Classroom acoustic conditions: Understanding what is suitable through a review of national and international standards, recommendations, and live classroom measurements

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ABSTRACT

Children spend 45-75% of their time in the classroom listening to their teacher and classmates. As current teaching methods have a strong focus on group work activities, contemporary classrooms are prone to high noise levels. Therefore, the classroom acoustic environment needs to be designed appropriately. The AS/NZS2107:2000 standard currently has recommendations for unoccupied classroom ambient noise levels and reverberation times, however, these are not enforced. Furthermore, there are no recommendations for occupied classroom acoustic conditions. Therefore, the aim of this paper was to review current classroom acoustic standards and recommendations around the world, summarise typical noise levels found in classrooms, and provide recommendations on the unoccupied and occupied classroom acoustic conditions needed for children at different ages and children with special educational needs.

1. INTRODUCTION

The primary modes of communication in the educational setting are speaking and listening, with it being estimated that children spend 45-75% of their time in the classroom comprehending their teacher's and classmates' speech (American Speech-Language-Hearing Association, 2005; Rosenberg et al., 1999). Recent shifts in teaching methods have seen a move away from traditional didactic teaching to a stronger focus on group work activities (Rowe, 2006; Mealings, Demuth, et al., 2015a). As a result, contemporary classrooms are prone to high noise levels (Shield et al., 2010; Mealings, Buchholz, et al., 2015). Studies show that children from classrooms with poor acoustics have lower literacy and numeracy skills, are less productive in the workforce, and tend to be in lower paid jobs than those from classrooms with good acoustics (James et al., 2012; Anderson, 2001). Therefore, it is vital that the classroom acoustic environment is designed to allow children to accurately discriminate what their teacher and the children in their group are saying amongst the other dynamic classroom noise (Mealings, Demuth, et al., 2015b; Mealings, Demuth, et al., 2015c; Mealings, Dillon, et al., 2015). The AS/NZS2107:2000 standard currently has recommendations for unoccupied classroom ambient noise levels (< 35-45 dBA) and reverberation times (< 0.4-0.5 s), however these are not enforced so are rarely achieved. Furthermore, there are no recommendations for occupied classroom acoustic conditions. Therefore, the aims of this paper were to:

- Review and summarise the current classroom acoustic standards (e.g. noise levels, reverberation times, signal-to-noise ratios, and speech transmission index scores) from countries around the world, as well as the recommended levels published in research papers.
- Identify and summarise the typical classroom acoustic conditions found in primary schools from research conducted in Australia, New Zealand, and other countries.
- Provide recommendations on what are considered as "Good", "OK", and "Poor" unoccupied and occupied classroom acoustic conditions for typically developing children, children at different ages, and children with special educational needs, based on the findings of aims 1 and 2.

2. METHOD

This paper provides a review of national and international classroom acoustic standards, and a review of academic literature and experimental studies that assess how noise and reverberation affect children's speech perception. Initially, databases such as Web of Science were used to identify key peer-reviewed articles using relevant search terms, for example "primary school classroom acoustics". The bibliographies of these key articles were then used to identify additional research papers and classroom acoustic standards for different countries. Effort was made to include recommendations and results for both enclosed and open plan classrooms, as well as

recommendations for both typically developing children and those with hearing or language impairments. Forty-three papers in total were included in the final review. The findings from these papers are shown below and a summary of the findings for each category are provided at the bottom of each table. The paper concludes with acoustic recommendations for classrooms drawn from these studies.

3. RESULTS

3.1 Recommended Classroom Acoustic Guidelines Around the World

Table 1 shows the recommended values for primary school classrooms based on National Standards or research paper recommendations by country. Values are shown for unoccupied ambient noise levels (ANLs), signal-to-noise ratios (SNRs), unoccupied reverberation times (RTs), and speech transmission index scores (STIs). Breakdowns of the recommended values by age group are shown where applicable. Classrooms are also sorted by type (i.e. traditional enclosed classrooms versus open plan classrooms). An overall summary is shown at the bottom of the table. The values found in Table 1 are for typically developing children with normal hearing, whereas Table 2 shows the revised levels for children with hearing impairments or language delays who need more favourable listening conditions.

Table 1: Recommended classroom acoustic guidelines for typically developing children

Reference Type	Reference	Classroom Type	Unoccupied ANL (dBA)	SNR (dB)	RT (s)	STI
National Standards/ Recommendations	Australia/New Zealand Standard (2000)	Enclosed	< 35 (satisfactory)		< 0.4-0.5	
			< 45 (max)			
	South Australia (1993)	Enclosed	< 40		< 0.4-0.5	
		Open	< 45		< 0.4-0.5	
	American National Standards Institute (2010)	Enclosed	< 35		< 0.6	
	USA (American Speech-Language-Hearing Association, 1995)	Enclosed	< 30		< 0.4	
	UK (1981)	Enclosed	< 40		< 0.5-0.8	
	World Health Organization (1999)	Enclosed	< 35		< 0.6	
	Finland (1991)	Enclosed	< 35		0.6-0.9	
	Japan (Fukuchi & Ueno, 2004)		< 40		< 0.6	
	England/Wales (2003)	Open	< 40		< 0.8	> 0.6
	Denmark (Boligstyrelsen, 2004)	Open	< 30		< 0.3-0.4	> 0.6
	Sweden (2007)	Open	< 30		< 0.4	
	Norway (2008)	Open			< 0.4	
	Iceland (2011)	Open			< 0.4	> 0.6

Table 1 Continued

Reference Type	Reference	Classroom Type	Unoccupied ANL (dBA)	SNR (dB)	RT (s)	STI
Other Country Standards Reported in Losso et al. (2004)	Belgium		< 30-45			
	Brazil		< 40-50			
	France		< 38		< 0.4-0.8	
	Germany		< 30			
	Italy		< 36			
	Portugal		< 35		< 0.6-0.8	
	Turkey		< 45			
	UK		< 40			
Research Papers	Australia (AAAC, 2010)	Enclosed	< 35		< 0.4-0.5	
		Open				> 0.6
	Australia (Mealings, Dillon, et al., 2015; Mealings, Demuth, et al., 2015d)	Enclosed and Open	< 45.9 (occupied)	> +14.5		> 0.75
	USA (Siebein et al., 2000)	Enclosed	< 30-35			
	USA (Seep et al., 2000)	Enclosed	< 35	> +10	< 0.4-0.6	
	USA (Bradley & Sato, 2008)	Enclosed	< 35	6 y/o: > +20		
				8 y/o: > +18		
				11 y/o: > +15		
	USA (Anderson, 2001)	Enclosed	< 25	> +15	< 0.4-0.6	
	NZ (Wilson, 2002)	Enclosed	< 35		< 0.4	
	Canada (Picard & Bradley, 2001)	Enclosed	6-7 y/o: < 28.5		< 0.5	
			8-9 y/o: < 34.5			
			10-11 y/o: < 39			
			12+ y/o: < 40			
	Sweden, Denmark, Norway (Borrild, 1978)		< 35		< 0.9	
	England (Greenland & Shield, 2011)	Open		6 y/o: > +15.5	< 0.4	> 0.75
				8 y/o: > +12.5		> 0.69
				11 y/o: > +8.5		> 0.61
	Compilation (Picard & Bradley, 2001)		< 30-40		< 0.4-0.9	
Overall Summary	**Noise Level: < 25-50 dBA**		**SNR: > +8.5 +20 dB**	**RT: < 0.3-0.9 s**		**STI: > 0.6-0.75**

Table 2: Recommended classroom acoustic guidelines for children with hearing impairments or language delays

Reference Type	Reference	Classroom Type	Unoccupied ANL (dBA)	RT (s)
National Standards/ Recommendations	South Australia (1993)	Enclosed	< 40	< 0.4
	UK (1981)	Enclosed	< 30	< 0.3-0.6
	USA (American Speech-Language-Hearing Association, 1995)	Enclosed	< 30	< 0.4
Research Papers	Australia (AAAC, 2010)	Enclosed	< 30	< 0.4
	Scotland (Airey, 1998)	Enclosed	< 20-30	< 0.3-0.6
	Canada (Picard & Bradley, 2001)	Enclosed	6-7 y/o: < 21.5 8-9 y/o: < 27.5 10-11 y/o: < 32 12+ y/o: < 33	< 0.5
	Sweden, Denmark, Norway (Borrild, 1978)		< 25	< 0.5
	Compilation (Picard & Bradley, 2001)		< 20-35	< 0.3-0.7
Overall Summary			**< 20-35 dBA**	**< 0.3-0.7 s**

3.2 Acoustic Levels Found in Classrooms Around the World

Table 3 shows the typical acoustic levels found in primary school classrooms from research papers by country. Values are shown for unoccupied ambient noise levels (ANLs), occupied background noise levels (BNLs; broken down by class activity where applicable), signal-to-noise ratios (SNRs), unoccupied reverberation times (RTs; or occupied RTs as noted), and speech transmission index scores (STIs). A description of the number and type of classrooms involved in the studies are also provided. An overall summary is shown at the bottom of the table.

Table 3: Typical acoustic levels found in classrooms

Country	Reference	Classroom Type	Unoccupied ANL (dBA)	Occupied BNL (dBA)	SNR (dB)	RT (s)	STI
Australia	Rural Queensland (Massie et al., 2004)	4 primary school classrooms		62-75	-9 to -3	1.3-1.8	
	Australia (Massie & Dillon, 2006)	12 Year 2 classrooms		64-72 *M* = 68		1.0-1.9 *M* = 1.5	
	Sydney (Mealings, Buchholz, et al., 2015)	4 enclosed/ open plan primary school classrooms (5-6-year-olds)	36-46	68-72	-6 to +16[b] -16 to -5[c,d]	0.5-0.7	0.30-0.88

Table 3 Continued

Country	Reference	Classroom Type	Unoccupied ANL (dBA)	Occupied BNL (dBA)	SNR (dB)	RT (s)	STI
New Zealand	Auckland (Wilson, 2002)	12 primary school classrooms		50-70	*M* = -8	0.35-0.63[a]	
	Auckland (Harper, 1995)	5 primary/ intermediate classrooms	28-55 *M* = 37		-5 to +11 *M* = +6	0.37-0.56 *M* = 0.43	0.72-0.82 *M* = 0.76
	Wellington (Blake & Busby, 1994)	106 primary school classrooms (5-7-year-olds)			0 to +23 *Median* = +6 (+10[b] ; +1[c,d])		
	Auckland (See Wilson, 2002)	4 enclosed classrooms	47		+1 to + 8	*M* = 0.73	
	Auckland (See Wilson, 2002)	4 open plan classrooms	60 (main class empty, other classes occupied)		+4.5 to +7.5	*M* = 0.76	
United Kingdom	Edinburgh (MacKenzie & Airey, 1999)	60 primary school classrooms	44.1-44.7	49-85		*M* = 0.7 (but many between 0.9-1.0)	0.5-0.7
	Edinburgh (Airey, 1998)	Enclosed untreated primary schools	55.5	69.6[b] 77.3[c,d]		*M* = 0.7 *M* = 0.6[a]	0.5
	Edinburgh (Airey, 1998)	Enclosed treated primary schools	46.5	70.0[b] 70.1[c,d]		*M* = 0.4 *M* = 0.4[a]	0.7
	Edinburgh (Airey, 1998)	Open plan primary schools	56.6	63.6[b] 72.1[c,d]		*M* = 0.6 *M* = 0.4[a]	0.5
	England (Greenland & Shield, 2011)	42 semi-open plan primary school classrooms	33-40 *M* = 35		+11.7[b] +6.7[c] +3.9[d]	0.26-0.64	0.65[b] 0.55[c] 0.49[d]
	London (Shield & Dockrell, 2004)	140 primary school classrooms	47	66.3-74.3 *M* = 72			

Table 3 Continued

Country	Reference	Classroom Type	Unoccupied ANL (dBA)	Occupied BNL (dBA)	SNR (dB)	RT (s)	STI
Canada	Ottawa (Bradley & Sato, 2008)	41 primary school classrooms			*M* = +4.5	*M* = 0.42	
	Ottawa (Sato & Bradley, 2008)	41 primary school classrooms	42.2	49.1	*M* = +11.1	*M* = 0.45 *M* = 0.41[a]	
	Ottawa (Bradley, 1986)	10 primary school classrooms (12-13-year-olds)	38-45			*M* = 0.7	
United States	Compilation (Berg et al., 1996)		30-50	55-85 *M* = 60		0.3-1.5	
	Ohio (Knecht et al., 2002)	32 elementary schools	34.4-65.9				
	Hawaii (Pugh et al., 2006)	79 primary school classrooms	51.2			0.2-1.27	
Europe	Sweden (Norlander et al., 2005)	Combined primary/high school		63.24			
Asia	Hong Kong (Choi & McPherson, 2005)	47 primary school classrooms		54.1-67.6 *M* = 60.74	*M* = +13.53		
	Japan (See (Sato & Bradley, 2008))		22-59			0.2–1.0	
	Japan (Tsuchiya et al., 2004)	Open plan				0.7	0.65-0.75
South America	Brazil (Losso et al., 2004)		51.5-70.5			1.15-1.68	

Table 3 Continued

Country	Reference	Classroom Type	Unoccupied ANL (dBA)	Occupied BNL (dBA)	SNR (dB)	RT (s)	STI
Compilations	(Crandell & Smaldino, 2000)		41-51	48-65	-7 to +5	0.35-1.2	
	(American Speech-Language-Hearing Association, 2005)		32-67		-7 to +5	0.4-1.2	
	(Picard & Bradley, 2001)	Primary school classrooms		51.7-75	-4.5 to +23	0.7-1.2 0.2-0.9[a]	
Overall Summary			**22-70.5 dBA**	**48-85 dBA**	**-16 to +23 dB**	**0.2-1.9 s**	**0.30-0.88**

[a] Occupied reverberation time
[b] Noise levels during whole class teaching
[c] Noise levels while children are working at tables
[d] Noise levels while children are working with movement

4. CONCLUSIONS

This paper has reviewed current classroom acoustic standards and recommendations around the world and summarised typical noise levels found in classrooms. The final aim of this paper was to bring these findings together and conclude with recommendations on the unoccupied and occupied classroom acoustic conditions needed for typically developing children at different ages as well as children with special educational needs. Table 4 provides recommendations on what are "Good", "OK", and "Bad" overall acoustic levels for primary school classrooms with typically developing children based on the findings of this paper. Subsequently, Table 5 provides a breakdown of these levels by age group. Finally, Table 6 provides recommendations on the classroom acoustic variables for children with hearing or language impairments. It is generally recommended that noise levels should be 10 dBA lower and RTs should be 0.2 s lower for these children as they are more adversely affected by poor classroom acoustic conditions (MacKenzie & Airey, 1999). Meeting the relevant recommendations in primary school classrooms will help ensure all children are able to learn effectively in every educational setting, and will also help minimise vocal health problems for teachers.

Table 4: Overall acoustic recommendations for primary school classrooms

Rating	Unoccupied ANL (dBA)	Occupied BNL (dBA)	SNR (dB)	RT (s) (unoccupied)	STI
Good	< 30 dBA	< 50 dBA	> +15 dB	< 0.4 s	> 0.75
OK	30-40 dBA	50-55 dBA	+10 to +15 dB	0.4-0.6 s	0.6-0.75
Bad	> 40 dBA	> 55 dBA	< +10 dB	> 0.6 s	< 0.6

Table 5: Acoustic recommendations for primary school classrooms for children at different ages

Age Group	Rating	Unoccupied ANL (dBA)	Occupied BNL (dBA)	SNR (dB)	RT (s) (unoccupied)	STI
6-7 years	Good	< 28 dBA	< 45 dBA	> +20 dB	< 0.4 s	> 0.75
	OK	28-35 dBA	45-50 dBA	+15 to +20 dB	0.4-0.6 s	0.7-0.75
	Bad	> 35 dBA	> 50 dBA	< +15 dB	> 0.6 s	< 0.7
8-9 years	Good	< 35 dBA	< 47 dBA	> +18 dB	< 0.4 s	> 0.7
	OK	35-40 dBA	47-53 dBA	+12 to +18 dB	0.4-0.6 s	0.6-0.7
	Bad	> 40 dBA	> 53 dBA	< +12 dB	> 0.6 s	< 0.6
10-11 years	Good	< 39 dBA	< 50 dBA	> +15 dB	< 0.4 s	> 0.61
	OK	39-40 dBA	50-56 dBA	+9 to +15 dB	0.4-0.6 s	0.6-0.61
	Bad	> 40 dBA	> 56 dBA	< +9 dB	> 0.6 s	< 0.6
12+ years	Good	< 40 dBA	< 50 dBA	> +15 dB	< 0.4 s	> 0.61
	OK	40-45 dBA	50-56 dBA	+9 to +15 dB	0.4-0.6 s	0.6-0.61
	Bad	> 45 dBA	> 56 dBA	< +9 dB	> 0.6 s	< 0.6

Table 6: Acoustic recommendations for primary school classrooms with hearing/language impaired children

Rating	Unoccupied ANL (dBA)	Occupied BNL (dBA)	SNR (dB)	RT (s) (unoccupied)	STI
Good	< 20 dBA	< 40 dBA	> +20 dB	< 0.3 s	> 0.75
OK	20-30 dBA	40-45 dBA	+15 to +20 dB	0.3-0.5 s	0.6-0.75
Bad	> 30 dBA	> 45 dBA	< +15 dB	> 0.5 s	< 0.6

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