Acoustic Design and Testing of Schools

Room acoustics – why and how?

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apex acoustics

Why add sound absorption to rooms?

- Increase intelligibility of teacher's voice for students?
- Improve SNR for students?
- Reduce sound from student activity?
- Reduce sound from external sources & HVAC?
- Reduce sound level of teacher's voice?
- Change student behaviour?
- Reduce build-up of sound in group activity?

What's the best room acoustic measure?

- Speech Transmission Index, STI?
- Occupied sound level, $L_{Aeq,T}$?
- Reverberation Time, T_{mf}?
- Early Decay Time, EDT?
- Signal to Noise Ratio, SNR?
- Clarity, C_{50}?
- Unfavourable ratio, U_{50}?
- Strength, G?

Speech intelligibility

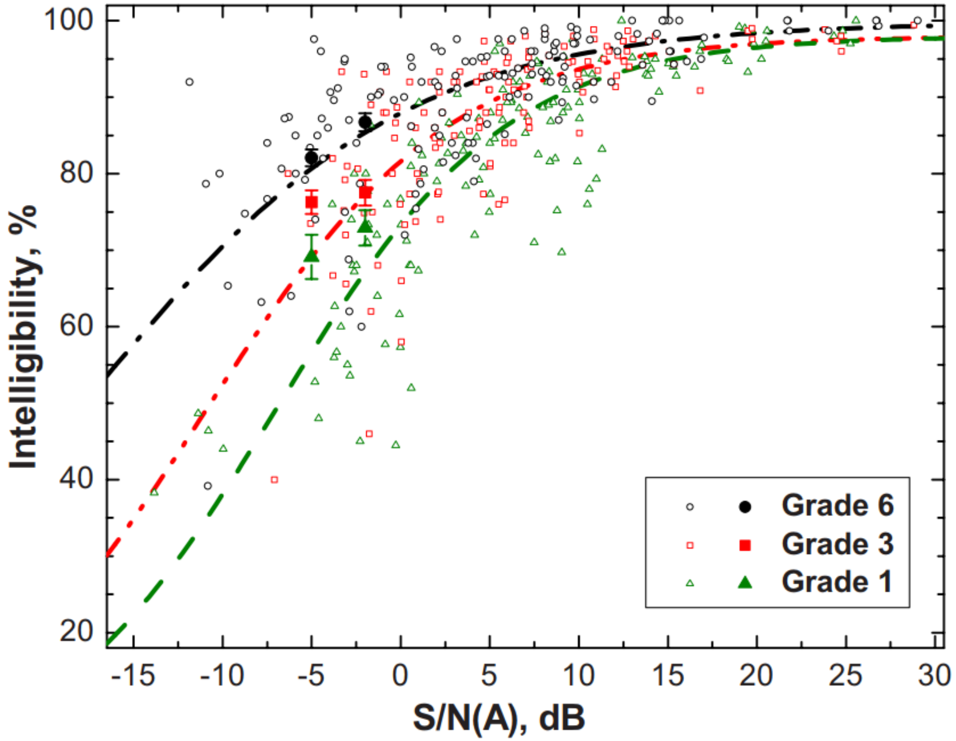
- STI
- SNR
  - $SNR = L_{p,voice} - L_{p,noise}$
- Clarity, C_{50}
  - $C_{50} = L_{p,early} - L_{p,late}$
- Unfavourable ratio, U_{50}
  - $U_{50} = L_{p,early} - L_{p(Late+Noise)}$

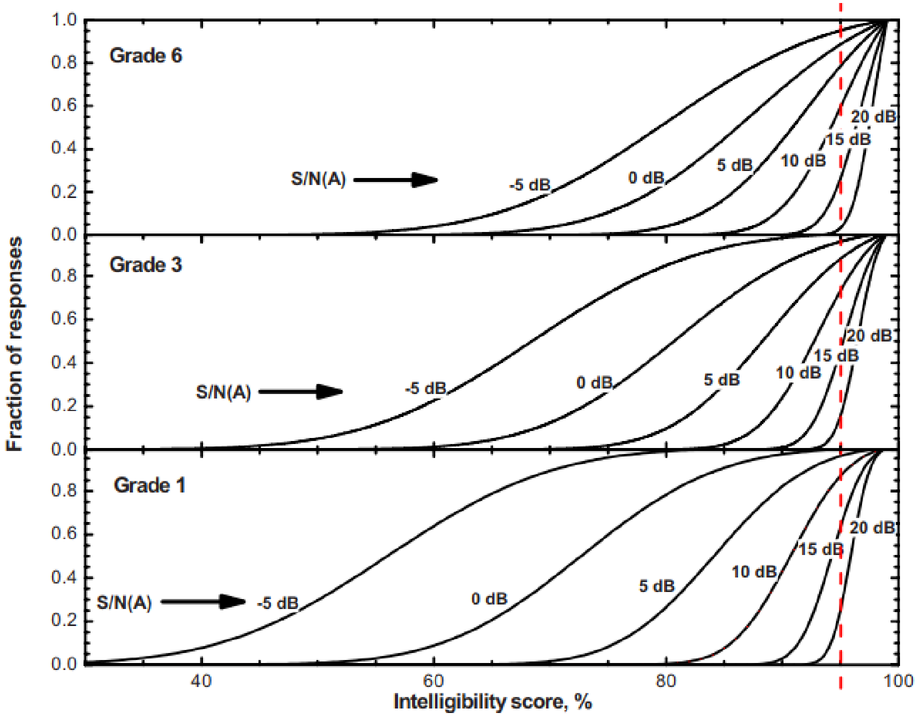
- BB 93 compared with other countries
- Why do primary & secondary classroom criteria differ?

Country	Longest Tmf, s	Notes
Australia / New Zealand	0.5 – 0.6, limits at 125Hz –2 kHz	In furnished unoccupied rooms
USA	<0.6	In furnished unoccupied rooms
Finland	0.6 – 0.8	Depends on class type
Sweden	0.5 – 0.8	Depends on class type
Germany	0.4-0.6.	Depends on volume of room
Denmark	<0.4- 0.6	125–4 kHz, tolerances in each O.B.
Norway	0.4 – 0.6	Depends on class type
Netherlands	<0.4 optimum <0.6 normal <0.8 minimum standard	Depends on class type
France	0.4 - 0.8	For classrooms < 250 m^3
Belgium	<0.8	For 150 m^3 classroom
Spain	<0.5	For classrooms < 350 m^3
Italy	Tott = 0.67	“Reference Optimum time” in furnished and 80% occupied state
Switzerland	0.42<T<0.63	250 Hz – 2kHz

Reverberation times for mainstream classrooms in different countries

Intelligibility of speech in classrooms, Sato & Bradley, 2008

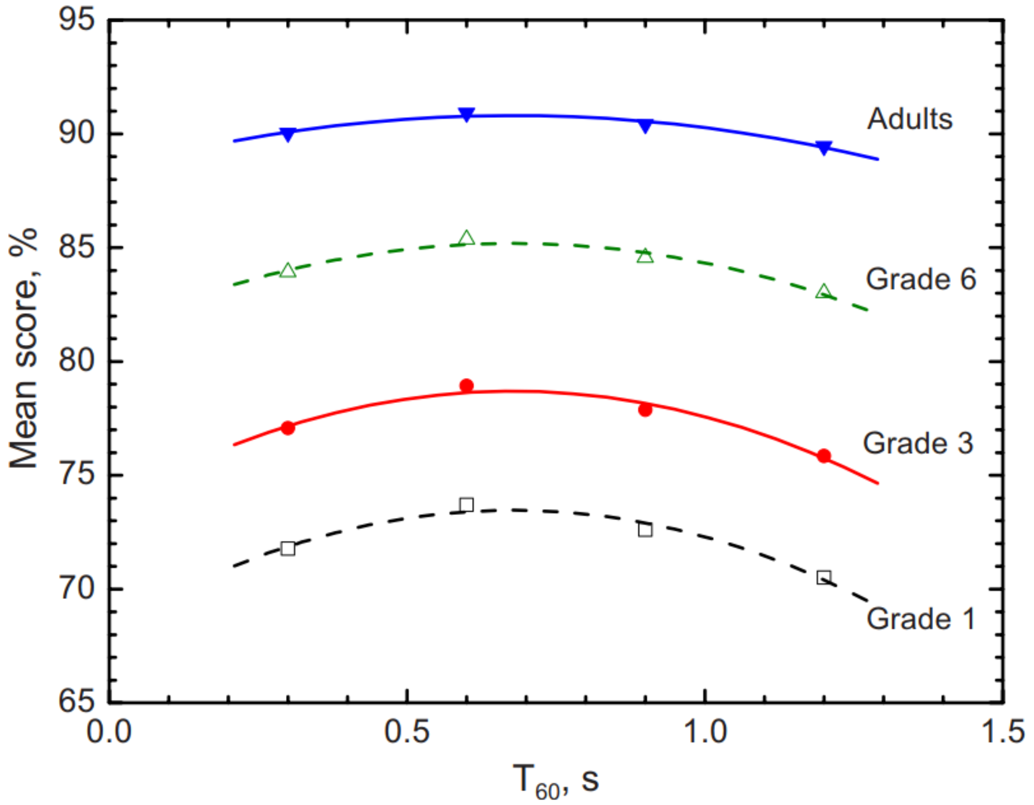




The intelligibility of speech in elementary school classrooms. J S Bradley, H Sato, JASA 2008

Intelligibility of speech in classrooms, Yang & Bradley 2009

- For constant SNR, intelligibility decreases with RT
- For realistic increases in SNR with RT, intelligibility scores near maximum for a range of reverberation times
- Effect of varied RT on the intelligibility of speech for young children was much less than the effect of varied SNR



Effects of room acoustics on the intelligibility of speech in classrooms for young children. W Yang, J S Bradley, JASA 2009

ANC ACOUSTICS & NOISE CONSULTANTS

Noise levels in secondary schools, B Shield, 2015

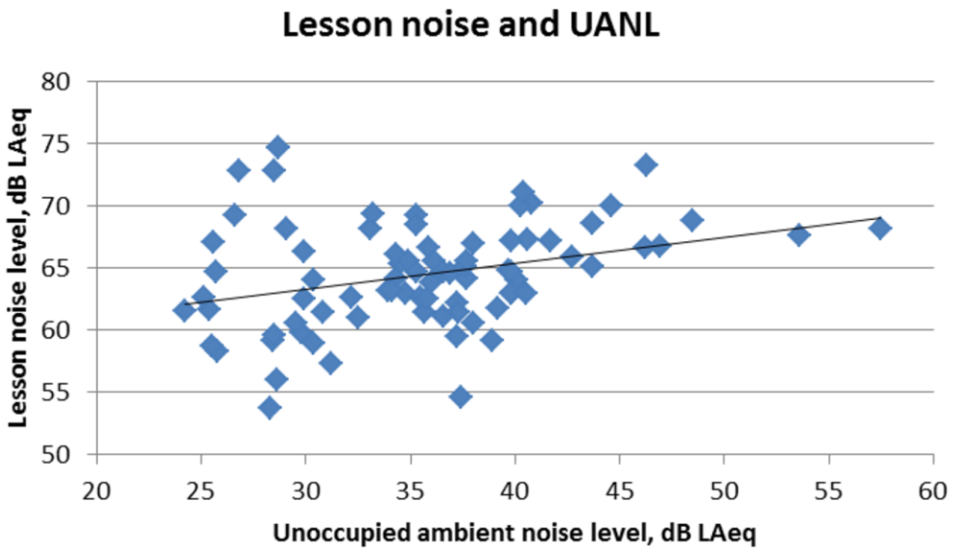


FIG. 4. (Color online) Scatter diagram showing the relationship between lesson noise and unoccupied ambient noise level.

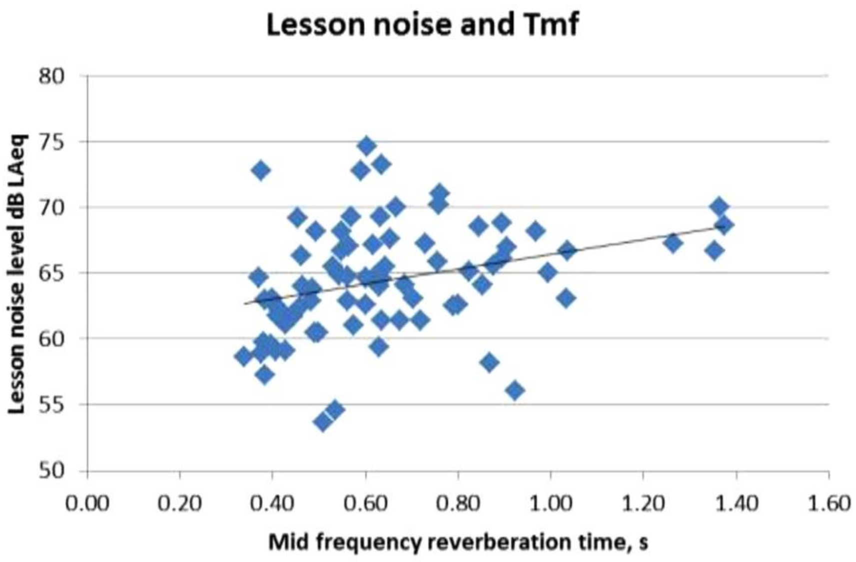
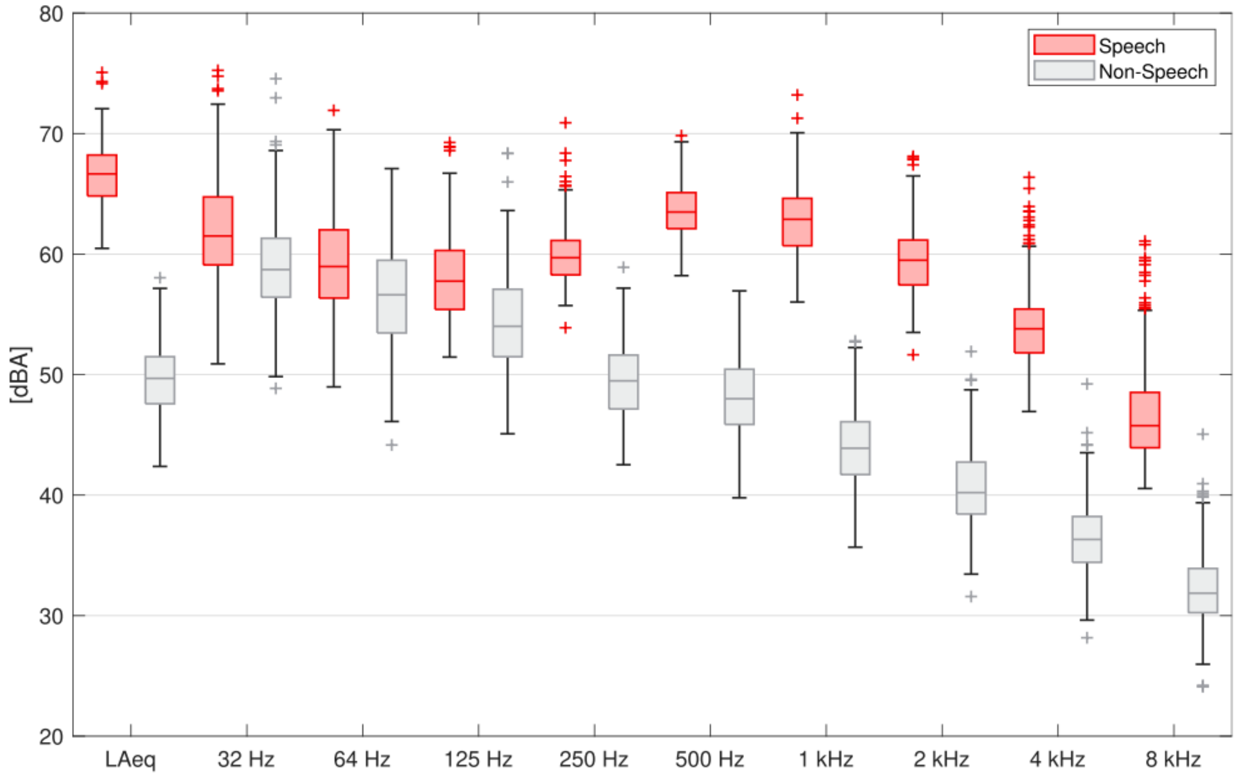


FIG. 3. (Color online) Scatter diagram showing the relationship between lesson noise and T_{mf}.

A survey of acoustic conditions and noise levels in secondary school classrooms in England
Bridget Shield; Robert Conetta; Julie Dockrell; Daniel Connolly; Trevor Cox; Charles Mydlarz
J Acoust Soc Am 137, 177–188 (2015)

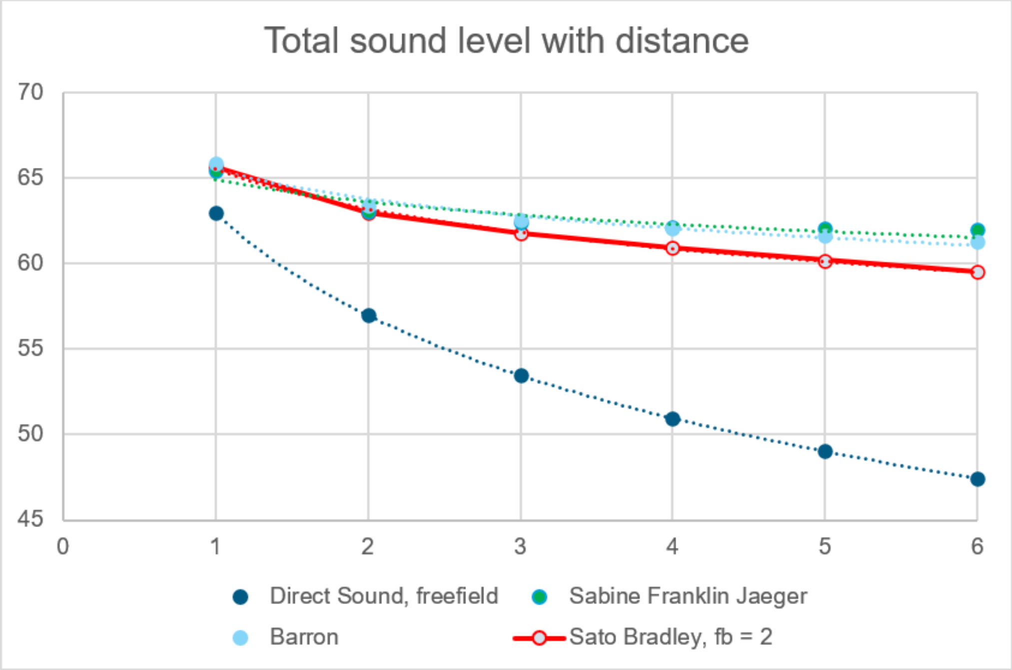
Classroom sound levels



Higher Sound Levels in K-12 Classrooms Correlate to Lower Math Achievement Scores. Laura C. Brill & Lily M. Wang. Frontiers in Built Environment, 2021

Theoretical model for spatial decay

- Spatial decay of sound
- $Diffuse\ sound\ level = \frac{4(1-\alpha)^{fb.d/mfp}}{A}$



Theory and measurement of early, late and total sound levels in rooms. Mike Barron. JASA 2015

The intelligibility of speech in elementary school classrooms. J. S. Bradley, H. Sato. JASA 2008;

Design using U_{50} - Nijs & Rychtáriková, 2011

$$L_p(r) = L_W + 10\log\left(\frac{Q}{4\pi r^2} + \frac{4(1-\alpha)}{\alpha S}\right)$$

$$L_{p,brn} = L_W + 10\log\left(\frac{Q}{4\pi r^2} + \frac{4(1-\alpha)^{fb\cdot r/mfp}}{\alpha S}\right)$$

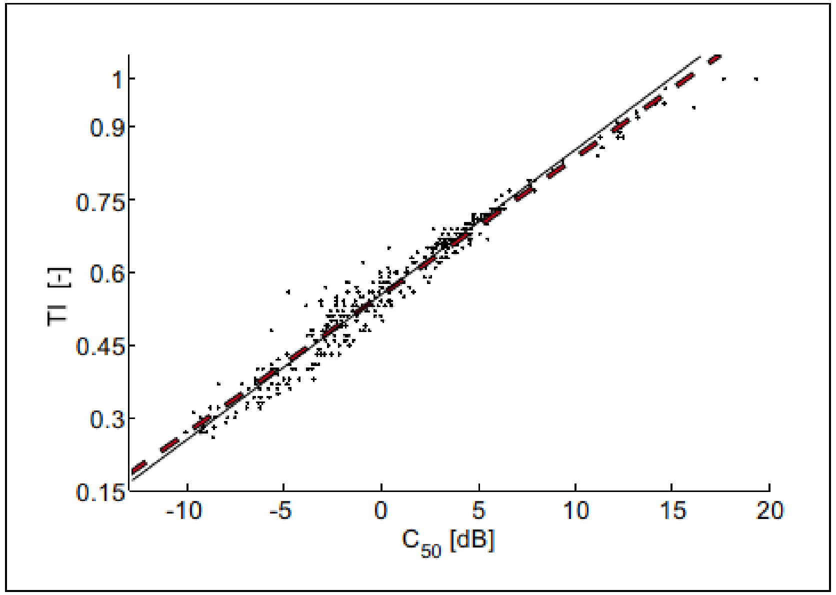
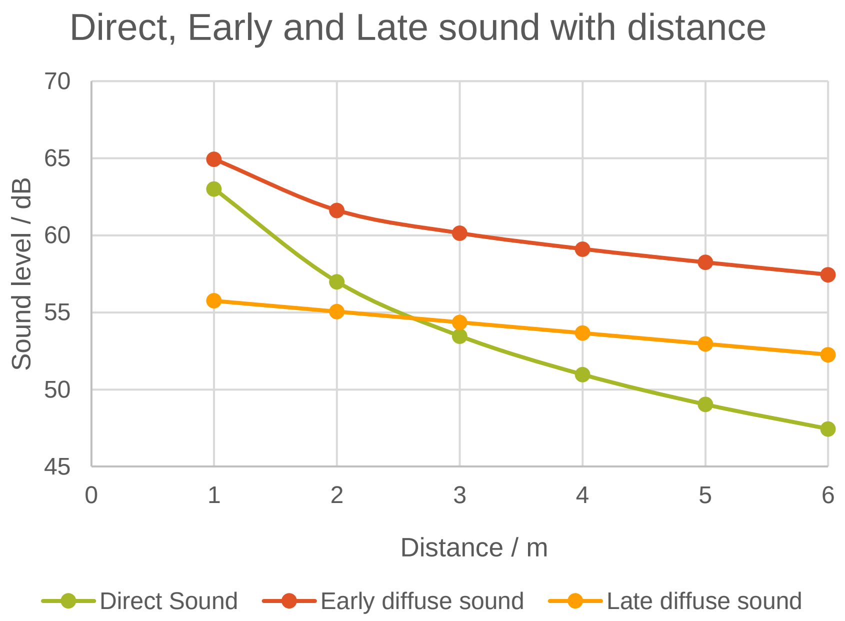
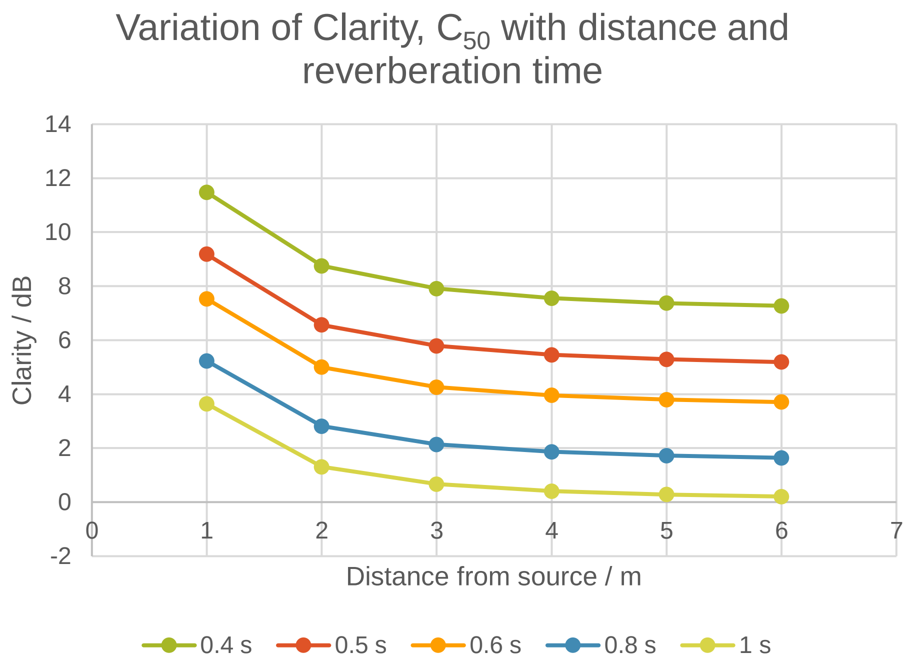


Figure 1. Correlations between TI and C_{50} values for the 2000 Hz octave band from about 300 source-receiver configurations (points). The dotted line gives best fit. The solid line was calculated with equation (15a).

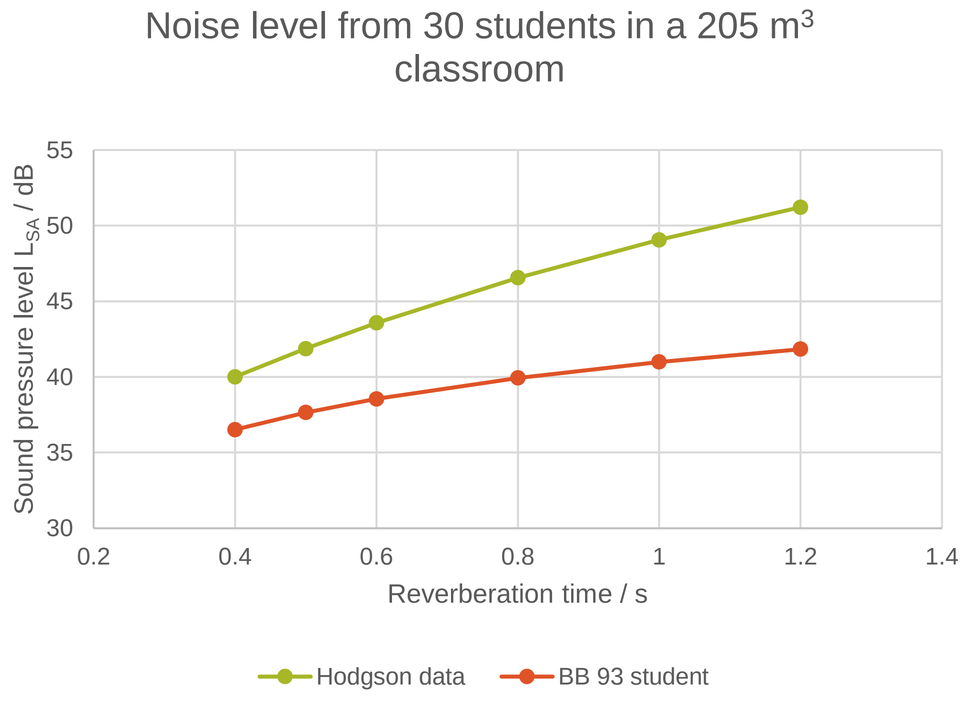
[Calculating the Optimum Reverberation Time and Absorption Coefficient for Good Speech Intelligibility in Classroom Design Using U50]
Nijs, Lau; Rychtáriková, Monika, Acta Acustica united with Acustica, 2011

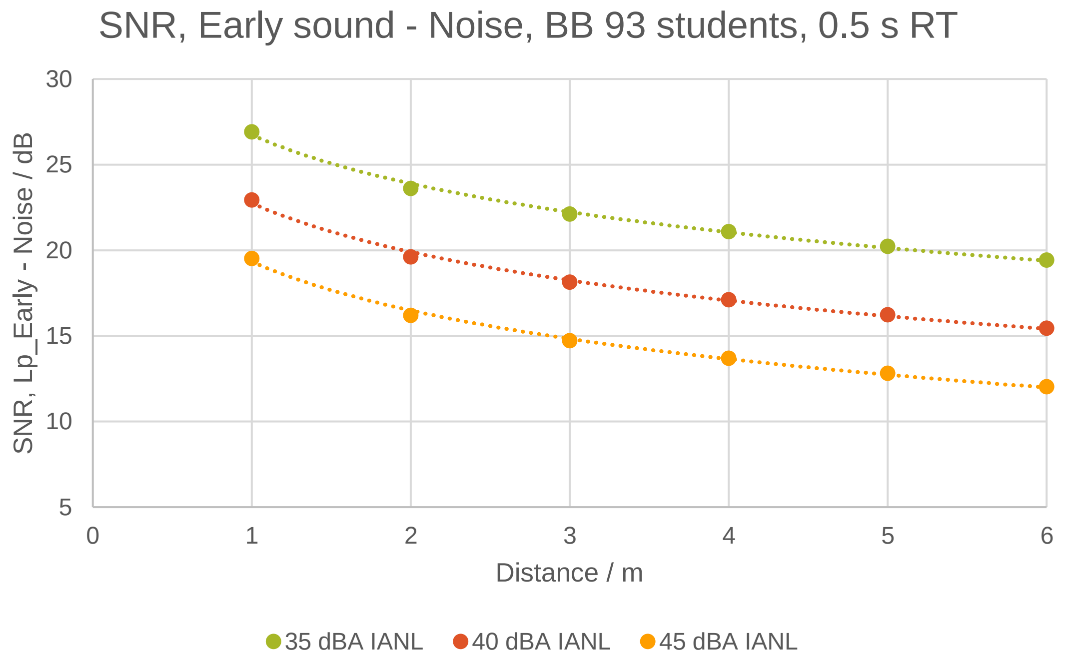
Theoretical model talking & listening



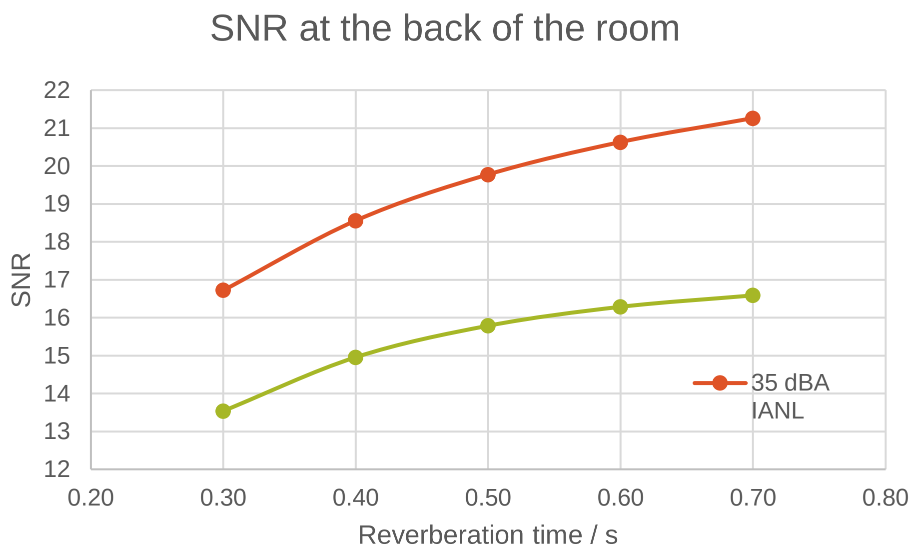


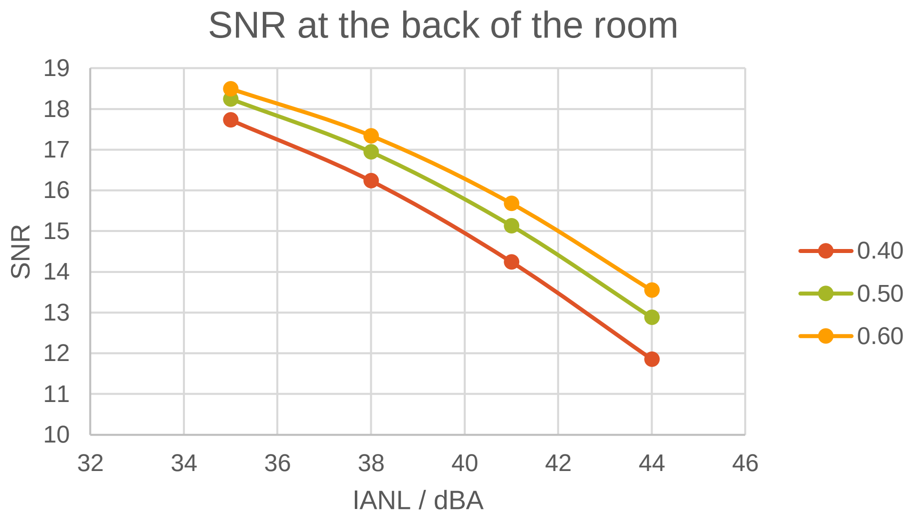
Theoretical model talking & listening





Theoretical model talking & listening





Theoretical model suggests 15 dB SNR achieved in standard classroom with:
IANL ≤ 40 dBA
RT 0.4 - 0.65 secs (occupied)

Speaker-orientated acoustics design. Pelegrin Garcia, 2014

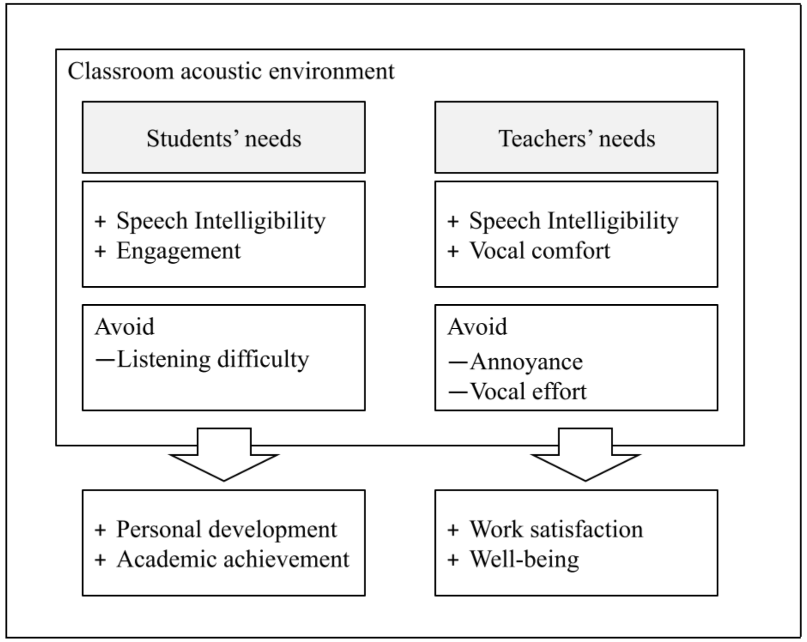


Figure 1. Needs of students and teachers in classrooms related to the acoustic properties of the environment.

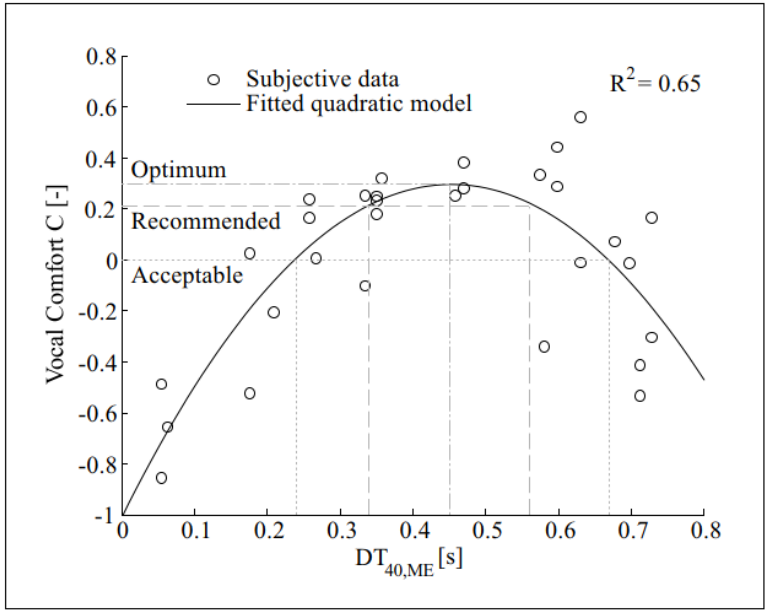
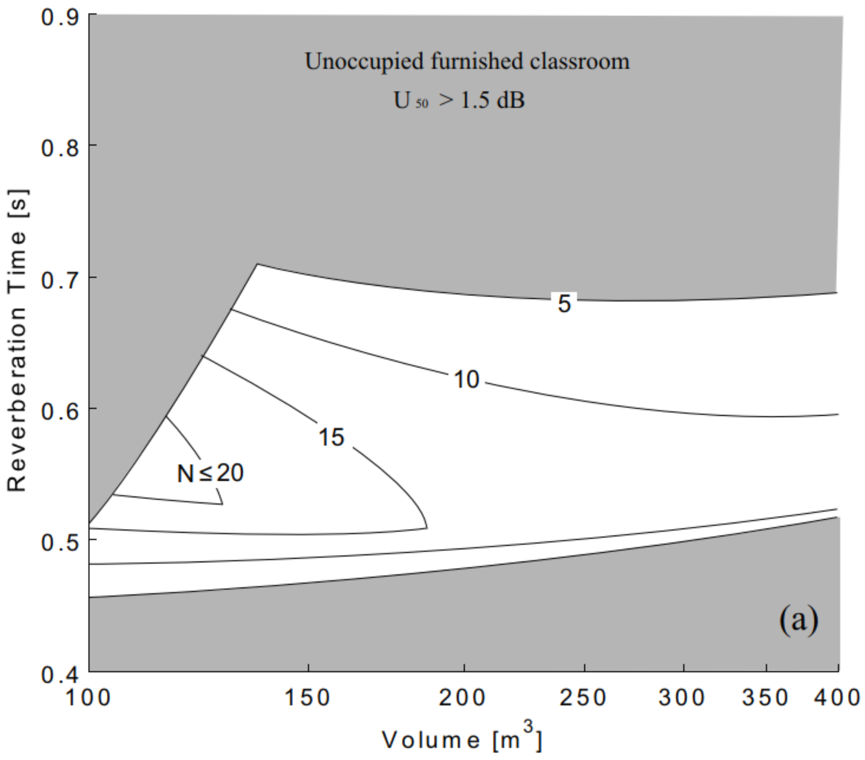
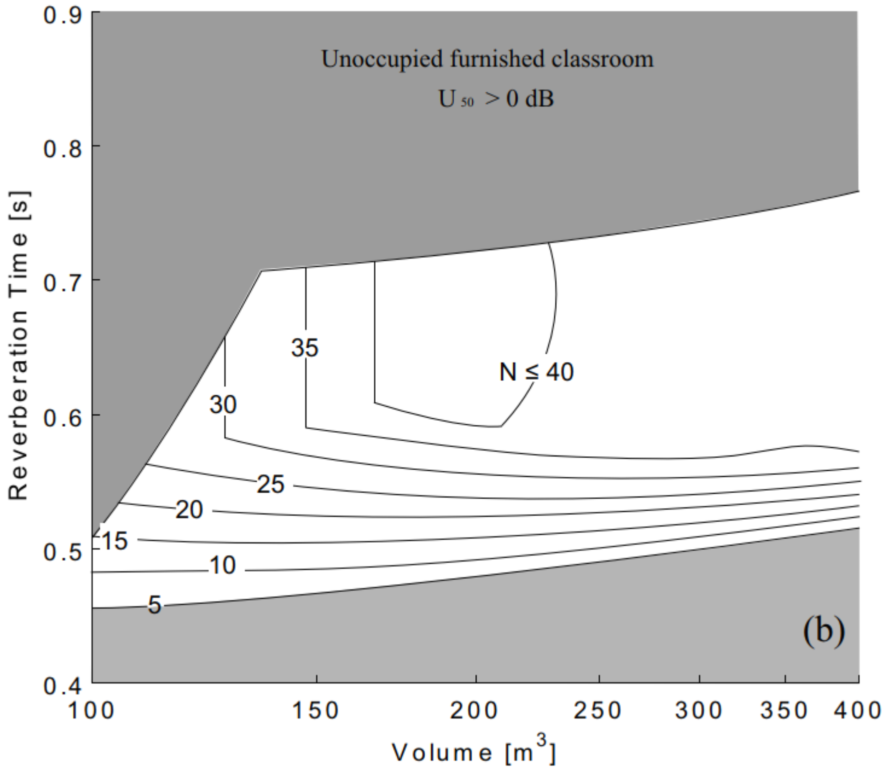


Figure 5. Vocal comfort $\hat{C}$ as a function of $DT_{40,ME}$ in the classrooms where subjects were asked to talk during an experiment. A quadratic regression model is shown, defining an optimum point and ranges of recommended and acceptable $DT_{40,ME}$ values.

Speaker-Oriented Classroom Acoustics Design Guidelines in the Context of Current Regulations in European Countries
David Pelegrín-García, Jonas Brunskog, Birgit Rasmussen. Acta Acustica united with Acustica, 2014

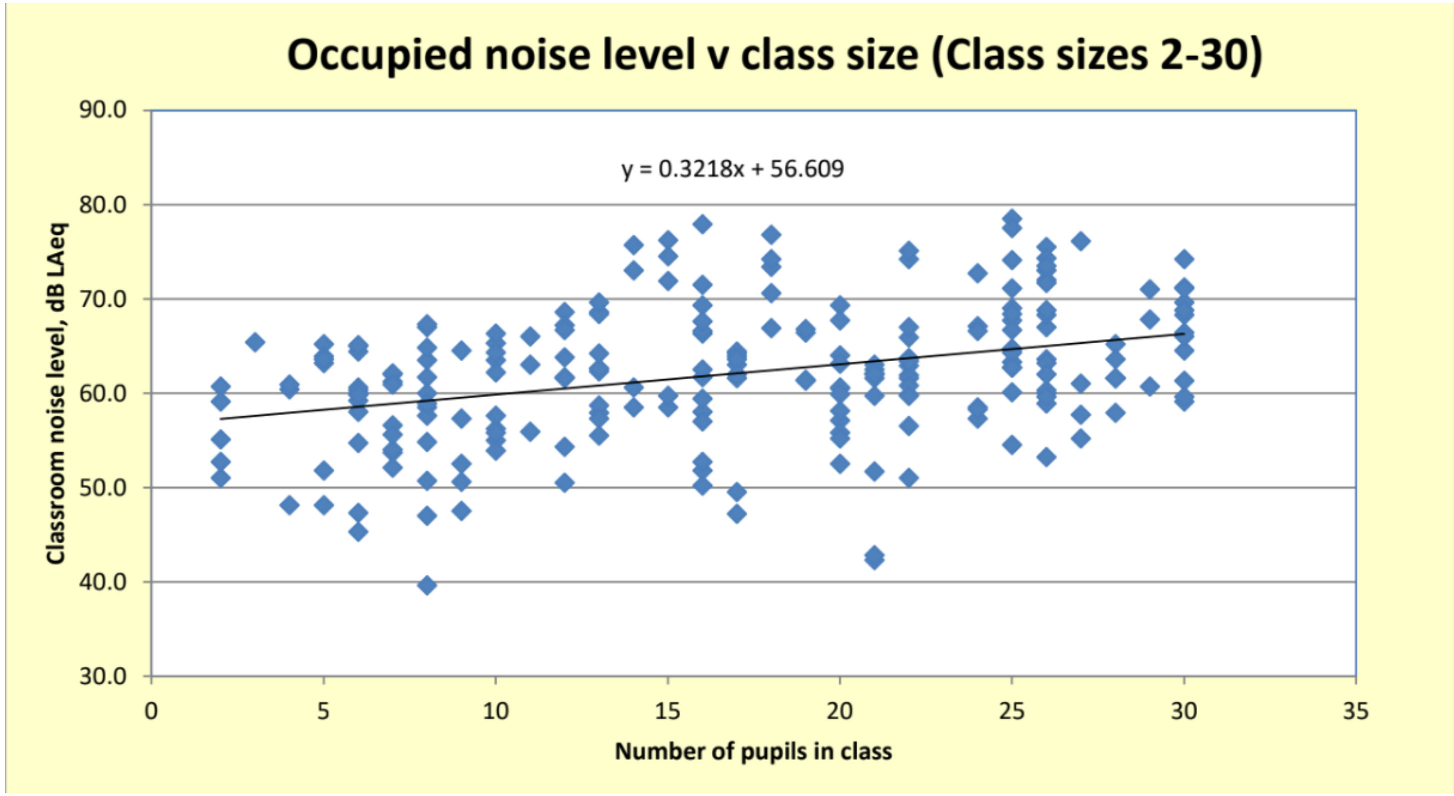
Speaker-orientated acoustics design. Pelegrin Garcia, 2014





[Speaker-Oriented Classroom Acoustics Design Guidelines in the Context of Current Regulations in European Countries]
David Pelegrín-García, Jonas Brunskog, Birgit Rasmussen. Acta Acustica united with Acustica, 2014

Class size



An investigation of classroom sound levels as a function of class size.
Adrian James, Inter-noise 2022, Glasgow

The Essex Study

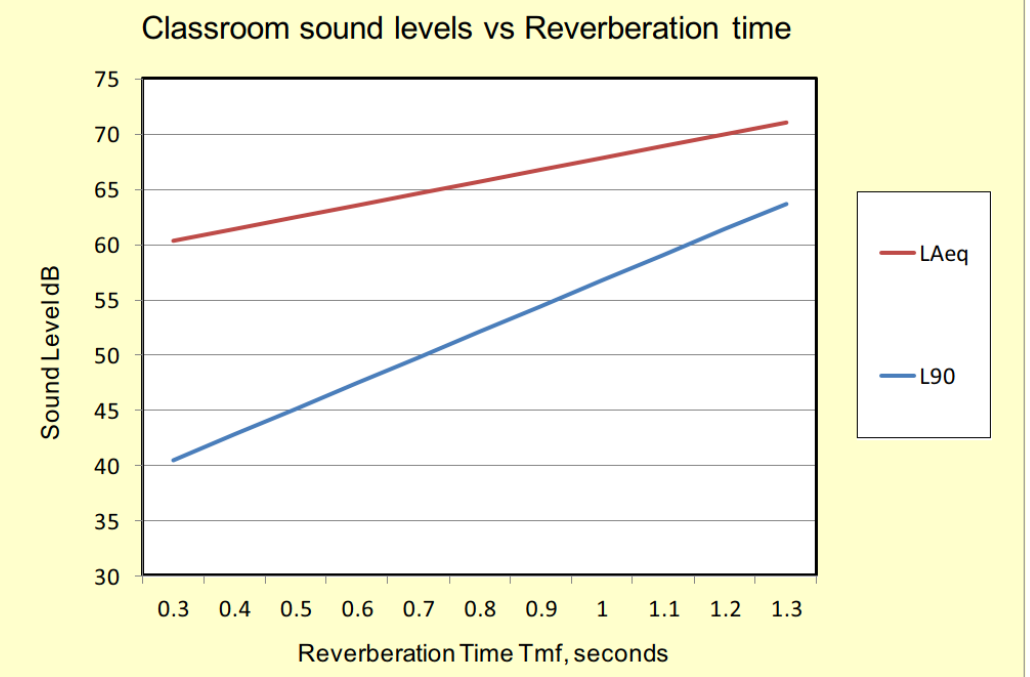


Figure 11 – sound levels as a function of RT

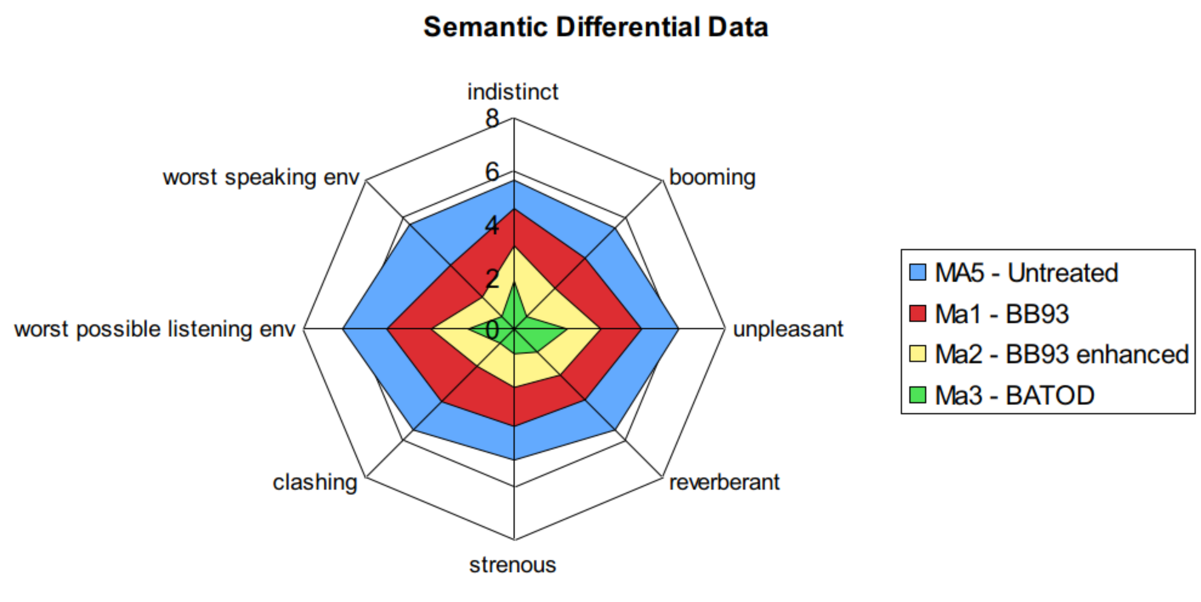
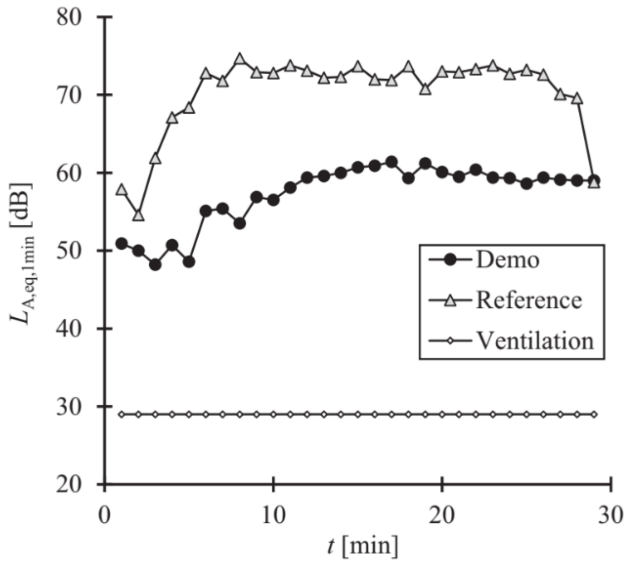
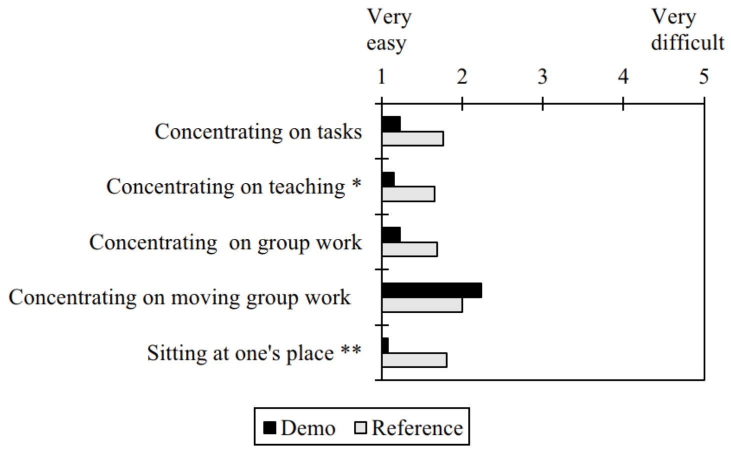


Figure 13 – Area plot of semantic differential data

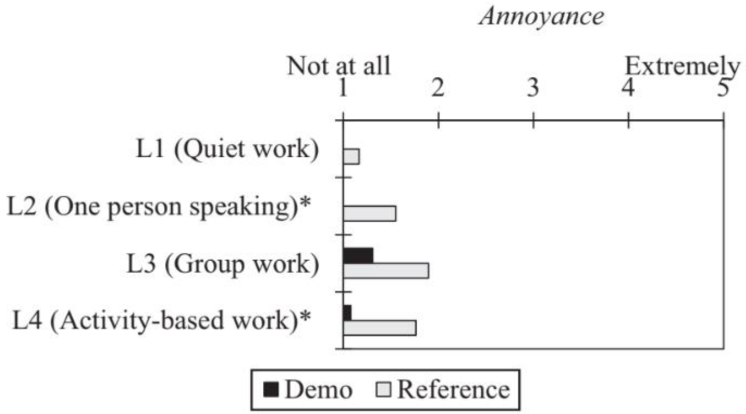
The Essex Study: Optimised classroom acoustics for all. David Canning & Adrian James, The Assoc. of Noise Consultants, 2012

Pupils’ experience of noise in two acoustically different classrooms





Notes: * and ** denote statistically significant differences between *classroom types* ($p < 0.05$); ($p < 0.01$), respectively



Notes: *Denotes statistically significant differences between *classroom types* ($p < 0.05$)

Pupils’ experience of noise in two acoustically different classrooms.
Jenni Radun, Mikko Lindberg, Aleksi Lahti, Marjaana Veermans, Reijo Alakoivu, Valtteri Hongisto. Facilities, March 2023

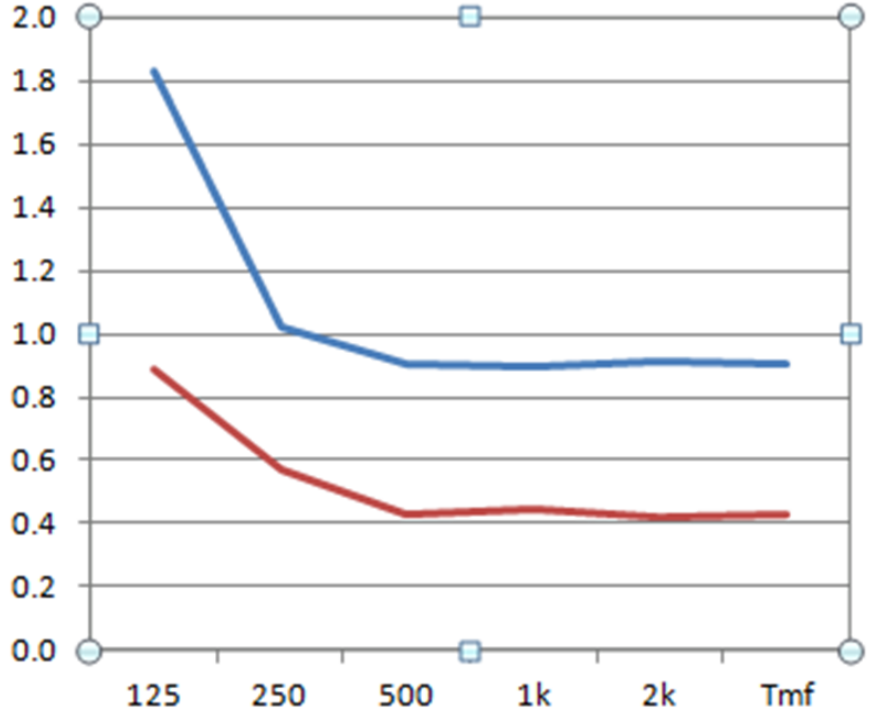
What’s the best room acoustic calculation?

- Sabine?
- Eyring?
- Number of children?
- BS EN 12354-6?
- Energy model?
- Geometrical room acoustic modelling (CATT, Odeon)?
- Finite element modelling, FEM?

Problems with Sabine / Eyring methods

- Most classrooms are not Sabine spaces - nearly all acoustic absorption is on the ceiling
- There is rarely much space (or money) for wall panels anyway
- Many classrooms have strong lateral room modes or even flutter echoes between reflective parallel walls
- These increase the measured RT when empty – until furnished

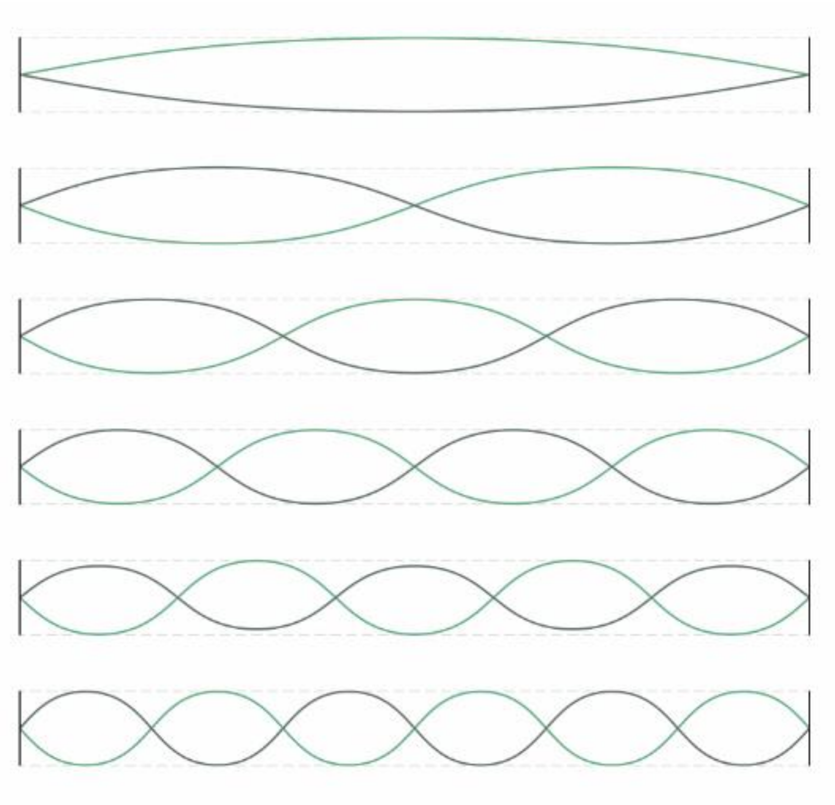
Measured effect of flutter echoes / room modes

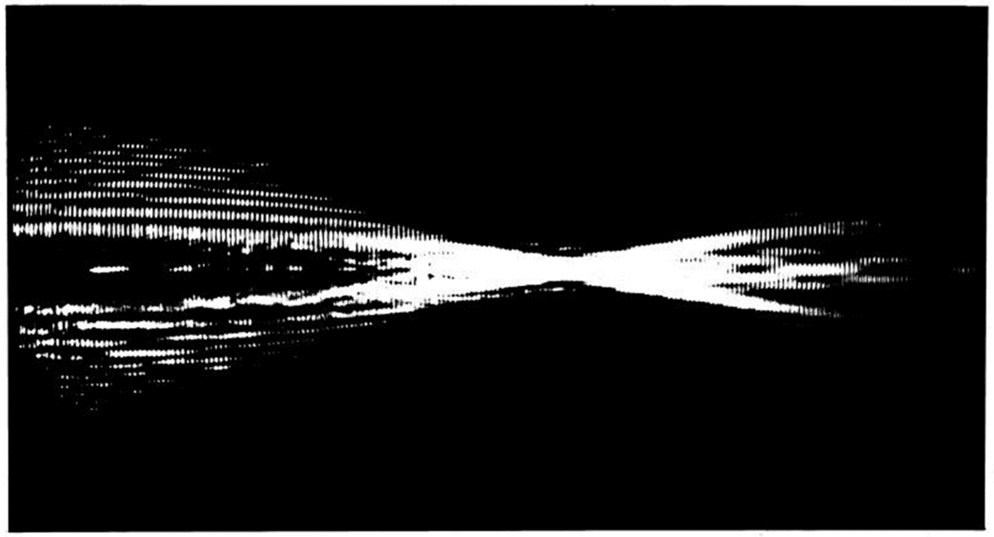


	octave band						
Reverberation time	**125**	**250**	**500**	**1k**	**2k**	**Tmf**	
D.0.03 Classroom	1.2	0.8	0.59	0.61	0.55	0.58	Unfurnished
B.1.04 Classroom	1.0	0.6	0.45	0.54	0.58	0.52	Unfurnished
D.0.04 Classroom	1.0	0.6	0.44	0.54	0.55	0.51	Unfurnished
B.0.07 Classroom	1.8	1.0	0.90	0.90	0.92	0.91	Unfurnished
B.0.10 Classroom	0.9	0.6	0.43	0.44	0.42	0.43	Furnished

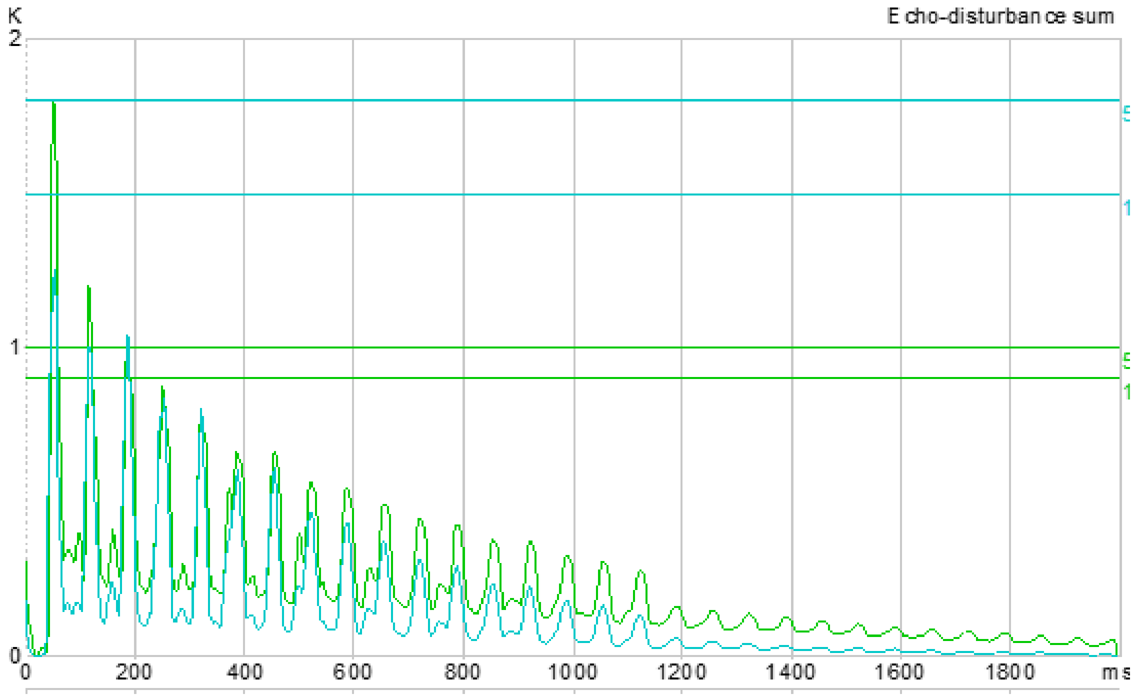
Classroom dimensions 8.4 x 8.4 x 3.8m to underside of suspended ceiling

All rectangular rooms have room modes and flutter echoes to some extent

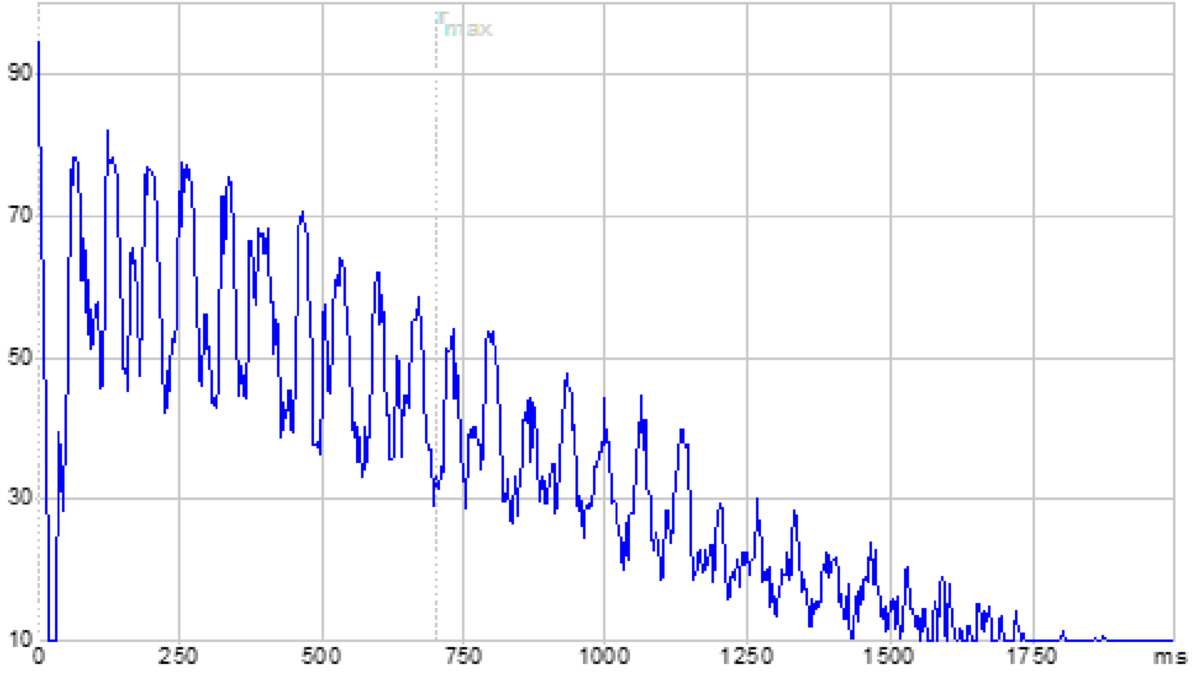




Predicting and calculating flutter echoes

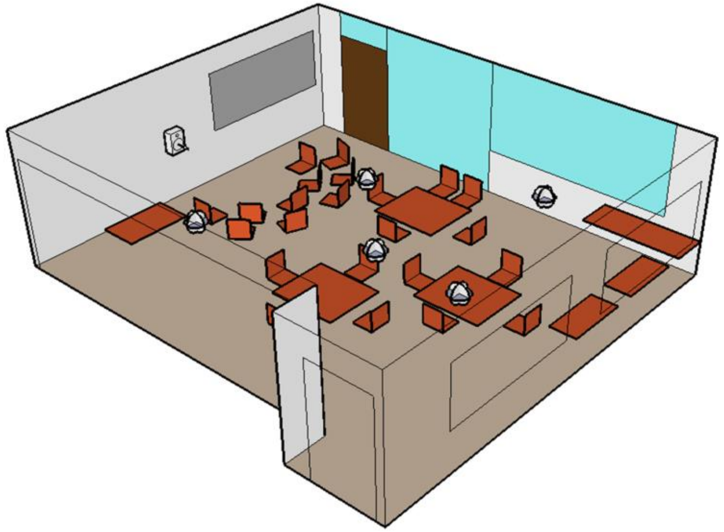


Echogram from Computer Model



Measured Echogram

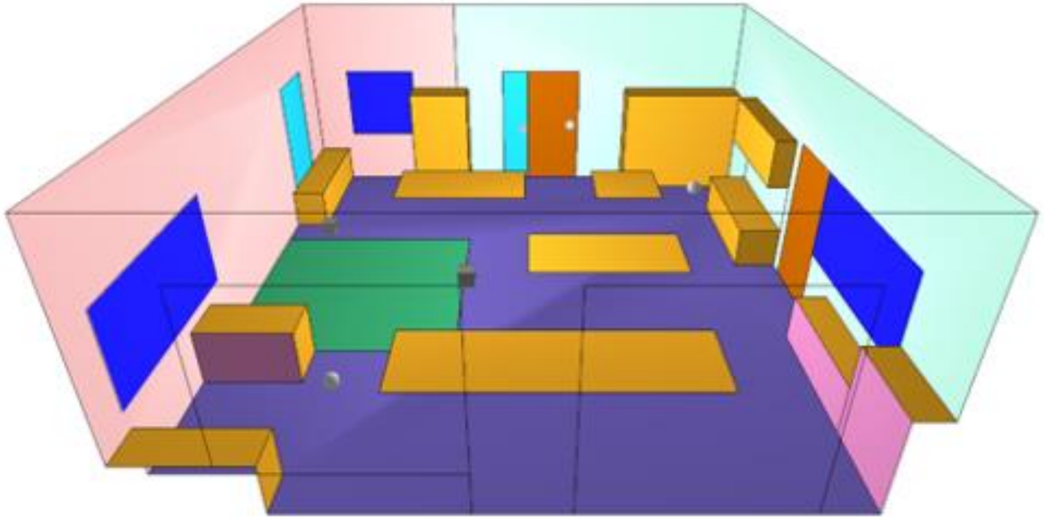
0.4s Tmf can be achieved even in large rooms



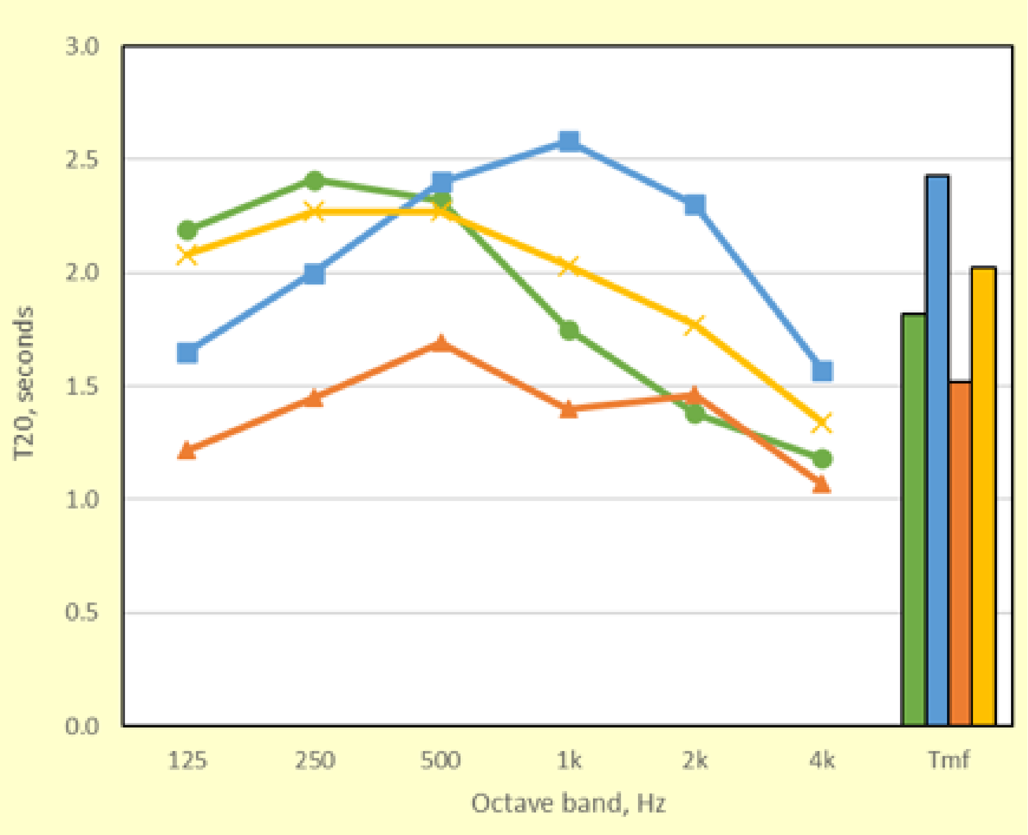
Measured Reverberation Times

	Octave Bands (Hz)					
Room no.	**125**	**250**	**500**	**1k**	**2k**	**Tmf**
G.37 Younger PMLD	0.60	0.53	0.42	0.38	0.34	0.38
G.23 Reception	0.64	0.44	0.41	0.37	0.34	0.37
G.89 KS2 ASD/GLD	0.62	0.61	0.49	0.44	0.42	0.45
1.15 Group Room	0.46	0.41	0.38	0.37	0.38	0.38
1.81 KS2 ASD/GLD	0.46	0.38	0.35	0.33	0.31	0.33
1.68 Year 4 KS2	0.63	0.54	0.46	0.45	0.40	0.44
1.14 Year 1 KS1	0.51	0.41	0.39	0.33	0.30	0.34
1.26 KS2 ASD/GLD	0.69	0.44	0.40	0.39	0.40	0.40
1.81 KS2 ASD/GLD	0.53	0.44	0.37	0.34	0.34	0.35

Comparison of computer modelling for classroom with suspended acoustic rafts



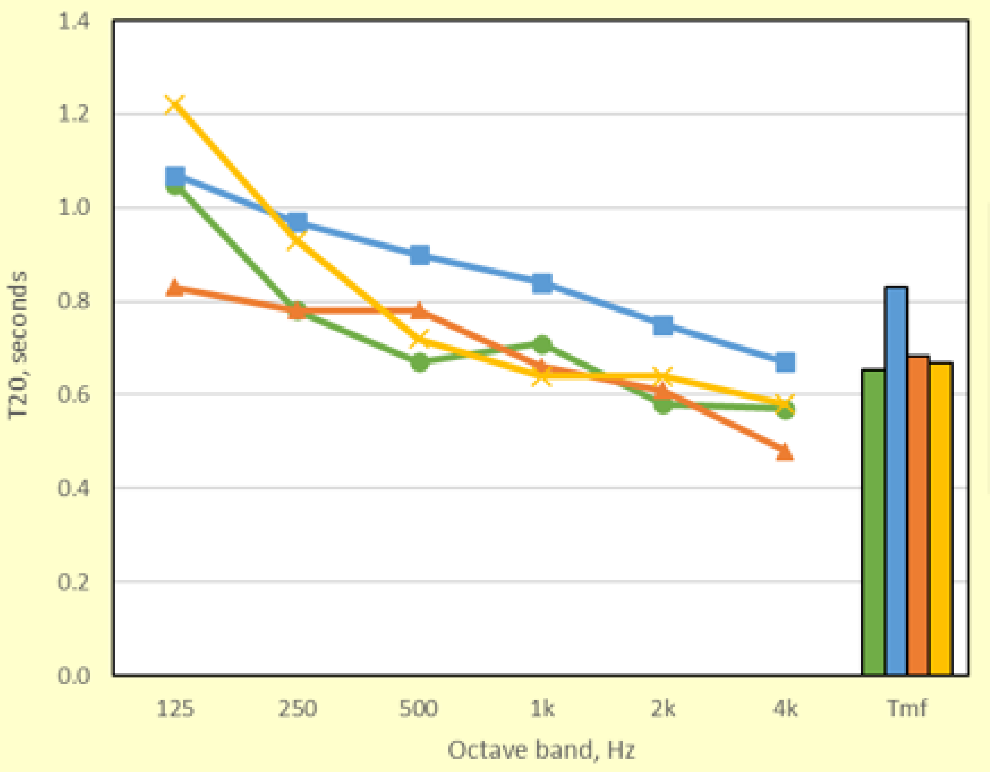
Fixed and loose furniture, no acoustic treatment



RTs modelled by 4 different acoustics consultancies

Comparison of computer modelling for classroom with suspended acoustic rafts

Fixed and loose furniture, acoustic rafts under 40% of ceiling
(N.B Rafts are very difficult to model !)



RTs modelled by 4 different acoustics consultancies

Conclusions about RT calculation methods

- Classrooms are not Sabine spaces (very few rooms are)
- All classrooms have uneven distribution of absorption, and all have room modes and flutter echoes to some extent
- Hence Sabine-based methods will normally under-estimate RT, especially in unfurnished rooms
- All of these effects can be calculated with skilled computer modelling, informed by understanding of acoustics, measurement data and experience.
- As with all computer modelling, GI=GO (but how does the client know that ?)
- There is a lot of G about, but it's amazing what you can get away when acoustic commissioning is not a legal requirement.

Calculating reverberation time – empirical approach


Figure 3: Typical Primary school with 2.4 * 1.2 m rafts and wall panels


Figure 4: Primary school classroom. The underside of the bulkhead can be seen in the foreground, top left of the picture.

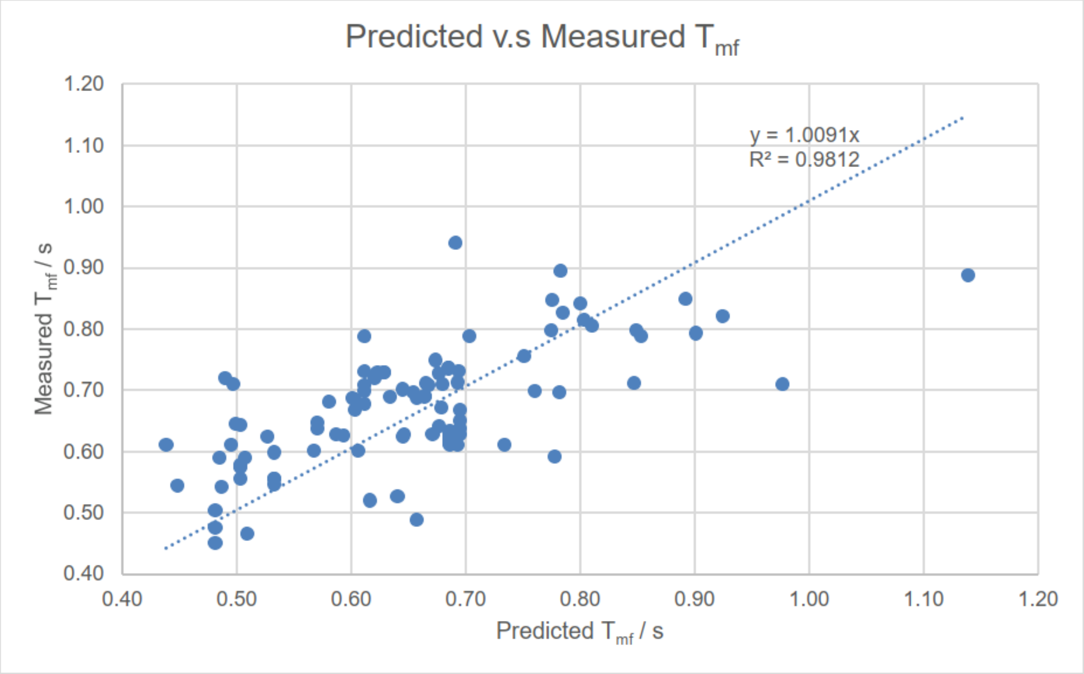
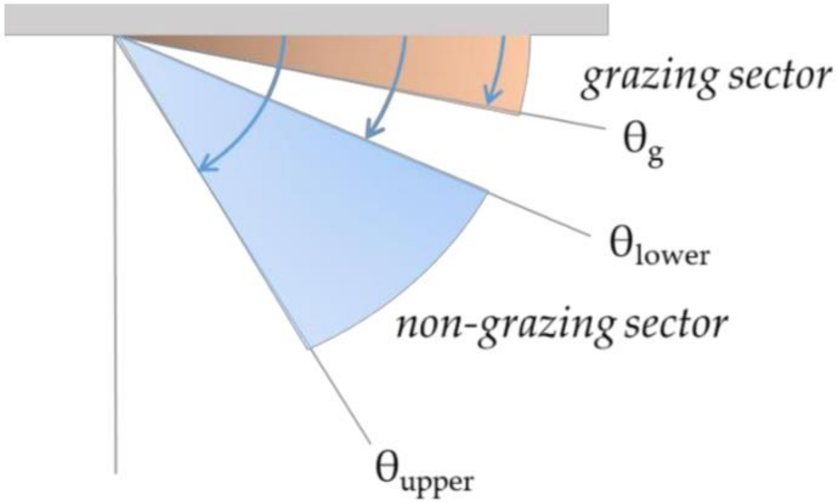
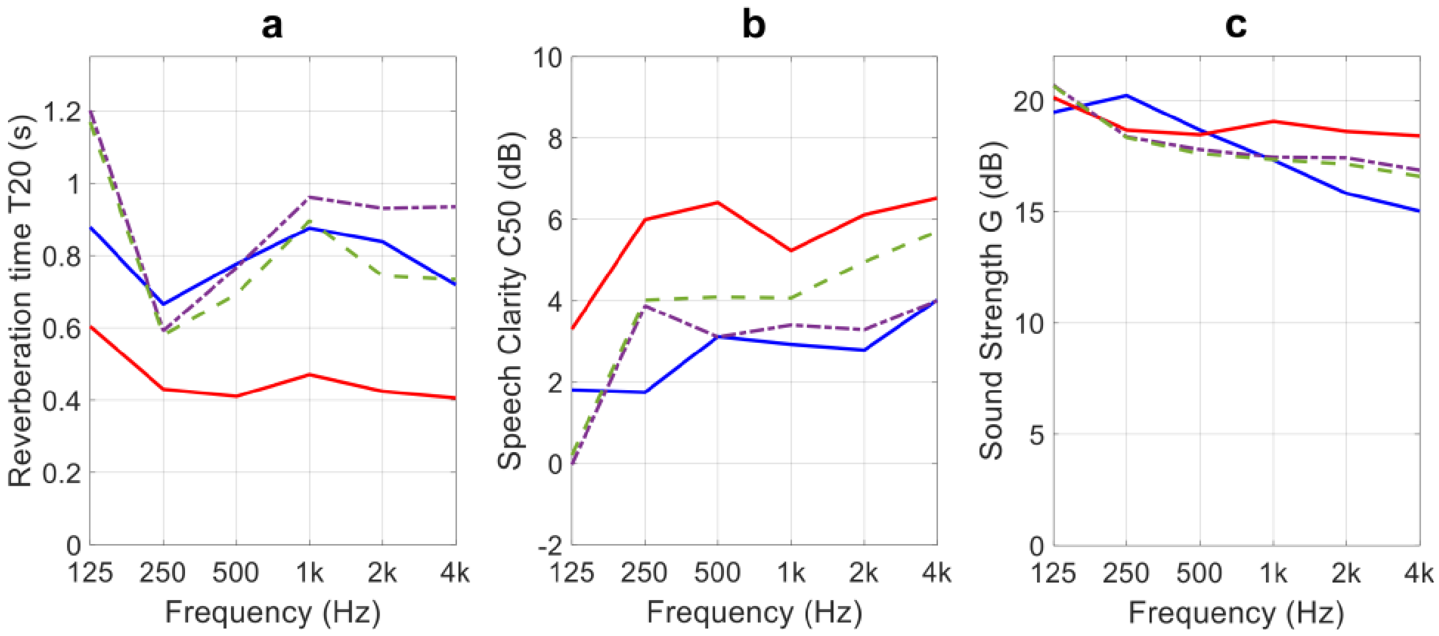


Figure 12: Calculated T_{mf} based on EN 12354-6, against measured T_{mf}

Confidence in room acoustic design: an empirical approach for classrooms.
J Harvie-Clark, W Wei, Inter-noise 2022.

Calculating reverberation time – energy model





An Energy Model for the Calculation of Room Acoustic Parameters in Rectangular Rooms with Absorbent Ceilings.
Erling Nilsson & Emma Arvidsson. Applied Sciences, 2021

We should be able to demonstrate compliance with a reverberation time criterion by:

- Compliance with Building Regs demonstrated by design
- BB 93 has no description of design method
- Spreadsheet?
- Room acoustic modelling?
- Back of an envelope?