Minimal input models for sound level and reverberation time prediction in enclosed spaces

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Highly advanced computer models for the prediction of sound in rooms are now available. However, these tools are complex and require a skilled acoustician to use them effectively and hence there is a need for simpler models. A simple model needs to be accurate and quick to use, but most importantly should require a minimum amount of input data to construct the model. The resulting models are freely available to use and can be found at http://www.sbu.ac.uk/acogrp/steve.html.

1. INTRODUCTION

The advent of modern desktop computers has allowed complex mathematical models to be implemented for the prediction of sound in rooms [1,2]. However, these models only become useful tools when used by highly skilled and experienced acousticians with accurate descriptive information, time to collate the necessary information and time to let the program execute. Recently, research has been undertaken to simplify prediction models for room acoustic problems [3,4,5].

Here we will investigate prediction models available freely on the web using only a browser e.g Microsoft Internet Explorer. The criteria of a simple prediction model can only be met if the scope of the problem is reduced to that of typical situations and what is considered important in terms of modelling [6]. Typically rooms are rectangular, have uniform walls and all objects in the room are located on the floor, see Figure 1. Hence, the application is to the typical rather than the atypical room, and only reverberation time and sound levels should be predicted, reverberation time and sound levels being the best understood acoustic characteristics of rooms.

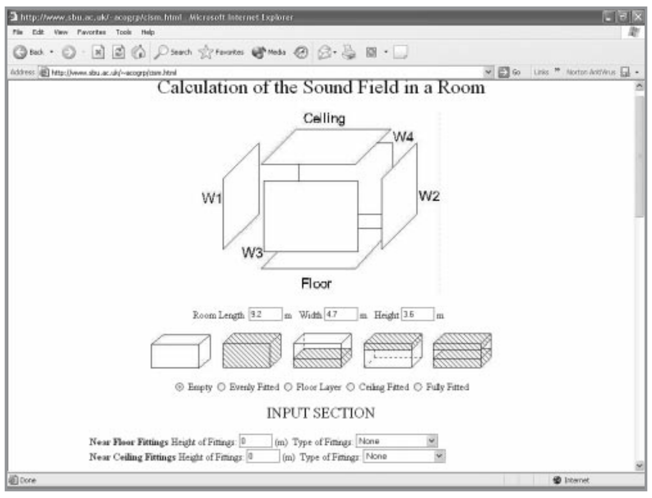

Figure 1. The geometry section of the room for the web model

2. THE WEB MODEL

The web model is based on the same theory as the commercial software packages [7] but all the extras provided have been stripped, what remains is an accurate prediction for six octave band sound levels using minimal input data for typical rooms, yet able to run in a few seconds [3,4,5]. It is also important that the overall sound level in the A weighting be predicted, see Figure 3. Previously simple models were based on Excel spreadsheets; using the browser it was possible to rewrite these empirical models as well, called Heerema & Hodgson [5], and Hodgson [8], also available on the web site http://www.sbu.ac.uk/acogrp/hodgson.html.

The web model was designed to allow input in three sections. Section 1: room geometry includes the names for each surfaces, the room dimensions, and the position of any objects in the room, see Figure 1. The information in figures 1-3 represent configuration 5 in Figure 6.

Section 2: The input which includes the objects in the room height, whether they are near the floor or ceiling, none in the case of Figure 2. The type of construction for each room surface, and finally an option area for noise control information. If no noise control information is required then it can be left empty, otherwise it can be used to describe up to six tiles or barriers. In Figure 2 half the floor area is described as absorptive as well as a foam padded door. Below is the single sound source, which is assumed to be omni-directional, with a position and the octave band sound power levels. Finally,

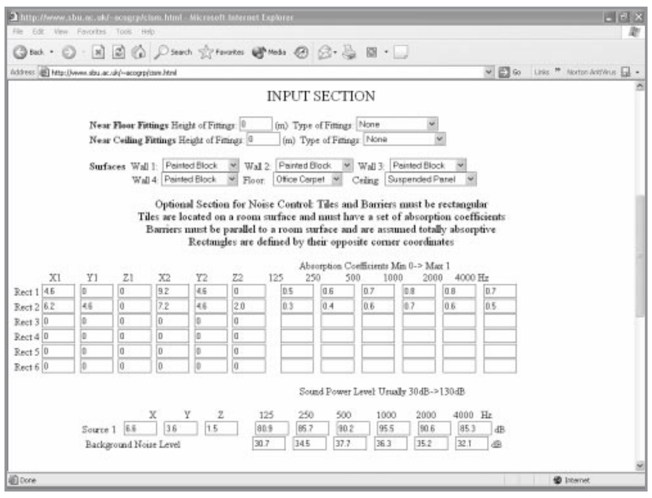

Figure 2. The input section of the web model

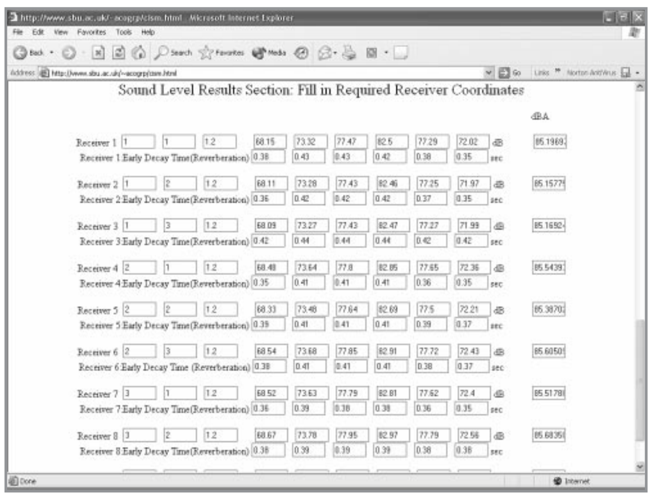

Figure 3. The receiver and results section of the web model.

the background noise levels can be entered, although this is optionally.

Section 3: The receiver and results section allows up to nine positions to be predicted. When the run button is clicked the web model fills the results area with the predicted octave band sound levels, overall dBA prediction, and the reverberance of the room at each location. It will also display the length of time the model took to run, usually around 3 seconds. In the case of Figure 3, the overall sound level is around 85 dBA and the reverberance of the classroom is approximately 0.4 seconds.

3. VALIDATION AND COMPARISON OF THE WEB MODEL

The web model has been validated in laboratory rooms, industrial rooms and classrooms. Its predictions have been compared to other simplified models [5,8], available on the web site and a classical acoustic formulae. Below, only a sample of the predictions are presented, for more information see [9,10,11].

The three models will be validated firstly, in a laboratory representative of six textile workrooms, where all the unknown parameters are minimised; secondly, in a real mechanical engineering workshop; thirdly, in a bottling plant; and fourthly in a simulated classroom in nine configurations.

SIMULATED TEXTILE WORKROOM

The laboratory was 30 m long, 8 m wide and 3.85 m high and of a light-weight construction. The characteristics of the laboratory room were similar to those found in the textile industry. The fittings, each 0.25m^3, were absorptive and thus representative of equipment and stock in the textile industry. Case 1-3 used a reflective ceiling with 40, 120 and 240 polystyrene fittings. Cases 4-6 used the absorptive ceiling with 40, 120 and 240 fittings. The prediction accuracy for the 2 kHz octave band is summarised in table 1.

The web model was accurate in all three reflective ceiling configurations, cases 1-3, with three densities of fittings, giving an average error of 0.9 dB. The web model was marginally less accurate when predicting the treated room, cases 4-6, the average error ranging from 1.1 dB to 2.0 dB, an average error of 1.5 dB. However, for engineering accuracy it is necessary to predict within 2 dB of the measured sound level. The other simple models were less accurate, Hodgson 2.3 dB for cases 1-3 and 2.0 dB for cases 4-6, Heerema 1.2 dB for cases 1-3 and 2.1 dB for cases 4-6.

MECHANICAL ENGINEERING WORKROOM

The mechanical engineering workroom was 23.6 m long by 22.8 m wide by 9.5 m high with a flat roof, giving a volume of 5112m^3 and a surface area of 1958m^2. The walls are mainly brick with asbestos panels and some windows. The floor was concrete and the ceiling was formed from asbestos with glass panels. The noise sources were lathes located on one side of the room and the equipment was that typical for a mechanical workshop, with an average height of 1.8m. The machines in the room were typically giving fitted density, q=0.013m^{-1}. Fifty-seven measurement positions were recorded evenly across the shop floor, whilst thirteen machines were running. This requires the web model to be run 13 times for each sound source and 7 times to predict every measurement position, i.e. the web model is no longer a quick, simple model as 91 runs were required.

It was found that all three models could predict the sound level in the workroom accurately, for the 500 Hz octave band, see Figure 4. The CISM model produced the most accurate predictions resulting in an average error of 0.9 dB, Hodgson gave a 1.0 dB average error and the Heerema model produced a 1.2 dB average error. It can be seen from Figure 8 that the measured sound levels ranged from 82 dB to 91 dB, levels at which noise induced hearing loss would occur with prolonged exposure.

Table 1. Average simple model prediction errors in the simulated textile workroom

Case	1	2	3	4	5	6
Web Model	1.1	0.8	0.9	1.1	2.0	1.5
Hodgson	3.3	2.1	1.2	2.2	1.3	2.3
Heerema	0.4	1.5	1.5	1.7	2.3	3.4

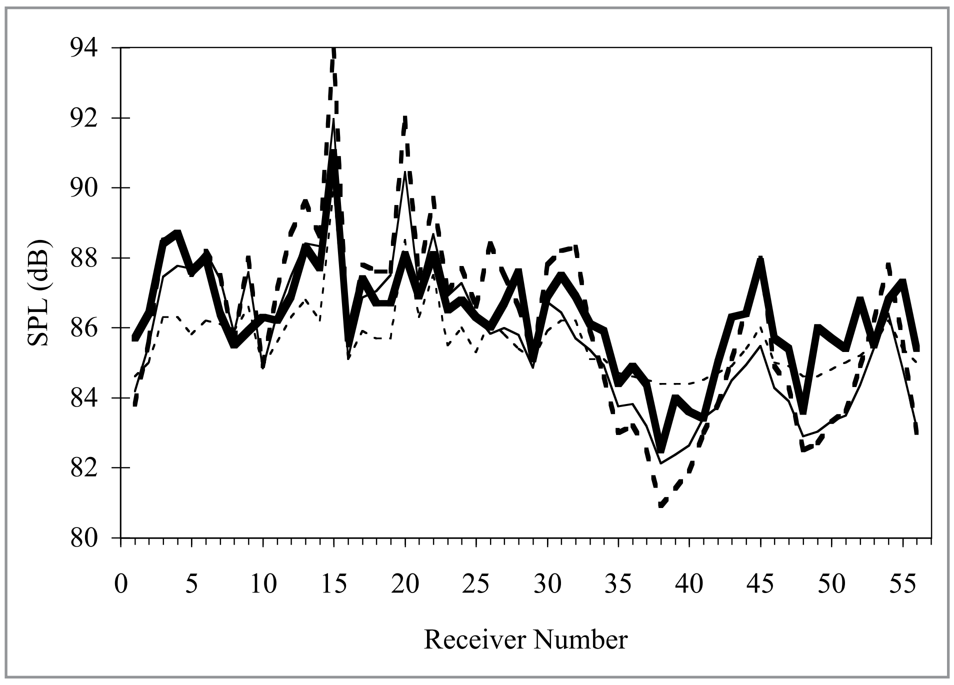

*Figure 4. Sound levels predicted (-----) CISM, (- - -) Heerema, (—) Hodgson and (**—**) measured.*

THE BOTTLING PLANT

This industrial hall was large with dimensions 71.7 m by 53 m with a multi-pitched roof of height 7.3 m to 10.0 m, equally a volume of 32870 m^3 and a total surface area of 9570 m^2. The construction was modern with a portal frame with painted brick walls, a concrete floor and a ceiling of plastic on fibreboard backed to aluminium. The machines were all metal and evenly distributed around the shop floor with

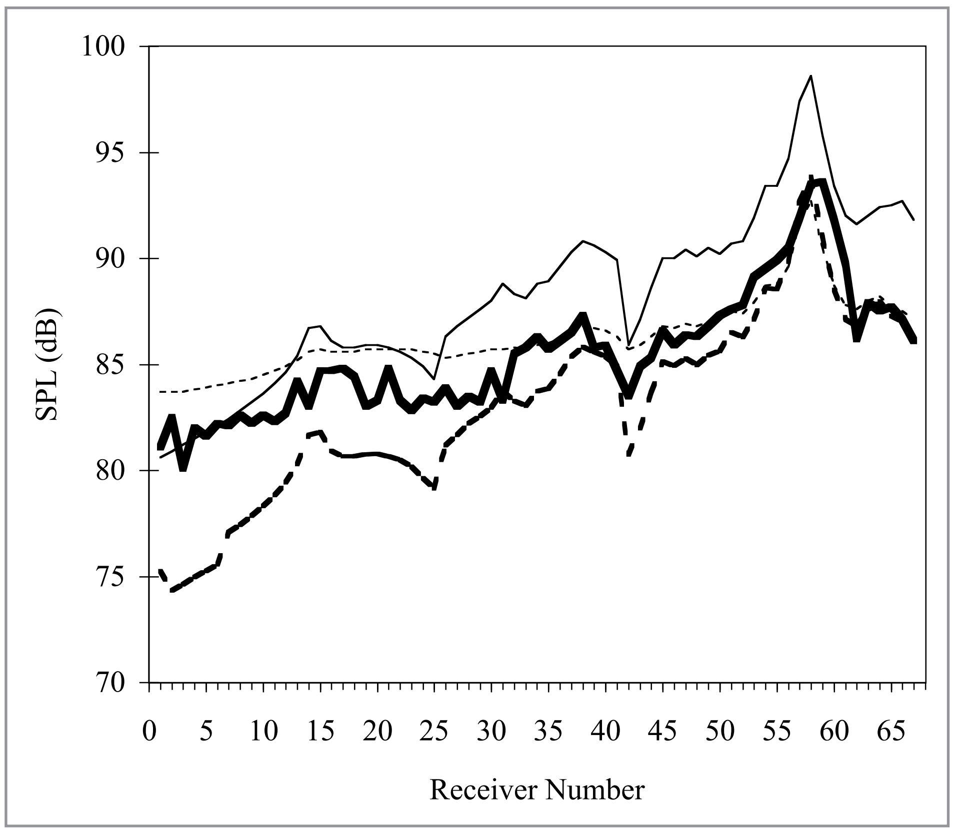

Figure 5. *Sound levels predicted (-----) CISM, (---) Heerema, (—) Hodgson and (**—**) measured.*

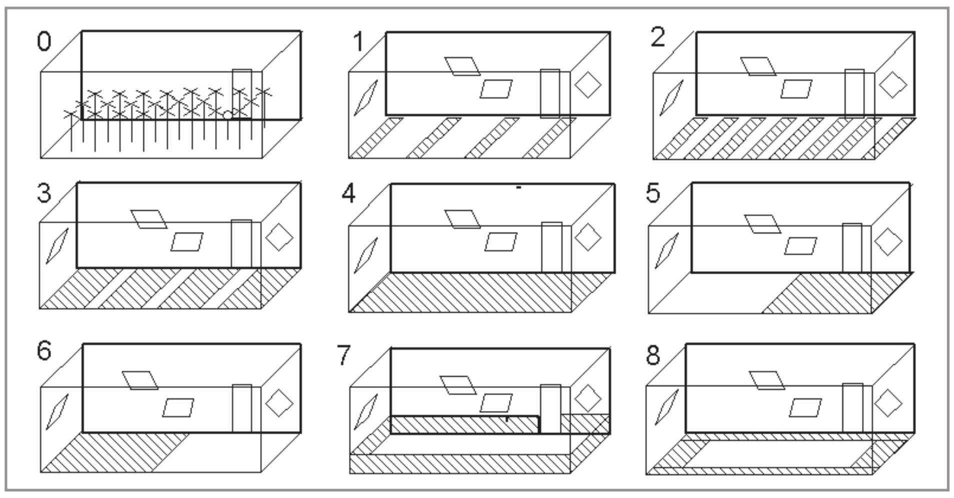

Figure 6. *The simulated classroom with varying amount of absorption, shaded area.*

an average height of 3.0 m, giving a high fitting density q=0.082 m^{-1}. Twenty-one machines acted as the sound sources and sixty-seven receiver positions in the three gangways were measured. The web model needed 21 x 8 runs to predict all the measurements.

It was found that all three models predicted the sound level to within 3.0 dB of that measured at 500 Hz octave band. However, the Hodgson model was the least consistent producing a standard deviation of σ=4.34 dB and an average error of 3.0 dB. The Heerema model predicted marginally more accurately than the Hodgson model, giving a 2.9 dB average error, although, the variation was greatly reduced, σ=1.66 dB. The web model was the most accurate model giving an average error of 2.0 dB (σ=1.76).

SIMULATED CLASSROOMS

A simulated empty classroom, 9.2m long, 4.7m wide and 3.6m high, was modelled with various acoustic treatments, see Figure 6. The treatment was acoustic ceiling tiles (semi rigid glass fibre) and the room surfaces were acoustically hard. The reverberation time was measured and predicted in various locations and averaged to give a single RT characterising the room. A single omni-directional sound source was used to generate the noise and only the 1 kHz results are presented. As the other simple models could not predict RT, the classical acoustics formula developed by Eyring was applied, as typically used by consultants.

The web model was capable of more accurately predicting the reverberation in the classroom than the Eyring formula, 18.1% versus 26.7% average RT error, see Figure 7. This is still marginally outside engineering accuracy criteria, a 14.0% limit on prediction error. However, some of the room configurations were not realistic and hence for typical classrooms the web model could be considered reasonably accurate.

4. CONCLUSIONS

The web model allows any person with acoustic knowledge to simulate the acoustics of a room simply, quickly, and freely. The predictions produced are more accurate and more representative than those possible using classical acoustic theory or other simple models. The web model predicted to engineering accuracy criteria in classrooms and industrial halls, the model could predict the effect of common noise control techniques and could simultaneously predict both sound level and reverberation time in a few seconds.

The representational ability of the web model could be enhanced by including a selection of three-dimensional directional sound sources, such as male and female human voice at various loudnesses. The model can be extended to predict speech intelligibility. Further enhancements will be undertaken if the simplicity of the model can be maintained.

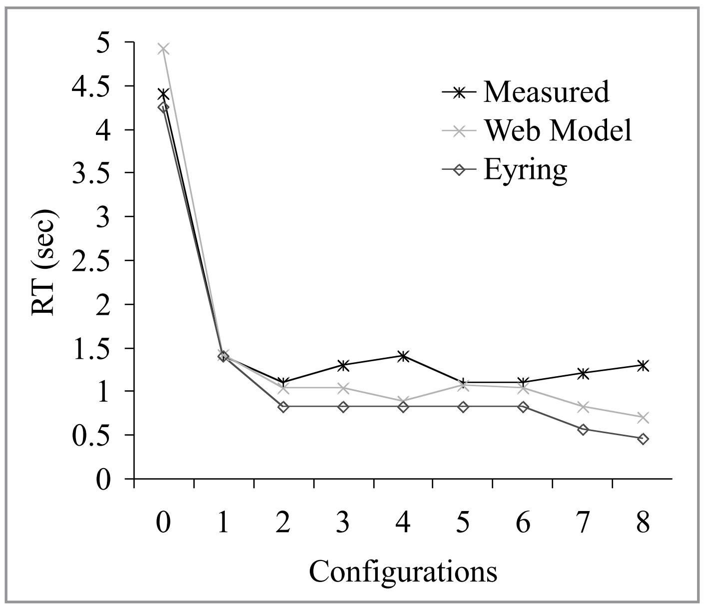

Figure 7. Measured and predicted reverberation times in the 9 simulated classrooms, 1kHz

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