Cost Benefit Analysis of Proposed Changes to the Building Code:

Acoustical conditions in classrooms and early childhood teaching spaces

A report prepared by
Infometrics Ltd

for

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David Grimmond

Infometrics

1. INTRODUCTION

The Building Industry Authority has commissioned Infometrics to undertake a cost benefit analysis of its proposed changes to the Building Code in relation to the application of Clause G6 (Airborne and Impact Sound) to educational facilities. In particular the inclusion of clauses G6.1.1 (c) [the safeguarding of people from possible injury, illness or loss of amenity as a result of poor room acoustics] and G6.1.2 [ensuring that acoustical conditions adequately support teaching and learning activities] have been proposed to address a specific need in schools and early childhood centres.

The analysis presented is necessarily an indicative one – actual costs will be case specific. We base our costs here instead on the hypothetical extra costs associated with making adjustments to the inputs required for one of the Ministry of Education's suggested building plans for a relocatable module classroom. Benefits accrue due to cost savings to schools resulting from fewer teacher sick leave days and potential gains to earnings in students' later working lives as a result of being able to hear more in the class environment, which effectively increases the amount of schooling they receive.

To address the considerable amount of uncertainty involved in all of these calculations, we undertake a wide range of sensitivity tests. Our conclusions are that:

- The commercial incentives for individual schools, ie savings from teacher reliever costs, are unlikely to be sufficient to justify schools to adopt improved classroom acoustic designs on a unilateral basis.

- The gains from improvements in students' life time earning prospects are likely to be significantly greater and potentially very dramatic; our central scenario estimates the net present value of benefits to exceed initial costs by a multiple of 68.

- Even if the marginal impact of better classroom acoustics on each individual student is very modest, there is still likely to be a net positive benefit; our worst case scenario yields a benefit-cost ratio of 1.7.

- The unit of analysis here is the classroom. Calculations of benefits are based on the potential benefits accrued to students occupancy of classrooms for one school year. The lifetime benefit to individual students is likely to increase with the number of school years they are taught in classrooms with higher acoustic qualities, but this is not considered in the current report.

The analysis does not consider the costs and benefits associated with remedial work to improve the acoustic standards of existing classrooms. While the types of associated benefits are likely to be similar to those considered here, the costs will be very much more case specific and there will be less scope to reduce costs through design.

In the next section we discuss the importance of acoustics to teaching performance and the implications for conditions in New Zealand. We then present our approach to estimating the benefits and costs. Sensitivity tests on the impact of various assumptions are followed by a conclusion.

2. ACOUSTICS IN THE CLASSROOM

Why are acoustics important?

The key argument behind having good acoustic standards in classrooms is that excessive noise and reverberation interferes with speech intelligibility resulting in reduced understanding and therefore reduced learning. Seep et al (2000) report that many classrooms in the United States have a speech intelligibility rating of 75% or less. This means that listeners with normal hearing can understand only 75% of the words read from a list. Or put another way, students on average potentially miss every fourth word spoken by their teacher.

Classroom learning typically involves intensive speech communication between teachers and students, and among students. The effectiveness of this communication, and hence the effectiveness of the learning process is mediated by acoustical conditions in the classroom. With good classroom acoustics, learning is potentially easier, deeper, more sustained and less stressful.

Poor classroom acoustics (excessive background noise and reverberation) degrades the education process for all students and teachers. But noise and reverberation can potentially impose selective barriers to learning. Students with hearing, language, speech, attention deficit or other learning disabilities are especially vulnerable to marginal or poor acoustics (Lubman and Sutherland 2001). Young children, who are less able to predict from context than older students, are also especially dependent on good acoustics. With their limited vocabulary and experience, if they miss a few words they are less able to fill in the missing thoughts (Seep et al 2000).

New Zealand specific arguments for raising classroom acoustic standards include:

- The National Vision Hearing Screening Programme that screens the hearing of all new entrant children showed that the national average failure rate in 1999/00 was 7.7%.
- Over 90% of children with permanent sensorineural hearing loss are mainstreamed.
- There is a high incidence of temporary conductive hearing loss associated with middle ear disorders for young New Zealanders.
- Noise levels in New Zealand primary school classrooms have risen due to the emphasis of group and incidental learning methods[1].

[1] For example a recent survey of 120 primary teachers indicated that much of the traditional lecture-style has been replaced with mat and group work. Indeed they reported just 12% of their time spent teaching was devoted to blackboard/didactic activities (Oticon 2002).

Important factors for improving classroom acoustics

The best way to solve acoustic problems is to prevent them, not correct them after the fact. During the design process, acoustic problems can usually be avoided with some forethought and a different arrangement of the same building materials. Renovation of poorly designed classrooms is much more expensive (though not necessarily uneconomical). (Seep et al 2000)

For a given level of signal (teacher speech volume) speech intelligibility is directly dependent on the level of background noise, reverberation and the shape of the room. In a normal classroom good speech intelligibility can be achieved if background noise can be kept under 30 dBA and the reverberation time (RT) does not exceed 0.5 seconds (Saint-Gobain Ecophon 2002)[2]. The American Speech-Language-Hearing-Association Acoustical Guidelines[3] recommend that:

- Unoccupied classroom noise levels should not exceed 30 dBA
- Reverberation times should not exceed 0.4 seconds, and
- The signal to noise ratio at a students ear should exceed a minimum of +15dB (ie the sound of the teacher should be 15 dB louder than other background noise)

There is more detail involved in the current building code proposals, but they are generally consistent with, but slightly less stringent than, these recommendations. To begin with building codes are by their very nature about prevention. The details of the proposals provide for control of noise intrusion and room acoustical properties appropriate to the room's intended use. Perhaps understandably, given the complexity of contributory factors that potentially go beyond building code jurisdiction, the code does not stipulate any signal to noise requirements. Enforcement of signal to noise requirements would also be problematic.

Noise control

Background noise can be influenced by placement, use of buffer spaces and other design features and by the use of building materials that limit the transmission of external noise into the classroom.

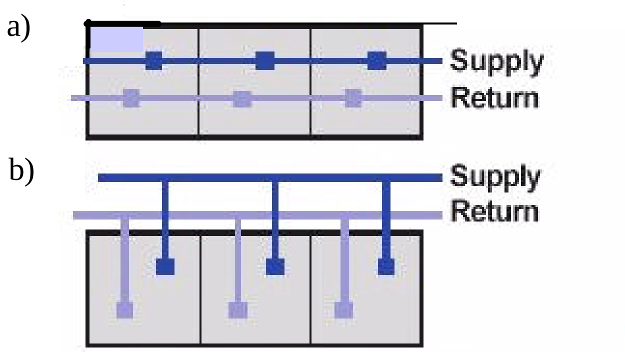
The impact of external noise can be reduced by locating classrooms away from external noise sources such as roads or sportsfields. Even when the scope to do this is limited, there may still be a number of other low cost design solutions to reducing the impact of external noise on classrooms. For example buffer spaces like store rooms or hallways can be used to separate critical listening areas from noise sources. Care with the placement of doors can also influence the extent of external noise intrusion. For buildings with mechanical ventilation systems (not that common in New Zealand schools, but a common source of excessive

[2] Reverberation time (RT) is the time it takes for the sound pressure level to fall by 60 dB after the sound has been turned off. Reverberation times will vary with noise frequency, but essentially they are a measure of sound absorption, the lower the reverberation time the greater the degree of sound absorption.

[3] Quoted from Oticon (2002) p 26

ambient noise in US schools), thought about the placement of ducting systems can mitigate the potential noise intrusion (see Figure 1).

Figure 1: Duct Arrangements



a) Bad duct arrangement – sound travels through the duct work from room to room
b) Better arrangement – sound has a longer path to travel

Source: Seep et al (2000)

Transmission of noise through exterior walls and walls that co-join with potential noise sources can be reduced by the use of fibrous sound absorber and double studding. Double glazing of windows and choice of doors can also mitigate noise transference. Use of such materials will potentially add to building costs, but will also provide a potential reduction in heating costs as well as noise reduction benefits.

New Zealand specific issues include:

- There is a low use of mechanical ventilation in New Zealand schools, but the offset is that external noise from open windows in summer is more likely.
- The use of “relocatable” module classrooms has been associated with poor acoustic qualities.
- 86% of Respondents to the Oticon teacher survey reported problems with noise generated outside the classroom. Traffic, lawn mowing, other classrooms, corridors/traffic decks, sport fields, rain and ablutions have been identified as key sources of external noise by New Zealand primary school teachers (Oticon 2002).
- 71% also reported noise generated within the classroom as a problem. Students are the prime source of this internal noise, with computers the next most common other source of classroom noise.

Room acoustics

In classrooms with signal to noise ratios less than +10dB speech intelligibility is significantly degraded for children with average hearing. Children with impaired hearing need a signal to noise ratio of at least +15dB (Seep at al 2000, p4). Signal to noise measures in New Zealand classrooms in a variety of listening conditions have ranged from -5 to +10dB (Oticon 2002, p8). Such measures are at best borderline adequate.

Amplification systems are one way of improving signal to noise ratios. However amplification systems do not alleviate stress levels associated with occupying a high noise environment. Schools do not always have the funds to repair damaged equipment, and it does not necessarily facilitate student to student communication. Classrooms that were modified though the addition of acoustic ceiling tiles resulted in reductions in reverberation times from 0.69 to 0.43 as well as perceptions of “much lower” class activity noise levels (Oticon 2002, p24).

While there are many ways to improve the desired acoustic qualities of a room, reducing reverberation times are primarily achieved by decreasing room volume and/or increasing sound absorption. In classroom applications there is generally limited scope to significantly reduce room volumes, so attention tends to focus on room sound absorption qualities. Absorption is increased by adding more ‘soft’ materials, ie reducing the amount of reflective surfaces that noise can bounce off. Examples of this include carpet, fabric faced wall panels and sound absorbing ceiling tiles.

The Oticon report notes that “in New Zealand it is Ministry of Education standard to have a carpeted floor (albeit thin), which provides some degree of acoustic absorption at mid and high frequencies and also prevents excessive noise from chair scrape and footfall” (p26). However they also quote international evidence that top rated ceiling tiles are three to six times more efficient at absorbing sound than carpet.

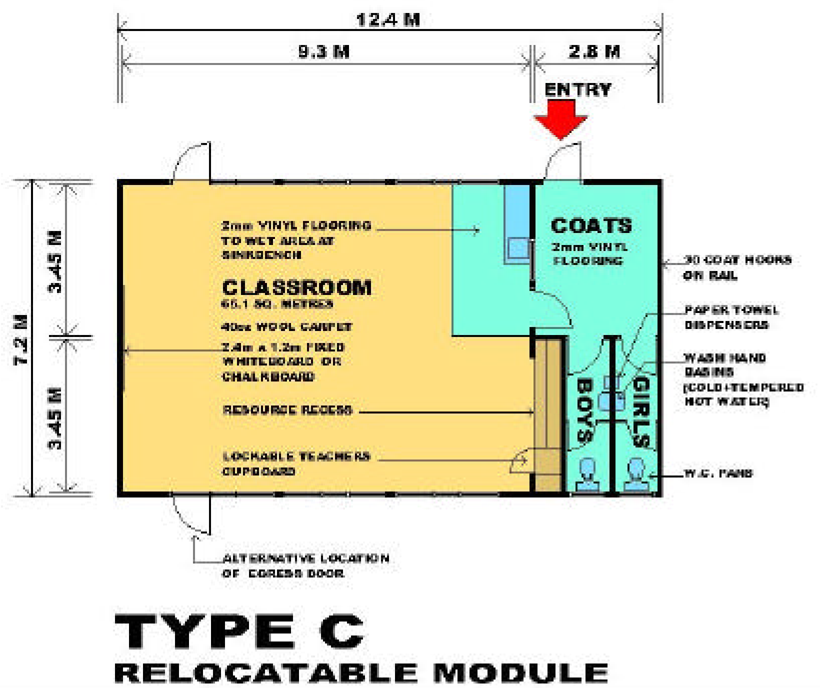
3. COST-BENEFIT CALCULATIONS

Cost calculations

Cost calculations are based around a standard Ministry of Education floor plan for a relocatable module (see Figure 2). A relocatable module was used because of their common use in New Zealand schools, particularly in primary schools, the availability of standard plans, and a personal communication with the Ministry that their construction costs were reasonably similar to that of fixed classrooms. No calculations have been made for more specialised teaching areas such as gymnasia, technology suites etc. as this was beyond the scope of the current analysis.

Type C was chosen from the eight examples provided on the Ministry's website as it seemed to incorporate more acoustic-friendly design aspects. In particular there are three sets of doors between the toilets and the classroom and the resource recess and teacher cupboard act as a further buffer zone between the classroom and the ablutions. However, the dimensions of the modules are all very similar and specific choice of module would not alter calculations greatly.

Figure 2: Model classroom used as base for cost calculations



Source: Ministry of Education
(URL:http://www.minedu.govt.nz/web/downloadable/dl3908_v1/im3a.jpg)

Specific cost calculations are provided in Appendix 1. The summary of the costs are presented in Table 1. While the design modifications included in the cost adjustments are expected to meet, and perhaps exceed, the new code requirements, this has not been formally established. It is our intention to err on the side of comprehensiveness rather than present unrealistically low costs.

As was noted in the previous section, in greenfield projects many acoustic improvements can be achieved through careful design rather than extra expense through more expensive materials. For example, a shift in floor design so that the classroom space is less rectangular and more closely approximates a square would most likely have acoustic benefits and perhaps even reduce building material requirements. Such design considerations are not considered in the analysis here.

The costs are calculated on a basis of additional cost requirements. That is, we are interested in the cost increase associated with complying with the proposed more stringent building code acoustic requirements, not the total classroom building costs. As a point of reference, however, the Ministry of Education currently use an estimated cost of classrooms of $130,000 (standard) and $230,000 (specialist)[4].

Specific items included in the calculations are as follows:

Ceilings	Ceiling tile costs are based on quotes for Ecophon Master F-beta finish (40mm thick) ceiling tiles provided by New Zealand suppliers Holden Architectural Ltd. Four possibilities are modelled based on full or partial ceiling coverage and whether additional installation labour costs of $20 per m^2 are included.
Carpet underlay	Priced at $4.00 per m^2 based on quotes from carpet suppliers
Internal wall	Flexible sealant in timber frame wall cavity between classroom and atrium and ablutions for extra sound insulation. Costing derived from tables provided in Rider Hunt (2004)
Exterior walls	Costs account for the extra cost for Titan or Exotec board in exterior walls. Allowance has been made for windows and doors. It is assumed that this is not needed around the foyer/passage and ablutions. Seven metres of seismic /acoustic joint in external cladding are also included. Costing derived from tables provided in Rider Hunt (2004)
Windows and exterior door	Extra cost for laminated glazing on windows and one door unit. Costing derived from tables provided in Rider Hunt (2004)
Internal door	Upgrading internal door between classroom and foyer/passage to acoustic door standard. Costing derived from tables provided in Rider

[4] Specialist has a long definition but is essentially a classroom that because of the nature of the curriculum requires a greater area or special plumbing, gas or electrical features.

	Hunt (2004)
Separation of deck foundations	A common theme in the Oticon report was the vibration caused by foot traffic on external walking decks. A way of mitigating this noise is to have decks and classrooms on independent foundation piles. I have not been able to ascertain whether this would entail any extra cost, but have incorporated an arbitrary $50 per metre cost addition into the cost calculations.

The summary of these cost calculations are presented in Table 1. The cost-benefit analysis that follows is based on the costs presented in column 2 of Table 1, ie $9,811, which includes a ceiling tile installation cost of $20 per m^2. While there may be some additional charges associated with installing acoustic ceiling tiles, we have chosen to err on the high side by adopting the $20 per m^2 labour cost assumption.

Table 1: Estimated extra costs to meet proposed building code changes

	1	2
Ceiling		
Total classroom	$3,248.49	$4,550.49
Partial classroom	$1,746.50	$2,446.50
Carpet Underlay	$243.00	$243.00
Internal wall for extra sound absorption	$256.50	$256.50
Exterior walls	$1,941.40	$1,941.40
Windows and exterior doors	$1,600.00	$1,600.00
Upgrading internal door to fire door	$600.00	$600.00
Separation of Deck foundations	$620.00	$620.00
Total extra cost (full ceiling)	$8,509.39	$9,811.39
Standard classroom cost	$130,000.00	$130,000.00
Costs of acoustic remedies as percent of standard classroom cost		
Just partial ceiling	1.3%	1.9%
Just full ceiling	2.5%	3.5%
Total package	6.5%	7.5%

Column 1 excludes labour cost component from ceiling costs
Column 2 includes these extra costs

.

Benefit calculations

There are three potential sources of economic benefit from higher classroom acoustic building standards:

- health improvements for teachers;
- education improvements for students;
- a spillover into reduced heating costs due to better insulated classrooms.

Heating

No calculations have been made here to account for any potential reductions in heating costs that might accrue as a spill-over from design features introduced for classroom acoustic reasons. It would seem likely that some positive spill-over would exist from this source, as many of the initiatives designed to insulate the classroom from external noise would also insulate the classroom from external temperature differences. Without further assessment of this potential effect we must just conclude that actual benefits are likely to be moderately greater than presented here.

Teacher health

The key occupational hazard resulting from poor classroom acoustics identified in the literature is vocal strain, as teachers are required to talk for long periods at an elevated voice level. An international study noted that 80% of teachers reported vocal strain compared with 5% of the general population[5]. Lubman and Sutherland (2001) report that US teachers lost an average of 2 days in 2000 due to vocal fatigue caused by raising their voices to talk over noise. This represents a significant additional education cost as the system has to continue paying for the sick teacher as well as the costs of a relief teacher. There would also be a disruption effect on students that would be difficult to assess.

Unfortunately there is no central collection of statistics in New Zealand on sick leave taken by teachers, nor the reasons why they might be sick. Also we need to be cautious in assuming that overseas conditions apply in New Zealand. In particular, as has already been noted, New Zealand teachers particularly in primary schools place a high emphasis on incidental teaching methods. Much time is put into group work, mat work and one on one teaching. Indeed blackboard/didactic teaching appears to be a minority activity in New Zealand primary schools, with the Oticon report indicating it amounts to just 12% of teachers' teaching time (p14).

Anecdotal evidence through conversations I have had with the NZEI, the NZ School Trustees and school principals suggests that vocal strain is not an obviously big issue here in New Zealand. However, this does not mean that health impacts on teachers from poor classroom acoustics

[5] Sapienza C, Crandell C and Curtis B (1999) "Effects of Soundfield Frequency Modulation Amplification on Reducing Teachers Sound Pressure Level in Classrooms" *Journal of Voice*, Vol 13, No 3, pp 375-81, quoted in Oticon (2002)

should be dismissed. Working in a noisy environment can raise stress levels even if it does not result in voice strain. Noise related high stress levels could potentially lead to increased incidence of sickness and sick leave, even if the actual sickness might not appear to be directly noise related.

We have thus made calculations to estimate the financial benefit of reduced teacher sick leave, or more correctly lower relief teacher costs. The calculations are based on a reliever teacher cost of $200 per day, which is lower than the 2003 average teacher daily cost of $256[6]. The net present values of a number of scenarios are presented in Table 2. Cost savings are calculated based on a half day (low), one day (medium) and two day (high) reduction in relief teacher requirements per year. The effective life of a classroom will also impact on calculations, as will the choice of discount rate.

Table 2: NPV of lower per classroom relief teacher costs

	4% discount rate		
Classroom life	Low	Medium	High
10 years	$811	$1,622	$3,244
15 years	$1,112	$2,224	$4,447
20 years	$1,359	$2,718	$5,436

	5% discount rate		
Classroom life	Low	Medium	High
10 years	$772	$1,544	$3,089
15 years	$1,038	$2,076	$4,152
20 years	$1,246	$2,492	$4,985

	10% discount rate		
Classroom life	Low	Medium	High
10 years	$614	$1,229	$2,458
15 years	$761	$1,521	$3,042
20 years	$851	$1,703	$3,405

Our preferred estimate is $2,076, which assumes that improvements in classroom acoustics will lead to a one day per year reduction in use of relief teachers per classroom. This is based on a 15 year effective classroom life and a 5% discount rate[7]. However, the sensitivity tests

[6] Calculation based on an average annual salary of $50,000 and a 39 week teaching year.

[7] The choice of discount rate is based on the results of the study by Belzil and Hansen (1999) on the interaction between education and household characteristics and ability. With use of the National Longitudinal Survey (US) they estimated a subjective annual discount rate between 4 and 5%. We use a 10% discount for the high discount rate sensitivity test given that this is the benchmark rate often used to discount government project benefit streams. The choice of effective classroom life is deliberately conservative.

suggest that the net present value of potential cost reductions could plausibly range from around $600 to almost $5,500 for each new acoustically enhanced classroom.

An implication of this result is that while individual schools may see the merits of enhanced acoustics in classrooms, the economics faced by the school for a comprehensive approach is at best marginal. The key issue is that public schools receive little economic benefit from improved student outcomes, so a building cost increase will need to be offset by cost reductions elsewhere. It is not apparent that lower relief teacher costs and heating cost savings would be sufficient for schools to introduce the proposed building code acoustic improvements on their own volition. Some schools might (and indeed have) but the general standard would not be as high as currently proposed.

Student benefits

The key argument behind devoting more effort and finances to improving classroom acoustics is about improving the educational outcome of students. Unfortunately, while it seems logical that improved room acoustics should improve educational outcomes it has so far proven quite difficult to demonstrate this in a comprehensive way. For example in the 2002 Oticon study, a number of classrooms were modified (acoustic ceiling tiles were added to the middle 35 m^2 of the classroom ceiling). While subjective responses to the modifications by teachers and students were generally positive, there was little discernible improvement in speech intelligibility tests. This suggests that some caution should be taken in not overstating the positive impacts of better classroom acoustic conditions.

However, the impact should still be expected to be greater than is suggested from the objective measures obtained from the Oticon study. To begin with the modifications offered were partial in nature; the acoustic tiles used were not all high perfromance acoustic tiles and the coverage of the ceiling was not complete. In addition the modifications did not address any background noise issues. Indeed subjective responses indicated that the improved classroom acoustics raised awareness of external noise (p24). Even though the modification was partial, there was a significant reduction in pre and post mid-frequency reverberation time measurements, from 0.69 seconds to 0.43 seconds (p23).

On balance we base our calculations around a middle assumption that better room acoustics improve normal hearing intelligibility by 5%. We also undertake sensitivity tests based on 1% and 20% improvements. The latter is very large, but is used more to calculate the possible impact that might accrue to the hearing impaired.

Governments invest in education because they expect long term social and economic benefits to accrue from having a better educated population[8].

[8] From a public policy perspective education is often described as a merit good; the benefits to society from education exceed the benefits received by individuals. For example, I benefit if I work for a well trained and able manager and I also benefit if the government employs well trained and able policy advisors. But because the private benefits are lower than the social benefit, the

While the way that the benefits from education can be varied and wide ranging[9], economic analytical methods attempt to quantify and measure the net aggregate benefits to society. While there is general acceptance that society benefits from education, the magnitude of these economic benefits is a hotly debated issue[10]. Temple (2001) notes that there is a growing consensus that the private returns from extra education ranges from 5 to 15%. That is, an extra year of schooling will on average result in individuals being able to command wages 5 to 15% higher than they would have received without the extra year of schooling. But there is also a growing consensus that economic returns, ie changes in the nation's productive capability, are lower. The reasoning behind this perspective is that while a higher level of education may make a worker more productive, it may also yield a greater private return if education record is used as a signalling device by employers for choosing prospective workers. If this is true it implies that there is a degree of over-education that, by implication, is paid for by a widening in the income distribution.

The ability of research techniques to isolate the growth impact of education is an important contribution to differences in views on this issue. Here we use a central assumption that an extra year of schooling results in a one-off, but sustained 5% improvement in wages. This choice is heavily influenced by the recent results of Bassanini and Scarpetta (2001). We presume that this is the amount of the private return that is shared with the economy. As a sensitivity test around this we have used a low assumption of 2.5% and high assumption of 10%.

Effectively the modelling in our central scenario assumes that the results of students being able to hear more clearly what is going on around them in classrooms with better acoustic standards has the equivalent educational effect as extending the school year by 5% would. Thus the 5% economic benefit assumption implies that for each year that the student is an acoustically superior classroom they will receive a one-off, but sustained 0.25% (ie 5% of 5%) increase in the wage they receive in their working life than would have happened if they were taught in a standard, but acoustically inferior classroom.

The key word in the preceding paragraphs is "assumption". We can not be definitive about either the impact of acoustic improvements on teaching quality or the subsequent impact this has on the economy and society. While our central assumptions incorporate our best judgement on the likely impacts, actual impacts could be higher or lower. We allow for this in our calculations by testing the sensitivity of the results to these and other assumptions.

Other critical assumptions used in the calculation of student benefits resulting from acoustic improvements to classrooms are presented in Table 3.

amount of education consumed is likely to be less than the social optimal amount, if it is left solely to individual's market choices. Government provision of education services is aimed at correcting for this potential under-investment in education.

[9] For a discussion of the ways that education can make a difference to people's lives see Johnston (2004)

[10] See for example Norton et al (2000), Sianesi and Van Reenan (2002) and Temple (2001) for reviews on the literature in this field.

To obtain a dollar amount changes need to be applied to a wage assumption. Our central assumption is that this is $30,000, which is above the $28,000 average income reported in the June 2003 Income Survey, but below the average wage of $40,000 implied by the March 2004 Quarterly Employment Survey. A low figure of $20,000 and a high of $40,000 are used for sensitivity tests.

How long one works for, the number of students per class, the effective life of the new classroom and the discount rate used will also influence calculations. Our central scenario implies a working life of 45 years, a class size of 20 pupils, an effective classroom life of 15 years and a 5% discount rate[11].

Table 3: Assumptions used in student benefit calculations

Assumptions	low	medium	high
1. Improvement in hearing	1%	5%	20%
2. Private/economic return	2.5%	5.0%	10.0%
3. Average wage	$20,000	$30,000	$40,000
4. Working life (years)	40	45	50
5. Class size	15	20	25
6. Classroom life (years)	10	15	20
7. Discount rate	10%	5%	4%

Calculation of the central scenario is presented in Table 4. The line numbers refer to lines in Table 3.

Table 4: Calculation of central scenario student benefit

% increase in wages	(line 1 x line 2)	0.25%	(A)
Individual increase in annual wage	((A) x line 3)	$75.00	(B)
Lifetime wage increase	NPV of (B) over 'line 5' years with 'line 7' discount rate	$3,214	(C)
Lifetime wage increase for single year class	((C) x line 6)	$64,286	(D)
Lifetime wage increase for life of classroom	NPV of (D) over 'line 6' years with 'line 7' discount rate	$667,264	(E)

[11] The working life assumes beginning work at the age of 20 and retiring at 65. According to Ministry of education figures the primary/intermediate school classroom ratio in 2001 was 22.47. The equivalent figure for Secondary schools was 18.41. See footnote 7 for a discussion about classroom life and discount rates.

The benefits to students accruing from an improvement in the acoustic quality of classrooms, as implied in this central scenario, are very large – both in terms of the comparison to our extra construction cost estimates and to the types of benefits that accrue to the school directly. When the benefits accruing to schools through reduced relief teacher costs are added to the calculation in Table 4, one obtains a central scenario NPV benefit estimate of $669,340, which is 68 times bigger than the estimated construction costs of $9,811.

Table 5: Impact of using extreme assumptions

	All low	All medium	All high
Effective increase in schooling (years)	0.01	0.05	0.20
% increase in wages	0.03%	0.25%	2.00%
Individual increase in annual wage	$5.00	$75.00	$800.00
Lifetime wage increase	$182	$3,214	$38,462
Lifetime wage increase for single year class	$2,727	$64,286	$961,538
Lifetime wage increase for life of classroom	$16,758	$667,264	$13,067,621

Table 5 presents the results if one uses extreme high and low assumptions, ie if the calculations are done using the numbers in each column of Table 3. The 'all low' scenario assumes that the proposed adjustment to the building code improves the education quotient by just 1%, that the impact on wages is 2.5% for extra year of school, that the improved student will have a base wage of just $20,000, classroom sizes are 15, the classroom will need refurbishment in 10 years time, and that a 10% discount rate is used for net present value calculations. This lowers our NPV estimate of benefits considerably from $667,264 to $16,758. Yet even with these much more stringent assumptions, the now more modest benefits still considerably exceed the estimated costs. Even assuming there are no benefits from reduced teacher sickness levels or reduced heating costs, the estimated net present value of benefits is 1.7 times the size of the estimated cost of $9,811.

The benefits implied by the 'all high' scenario seem implausibly high, but suggest that there still might be some significant upside on the central scenario.

The sensitivity of these student benefit calculations to changes in individual assumptions are presented in Appendix 2. The calculations are based on the central scenario. So each result presents the impact of changing just one assumption.

Table 6 presents a summary of four potentially plausible scenarios. The first is our central scenario based on what we regard as the most plausible set of assumptions.

Table 6: Summary results

	Central	Pessimistic	Low benefit/central	Special class
NPV of stimulus to lifetime earnings	$667,264	$16,758	$66,726	$2,669,055
NPV of cost saving from reduced teacher sick leave	$2,076	$0	$0	$2,076
Total Benefits	$669,340	$16,758	$66,726	$2,671,131
Cost	$9,811	$9,811	$9,811	$9,811
Benefit/Cost Ratio	68.2	1.7	6.8	272.2

The ‘pessimistic’ scenario is the lower bound of likely positive outcomes. A worse outcome is feasible, but this would require a nil benefit from the proposed changes to education outcomes.

The ‘low benefit/central’ scenario assumes that each student receives the modest 1% increase in education outcomes that the payoff into later wages is just 2.5%, but all other assumptions are per the central scenario. What this demonstrates is that even if the education outcomes and the translation of these benefits into later earnings are both quite modest, more normal expectations about average wages, classroom sizes, and the expected effective life of classrooms yields benefits almost seven times bigger than the estimated extra capital costs.

The special class scenario assumes that acoustic changes have a high impact on educational outcomes and earning improvements, but is based a low wage base ($20,000). Class size is assumed to be small (15) and all other factors are medium. This scenario is an attempt to quantify the potential benefits to special needs students. While the calculations are based on a dedicated classroom, this is merely a way of pooling the potential impact on special needs students.

The estimated size of these returns may be on the high side, but the key point is that net benefits are likely to be relatively greater for special needs students. As the starting point, say measured in speech intelligibility tests, is likely to be lower, the relative impact of each extra word understood is significantly more important for students with hearing-impairments. Also better communication with the rest of the class will provide more potential time for one-on-one attention with main streamed special needs students.

4. CONCLUSION

This report has presented an indicative cost-benefit analysis of the potential impact of proposed changes to the Building Code with respect to Airborne and Impact Sound for educational facilities.

The analysis has been based on the assumed extra costs of constructing a new relocatable classroom (Ministry of Education relocatable module C) that has extra features that improve the acoustics of the room. In doing this it is not clear to what extent our results can be generalised for other education uses such as early childhood education facilities or specialised education rooms.

The analysis also does not consider the costs and benefits associated with remedial work to improve the acoustic standards of existing classrooms. While the types of associated benefits are likely to be similar to those considered here, the costs will be very much more case specific and there will be less scope to reduce costs through design.

Given these limitations our conclusions are that:

- The commercial incentives for individual schools, ie savings from teacher reliever costs, are unlikely to be sufficient to justify schools to adopt improved classroom acoustic designs on a unilateral basis.
- The gains from improvements in students' life time earning prospects are likely to be significantly greater and potentially very dramatic; our central scenario estimates the net present value of benefits to exceed initial costs by a multiple of 68.
- Even if the marginal impact of better classroom acoustics on each individual student is very modest, there is still likely to be a net positive benefit; our worst case scenario yields a benefit-cost ratio of 1.7.
- The unit of analysis here is the classroom. Calculations of benefits are based on the potential benefits accrued to students occupancy of classrooms for one school year. The lifetime benefit to individual students is likely to increase with the number of school years they are taught in classrooms with higher acoustic qualities, but this is not considered in the current report.

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Appendix 1

Costs based on Relocatable Module, Type C

Classroom size is 65.1 m^2		Sources/notes
Carpet Underlay		
Area	60.75	
cost per m^2	$4.00	Based on quote from carpet suppliers
Total cost	$243.00	
Internal wall for extra sound absorption		
Area (m^2)	17.1	
Flexible sealant in timber frame wall cavity		
cost per m	$15.00	Rider Hunt (2004)
Total cost	$256.50	
Exterior walls		
Area (m^2)	35.4	
Extra cost for Titan exotec board		
Extra cost per m^2	$41.00	Rider Hunt (2004)
Total cost	$1,451.40	
Seismic /acoustic joint in external cladding		
Required metres	7	
cost per m	$70.00	Rider Hunt (2004)
Total current cost	$490.00	
Windows and exterior doors		
Extra cost for laminated glazing		
No of 2.6x1.2 aluminium window units	3	
Extra cost per unit	$200.00	Rider Hunt (2004)
Total cost	$600.00	
Extra cost for laminated glazing on door units		
No of 2.7x2.4 aluminium door/window units	1	
Extra cost per unit	$1,000.00	Rider Hunt (2004)
Total cost	$1,000.00	
Upgrading internal door to fire door		
No of doors	1	
Extra cost per door	$600.00	Rider Hunt (2004)
Total cost	$600.00	
Separation of Deck foundations		
Length	12.4	
cost per metre	$50.00	There is no basis for this cost
total cost	$620.00	

Ceiling[12]

Total classroom		with extra labour costs
Area	65.1	65.1
Cost per m^2	$59.90	$79.90
Total cost	$3,899.49	$5,201.49
Current cost per m^2	$10.00	$10.00
Total cost	$651.00	$651.00
Cost difference	$3,248.49	$4,550.49

Partial classroom		
Area	35	35
Cost per m^2	$59.90	$79.90
Total cost	$2,096.50	$2,796.50
Current cost per m^2	$10.00	$10.00
Total cost	$350.00	$350.00
Cost difference	$1,746.50	$2,446.50

♣[12] Ceiling tile costs are based on quotes for Ecophon Master F-beta finish (40mm thick) ceiling tiles provided by New Zealand suppliers Holden Architectural Ltd. A labour cost of $20 per m^2 was also provided

Appendix 2

Sensitivity of:	**Low**		**High**	
	$	% diff from central	$	% diff from central
Improvement in hearing	$133,453	-80.0%	$2,669,055	300.0%
Private/economic return	$333,632	-50.0%	$1,334,527	100.0%
Average wage	$444,842	-33.3%	$889,685	33.3%
Working life (years)	$593,123	-11.1%	$741,404	11.1%
Class size	$500,448	-25.0%	$834,080	25.0%
Classroom life (years)	$496,397	-25.6%	$801,142	20.1%
Discount rate	$466,737	-30.1%	$721,626	8.1%