printing machines were introduced. These metal machines had average dimensions of 3 m x 3 m x 2 m high. Introduction of the furnishings has only a small effect on the sound propagation function at small source/receiver distances but significantly decreases it at larger distances. For reference, Figure 1 also shows the sound propagation function curve predicted by diffuse-field theory for the empty factory, and that for a point source in a free field. Figure 2 shows the sound propagation function predicted by a ray-tracing model for four furnished, parallelepipedic rooms with different dimension ratios, but the same total surface area,

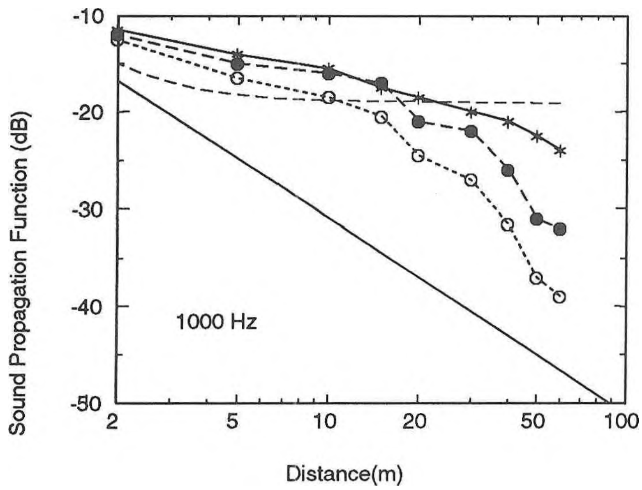

Figure 1. Measured 1000 Hz octave band sound propagation function in a factory when empty ( ), partly furnished ( ) and fully furnished ( ). Also shown for reference are the functions predicted by diffuse-field theory for the empty factory ( ) and for a point source in the free field ( ).

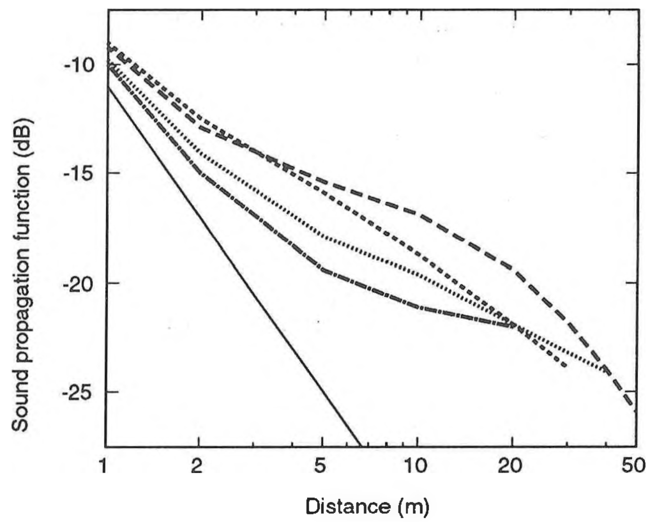

Figure 2. Sound propagation function predicted by ray tracing in four furnished factories with different length:width:height ratios: ( ) 1:1:1, ( ) 5:2.5:1, ( ) 10:10:1, ( ) 10:1:1. The curve for the cubic room is similar to that predicted by diffuse-field theory. Also shown for reference is the function for a point source in the free field ( ).

absorption and furnishing density. In all cases, the source and receiver are at half height and width; the source is at 5 m from one end wall. According to diffuse-field theory, all rooms should have the same sound propagation curve (that shown for the cubic room). Clearly this is not in fact the case; predicted levels vary significantly with dimension ratio. Figure 2 also shows the sound propagation curve for a point source in the free field.

Note also the characteristic shapes of the sound propagation curves. Only in certain cases is the slope of the curve approximately constant. More generally the slope varies with source/receiver distance. In particular, the slope tends to increase with distance at large distances from the source - especially in densely-furnished factories. The slope of the sound propagation curves also increases with room dimension ratio and furnishing density. Note also that levels even as close as 1 m to a source may be several decibels above free-field levels.

4. MODELS

We present six models, in chronological order of publication. In each case the model is briefly described. To what extent each model was validated by its author(s) is then discussed. Finally, each model is evaluated with respect to the extent to which it accounts for the factory-acoustic parameters and sound-field characteristics discussed above. These latter results are summarized in Table 1 for easy comparison of the models.

4.1 Friberg Model

Friberg[2] developed an empirical formula, from measurements in many factories, for predicting the slope, assumed constant, of the A-weighted sound propagation function curve. It applies to long, parallelepipedic factories of any height to width ratio, without internal barriers. The factory furnishings are assumed to be located on the floor and to have some average height. The surface absorption is quantified by the ceiling absorption coefficient at "around 1000 Hz", α'. The slope, in dB/dd, is given by $-(a\alpha' + b)$, in which a and b are constants whose values depend on the furnishing density, as determined by qualitative descriptors, and on the room's height to width ratio, as shown in Table 2.

Friberg presented measured and predicted slopes for six factories with and without absorptive ceiling treatments. In general, the average slopes of the sound propagation function curves, which varied from -2.5 to -8 dB/dd, were predicted within 2 dB/dd. Prediction tended to underestimate the slope.

The Friberg model can be applied to long factories of any height to width aspect ratio. Ceiling but not wall absorption is taken into account. Furnishing density is modelled, but the furnishings are assumed to be isotropically distributed over the floor area; their absorption is not specifically considered. The source power is not included; the user is left to decide how to de-normalize the sound propagation

Table 1. Summary of the extent to which existing simplified models account for the main factory-acoustic parameters and sound propagation characteristics: Y= taken into account fully; ? = taken into account partially or approximately; N = not taken into account or modelled incorrectly.

	PARAMETERS										CHARACTERISTICS	
MODEL	Geometry		Absorption		Furnishings			Source		Receiver	SPF curve	Freq
	Shape	Barriers	Magn.	Dist^n	Density	Abs^n	Dist^n	Power	Pos^n	pos^n	shape	var^n
FRIBERG	?	N	Y	N	Y	N	?	N	N*	N*	N	N
THOMPSON ET AL	?	N	Y	N	N	N	N	Y	N*	N*	N	Y
WILSON	?	N	?	N	?	N	N	N	N*	N*	N	N
EMBLETON/RUSSELL	?	N	?	Y	N	N	N	?	?*	N*	N	Y
ZETTERLING	?	N	Y	?	Y	N	N	N	N*	N*	Y	N
SERGEYEV	?	N	?	?	?	?	?	Y	N*	N*	?	Y

* includes the source/receiver distance as a prediction parameter.

Table 2. Constant required for predictions according to the Friberg[2] model. The room shape and contents are categorized as follows (h = average furnishing height, H = room height, W = room width):

Room Shape
N - rooms with W < 4 H
M - rooms with 4H < W < 6H
B - rooms with W > 6H

Room Contents
L - rooms with zero or low furnishing density, or densely furnished with h < H/8
M - rooms with medium density of high furnishings, or high density of furnishings with H/8 < h < H/4
H - rooms with high density of furnishings with h > H/4

Room category	*a*	*b*
BH	-3.0	-4.0
BM	-2.5	-3.75
BL	-2.0	-3.5
NH	-3.0	-3.0
NM	-2.75	-2.75
NL	-2.5	-2.5

function curve. Only the source/receiver distance, and not the exact source and receiver positions, is accounted for. Presumably the model applies only to fairly flat source sound-power spectra. Sound propagation function curves are assumed be of constant slope. The model predicts the slope of only the A-weighted curve.

4.2 Thompson et al. Model

On the basis of experimental observation, Thompson, Mitchell and Hurst[3] proposed a modification to the expression describing steady-state levels according to diffuse-field theory, to allow its application to irregularly proportioned factories, as follows:

$$L_p = L_w + 10 \log_{10} [1/4\pi r^2 + 4MFP/r(\alpha S+4mV)]$$

in which

r is the source/receiver distance, in m;

MFP = 4V/S, is the room mean free path, in m;

α is the average room absorption coefficient;

S is the room surface area, in m^2;

m is the air absorption exponent, in Np/m;

V is the room volume, in m^3.

Predictions were compared with experiment in octave bands for three empty rooms and good agreement was found.

The Thompson et al. model accounts for room geometry according to its volume and surface area; internal barriers are not considered. Surface absorption is assumed to be uniformly distributed. Furnishings are not taken into account. The source power is included. Source and receiver positions are described only by their relative distance. The slope of the sound propagation function curves at large distances is assumed to be always -3 dB/dd. The model allows full frequency-varying information to be obtained.

4.3 Wilson Model

Wilson[4] proposed a very simple method for predicting the slope of the A-weighted sound propagation function curve in parallelepipedic factories with width and length at least four times the height, and without internal barriers. It is based on his experimental observations of the extent to which the average slope of the sound propagation function curve increases with increased absorption and/or furnishings. The slope is assumed to be constant with the following values:

-3 dB/dd in acoustically hard, empty factories;

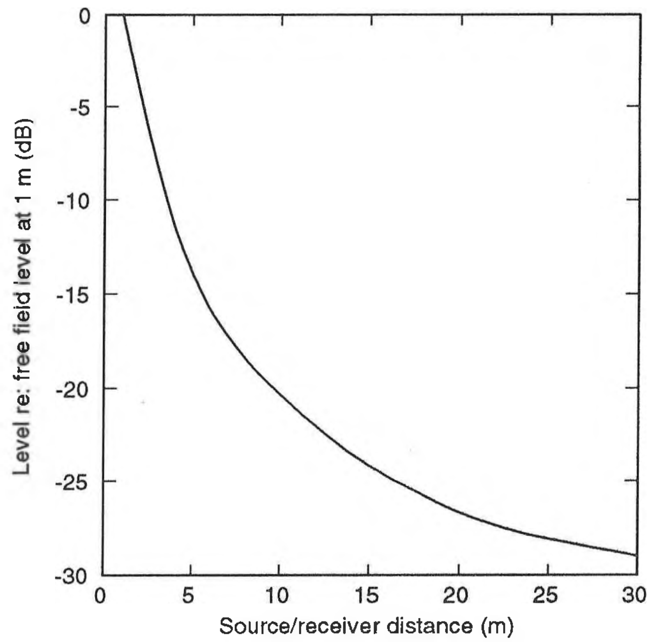

Figure 3. Noise levels relative to free-field levels at 1 m from a source in factories without ceiling and walls, according to the Embleton/Russell model[1].

-4 dB/dd in acoustically hard, furnished factories or in absorbent-lined, empty factories;

-5 dB/dd in absorbent-lined factories with furnishings.

No comparisons between prediction and experiment were presented to validate the model.

The Wilson model applies only to long and wide factories. Surface absorption and furnishings are accounted for according to whether or not they are present in significant quantity. The source power and exact source and receiver locations are not modelled. Sound propagation function curve shape is not correctly modelled (that is, the experimentally-observed characteristics are not reproduced) and no frequency-varying information is provided.

4.4 Embleton/Russell Model

The Embleton/Russell model[1] constitutes the existing Canadian standard. It predicts levels assuming the existence of free-field levels at 1 m from a source. It applies to empty rooms with rectangular plan shape and relatively-constant height, with length and width which are at least four times the height, and which contain no internal barriers. Levels as a function of source/receiver distance are first determined for the room without ceiling and walls using Figure 3.

Table 3. Corrections to noise levels for ceiling and wall reflections according to the Embleton/Russell model[4].

A. Ceiling corrections

Distance / Height	Highly absorbing ceiling (dB)	Partly absorbing ceiling (dB)	Poorly absorbing ceiling (dB)
1.0	0	0	0
1.25	0	0.25	1
1.6	0	1.0	2
2.0	0	1.5	3
2.5	0	2.0	4
3.2	0	2.5	5
4.0	0	3.0	6
5.0	0	3.5	7
6.3	0	4.0	8
8.0	0	4.5	9
10.0	0	5.0	10
12.5	0	5.5	11
16.0	0	6.0	12
20.0	0	6.5	13

B. Wall corrections

Side wall absorption	dB
Poorly absorptive	3
Partly absorptive	2
Highly absorptive	1

These levels are then corrected for ceiling and wall reflections using correction factors, presented in Table 3. The corrections depend on the source/receiver distance, the room height, the distance from the source to side walls, and whether the reflecting surfaces are "poorly", "partly" or "highly" absorptive. No attempts were made to validate the model.

This model accounts for arbitrary geometry in parallelepipedic rooms. Surface absorption is taken into account to some extent. Furnishings are not considered. The source power is included; it is assumed that free-field levels exist at 1 m from any source. Horizontal source and receiver positions are taken into account. The shape of the sound propagation function curve is apparently not correctly modelled in the case of furnished rooms. The variation of levels with frequency is predicted in a highly approximate manner.

4.5 Zetterling Model

Zetterling[5] proposed a model to predict the reduction of dB(A) noise level relative to the level at 1 m from a source in parallelepipedic factories of any shape without internal barriers. First, the "acoustic quality of the room" is quantified by a "total score" using Figures 4 a,b and c which relate this quantity to, respectively: 1) the room volume; 2) the ceiling height and average mid-frequency absorption coefficient; 3) the room width and average mid-frequency wall absorption coefficients. The reduction is then determined from the total score, the source/receiver distance and the estimated furnishing density using the appropriate version of Figure 4d, or extrapolating between them.

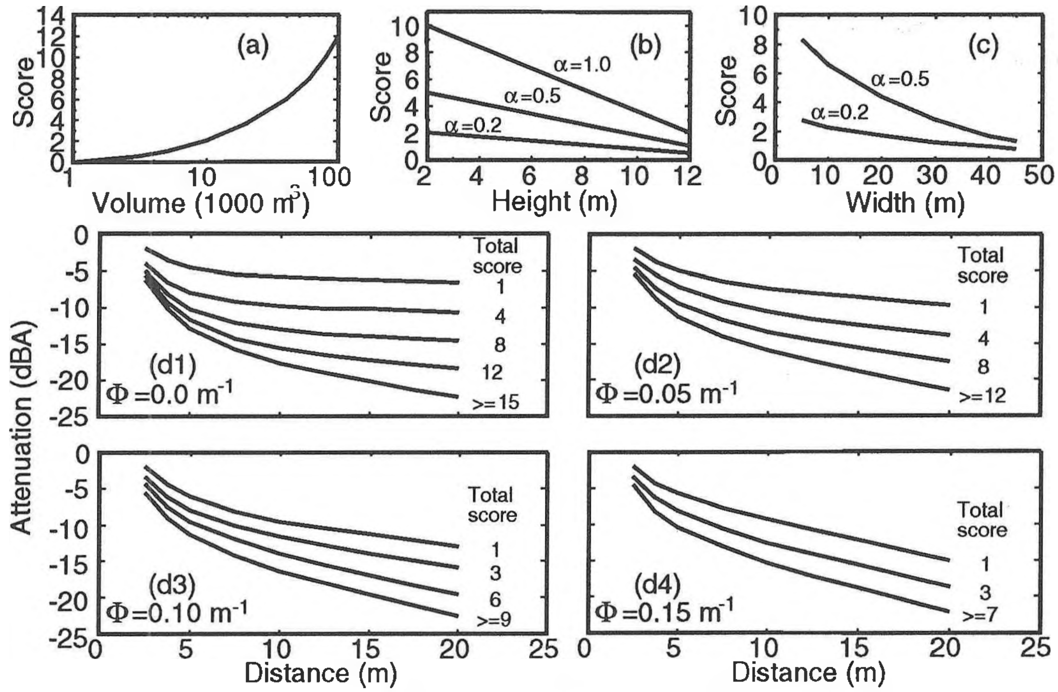

Figure 4. Curves relevant to prediction according to the Zetterling model[5] (Φ = furnishing density).

By way of validation, Zetterling presented comparisons between measured and predicted dB(A) levels at distances of 4-22 m from a source in five empty and furnished factories. Differences were typically 0-5 dB(A).

The Zetterling model is flexible with respect to building geometry. Ceiling and wall absorption are included but all walls are assumed to have the same absorption. The factory furnishings are assumed to be isotropically distributed. Source power is not modelled. Source and receiver locations are described by their relative distance; the prediction curves extend only to 20 m. In principle, the shape of the sound propagation function curve is correctly modelled, but the model provides no frequency-varying information.

4.6 Sergeyev Model

The Sergeyev model[6] predicts noise levels at positions not too close to a source. It applies to untreated, parallelepipedic factories of typical construction containing furnishings with average densities, and without internal barriers. Noise levels are determined using the following formula, found by fitting a regression line to experimental results:

$$L_p = L_w + 10 \log_{10} \{ 1/2\pi r^2 + (1-\alpha) (r+W) J(\alpha,\rho) / [H W (r+H)] \}$$

with $J(\alpha,\rho) = 0.1 / [\alpha + \rho^2 \exp (0.65 \rho)]$

and $\alpha = 1 - (1-\alpha) \exp (-m \bullet MFP)$

in which

ρ = $-r \ln (1-\alpha) / MFP$ is a dimensionless distance;

r is the source/receiver distance, in m;

α is the average absorption coefficient of the room surfaces calculated as if the room were empty, using Table 4. The "empty factory" values are used for the walls and ceiling; the values for the appropriate industry are used for the floor;

W is the room width, in m;

H is the room height, in m;

MFP=4V/S is the mean free path, in m;

V is the room volume, in m^3;

S is the total room surface area, in m^2;

m is the air absorption exponent, in Np/m.

Absorption coefficients were determined for typical empty factories and for furnished factories in various industries (textile, metal working, printing, as shown in Table 4); thus, they in principle account for differences in furnishing density and absorption for equipment in different

Table 4. Effective octave-band absorption coefficients for typical empty factories and furnished factories in various industries for use in the Sergeyev model[6].

	Octave band (Hz)				
Case	250	500	1000	2000	4000
Empty factories	0.09	0.09	0.09	0.08	0.09
Textile industry	0.25	0.29	0.40	0.40	0.43
Printing industry	0.31	0.27	0.26	0.31	0.31
Metalworking industry	0.32	0.30	0.34	0.34	0.38

industries. Comparisons between prediction and experiment were presented for validation; agreement within 2-3 dB was generally found.

The model deals with regularly-shaped rooms. Surface absorption and furnishings are taken into account on the assumption that the factory is of typical construction and typically furnished. Source power is included, as is the source/receiver distance. The shape of the sound propagation curve is, in principle, accurately modelled. Levels can be predicted as a function of frequency.

5. CRITIQUE

Let us discuss the merits and short-comings of the models one parameter at a time with an aim to comparing and evaluating the models and to envisaging how a better model could be developed.

Geometry

All of the models assume the factory to be of parallelepipedic shape and to be without internal partitions. These are reasonable assumptions for a simplified model to make, given the difficulties associated with taking arbitrary geometry and barrier diffraction effects into account. The Friberg, Wilson and Zetterling models are limited to long factories. The Wilson model applies to long and wide factories, while the other two models allow variable height to width ratios. The Thompson et al. model inaccurately accounts for shape according to the volume and surface area. The Sergeyev model does so via the floor area, thereby assuming typical height. Only the Embleton/ Russell model accounts for arbitrary shape by considering reflections from individual surfaces.

Surface absorption

The Wilson model accounts for the magnitude of the surface absorption simply by its absence or presence; that is, according to whether or not the building is acoustically treated. The Embleton/Russell model uses the qualitative descriptors "poorly, partly and fully" absorbing. The other models more accurately employ the absorption coefficient.

Only the Zetterling and Embleton/Russell models take the distribution of absorption into account. However, the Zetterling model assumes uniform wall absorption. Only the Embleton/Russell model allows the absorption of individual surfaces to be considered.

Furnishings

The Thompson et al. and Embleton/Russell models ignore furnishings completely.

The Wilson and Sergeyev models assume the factory to contain average densities of furnishings, and thus cannot deal with non-typical situations. Friberg uses qualitative descriptors and the average furnishing height to determine their density. Zetterling quantifies furnishings by the more rigorous average furnishing scattering-cross-section volume density. Unfortunately, it is not yet known how to determine this quantity accurately; it can only be estimated by approximate means and from experience.

As far as the furnishing absorption is concerned, only the Sergeyev model takes this into account. The parameter is included implicitly in the effective absorption coefficients used in the model. Only the Friberg model accounts in any way for non-isotropic furnishing distributions, and this only in the vertical plane; the furnishing height is a parameter of the model.

Source and receiver

Surprisingly, since this parameter is necessary to determine noise levels from the sound propagation function, the source power is not a parameter of all models. The Friberg and Wilson models do not include this parameter. The Zetterling model predicts levels relative to that at 1 m from a source, leaving the user to estimate this level from the sound power, for example. The Embleton/Russell model incorrectly assumes free-field levels at 1 m from a source.

Only the Thompson et al. and Sergeyev models include the source sound power level explicitly.

The Embleton/Russell model accounts for the source position in the horizontal plane in that it corrects levels according to the distance of the source to each wall. Neither the vertical position, nor the exact position of the receiver is considered. However, all models calculate noise levels using the source/receiver distance.

Sound propagation function curve shape

The Friberg and Wilson models incorrectly assume that all sound propagation function curves have constant slope. The Thompson et al model incorrectly assumes the slope to be -6 dB/dd near a source and -3 dB/dd far from a source. Since the Embleton/Russell model does not include furnishings, it would not be expected to predict the correct curve shape. Both the Zetterling and Sergeyev models apparently predict the correct curve shapes since they are based on measured curves.

Variation with frequency

The Friberg, Wilson and Zetterling models only predict noise levels in dB(A). The Thompson et al., Embleton/Russell and Sergeyev models allow octave-band predictions to be made.

6. CONCLUSION

Clearly, all of the existing models have merits and shortcomings. All are easy to use. All are limited to rooms of parallelepipedic shape without barriers. None accounts for arbitrary furnishing absorptions and distributions, nor for exact source and receiver positions. However, given the objectives of simplified models, these do not represent serious limitations. More seriously, the Thompson et al. and Embleton/Russell models ignore furnishings. The Friberg and Wilson models do not include the source power. The Friberg, Thompson et al., Wilson and Embleton/Russell models do not correctly model the shape of the sound propagation function curve. The Friberg, Wilson and Zetterling models do not allow octave-band predictions. The Embleton/Russell model stands out in its flexibility with respect to geometry, absorption distribution, source position and frequency variation. The Zetterling model has the advantage of modelling furnishings in a comprehensive way. The Sergeyev model is interesting in that it models absorption, furnishings and frequency variations, but depends heavily on the statistical accuracy of the data on which it is based. In summary, it is not obvious which models would perform best if evaluated in comparison with reliable experiments. There is a definite need for a careful evaluation of the models.

There is also an apparent need for a model that better takes into account the relevant parameters and better predicts the main sound-field characteristics. Either a new approach could be taken, or a model could be developed from the strong points of the various existing models. Including furnishings and octave-band surface-absorption variation into an Embleton/Russell approach is one possibility. Incorporating frequency variability into a Zetterling approach is another. Improving the data base behind a Sergeyev approach would be a third. These options require careful evaluation, but the development of an accurate, comprehensive simplified model appears entirely feasible Finally, the resulting model should be carefully validated before being put into use, particularly as a Canadian standard.

REFERENCES

1. Canadian Standard Z107.52-M1983, "Recommended practice for the prediction of sound pressure levels in large rooms containing sound sources".

2. R. Friberg, "Noise reduction in industrial halls obtained by acoustical treatment of ceilings and walls", Noise Control Vibration Reduction **6**, 75-79 (1975).

3. J. K. Thompson, L. D. Mitchell and C. J. Hurst, "A modified room acoustics approach to determine sound pressure levels in irregularly-proportioned factory spaces", Proc. Inter-Noise '76, 465-468 (1976).

4. P. M. Wilson, "A pragmatic look at sound propagation in real factory spaces", Proc. IOA Conference on Noise Control in Factory Buildings, 24-27 (1982).

5. T. Zetterling, "Simplified calculation model for noise propagation in large factories", Proc. Inter-Noise '86, 767-770 (1986).

6. M. V. Sergeyev, "Propagation of airborne noise in workshops of manufacturing companies", Reduction of Noise in Buildings and Residential Districts, Ch. 5. (Moscow Building Publications, Moscow, 1987). In Russian.