A review of the scope of scientific studies relating indoor environment and student performance

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ABSTRACT: In 2006-7 the Australian government will invest $9.3 billion in state government and non-government educational facilities (DEST 2006[1]). One area of particular interest to both government and school designers is maximising this investment through providing students with healthy and productive indoor learning environments. The lack of post-occupancy evaluations carried out in schools (Lackney 2001) means that designers are reliant on "best practice" indoor environment quality guidelines developed primarily from scientific studies. The problem with scientific evaluation is that often the complexity of the influences upon student performance is simplified in order to gather information, rather than necessarily providing a more holistic and realistic explanation of any improved outcomes. This paper examines the scope of various studies of classroom indoor environment qualities that have thus far contributed to current understanding of their impact on student learning outcomes. The review demonstrates the lack of comprehensive research into the full range of influences on student performance and offers a better understanding of the limitations of knowledge about indoor environment qualities. This information provides valuable input to research development and post-occupancy evaluation that can better integrate the full range of influences upon students of school facilities and test the assumptions made about "best practice".

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INTRODUCTION

Understanding the impact of school design on student performance is important for designers to provide effective learning environments in schools (Daisey et al 2003, Mendell and Heath 2005, Freitag et al 2002). Past studies have demonstrated the influential links between indoor environment quality and office worker performance (Leaman and Bordass 1999, Seppanen et al. 1999), thus leading building professionals to investigate the impact of school indoor environments on student performance.

Measures of indoor environmental quality (IEQ) encompass the assessment of those aspects of an environment that have an impact on the health and comfort of occupants. Scientific studies of IEQ have attempted to demonstrate the link between the impact of, for example, indoor air quality, ventilation rates, temperature, lighting and acoustics on student performance outcomes which can range from mental or physical well-being, student engagement and motivation through to academic achievement or even language development. The method adopted for analysis of the scientific studies in this review, involves the categorising and coding of studies into three performance output measures: productivity, behaviour and health. Thus student *Productivity:* is taken to refer to studies using measures of academic achievement, task performance, task persistence, concentration, work errors, learning rates, ability to learn, perceptual learning, concept formation, language development and creative/aesthetic growth (Lackney 1999, Heschong et al 2002, EPA 2005, Opdenakker and Van Damme 2000); student *Behaviour:* concerns research using measures of student attitudes, engagement and motivation (Milton et al 2000, Lackney 1999, Ainley 2004); and student *Health:* encompasses studies using assessments of mental wellbeing, physical wellbeing and comfort (Milton et al 2000, Shendell et al 2004, Lackney 1999, Opdenakker and Van Damme 2000).

This paper reviews the current body of research of indoor environment qualities (indoor air quality, ventilation rates, temperature, lighting and acoustics) against these three aspects of student performance outcomes (productivity, behaviour, and health), and seeks to demonstrate the limitations of scientific investigation in such research in both breadth of approach and reliability. Scientific method requires simplification of complex systems in order to make them testable and thus gather information. As a result, when scientific method is used to investigate school indoor environment quality, only one or two aspects are selected for testing and the conclusions drawn may not adequately consider the full range of influences or measure the full range of outcomes. For example, studies take no account of external or internal influences upon student performance (for example, home environment and parental support, teacher calibre, or student motivation and interest in a subject) which are highly likely to have a major influence upon student achievement. An example of the difficulties of separating the most influential aspects of school environment on student performance is provided by one case study that measured the impact of the comprehensive overhaul of an inner-city school (Berry 2002) on student academic achievement and student behaviour. Whilst problems identified with the indoor environment qualities of its' classrooms were rectified, a wide range of educational and community programs were also instituted. Significant improvements in student productivity, measured by academic

[1] http://www.dest.gov.au/sectors/school_education/default.htm

achievement and in student behaviour, ascertained in attitudinal surveys and attendance records, were identified, but no health outcomes were measured. The scope of the school's overhaul has made it impossible to determine which of the changes proved to be responsible for different productivity and behaviour improvements. Indeed, a review of studies of the influence of indoor environmental quality on student performance by Mendell and Heath (2005) concluded that there was insufficient good quality research to form any solid conclusions.

It is therefore important for school designers to understand the nature of the limitations of current "best practice" information, both to inform further research and to critically implement strategies recommended by current guidelines. School design needs to be informed by broader-based more comprehensive studies that examine the complexities of the relationship between student performance and elements of the school environment.

1. INDOOR AIR QUALITY

Evidence suggests that, due to its impact on both health and productivity, the quality of air in the classroom has the largest impact of all indoor environment quality factors on student performance (Schneider 2002). It has been estimated that poor indoor air quality affects more than 15,000 schools, or over 8 million children, in the United States (Schneider 2002). The young are particularly susceptible to pollution, as they have had less lifetime exposure to environmental conditions to develop resistance and they breathe higher volumes of air relative to their body weight (Heath and Mendell 2003, Kahn 2004).

Scientific studies utilising measures of indoor air quality have been analysed and categorised for their contributions to research knowledge according to the three student performance outcomes. Table 1 illustrates the distribution of this research undertaken into the effect of indoor air quality on student performance. The research studies tend to measure either productivity or health and only one study attempts to measure the effect of indoor air quality on student behaviour (Berry 2002).

Table 1: Research into the Influence of Indoor Air Quality on Student Performance

Indoor Air Quality Research	***Student performance outcome measure***		
	Productivity	***Behaviour***	***Health***
Berry 2002	X	X	
Clements-Croome et al. 2005	X		X
Daisey et al. 2003			X
Fisher 2001	X		X
Heath and Mendell 2002	X		
Schneider 2002	X		
Smedje et al. 1997			X

Student health and wellbeing is a fundamental factor affecting their attendance (Heath and Mendell 2002), behaviour in the classroom, and productivity (Clements-Croome et al 2005). The results of Smedje et al (1997) suggest that asthma symptoms are exacerbated by school environments with large classrooms, furnished with dust-holding fittings, low air exchange rates, moisture damage from poor maintenance and high airborne allergen burdens. However, in most cases, studies that measured indoor air quality did not measure health symptoms in those schools (Daisey et al. 2003). According to Daisey et al. (2003), evidence was strong that schools in the USA and Canada experienced poor indoor air quality, however few studies went on to investigate the subsequent effect on student health in these conditions. Those studies which did measure both air quality and student performance outcomes were unlikely to cover even two categories of performance outcomes from the full spectrum.

Whilst providing encouraging links between indoor air quality and student performance, none of the research actually investigated the impact of air quality in the classroom on all outcome types: productivity, behaviour and health. Overall, the scientific studies of indoor air quality do not offer assured outcomes of improving student performance and the precise impact that indoor air quality has on student learning remains indeterminate.

2. VENTILATION RATES

Adequate ventilation can reduce the effects of poor air quality in classrooms (Daisey et al. 2003) and evidence also illustrates the links between student performance/attendance and poor ventilation (Heath and Mendell 2002). Although this evidence is inconclusive, it is important to note that poor ventilation of rooms has been related to productivity and health effects, including lower student concentration levels and higher numbers of health complaints (Mendell and Heath 2003), increased student absence (Shendell et al. 2004), and lower performance in both children and adults (Mendell and Heath 2005).

Of particular concern is the occurrence of very high levels of carbon dioxide in classrooms. Schneider (2002) reports that concentrations of carbon dioxide from 1000 parts per million (ppm) and above cause headaches, drowsiness and attention problems, while Clements-Croome et al. (2005) and Daisey et al.(2003) indicate that carbon dioxide in classrooms can reach up to 4000ppm. Benefits of improved ventilation through the instalment of operable windows were measured by the Heschong Mahone Group (1999) to increase student progression by 7-8% compared to rooms with fixed windows irrespective of air conditioning systems.

Table 2: Research into the Influence of Ventilation on Student Performance

Ventilation Research	***Student performance outcome measure***		
	Productivity	***Behaviour***	***Health***
Clements-Croome et al. 2005	X		X
Daisey et al. 2003			X
Mendell and Heath 2003	X		X
Heath and Mendell 2002	X	X	
Heschong Mahone Group 1999	X		
Mendell and Heath 2005	X		X
Myhrvold 1996	X		X
Schneider 2002	X		X
Shendell et al. 2003		X	X

Table 2 shows the distribution of research into the effect of ventilation on student performance. While it is commonly accepted that ventilation levels affect health and productivity, where the reviewed research above falls short is in its' rigid interpretation that absentee rates are the sole behavioural outcome of poor ventilation. The researchers fail to take other factors into account; students may be absent due to illness, as well as truancy, but the research figures do not differentiate between those reasons. Chen et al. (2000) suggests that outdoor pollution levels are also strongly linked to school absenteeism, which is again not clarified as a behaviour or health symptom. Most of the research investigated student performance, as affected by ventilation, as both productivity and health outcomes. Whilst ventilation design for classrooms can be strongly linked to improved productivity and health for students, the impact on behaviour is less well understood in these research investigations. This means that "best practice" guidelines for school design which recommend high levels of fresh air for classrooms are not based on any proven causal relationships.

3. TEMPERATURE

The temperature and humidity conditions inside a classroom have been linked to student task performance, attention to task spans and reported levels of comfort (Lackney 1999, Smith and Bradley 1994)). Evidence suggests temperatures ideal for learning are dependant on individual comfort preferences and external climate (de Dear et al 1997). Higher temperatures increase discomfort among students leading to shorter attention spans and lower achievements, while lower temperatures affect dexterity (Schneider 2002, Fisher 2001, Lackney 1999). Schneider (2002) reports that teachers surveyed felt that the issue of thermal control was integral to the performance of students and teaching staff in the classroom. Higgins et al (2005) agrees that the control of the thermal environment is most important, a lack of control contributing to lower productivity and absenteeism. Jago and Tanner (1999) conclude that the classroom thermal environment affects student productivity at all grades of learning. Schneider's (2002) survey reported the importance of temperature to performance observed by teachers first-hand in the classroom. Table 3 demonstrates the results of these scientific studies to understand the impact of the thermal environment on student performance.

Table 3: Research into the Influence of Temperature on Student Performance

Temperature Research	***Student performance outcome measure***		
	Productivity	***Behaviour***	***Health***
Berry 2002	X	X	
Fisher 2002	X		X
Higgins et al. 2005	X	X	
Jago & Tanner 1999	X		
Lackney 1999	X		
Mendell and Heath 2004	X		X
Schneider 2002	X		

Investigations into the effect of temperature on performance outcomes for students are mainly focussed on productivity, not on student behaviour which would be an obvious counterpart to overall performance measures. The research suggests that productivity is affected by extreme temperatures and lack of environmental control, however, since Mendell and Heath (2005) warn that the results of the influence of temperature on performance are mixed, largely owing to personal responses to temperature, the understanding of "best practice" temperature tolerances on student health and behaviour is not conclusive.

4. LIGHTING

Research in the field of lighting and student learning environments has shown that daylight significantly affects learning rates: elementary school children performing 20% faster in Mathematics and 26% faster on reading tests in one year in classrooms with high exposure to daylight compared with those with minimal exposure (Heschong Mahone Group 1999). Schneider (2002), however, suggests errors in their methodology because it had not been proven that teachers in those classrooms compared in the study were of similar calibre. Plympton et al. (2000) compared the results of four case study schools with improved daylighting and concluded that there are both productivity and health benefits for students.

Heschong Mahone Group (1999) also showed that students in classrooms with diffused daylight improved 19-21% faster than those students in classrooms without daylight diffusing skylights. Schneider (2002) Fisher (2001) and Lackney (1999) concur that classroom behaviour benefits from well designed natural and artificial classroom lighting. Fisher (2001) concludes that full spectrum lighting offers health benefits, while Nicklas and Bailey (1996) suggest that vitamin D in full-spectrum lighting can offer student enhanced dental health and more growth than students in average lighting conditions. In a study investigating the effects of brightly lit and dim reading settings, Lackney (1999) concluded that the amount of light appropriate for a task will be determined by the individual student's learning style, therefore the teacher's ability to provide a combination of bright and dim spaces for reading activities was important to improved learning outcomes.

Table 4: Research into the Effect of Lighting on Student Performance

Lighting Research	***Student performance outcome measure***		
	Productivity	***Behaviour***	***Health***
Berry 2002	X	X	
Fisher 2001	X	X	X
Heschong Mahone Group 1999	X		
Lackney1999	X		
Nicklas and Bailey 1996	X	X	X
Olson & Kellum 2003	X		
Plympton et al. 2000	X		X
Schneider 2002	X		

Table 4 details scientific studies utilising lighting improvement measures analysed and categorised for their contributions to research knowledge according to the three student performance outcomes. Fisher (2001) and Nicklas and Bailey (1996) review existing research and conclude that lighting has an impact on all three aspects of student performance outcomes. As in the case of the other indoor environment qualities, the effect of lighting is generally measured against student test scores – and seen to primarily influence their productivity. Berry's (2002) case study of the *Charles Young Elementary School* presumed daylighting improvements influenced behaviour, and productivity. Unfortunately, the *Charles Young* study involved too many interventions to be able to determine which of the improvements to the indoor environment impacted most highly on student behaviour, or proved any causal relationship. Overall, most studies suggest that lighting does impact on student learning outcomes, however, individual learning styles often can mask attempts to link performance to lighting levels and few studies take health or behavioural issues into account.

5. ACOUSTICS

Current research indicates that high levels of external noise are particularly detrimental to the learning process (Lackney 1999, Fisher 2001, Schneider 2002). Noise interferes with communication within the classroom (Berry 2002) and causes disruption with the child's information processing, feelings of personal control and level of arousal Lackney 1999). Schneider (2002) also reported negative responses to high levels of noise in the classroom, including loss of concentration, less task persistence and higher levels of work error. Fisher (2001) and Schneider (2002) found increased blood pressure in students exposed to high levels of noise in the classroom, while Fisher (2001) again, cites higher levels of stress amongst students who are exposed to prolonged periods of noise. A recent overview of literature on school environments by Higgins et al. (2005) concluded that exposure to high levels of noise hinders cognitive processes in children and is detrimental to academic achievement in students.

Table 5: Research into the Effect of Acoustics on Student Performance

Acoustics Research	***Student performance outcome measure***		
	Productivity	***Behaviour***	***Health***
Berry 2002	X	X	
Fisher 2001	X		X
Higgins et al. 2005	X		
Lackney1999	X		
Schneider 2002	X		X

The body of information reviewed regarding the acoustics of learning environments, is largely concerned with how exposure to sound affects students' stress levels and their academic achievement. Table 5 illustrates how selective these studies are – with limited research attempting to understand the impact of acoustics on student behaviour in particular. None of the studies listed in Table 5 comprehensively engage with the full scope of student performance outcomes impacted by acoustics in the learning environment. The studies do not fully assist with guidelines as to how to overcome noise or acoustical problems in school design.

CONCLUSION

What has been determined from the research is that there are demonstrable effects of the quality of school indoor environments on student performance (Mendell and Heath 2002, Daisey et al. 2003, Schneider 2002). Clean air, good light, quiet, comfortable and safe learning environments appear to impact on student achievement (Schneider 2002**,** Lackney 1999, Heschong Mahone Group 2002, US EPA 2000, Mendell and Heath 2002, Heath and Mendell

2004). However, the exact nature of the inter-relationships is often poorly defined and causal relationships are not always proven, the full range of influences are not always measured, which means that guidelines issued for designing healthy, productive schools are not soundly based.

The problem with scientific evaluations such as these, is that often the complexity of the influences upon student performance is simplified in order to gather information – student performance outcomes are often reduced to test score performance for example. The tabulation of the school indoor environment quality studies above, clearly illustrate the effect of scientific rationalisation that reduces the complex real-world classroom environment into measurable features. Certainly none of the individual indoor environment qualities, indoor air quality, ventilation, temperature, lighting and acoustics, have been subjected to a thorough and comprehensive investigation of their impact on the full range of student performance outcomes – ie student productivity, student behaviour and student health. Additionally, these studies take no account of external or internal influences upon student performance (home environment and parental support for example, or motivation and interest in a subject) which could have a major influence upon student achievement. There is a lack of good quality research on which to base any sound conclusions (Mendell and Heath 2005). These findings strongly argue for a more holistic approach to scientific research design, to take into account the full spectrum of student performance outcomes. This extensive review and categorisation of current research offers a better understanding of the limitations of knowledge about indoor environment qualities and illustrates how student performance outcomes are often too narrowly defined. This information provides valuable input to research development and suggests the need for post-occupancy evaluation that can better integrate the full range of influences upon students of school facilities and test the assumptions made about "best practice". School design needs to be supported by better designed trans-disciplinary research that reflects real world situations if the academic and social goals of education providing effective teaching and learning environments are to be realised.

REFERENCES

Ainley, M. (2004) *What do we know about student motivation and engagement?* Australian Association for Research in Education, Melbourne.

Berry, M. A. (2002) *Healthy School Environment and Enhanced Educational Performance, The Case of Charles Young Elementary School Washington, DC* Prepared for The Carpet and Rug Institute.

Chen, L., Jennison, B. L., Brian, L., Yang, W., and Omaye, S. T. (2000). *Elementary School Absenteeism and Air Pollution* Inhalation Toxicology Vol 12, pp.997-1016.

Clements-Croome, D. J., Awbi, H. B., and Williams, M. (2005) *Ventilation rates in schools* The University of Reading

Daisey, J. M., Angell, W. J., and Apte, M.G. (2003) *Indoor air quality, ventilation and health symptoms in schools: an analysis of existing information*, Indoor Air, Vol 13, pp.53-64

de Dear, R., Brager, G., Cooper, D., (1997) *Developing an Adaptive Model of Thermal Comfort and Preference Final Report on RP-884* Macquarie University: Sydney.

Fisher, K. (2001) *Building Better Outcomes: The Impact of School Infrastructure on Student Outcomes and Behaviour*, Schooling Issues Digest, Department of Education and Training: Australian Government, Canberra, 6pp http://www.dest.gov.au/archive/schools/publications/2001/digest/building.pdf

Fisk, W. (2000) *Review of health and productivity gains from better IEQ* Proceedings of Healthy Buildings, Vol 4, pp.23-34.

Fisk, W. J. (2000) *Health and Productivity Gains from Better Indoor Environments and their Implications for the U.S. Department of Energy* E-Vision 2000 Conference, Washington DC.

Freitag, P. K., Woods, J. E., Hemler, B. Sensharma, N. P., Penney, B. A., and Marx, G. (2002) *Health, Energy and Productivity in Schools: Measures of Occupant Performance* Indoor Air, The Ninth International Conference on Indoor Air Quality and Climate, Monterey, CA, pp.834-839.

Heath, G. A. and Mendell M. J. (2002) *Do indoor environments in schools influence student performance? A review of the literature,* Proc. Indoor Air 2002, pp.802-807

Heschong Mahone Group (1999) *Daylighting in Schools: An Investigation into the Relationship Between Daylighting and Human Performance*. College of Education, University of Georgia.

Heschong L, Elzeyadi I, and Knecht C (2002) Daylighting in Schools: Reanalysis Report. California Energy Commission, Public Interest Energy Research Program (PIER), Sacramento, CA. New Buildings Institute, White Salmon, WA. 105p.

Higgins, S., Hall, E., Wall, K., Woolner, P., McCaughey, C. (2005) *The Impact of School Environments: A literature review* University of Newcastle Design Council.

United States Environmental Protection Agency (2005) *Indoor Air - IAQ Design Tools for Schools: High Performance Schools*, (2005): United States http://www.epa.gov/iaq/schooldesign/

Jago, E. and Tanner, C. K. (1999) *Influence of School Facility on Student Achievement* University of Georgia.

Kahn, M. (2004) *Does Pollution affect School Absenteeism?,* Amherst College, Bucks, UK 6pp.

Kinshella, M. R., Van Dyke, M. V., Douglas, K. E. and Martyny, J.W. (2001) *Perceptions of Indoor Air Quality Associated with Ventilation System Types in Elementary Schools* Applied Occupational and Environmental Hygiene, Vol 16, No 10, pp.952-960.

Lackney, J. A. (1999) *The relationship between Environmental Quality of School Facilities and Student Performance* School Design Research Studio, Environmental Design Research Association.

Lackney, J. A. (2001) The state of Post-Occupancy Evaluation in the Practice of Educational Design. Annual Meeting of the Environmenatl Design Research Association, Edinburgh, Scotland, July 3-6 2001. http://schoolstudio.engr.wisc.edu/poe.html

Leaman, A., and Bordass, W. (1999) *Productivity in buildings: the 'killer' variables* Building Research and Information, Vol 27, No 1, pp.4-19.
Mendell, M. J. (2003) *Commentary Indices for IEQ and building-related symptoms* Proc. Indoor Air, Vol 13, No 4, pp.364-368.
Mendell, M. J. and Heath G. A. (2003) *How Does Indoor Air Quality Affect a Child's Ability to Learn?* (2003) United States Environmental Protection Agency, 8pp
http://www.epa.gov/iaq/schools/pdfs/publications/iaq_and_student_performance.pdf
Mendell, M. J. and Heath G. A. (2005) *Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature* Indoor Air, Vol 15, pp.27-52.
Milton, K., Glenross, P. And Walters, M. (2000) *Risk of sick leave associatted with outdoor air supply rate, humidification, and occupant complaint*. Int. Journal Indoor Air Quality and Climate Vol 10, pp. 211-221
Myhrvold, A. N., Olsen, E., and Laurisden, O., (1996), *Indoor environment in schools: Pupil's health and performance in regard to CO_2 concentrations*, The Seventh International Conference on Indoor Air Quality and Climate, *Indoor Air 1996*, Vol 4, pp,369–371.
Nicklas, M. H. and Bailey G. B. (1996) *Analysis of Performance of Students in Daylit Schools* Innovation Design.
Olson, S. and Kellum S. (2003) *The Impact of Sustainable Buildings on Educational Achievements in K-12 Schools* Leonardo Academy Cleaner and Greener Report: Leonardo Academy Inc.
Opdenakker, M., and Van Damme, J. (2000) *Effects of Schools, Teaching Staff and Classes on Achievement and Well-Being in Secondary Education: Similarities and Differences Between School Outcomes* School Effectiveness and School Improvement Vol 11, No 2, pp.165-196.
Plympton, P., Conway, S., Epstein, K. (2000) *Daylighting in Schools: Improving student performance and health at a price schools can afford* American Solar Energy Society Conference, Madison, Wisconsin, National Renewable Energy Laboratory.
Purkey, S. C. and Smith, M. S. (1983) *Effective Schools: A Review* The Elementary School Journal, Vol 83, No 4, pp.426-452.
Schneider, M. (2002) *Do School Facilities Affect Academic Outcomes?* National Clearinghouse for Educational Facilities: Washington, DC http://www.edfacilities.org, accessed 16/04/2006
Seppänen, O. A., Fisk, W. J. Mendell, M. J. (1999) *Association of Ventilation Rates and CO2 Concentrations with Health and Other Responses in Commercial and Institutional Buildings* Indoor Air, Vol 9, pp.226-252.
Shendell, D. G., Apte, M. G., Kim, J., Smorodinsky, S. (2003) *School Indoor Environmental Quality Assessments and Interventions: Benefits of Effective Partnerships in California* Journal of School Health, submitted as "commentary" December 29, 2003.
Smedje, G., Norbäck, D., Edling, C. (1997) *Asthma among secondary schoolchildren in relation to the school environment* Clinical and Experimental Allergy, Vol 27, pp.1270-1278.
Smith, R. and Bradley G. (1994) *The Influence of Thermal Conditions on Teachers' Work and Student Performance* Journal of Educational Administration, Vol 32, No 1, pp.34-42
Tanner, C. K. (1999) *School Design Factors for Improving Student Learning* Department of Educational Leadership: University of Georgia.
Woods, J. E., Penney, B. A., Freitag, P. K., Marx, G., Hemler, B., Sensharma, N. P., (2002) *Health, Energy and Productivity in Schools: Overview of the Research Program,* Proc. Indoor Air 2002, 56-61.