MODELLING ROOMS WITH ABSORBENT SURFACES

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SUMMARY

This paper investigates the accuracy of commercial and in-house computer models when predicting rooms which include a significant amount of absorbent material. Three aspects are investigated in this preliminary work, diffusion models, absorption coefficients and modelling approaches. A room in which the absorptive material was rearranged into eight configurations was used for the preliminary investigation with measurements taken in six central octave bands. It was found that the inclusion of diffusion consistently improved prediction accuracy, Millington absorption coefficients marginally improved prediction accuracy in one of the models and all the classical formulae produced similar but less accurate predictions than the computer models.

1. INTRODUCTION

Recent research in room acoustics has concentrated on diffusion [1,2]. The importance of this parameter to more fully describe room surfaces cannot be underestimated. Currently, the diffusion coefficient is estimated from the size of the surface and it smoothness, with values ranging from 0 (specular reflection only) to 1 (completely diffusing). Recently, the scattering and diffusion coefficients have been standardised [3,4].

It has been suggested that in noise control applications where highly absorbent materials are used, a Millington absorption coefficient might more accurately represent the surface than a Sabine based coefficient [5-8]. However, this work focused on the 1 kHz octave band rather than across the frequency range. The research presented here aims to preliminarily establish whether Millington absorption coefficients provide a more accurate prediction in rooms with highly absorptive room surfaces than Sabine coefficients for a range of frequencies. The investigation is based on the measurements of Bistafa and Bradley [9], plus further analysis of their data. The research also undertakes to investigate a) how diffusion might improve reverberation time prediction accuracy and b) what type of modelling approach should be used.

Two computer models, one commercial and one in-house, were used to predict the reverberation time in 8 configurations of a room. In addition the classical formulae were used as a baseline in terms of prediction accuracy for reverberation time.

2. THE PREDICTION MODELS

The accuracy of two models was investigated: FAME, the in-house ray-tracing model and CATT 7.2, a commercial software package.

2.1 The FAME Model

FAME [10] is the South Bank University in-house model which is based on the ray-tracing technique. The rays are traced until 99% of their energy is absorbed, as given by the energy discontinuity equation, defined by Dance and Shield [11]. The number of rays traced is determined by ten times the volume of the room.

FAME defines the rooms using plane equations with each plane assigned an absorption and diffusion coefficient. Diffusion is modelled either by a random redirection of the ray on reflection from a diffusing surface, or by a Lambert diffusion coefficient. If a random number is greater than the diffusion coefficient then specular reflection is assumed, otherwise the ray is randomly reflected from the diffusing surface after appropriate attenuation. Lambert diffusion is similar but rather than random diffusion the reflection must follow a cosine distribution, which in practice means oblique reflections are rare. When running the model, each octave band should be calculated separately. All results are presented for RT20.

2.2 The CATT-Acoustic Model

CATT [12] is a commercial software package which models sound in a room using a combination of modelling techniques, called Randomised Tail Corrected Cone Tracing [13]. The early reflections are modelled using the image-source model and the higher order reflections, greater than two, are traced using a cone tracing method.

CATT defines the room using vertices and planes with each plane given an appropriate surface type. Each surface type has a set of absorption coefficients and Lambert diffusion coefficients for the six central octave bands. The model simultaneously predicts each octave band.

When running the model, the surfaces which are diffusing should be identified, the number of rays to be traced determined or set to automatic, and the length of time in milliseconds that each ray should be traced set either manually or automatically. If the automatic system fails, advice given by CATT should be followed until the model is satisfied with the result. All results are presented for RT15.

3. ROOM CONFIGURATIONS

Eight of the ten original configurations of Bistafa and Bradley, representing a simulated classroom, were used in this investigation [9]. One configuration, equivalent to 50% absorption on the floor, produced unstable results in CATT and was hence excluded from this investigation, as was the configuration without absorption. The eight configurations are shown in Figure 1 together with the empty room illustrating the measurement positions. The room was parallelepiped, 9.20 m long, 4.67 m wide and 3.56 m high. The absorptive material was a ceiling tile of semi rigid glass fibre, 1.21m long by 0.6m wide. The room surfaces were acoustically hard, and the door was covered in foam.

Table 1 shows the Sabine and corresponding Millington absorption coefficients for the four types of material used in the construction of the simulated classroom.

TABLE 1. Sabine and Millington absorption coefficients for the simulated classroom

	125 Hz		250 Hz		500 Hz		1k Hz		2 kHz		4 kHz	
	Sabin	Mill	Sabin	Mill	Sabin	Mill	Sabin	Mill	Sabin	Mill	Sabin	Mill
Hard Surface	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03
Absorb Tile	0.08	0.08	0.44	0.37	0.94	0.62	1.15	0.70	1.01	0.65	0.75	0.54
Diffuser	0.04	0.04	0.02	0.02	0.03	0.03	0.03	0.03	0.05	0.05	0.06	0.06
Door	0.29	0.27	0.83	0.57	1.08	0.68	0.87	0.60	0.81	0.57	0.71	0.52

Table 2 outlines the amount of absorption in each of the eight configurations and the averaged measured reverberation times. It should be noted that absorption of 100% means that the area equivalent to the floor area was covered with the absorptive material. In addition to the original data, the perimeter of the absorption material has been calculated and is also shown in Table 2.

TABLE 2 Measured Reverberation Times and Absorbent Material,125 Hz- 4kHz Octave Bands

Case	1	2	3	4	5	6	7	8
Absorbent Material	25% Floor	50% Floor	75% Floor	100% Floor	50% Half Receiver	50% Half Source	50% PartialWall	50% PartialFloor
Absorbent	42.1m	84.3m	51.8m	27.7m	18.5m	18.5m	55.5m	50.6m

Perim								
125 Hz	5.5	4.6	3.9	3.3	4.1	4.3	3.9	4.0
250 Hz	2.7	2.0	1.6	1.4	2.2	2.0	1.9	2.0
500 Hz	1.6	1.1	1.2	1.3	1.4	1.5	1.2	1.2
1 kHz	1.4	1.1	1.2	1.3	1.3	1.4	1.1	1.1
2 kHz	1.4	1.1	1.1	1.2	1.2	1.3	1.2	1.1
4 kHz	1.35	1.0	1.0	1.0	1.0	1.2	1.1	1.1

By considering Cases 1 to 4 in Table 2 it can be seen that the effects of increasing absorption on the reverberation time cease at 50% floor absorption at frequencies of 500 Hz and above; the reverberation time increases with additional absorption. At 500 Hz the wavelength is similar to that of the width of the absorbent tile, 0.6m, and the spacing between tiles, hence the diffractional effects are maximised

With further analysis of the 500 Hz octave band measurements for the 50% absorption cases (Case 2 and Cases 5-8) it can be seen that the longer the absorptive perimeter the lower the reverberation time. Hence diffractional effects should be considered. Similar trends were found for the 1 kHz, 2 kHz and 4 kHz octave bands.

4. PREDICTIONS USING CLASSICAL ACOUSTICS

The reverberation time for each room configuration was calculated across the octave bands, 125 Hz to 4 kHz using the classical formulae of Sabine, Eyring and Millington [14-16] and compared to that measured. For conciseness the percentage errors have been averaged over all 8 configurations and are presented in Table 3.

TABLE 3 Average Reverberation Times Percentage Error for Classical Acoustics Formulae

Octave Band	Sabine	Eyring	Millington
125	8	8	5
250	15	18	18
500	31	36	32
1000	30	34	38
2000	28	34	31
4000	18	22	19
Average Error	22	25	24

It can be seen that all the classical formulae gave similar results across the frequency range based on the average reverberation time errors for the eight configurations of the room. The most accurate predictions were at 125 Hz, where the wavelength is long and the absorption coefficient of the absorbent material is small, 0.08. The predictions are worst at the mid frequencies when the absorption coefficient of the absorptive material is high, greater than 0.9, see Table 1. Hence, at all but the lowest frequencies, the sound field in the room was non-diffuse. These predictions also provide a comparative benchmark for the computer simulations.

To complete the analysis: for the lower frequencies, 125 Hz and 250 Hz, the absorption material was significantly less absorptive, see Table 1, and the wavelength of interest was larger than the absorptive tiles; hence the sound field in the room behaved as a diffuse field (i.e. the more absorption the lower the reverberation times). This can be seen from Table 3 which demonstrates significant prediction accuracy for the 125 Hz and 250 Hz octave bands (5-8% prediction error at 125 Hz and 15-18% at 250 Hz for all three classical formulae).

5. PREDICTIONS USING COMPUTER MODELS

5.1 CATT Predictions

The simulations described below compare predictions using Sabine and Millington absorption coefficients in the CATT model. In addition, two different methods of defining the number of rays to trace and the truncation time were used: the automatic setting 'Auto' and the Dance and Shield [11] approach 'Manual'. The manual setting uses number of rays based on room size, and truncation time based on 99% energy discontinuity.

TABLE 4. Average Reverberation Time Percentage Errors for CATT using Sabine/Millington Absorption Coefficients and Auto/Manual Settings

Octave Band	Sabine Auto	Millington Auto	Sabine Manual	Millington Manual
125	10	14	53	22
250	6	10	14	8
500	12	30	14	24
1000	13	21	15	27
2000	11	20	13	24
4000	7	13	7	14
Average Error	10	18	19	20

It should be noted that the diffraction coefficient was included in all the CATT models. The diffraction coefficient was set to 0.1 at all frequencies for all surfaces, except for the diffuser which was given a coefficient of 0.7 at 125 Hz to 1 kHz, and 0.4 for 2 kHz and 4 kHz octave bands.

It can be seen from Table 4 that CATT produced more accurate predictions than the classical formulae. The CATT predictions using Sabine absorption coefficients with automatic settings were the most accurate with a 6-13% average error for the octave bands, significantly more consistent then any of the other approaches. Hence, the manual approach was not appropriate in this case for the CATT model. Also, it was found that Millington absorption coefficients produced less accurate predictions than Sabine absorption coefficients.

5.2 FAME Predictions

The FAME model predicted the reverberation times using the Lambert diffusion model, random diffusion, and a 'No diffusion' model. The settings for ray number and truncation time were as above, and no automatic settings were available.

TABLE 5. Average Reverberation Time Percentage Errors for FAME using Sabine/Millington Absorption and Lambert/Random/No Diffusion

Octave Band	Sabine Lambert	Millington Lambert	Sabine Random	Millington Random	Sabine No Diffusion	Millington No Diffusion
125	35	35	6	6	28	36
250	23	18	10	3	33	51
500	19	13	21	15	28	74
1000	15	13	20	20	46	74
2000	21	14	14	17	23	50
4000	17	9	8	12	16	30
Average Error	22	17	13	12	29	52

For the FAME model it is clearly shown in Table 5 that modelling diffusion significantly improves the accuracy of the predictions. The average errors across all octaves and room configurations with Sabine absorption coefficients are 22% / 13% / 29% using Lambert / Random / No diffusion methods; and for Millington absorption coefficients 17% / 12% / 52%, respectively. Secondly, it can be seen that randomly redirected rays produce more accurate predictions than using a cosine distribution for diffuse reflections based on single rays, 12-13% compared to 17-22%, respectively. Thirdly, using Millington absorption coefficients produced marginally more accurate predictions than Sabine coefficients, 1% or 5% more accurate for random and Lambert diffusion, respectively.

6. CONCLUSIONS

From these preliminary simulations it can be seen that all the classical formulae predicted to a similar level of accuracy in all the room configurations and frequencies, with approximately 23% error. For the computer models CATT was the more accurate, with a 10% average error in the best case, and FAME was more accurate in all cases when diffusion was modelled, a 12% average error in the best case across the frequency range.

More detailed predictions were undertaken and it was found that Sabine absorption coefficients produced more accurate predictions for the CATT model, whereas Millington absorption coefficients were more accurate for the FAME model.

In future work, the rooms will be repredicted using the FAME model, but with more diffusion models [1] based on splitting the ray into several separate parts. In addition, more commercial models will be tested to determine if Sabine or Millington absorption coefficients produce more accurate predictions in rooms with highly absorbent room surfaces.

6. REFERENCES

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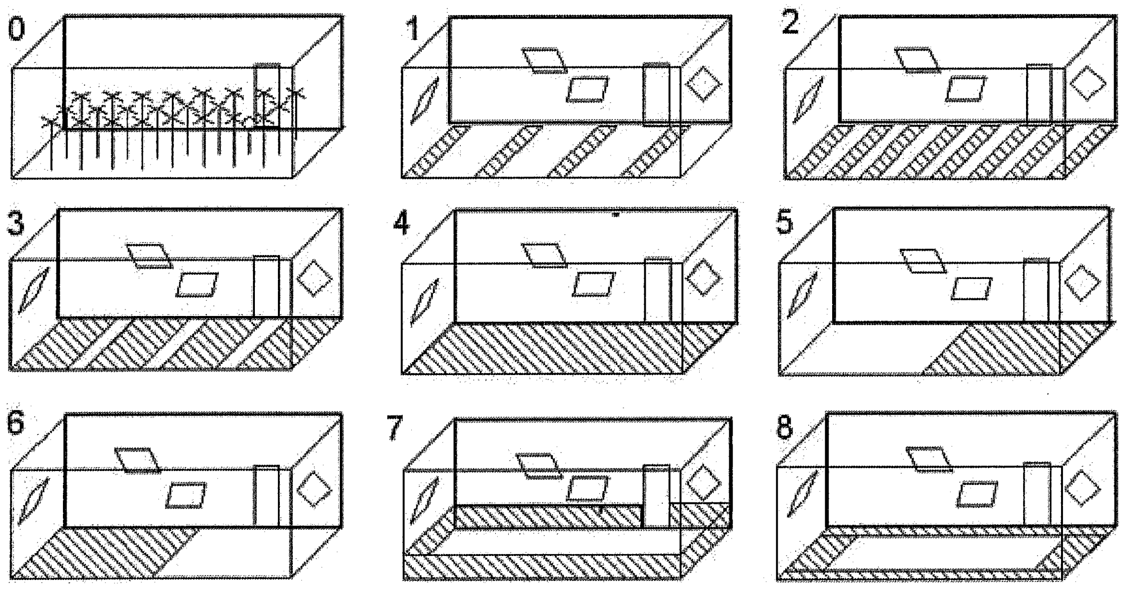
Figure 1. Shows the source and receiver positions and the 8 configurations of the room, each with 4 diffusing elements on the walls.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