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Research Survey 6/1

PRIMARY SCHOOLS: THE BUILT ENVIRONMENT

Karl Wall, Julie Dockrell and Nick Peacey
Institute of Education, University of London

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This is one of a series of 32 interim reports from the Primary Review, an independent enquiry into the condition and future of primary education in England. The Review was launched in October 2006 and will publish its final report in late 2008.

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A briefing which summarises key issues from this report has also been published. The report and briefing are available electronically at the Primary Review website: **www.primaryreview.org.uk**. The website also contains Information about other reports in this series and about the Primary Review as a whole.

We want this report to contribute to the debate about English primary education, so we would welcome readers' comments on anything it contains. Please write to: **evidence@primaryreview.org.uk** .

The report forms part of the Review's research survey strand, which consists of thirty specially-commissioned surveys of published research and other evidence relating to the Review's ten themes. The themes and reports are listed in Appendices 1 and 3.

This survey relates to Primary Review theme 6, **Settings and Professionals**.

The authors are at the Institute of Education, University of London: Karl Wall is Research and Development Officer for the Mobility 21 Project; Julie Dockrell is Professor of Psychology and Special Needs; Nick Peacey is Co-ordinator, Special Educational Needs Joint Initiative for Training.

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PRIMARY SCHOOLS: THE BUILT ENVIRONMENT

1 THE PRIMARY SCHOOL AS A BUILT SPACE

1.1 Introduction

Children experience a key part of their childhood in their primary school and it forms one of their principal social spaces (Dudek 2000). The school site, its buildings and grounds, provides the infrastructure which supports learning and development. 'School buildings should inspire learning. They should nurture every pupil and member of staff. They should be a source of pride and a resource for the community' (Ministerial introduction to the Building Schools for the Future consultation, DfES 2003a). Nurturing pupils means examining the ways in which school buildings contribute to, or become a barrier to, accessing the curriculum and meeting the core principles of the *Every Child Matters* agenda (DfES 2004). The design, disposition and use of school buildings transmit educational and social values (Alexander 2001: 176); so does the value placed by society on the quality and appropriateness of the spaces it provides for children's learning, inside and outside of school. To understand the ways in which school buildings impact on children and teachers it is necessary to consider a number of key features of the built environment: the school's location; its size; the ways in which classrooms are lit, ventilated, heated and exposed to different types of noise.

The focus of this review is the impact of the interconnected spaces of the English primary school as an environment for living and learning. To address this question we begin by considering the primary school as a building and the ways in which various social changes and political directives have impacted on its development. The evidence base examining the effects of noise, ventilation, heating and lighting in schools is then considered. For each environmental variable we consider relevant outcome measures. These outcome measures include pupil educational attainment and pupil and teacher well being and health. The limitations of the current data are discussed. The concluding section considers the factors that limit the 'future proofing' of schools and the impact of schools on environmental sustainability.

1.2 School design, pupil welfare and pedagogy

The quality of the built environment relates in part to the physical nature of its walls and roof (the built 'envelope') and the way these are constructed to create particular spaces, such as rooms and halls. Current school building stock necessarily embodies previous ideas of design, construction, purpose, maintenance and pedagogy. They also embody past assumptions and relationships between the communities served by the school and its staff and pupil body. Different perspectives and priorities have informed this basic view of the English school building as a 'used' space since the first great expansion in school building following the 1870 Act. The resulting building programmes were coherent and used relatively standard technical and architectural approaches. Building proceeded quickly in part because standardised designs were used. Two interrelated strands impacted on school building development; a welfare informed design strand and a pedagogy informed design strand.

Pupil welfare has been an explicit feature of school design since the 1870s. The introduction of Board Schools in this period brought with it the provision of spaces for pupils to be active in, the provision of adequate latrines and the creation of a robust and safe environment

(Dudek 2000). Edwardian school designs reflected wider concerns that children should have access to daylight (through the provision of large windows) and access to fresh circulated air (Lowe 2007). The 1931 Hadow Report (Board of Education 1931) took the view that buildings would be single storey with plenty of sunlight and fresh air where 'cross ventilation would be a prerequisite for classrooms expected to take 50 or more pupils' (Maclure 1984). After the Second World War this belief in the need for fresh air and light was linked to emerging ideas of the importance of making spaces outside a classroom 'healthy'; ideas of a 'vista'- an immediate view, and the nature of spaces adjacent to a classroom began to be important (Maclure 1984). This is apparent in more contemporary views, which also emphasise the importance of outdoor areas as an ideal vehicle for learning and socialisation across abilities and ages (Hayhow 1995).

Effective socialisation, which manages pupil learning, safety and wellbeing, needs to consider spaces both inside and outside the classroom. The recent Steer Committee Report (2005) noted that building layout affected pupil behaviour; that hidden spaces could prevent appropriate supervision of pupils and that narrow corridors encouraged jostling between pupils. The organisation of classrooms and offices and their relation to each other impacts on school atmosphere, potentially compromising a sense of focus and calmness. More broadly the same committee suggested that school design should support members of a school community in feeling safe, motivated, valued and respected.

Concerns about the school environment have typically focused on the needs of children. More recently there has been equal concern for school staff, focusing on morale, effectiveness and well-being. Research has demonstrated that the school environment has perceived and identifiable effects, both positive and negative, on school staff (USA: Corcoran, Walker & White 1988; UK: PriceWaterhouseCooper (PwC) 2001; Steer Committee Report 2005; McIntyre 2006).

The ways in which school design factors impact on children's behaviour and school ethos is complex. Both direct and indirect effects need to be considered and, as we shall see in the later sections, it is often difficult to quantify these effects and how they interact with each other. Two examples serve to illustrate these points. School toilets have a clear and specific intended use. Poorly maintained and managed toilets are a concern to pupils and staff alike. Moreover, pupils may find them unwholesome and frightening places because of substantiated risks of bullying (Vernon, Lundblad & Hellstrom 2003). The need to balance privacy and pupil security and safety with appropriate supervision for pupils in relation to toilets is acknowledged in current guidelines (DfES: Building Bulletin 99, 2006: 45-47). Direct impacts on pupil health may occur if pupils refrain from using toilets for long periods during the day, leading to potential urinary and bowel problems, prolonged ill health and missed schooling (Vernon, Lundblad & Hellstrom 2003). By corollary if pupils perceive their school toilets to be unsanitary or risky places, absenteeism may be encouraged as pupils seek to go home to use the toilet.

School dining areas illustrate another dimension of the built environment. Primary halls are often the venue for physical education (PE), assemblies, drama, dance, and other activities, as well as being let out for community use in the evenings and used for dining at lunchtime. Typically these areas are compromise spaces, which have multiple functions during a working day or at different times of the academic year (DfES: Building Bulletin 99, 2006: 38-39). The Steer Committee Report (2005) suggests that communal areas such as dining areas need to be civilised and well-ordered places that motivate pupils to remain in school over lunchtime and make a positive contribution to a healthy eating lifestyle. Such spaces should offer opportunities for positive and relaxed social interactions between pupils and adults. Recent guidelines even suggest that dining does not need to take place in the main hall of a primary school: consideration of in-class dining offers an alternative approach, depending on how meals are provided in the school (DfES: Building Bulletin 99, 2006: 38-39).

Prior to the Board schools, teaching involved large numbers of pupils being taught in rows in large communal rooms. According to Dudek (2000), Robson, in the Board School Reforms, introduced the use of separate classrooms, with sufficient circulation space for a teacher to inspect each pupil's work. The arrangement allowed each child to leave its desk during the lesson. Classrooms also included a generous area at the front for display, presentation and general circulation. Many primary schools built in this period and informed by these pedagogic principles remain in use today. In Board Schools most knowledge was transmitted from teacher to pupil; post-First World War policymakers adopted a different stance. They increasingly viewed the curriculum in terms of promoting a variety of experience and activity. The implications of the pre-Second World War decision to separate primary and secondary schools was still being consolidated after the Second World War, spurred on by the many schools that had been damaged or destroyed in the war and the government's raising of the school-leaving age.

Pedagogy changed over the period: knowledge ceased to be just about what could be acquired and stored. This change in pedagogy influenced changes in school buildings. Spaces were created to facilitate the ideal of the pupil as the agent of their own learning, development and social being. Despite the rhetoric of changes in learning, the dominance of the 3Rs in the primary school was maintained by history and selection at age 11 with an overwhelming focus on literacy and numeracy and little else (Alexander 2001).

Maclure (1984) has identified four threads in the Plowden Report (1967) which had a direct bearing on building approaches: the teacher's authority moving from being 'autocratic' to 'facilitative'; the encouragement of vertical grouping in schools; the 'integrated' organisation of the day and a commitment to a wider range of areas of learning, beyond the three Rs. The link between school design and learning was apparent in the thinking of those advising the Department for Education and Science (DES). Eric Pearson (1975), a recently retired Her Majesty's Inspectorate (HMI) inspector, took the view, when advising the Architects and Buildings Branch of the DES, that learning was both personal and individual. In infant schools this could be accommodated, he felt, through the use of an integrated curriculum organised in the form of a 'free day' model, which allowed learning experiences to run on into each other instead of being restricted to regularly changing fixed periods of time devoted to particular subjects. Synthesis and understanding were the goals of learning, implying a need for more flexible and adaptable spaces. These spaces could then accommodate different activities with minimal disruption to learning.

In practice these pedagogic impacts on design were also influenced by cost and were exacerbated by the poor financial state of English school-building authorities in 1950 (Saint 1987). The war had left many schools damaged and a large programme of rebuilding and new building was needed; that it be achieved quickly and at the lowest possible cost was critical. One response to these pressures was the introduction of 'systems' built schools, using lightweight frames and panel construction. This reduced costs and could be justified on the basis of flexibility and adaptability, but was not defensible for long. The system building approach was not without its critics. Four key criticisms were levelled against the system building approach: initial calculations failed to cover the likely cost of maintenance; the constructional stability of the buildings produced was in doubt; there were concerns about fire safety, in particular the ease with which flames could spread quickly through roof related spaces; and the quality and effectiveness of acoustic insulation and the possible impact of noise (Ward 1976).

Scarcity of resources in subsequent periods encouraged architects to develop new approaches. The 1960s and 1970s are often characterised as the period in which 'open-plan' classrooms, consequent on changes in educational theory, held sway. 'Open plan' classrooms may have had their origins in earlier developments. Maclure (1984) cites a Ministry of Education pamphlet from 1952, which compares primary schools of the early 1950s with those from the late 1940s. The former had 20 per cent of their space for circulation, the latter, 7 per cent. In effect this recreated the large spaces moved away from in the 1870s. The plan of the school therefore had fewer but larger classrooms (for example 61 to 83 square metres). This can be compared with the most recent Building Bulletin (DfES: Building Bulletin 99, 2006: 31) on primary school space which suggests a 'standard classroom' of 56 to 63 square metres, 'with the top to mid range used for inclusive classrooms,' and 'large classroom areas' of 63 to 70 square metres.

System-building, with other measures, was successful in delivering the numbers of buildings required across much of the country. In 1976 (DES/WO 1977) there were 5.8 million (m) places in primary schools in England and Wales, 1.1m (20 per cent) were in buildings completed before 1903, 1m (17 per cent) in buildings completed between 1903 and 1945 and 3m (51 per cent) between 1946 and 1976 (0.6m places (11 per cent) were in 'temporary accommodation'). Though the last statistic is depressing, building had proceeded since 1945: 10,500 schools had been built between 1945 and 1975. In comparison it should be noted that of the 17,504 schools forming England's Primary school stock in 2006, 3,400 (19 per cent) were built before 1919 (Patel 2007). If this was the height of school building in the 20th century, its low point followed the loss of power of the Labour government in 1979.

The change of government in 1979 ushered in 25 years of neglect – the importance of the school environment ceased to be an issue. Effective learning and teaching was reported to occur despite adverse physical conditions and lack of resources (Rutter, Maughan, Mortimore & Ouston 1979). As there was no evidence that school buildings made any difference to attainment there did not need to be much money spent on them. England reached a low point in its spending on school buildings (£600m a year) in 1996/1997. On the basis that the total number of school buildings in use at the time was approximately 23,000, £600m represented an allowance of £26,000 per school per annum. When Helen Clark published her review of the literature in 2002, she noted that

> The neglect of school buildings in the past quarter of a century corresponds with a lack of educational research into their use. Investigation into the physical environment as influencing learning outcomes has been largely ignored in favour of research into pedagogical, psychological and social variables… discussion… has ignored the fact that schools are physical entities as well as organisational units.
>
> (Weinstein 1984, cited in Clark 2002: 3).

The First National Commission of Education report *Learning to Succeed* (1993) made no reference to school buildings or architecture in its index. The follow-up study into the basis of improvement in ten disadvantaged areas (National Commission on Education 1996) indicated that while physical environment might not be a necessary pre-condition for improvement in some schools it was nonetheless an important and necessary condition for effective learning. Where improvements were found these were associated with careful attention to the physical environment. A significant study of school buildings, in terms of its effects on attainment, found evidence of indirect rather than direct relationships between buildings and attainment (PriceWaterhouseCoopers 2001). A similar conclusion was drawn in a more recent review (NRCNA 2007); however, in addition, the implications of many small effects in aggregation were highlighted.

1.3 Principles underlying school building in the future

A major programme of primary rebuilding and renovation is planned for England (Patel 2007). The question must be, however, the extent to which governments or other authorities now feel able to take the confident position of the Victorian builders and build schools, other than those which are not system-built, to a relatively standard pattern. The terms 'flexibility' and 'adaptability' have never been far from the thoughts of the builders of schools. Flexibility is normally taken as referring to a building's ability to be changed by its users; adaptability to refer to more major changes of use. The terms relate to architects' and other professionals' concerns to 'future-proof' their buildings, but also reflect a concern apparent in recent building guidance (DfES: Building Bulletin 99, 2006: 21-22).

School building design increasingly needs to take account of the actual uses to which the designed spaces will be put and the current costs. Learning needs change, and the spaces in which that learning takes place may also need to change. Two examples of impending change are illustrative. One is the acknowledged change in significance of the involvement of parents and carers in children's educational success (Desforges & Abouchaar 2003). Buildings that welcome and support parents' and carers' active involvement as partners in their children's learning are likely to be appreciated more than those that do not. A second example is the still developing impact of new communication technologies on classroom practice within and beyond the bounds of the physical space of a school in, for example, the use of wireless communication, text messaging and off-line and on-line interactive learning environments (BECTA 2007; DfES: Building Bulletin 99, 2006: 19).

Learning environments can have different implications for, and effects upon, different groups within the school population. Over the last ten years, it has become apparent that an education system can exclude or risk excluding pupils if it does not grow and adapt to remove barriers to their successful learning and participation. A drive to make buildings as supportive of inclusion as possible has developed alongside an increasing understanding of ways of removing barriers. The law (Disability Discrimination Act (DfEE) 1995; Special Educational Needs and Disability Act (DfES) 2001; Disability Discrimination Act (DfES) 2005) has reinforced this approach in relation to special educational needs and/or disabilities, supported by a series of Building Bulletins. This legislation has impacted powerfully upon contemporary approaches to school design and redesign because of its implications on provision for all, and in particular for those with a physical disability. The two areas of the school physical environment review that are showing the most rapid development are those relating to the acoustic and visual properties of learning spaces – both aspects that impact upon those with physical, behavioural and learning needs most directly. Many pupils identified as experiencing emotional and behavioural difficulties[1] have identified or unidentified communication impairments for whom the acoustic quality of classrooms is critical (Visser 2001).

Sustainability, both environmentally and socially, is important for the future of the design and building of primary schools. Sustainable design involves the use of energy saving techniques such as intelligent lighting systems, automatically adjusted temperature systems keyed to changes in room use, anti-glare systems and the use of low emissivity glass coupled with efficient monitoring and maintenance systems (McIntyre 2006; National Research Council of the National Academies of the USA (NRCNA) 2007; DfES: Building Bulletin 99, 2006).

Current policy suggests that schools will move from being primarily a place of instruction and teaching towards a broader-based centre for interaction, where many children's services

[1] Usually categorised by the DfES/DCSF census term 'behavioural, emotional and social difficulties'.

will be focused and used by a wider and more age diverse community (DfES: Building Bulletin 99, 2006: 19-21). This has implications for the way buildings are designed – it will no longer be relevant, as other guidelines suggest (for example DfES: Building Bulletin 87, 2003b) to view a school as only working between 8.30am and 3.30pm, or to assume that a large classroom will have four networked computers (DfES: Building Bulletin 99, 2006: 31) or be typically occupied by a group of 30 pupils (*ibid*. p29): room use parameters will need to be flexibly designed to accommodate their different uses.

Designs will also need to include provision for green spaces adjacent to, and as extensions of, buildings. These offer a variety of environmentally positive effects, for example cooling effects on air temperature in congested streets; interception of solar reflection; improved air quality by reducing airbourne pollutants; as well as social and psychological effects on people's moods, feelings and sense of wellbeing (McIntyre 2006).

Along with extended periods of use there will be a need to manage and maintain these settings, both through the year and in the course of a single day (NRCNA 2007; DfES: Building Bulletin 99, 2006). School buildings' windows and doors not only permit access for people – they also allow moisture-laden air, light and sound to enter and leave. In physically entering school buildings, pupils and staff modify the environment they enter and are in turn affected by that environment. Parents, pupils, staff and others from the local community all move between larger community spaces and the specific spaces of the school, negotiated through corridors, doors and partitions and the way interior spaces and exteriors spaces are accessed and interconnected. Sustainable building in the future will need to take into account these movements and variations in use and activity.

There is now a growing research basis to support the design and organisation of primary schools. School building programmes and modifications need to draw on this evidence base. In the subsequent sections we examine data that address these issues. We consider the evidence that addresses (and challenges) the view that when 'minimal standards are attained, evidence of the effect of changing basic physical variables is less significant' (Higgins, Hall, Wall[2], Woolner & McCaughey 2005).

2 NOISE[3]

2.1 Background and noise parameters

The ways in which classroom acoustics can impact on children's learning and attainments have been relatively neglected in education. Yet there is increasing evidence that poor classroom acoustics can create a negative learning environment for many students (Shield & Dockrell 2002), especially those with hearing impairments (Nelson & Soli 2000), learning difficulties (Bradlow, Krauss & Hayes 2003) or where English is an additional language (Mayo, Florentine & Buus 1997). Excessive noise in the classroom can serve as a distraction and annoyance for teachers and pupils alike (Dockrell & Shield 2004). To address these concerns many countries have recently introduced or revised legislation and guidelines relating to the acoustics of schools, for example 'Building Bulletin 93: Acoustic Design of Schools' in the UK (DfEE 2003) and ANSI standard S12.60 'Acoustical Performance Criteria, Design Requirements and Guidelines for Schools' (ANSI 2002) in the USA. The purpose of such guidelines is to improve the teaching and learning conditions for pupils and teachers in schools.

[2] Dr Kate Wall.
[3] Professor Bridget Shield contributed to the evaluation of the evidence presented here

There are two main acoustical parameters to consider in classrooms that will affect speech intelligibility: noise and reverberation. Noise levels are recorded in decibels. The decibel is a logarithmic unit which means that a doubling of sound energy, caused for example by doubling the number of speakers in a room, results in an increase in noise level of 3 dB. Environmental noise is usually measured using the A weighted decibel, dB (A), which approximates to the response of the human ear to sound. Reverberation occurs when sound is reflected off surfaces. Reverberation (commonly known as an echo) is defined as the persistence of sound in a room after the source has stopped. In a reverberant space, successive syllables blend into a continuous sound, through which it is necessary to distinguish the orderly progression of speech. The level at which this sound persists is determined by the size of the space, the speech level and the interior finish materials. Reverberation time (RT), the time it takes for a sound to die off, is measured in seconds, with a low value, around 0.5 seconds or less, being optimum for a classroom seating of about 30 children. In general, the harder or more reflective a surface is, the greater the amount of sound that is reflected back into the room. Reverberation alone has detrimental effects on listeners' understanding of speech, even in a quiet environment. Research suggests that RTs in excess of 0.4 seconds may be unacceptable for verbal communication and verbal learning by all children, especially when they occur in the presence of background noise. Both reverberation and background noise should be controlled to ensure that acoustical barriers to communication and learning are minimised.

Background or irrelevant noise in classrooms can occur from both external and internal sources and can be divided into speech and non-speech. The predominant external noise source, particularly in urban areas, is likely to be road traffic (BRE 2002; Shield & Dockrell 2002) although both aircraft noise and railway noise can affect schools in specific locations. Internal sources include noise from building services (heating, lighting, ventilation systems), noise of teaching aids (overhead projector, computers) and noise from the children themselves and other adults. The effects of irrelevant sound on learning and performance are influenced by both these noise parameters and whether the noise is speech or non-speech.

2.2 Impacts

2.2.1 Speech intelligibility

A major effect of noise and poor acoustics in the classroom is the reduction of speech intelligibility. Speech intelligibility is related to the signal to noise (S/N) ratio, which is the difference between the signal (in this case, speech) and background noise in a room. If children are unable to understand the teacher then the major function of a classroom in providing an environment that enables the exchange of information between teacher and pupil and pupil-to-pupil is impaired. Young children are far more susceptible to poor acoustic conditions than adults (Elliott 2002). Children under the age of 13 are particularly vulnerable to irrelevant noise interference (Johnson 2000). The negative effects of combined poor S/N (signal to noise) ratio with long RT (reverberation time) affect children with hearing loss more than children with hearing within the average range. Even when the hearing loss is minimal (less than 20 dB), moderate levels of noise and reverberation may have a marked and detrimental effect (Crandell 1993; Nabelek 1992).

There are other groups of children for whom understanding their teachers and their peers can be difficult in the classroom, for example children who are not being taught in their first language (Mayo, Florentine, & Buus 1997; Nelson 2003), children with disorders such as attention deficit/hyperactivity disorder (Breier 2002), and children with speech and language difficulties. These children may be easily distracted in poor acoustic conditions or may have general problems in processing language, which will be exacerbated in classrooms with poor acoustics. Given the high reported levels of middle ear problems in the early years (Bess, Dodd-Murphy, & Parker 1998) and current reported levels of special educational need (DfES 2006), speech intelligibility in classrooms is an important consideration

Both background noise level and reverberation time affect speech intelligibility, although noise level appears to be the more critical factor (Bradley 1986; Hodgson 2002). In work with adults, Bradley, Reich, and Norcross (1999) found that noise, rather than reverberation, was the most significant factor in understanding speech and that the most important parameter for speech intelligibility is the signal (that is, speech) to noise ratio. As the levels of teachers' voices vary, this means that it is particularly important to reduce the background noise level in a classroom. As a result of these studies the general guideline is that 30 dB (A) is an appropriate background noise level, with optimum reverberation times of 0.4 to 0.5 seconds.

2.2.2 Cognitive processes

There are both theoretical and empirical reasons to predict that classroom noise from children and noise from the environment will influence learning and performance in different ways (Beaman 2005). Studies with adults of the effects of irrelevant noise have highlighted the importance of the variation in the sound sources heard in the disruption of tasks (Hughes & Jones 2001; Jones, Madden & Miles 1992). In contrast, background speech is seen to have its most profound effect on performance on verbal tasks (Banbury & Berry 1997, 1998; Tremblay, Nicholls, Alford & Jones 2000). This would suggest that intermittent sources of sound, such as traffic, might be more disrupting to tasks requiring attention, while the noise from other children in the classroom may interfere, predominantly, with language based tasks. Irrelevant speech effects have been shown to interfere with literacy tasks (Dockrell & Shield 2006) and younger children are more susceptible to irrelevant speech effects (Elliott 2002). The majority of the research into the effects of noise on children's performance in the classroom has examined the effects of environmental noise. Two major studies around airports in the 1980s and 1990s involving children aged from 8 to 12 found impaired performance in noise exposed children (Cohen *et al.* 1981; Hygge, Evans, & Bullinger 1996). In these studies high noise exposure was associated with poor long term memory and reading comprehension, and decreased motivation in school children. Significant effects of train and road traffic noise on reading and attainments have also been recorded (Bronzaft & McCarthy 1975). However, the introduction of noise abatement programmes has indicated significant improvements are possible. Of particular concern is the high correlation between a school's external noise level and levels of deprivation – thereby, arguably, resulting in a double disadvantage for children attending these primary schools (Shield & Dockrell 2008).

Children are not equally at risk from noise interference. Children without additional learning needs may function adequately in an acoustically marginal classroom whereas those with learning or language-based problems may be differentially disadvantaged. There is limited (Johansson 1983; Masser, Sorensen, Kryter & Lukas 1978), and equivocal evidence (Fenton, Alley & Smith 1974; Nober & Nober 1975; Steinkamp 1980) to support this view. In support of this contention Cohen *et al.* (1981) found that children who have lower aptitude or other difficulties were more vulnerable to the harmful effects of noise on cognitive performance. More specifically, early laboratory research indicated that only children with suspected learning disabilities had difficulties in tracking an auditory signal against a background of competing, irrelevant speech (Lasky & Tobin 1973). By corollary, sentence processing in white noise is more adversely affected for children with learning disabilities than children without such problems (Bradlow *et al.* 2003). There is an increasing evidence base that children who already have difficulties in learning may be subjected to a secondary impediment resulting from the environment in which they learn.

2.2.3 *Children's voice*

The most widespread and well-documented subjective response to noise is annoyance. Recent research has begun to consider children's annoyance due to noise. Children's annoyance may be an important factor in determining the impacts of noise in classrooms (Lundquist, Holmberg & Landstrom 2000). Children at school have consistently been found to be annoyed by chronic aircraft noise exposure (Evans, Hygge & Bullinger 1995; Haines *et al.* 2001a; 2001b; 2001c). However, children may be aware of noise without necessarily being annoyed by it. A recent survey of over 2000 London primary school children aged 7 and 11 years, in schools exposed to a range of environmental noise sources, found that children were aware of, and some were annoyed by, specific noise sources (Dockrell & Shield 2004). The older children were more aware of the noise, while the younger children found noise more annoying. The most annoying noise sources were trains, motorbikes, lorries and sirens, suggesting that it is intermittent loud noise events that cause the most annoyance to children while at school. Importantly it was only the older children who provided indicative evidence of strategies that might minimise the effect of noise on speech intelligibility.

2.2.3 *Managing noise in classrooms: teaching and learning*

The ways in which the potential impacts of noise in classrooms can be modified by approaches to classroom organisation and management have not been the focus of current research. There is evidence that monitoring and modifying noise levels in classroom is not a feature of initial teacher training (Dockrell, Shield & Rigby 2004). More experienced teachers report attempting to militate against the distracting effect of external noise by arranging quiet times. Although many teachers felt that noise levels impacted on most class activities (39.2 per cent), teachers also report a limited range of classroom strategies to combat the effect of external noise sources. These include raising voices (33.3 per cent); specific attention-gaining strategies (21.6 per cent); stopping teaching (17.6 per cent); and ignoring the situation (3.9 per cent) (Dockrell *et al*. 2004). There is, importantly, a range of strategies that could support the maintenance of classroom noise levels at an acceptable level for relevant activities. These include classroom layout, class grouping, using classroom spaces in strategic ways. At a school level, organisation of playtimes and the introduction of quiet times could all provide the potential to manage noise levels.

In addition to children's hearing concerns, the effect of trying to compete with an acoustically difficult environment creates a problem of severe vocal chord strain for many teachers. Voice strain is being recognised as a serious and potentially incapacitating problem for teachers. However, effective acoustical treatment of a classroom can create benefits.

2.2.4 *Managing noise in the classroom: acoustic modifications*

In parallel with studies of the effects of noise at school, there have been several surveys of classroom noise and acoustics, and investigations into the way in which the acoustics of classrooms may be improved (Canning & Peacey 1998). There are a number of classroom modifications that can be implemented to reduce noise levels in classrooms, although there have been few detailed studies to examine the effects on children and teachers. Reverberation times and potential noise in a classroom can be reduced by the use of acoustic ceiling tiles (Maxwell & Evans 2000), wall coverings, and carpets to absorb sound (Tanner & Langford 2002). An acoustical consultant can advise on the acoustic design of a school and on quietening the HVAC and other noise sources.

Speech reinforcement systems are an alternative or complimentary approach (Smaldino & Crandell 2000). These systems amplify the teacher's voice through a portable microphone and feed it into the classroom via strategically located loudspeakers. Such systems are becoming more common for classroom situations. However, for primary schools, the two-way flow of information from teacher to pupil and vice versa may be affected. If the teacher has a microphone and is clearly heard the child's response might not be. Such systems also require high levels of maintenance and training which may not be available in all classroom situations.

2.3 Critical evaluation

Consideration of classroom acoustics offers scope for both improving learning and for providing more inclusive classrooms. It is important that teachers, parents and administrators understand the impact that a noisy classroom has on students' learning and work with noise control consultants and architects to create a quiet learning environment. Different areas of a school have differing acoustical requirements (DfES 2004), which depend to some extent on activities and types of teaching. Concern about the effects of noise on children's learning, and how they may be mitigated, is reflected in current work towards improving standards for classroom acoustics.

3 TEMPERATURE, HEATING, HUMIDITY, AIR QUALITY AND VENTILATION

3.1 Background and key parameters

Temperature, humidity, air quality and ventilation comprise four key and inter-related dimensions of a classroom's physical environment. The nature of these parameters in relation to schools in England is contained in a series of guidance documents (DfES: Building Bulletin 87, 2003b) and advice regarding school design (DfES Schools Buildings and Design Unit 2004). These advise users of desirable temperature and humidity ranges associated with school buildings at different times of the year and for different activity purposes. Ventilation and air quality guidelines similarly link physical variables to assumptions about particular conditions and user activities, including the significance of ICT equipment and its impact on physical environment variables such as heating levels. Unlike adults and older children, young pupils in the classroom have limited opportunities to modify their immediate environment. Moreover, young children and adults may have different physiological responses and sensitivities to the same environmental factor (for example carbon dioxide levels: Corsi, Torres, Sanders & Kinney 2002).

How temperature, humidity, ventilation and air quality separately (reviewed by Weinstein 1979; Stevenson 2001; Clark 2002) and in combination (for example, Hygge & Knez 2001; Mendell & Heath 2003; NRCNA 2007) directly affect children's learning activity and attainments in the primary setting are not clear. Research that is available has tended to draw on data from other settings (Kimmel *et al* 2000, in respect of ventilation and windows); or with other populations and activity contexts (for example adults and ventilation in offices); or the impact of performance on logical reasoning, typing and arithmetic (Wargocki *et al.* 1999); or in other countries, such as the USA (for example Schneider 2002; Mendall & Heath 2003; NRCNA 2007). The different pedagogic, activity foci and age of participants of these studies limit the application of these results to primary classrooms. In the absence of more specific work, such studies are indicative of the effects of classroom environments on primary school pupils and their teachers (Higgins *et al.* 2005).

3.2 Impacts

3.2.1 Temperature, heating and humidity

Among the limited research that may be related to primary school settings (for example Schneider 2002; Young *et al.* 2003), perceived links to the effect of physical factors have been reported: these draw on research in related areas (such as children's health) and make inferences about the effect of particular physical factors on the classroom. They have also considered room users' wellbeing.

Temperature, heating and air quality have all been associated with pupil achievement (Earthman 2004; Department of Education, Training and Youth Affairs (Australia) 2001) and perceived effects on pupil behaviour (Young *et al.* 2003).

Indicative research suggests that specific temperature ranges (between 20-23.3°C), have an impact on reading and mathematics learning, with negative learning effects above 23.3°C (Harner 1974). Current classroom heating guidelines for England suggest that 18°C is acceptable where there is a normal level of physical activity such as when teaching, engaging in private study or undertaking examinations and that excessive variation in heating should be avoided, particularly in the summer heating season (DfES: Building Bulletin 87, 2003b: 8-10). Task performance and apparent task-related attention span decrease as temperature and humidity increase (King & Marans 1979) with implications that heating and air conditioning affect learning conditions and so learning itself (McGuffey 1982).

Schnieder (2002) suggests that individuals may show different sensitivities to the same temperature. Notions of a 'comfortable temperature' have informed classroom-heating debates, but Schnieder (2002) queries whether it is possible to have a comfortable heating level that all in a room find comfortable. There is some specific evidence that changing heating levels is associated with altered levels of mental activity (Wyon 1991). Such studies, however, carried out in different locations (usually in the US), with different external climatic conditions, need to be evaluated in a UK context.

Heating levels also affect humidity as warmer air can hold a greater proportion of suspended water vapour than colder air. High humidity encourages the growth of bacteria and molds, high levels of which are associated with effects on respiratory health leading to illness and missed schooling (Schnieder 2002; Mendell & Heath 2003). Humidity has been found to interrelate with perceptions of indoor air quality (IAQ) when schools in which humidity is actively controlled are compared to those where it is not. There are perceived health and learning effects (Bayer, Hendry, Crow & Fischer 2002). Humidity changes may also arise from other sources such as floor moisture problems, with associated links to ill health (Ahman, Lundin, Musabasic & Soderman 2000).

3.2.2 Air quality

Air quality research has focused on the effects of suspended materials, gaseous aerial pollutants and airborne pathogens on room users' health. In England, guidance relating to ventilation and IAQ are linked (DfES: Building Bulletin 87, 2003b: 15-17). Here carbon dioxide concentration is taken as a key IAQ indicator (acceptable carbon dioxide concentrations are given as 1000 ppm, equivalent to a ventilation rate of approximately 8 litres per second per person (DfES: Building Bulletin 87, 2003b: 16)). Poor air quality leads to respiratory irritation symptoms, nausea, dizziness, headaches, fatigue or sleepiness – all of which reduce concentration and presumably affect cognitive activity (Schnieder 2002). Such effects would apply to teacher and pupils alike.

There is some indication that materials used in classroom flooring and furniture may contribute to levels of airborne irritants, including dust and fibers (Smedje & Norback 2001). These are thought to have an impact on young children's respiratory health (particularly asthma): poor air quality in terms of concentrations of airborne particles (dust, for example) may negatively affect learning by increasing the amount of absenteeism in nursery school settings (Rosen & Richardson 1999). The equivalent research for older pupils in primary settings appears not to have been undertaken yet.

3.2.3 *Ventilation*

Air quality is modified by how a room is ventilated. Ventilation is usually achieved through 'natural' ventilation (the opening and closing of windows) or 'mechanical' ventilation (using various forms of air conditioning), or a by combination of both. In England ventilation is assumed to be achieved by natural means alone for normal room occupancy, at a level of 8 litres per second per individual (DfES: Building Bulletin 87, 2003b: 16). This may vary however as room occupancy changes and, in the longer term, seasonally. Room ventilation alters the balance of respiratory gases, which may have an impact on general wellbeing as well as on learning activity through altered levels of concentration and perceived tiredness. A study of eight different European schools (Myhrvoid, Olsen & Lauridsen 1996) noted that elevated classroom carbon dioxide levels (that is to say above 1000ppm), arising through poor ventilation, were associated with decreased performance on concentration tasks when compared to classrooms with lower carbon dioxide levels.

Carbon dioxide levels may regularly exceed national indicative values in the UK (Coley & Beisteiner 2002) in the winter season, and even in the summer time when open windows might be expected to reduce carbon dioxide levels (Beisteiner & Coley 2002). Elevated carbon dioxide levels, above 2000ppm, were found to be associated with impaired cognitive function expressed in measures of task attention (Coley & Greaves 2004). Within the current research literature a carbon dioxide concentration of 1000ppm is increasingly taken as an indicator of inadequate ventilation (for example Lee & Chang 2000; Corsi *et al*. 2002). More direct physiological effects of low ventilation rates on pupil nasal congestion, as another factor and associated with increased absenteeism from school, have been reported in Sweden (Walinder *et al.* 1997).

3.2.4 *Multiple effects and interactions*

Opening windows (or altering air conditioning settings) does not just alter air flow: it may also modify room temperature, humidity and the extent to which particular pollutants or airborne pathogens are prevalent in the incoming and outgoing air. An open window may also bring in external noise; equally an air conditioning system may itself introduce additional noise (Shield & Dockrell 2004). In both cases this may affect pupil and teacher concentration or task activity. The impact of air conditioning is potentially more significant where localities have high external temperatures for all or part of the school year, but this is disputed (Higgins *et al*. 2005: 17). An important implication of these studies is that addressing the impact of one physical factor may compromise the optimising of the effects of another factor (Weinstein 1979; Higgins *et al*. 2005: 16).

Keeping a room comfortably warm in the winter may lead to the air becoming dry; this in turn may lead to both teacher and pupil tiredness. However, while differential effects on teachers and pupils do not seem to have been investigated directly, given that children breathe a larger volume of air in proportion to their body weight than do adults in the same conditions (for example Kennedy 2001; Moore & Warner 1998), they may be differentially and negatively affected. Smaller sized teaching rooms compared to offices, given the number of pupils in a classroom compared to adults in a typical office, will exacerbate this effect (Crawford 1998).

An elevated breathing level may make pupils more likely to lose water quickly (breathed out air is saturated with water and represents a body's largest continuous source of water loss), and so become dehydrated faster than adults. They will also be likely to experience dehydration-related tiredness more quickly. Higher levels of respiration lead to still higher levels of gas exchange, increased carbon dioxide levels and higher levels of water loss. Room humidity would increase as a result, allowing airborne bacteria and moulds to flourish, which, given elevated breathing rates, would be taken in by both children and adults to a greater extent. Such an environment would lead to reduced concentration, participation in the lesson and tiredness, and might, through increased exposure to infection, lead to missed schooling and intermittent learning experiences. Current understanding of the impacts of these factors on pupil learning and performance are based on inferences about what may be occurring (for example Rosen & Richardson 1999; Schneider 2002; Earthman 2004), and specific effects on learning have not yet been investigated.

3.3 Teachers and pupils

Classroom heat, humidity and ventilation affect teachers' workplace satisfaction, with a likely secondary effect on teacher effectiveness. Studies across different types of school buildings of different ages in one English county (Essex) identified heating, ventilation, lighting and acoustics as significant factors in affecting perceptions of the school environment (Cooper 1985). More recently in two American cities, Chicago and Washington, bad indoor air quality, uncomfortable temperatures, bad lighting and noisy facilities were identified as having negative impacts for teachers (Schneider 2003). These factors have also been idenitified as having a negative impact on teacher retention rates in US elementary schools (Buckley, Schneider & Yi 2004). Indirect effects may influence teachers who feel disempowered if they are unable to control the physical characteristics of the spaces they teach in (for example room temperature – Lowe 1990), believing that lack of control may affect pupil performance (Lackney 1999). As such, they suffer reduced morale and increased stress (Corcoran *et al*. 1988; Heschong-Mahone Group 2003a).

3.4 Critical evaluation

The physical characteristics of primary classrooms – temperature, heating, humidity, air quality and ventilation – have been little investigated as specific contexts for their effects on pupil learning and teacher activity. It must be noted that much of the research available focuses on perceptions, rather than on systematic measurements of any objective measures. The implications for the UK are uncertain since many studies are based in the USA. There is clearly a pressing need for research in the UK context, and this should be a priority in coming years given current government commitments to school building and maintenance.

Given the apparent complexity and inter-relatedness of the physical factors themselves, it is not surprising that linking them to specific effects on pupil concentration, pupil learning, motivation, performance and teachers' involvement in learning has been very difficult: there is little direct indication in the existing literature of any specific causal relationships among the factors discussed here. However, it may be that correlational studies offer the best possible indicators in the circumstances and a basis for future action. The lack of causal findings should not be used to justify research, funding, design or maintenance inaction – a view endorsed in the recent large-scale review by the NRCNA (2007).

Health effects associated with substantive and intermittent poor health or reduced learning readiness may be significant, as they reduce pupil and teacher learning focus in the classroom, day by day. Through episodes of missed schooling, this may lead to a reduced level of overall learning: such health related effects on learning are better supported in the literature, both for pupils and teachers.

Teachers, parents, administrators and designers should take into account that physical factors – temperature, heating, humidity, air quality and ventilation – may influence classroom activity by affecting pupil and teacher concentration, motivation and learning activity, and that this may be made manifest in pupil and teacher health and absenteeism. Poor maintenance and monitoring of the physical characteristics of established environments can have similar associational effects on classrooms, learners and teachers (see, for example, Young *et al*. 2003; Schneider 2002; NRCNA 2007).

4 LIGHTING

4.1 Background and key parameters

Light in the classroom serves three basic functions. First, it allows those in the room to perceive their immediate environment and thus retrieve environmental cues. Second, it allows pupils, teacher and other adults to engage with materials for learning purposes and, crucially, third, it allows pupils and adults to see each other, particularly for communicative purposes. This said, an explicit link between lighting and pupil performance has not been clearly demonstrated but a number of suggestive studies exist: Larson (1965) (elementary class children); Boyce, Hunter and Howlett (2003) (benefits of natural light); and Boyce (2004) (review of productivity effects of daylight). Light informs what objects in the environment look like and how we interpret and process visual information (our visual performance).

Light has a number of physical characteristics. These inform its potential impact on the classroom and those in it. Key among these is its source, natural or artificial, and its background level, where the illumination level may be high (at around 1500 lux) or low (around 300 lux, as defined by Knez, 1995). The colour spectrum of light is also important (Knez 1995), as are its distribution in the environment and its availability to particular users. Guidance on appropriate levels of these factors is contained in UK government building guidelines (DfES: Building Bulletin 87, 2003b) and vary according to designated room activity (teaching classroom, hall, gymnasium area and so on). However, light levels used in particular research studies vary *between* studies and *between* those conducted in the UK and USA. As much of the research informing this review is American, its implications for the UK setting can only be suggestive due, for example, to the different patterns of light availability in each geographical setting over the course of a typical year and different perspectives and practices about how spaces are illuminated.

Overhead lighting – which may be in the form of an illuminated ceiling (Spencer 2003), or discrete strips of light/ suspended lamps – tends to generate fewer shadows and a more uniform distribution of light. Wall mounted lighting tends to produce localised sources of light. The dimensions of the space, higher ceilings being associated with reduced light intensity for the same level of illumination compared to lower ceilings, may also have an effect (for example Earthman 2004).

4.2 Impacts

4.2.1 Natural and artificial lighting as light sources

There is an extensive literature on different aspects of light, lighting and its various sources relating to classrooms. From this it is not clear which form of lighting – natural or artificial – is likely to have the most impact on pupils' learning, however the consensus seems to be that a mixture is inevitable and that the greater the amount of natural light the better (for example Earthman 2004; Higgins *et al*. 2005; NRCNA 2007). That lighting levels directly impact on pupil performance is hotly debated.

What constitutes *adequate* lighting necessarily depends on the task being undertaken and its context. UK building regulations (DfES: Building Bulletin 87, 2003b: 18) suggest that priority should be given to using natural lighting where possible, with overall lighting levels for teaching spaces being 300 lux, and, where visually demanding tasks are undertaken, such as reading a text, a set minimum maintained illuminance levels of 500 lux. Basic optimum levels of lighting have been researched. These studies suggest that task-appropriate lighting levels may be associated with improved test scores, more on-task behaviour and positive student attitudes (Dunn, Krimsky, Murray & Quinn 1985; Jago & Tanner 1999). A recent review of fifty-three studies suggested that higher levels of daylight exposure were associated with improved student achievement (Lemasters 1997).

However, the often-cited work by the Heschong-Mahone Group (1999, 2001, 2003a, 2003b) is contradictory (for example in Schneider 2002) in relation to light sources. The 1999 study, which focused on elementary school classrooms, appeared to show a correlation between the amount of daylight in a student's classroom and their performance on test scores for Maths and English – it suggested that an increase in the amount of daylight would be associated with an increase in scores. However, Boyce's (2004) analysis of the regression data provided by the study suggests that only 0.3 per cent of the variance in the regression model was associated with daylight-related codes (a measure of daylight levels in a particular classroom), reflecting little impact on student performance. Subsequent research by the Heschong-Mahone Group (2003b) failed to find similar effects to those reported in their first study.

One compounding issue may be that of ceiling height, where, for the same level of background illumination, higher ceilings appear to reduce lighting and so adversely affect lighting levels. Earthman (2004) has argued that this may be a problem related, in turn, to the age of a school. This is relevant in a UK context as older, Victorian, schools have higher ceilings than those built more recently (Cooper 1985). On the other hand, higher ceilings may distribute light more uniformly and produce fewer shadows, particularly when such schools often have larger areas of window, admitting natural light from multiple directions.

The complexity of the issue of lighting and windows, ceilings aside, is also apparent in a later study by the Heschong-Mahone Group (2003b). This suggested that lighting-related effects were, in turn, related to physiological and psychological issues. The impact of different sources of glare; thermal discomfort linked to sunlight entering un-shaded windows; and being unable to control light entry through windows due to inadequate blinds or shades were all identified. All showed an effect on student performance; the more of each of these variables, the lower the student performance. However, the type of 'view' out of the window also had an effect. The more the 'view' was perceived to be poor, the more student performance declined.

Windows not only admit light but also allow the viewer to see outside of their immediate location into the world beyond. In any discussion of natural light effects, the issue of view may be a confounding variable. There is some literature on the effect of 'view outside a window' that suggests that the better the view, the better subject performance and affect for adult users of a room (for example Leslie & Hartleb 1990), including in a university context (Douglas & Gifford 2001). Financial and psychological effects in relation to views from buildings have also been noted (Kim & Wineman 2005). There is no current equivalent for children apart from that indirectly gleaned through the Heschong-Mahone Group (2003b) account. Rusak, Eskes and Shaw's review (1997) of links between human health and lighting suggested that apart from a year long study by Kuller and Lindsten (1992), which indicated that a lack of window access altered children's cortisol levels (a stress associated hormone), there was no current work establishing firm links between access to windows for light or 'view' and children's wellbeing. This remains the case today. Nonetheless, recent reviews (for example NRCNA 2007) and reports (for example McIntyre 2006) assert the importance of 'views' based on interviews and self reports.

4.2.2 *Light spectrum*

The spectrum of light available in classrooms is another issue to be examined. Daylight spectrum varies during the day along with light level: in contrast, artificial lighting is usually static in both composition and level. One debate has been about the effects, or not, of using full spectrum fluorescent lighting (this includes ultraviolet light as a part of the emission spectrum of the lamp). The more 'blue-end' of the spectrum in the emitted spectrum the more it is perceived as 'cold', while a greater emphasis on the red end of the spectrum is associated with a perception of 'warmth'[4] (Knez 1995).

In terms of pupil affect, various colour-related effects have been reported. UK building guidance notes that colour appreciation is important in educational contexts and supports the accurate rendering of the real colour of objects. To achieve this, lamps with a colour-rendering index of not less than 80 are recommended. The colour appearance of light itself, specifically its 'coldness' or 'warmness', is also identified as an important variable. The guidelines suggest that lamps with a warm to intermediate colour temperature should be used (in the range of 2800K and 4000K) (DfES: Building Bulletin 87, 2003b; DfEE: Building Bulletin 90, 1999). Colour 'temperature' has been identified as having several effects on people; lighting 'coldness' makes people feel negative and is associated with a decline in performance (Knez 1995 – but see Veitch 1997, for a contrary view). Performance under different types of lighting shows variations in terms of age and gender (Knez & Kers 2000). Research suggests that females are more perceptive to light than males and that both males and females perform differently under different types of lighting, informed by perceived lighting warmth and level of illumination (Knez 1995, 2001). However, little comparable research involving primary aged children is apparent in the literature. There is evidence that the perceived temperature of incident light has an effect on student long-term memory recall and that 'cool' light has more of a negative effect than 'warm' light (Knez & Hygge 2002). However, other researchers suggest little difference in effect between the use of full and limited spectrum lighting (Gifford 1994; Benya 2001).

4.2.3 *Glare*

Light reflecting off of surfaces that are highly polished or reflective (windows, computer monitors or interactive whiteboards, for example) or are light in colour creates 'glare'. UK guidance suggests that the overall glare index within a teaching space should not exceed 19 (DfES: Building Bulletin 87, 2003b: 18; DfEE: Building Bulletin 90, 1999). 'Disability glare' may be one outcome of excessive glare. Here, a burst of bright light interrupts visual performance and is associated with a loss of concentration and attention to the task in hand (Boyce 2003) – this effect varies with age, being more significant as a person grows older (Weale 1963, 1992). In a classroom context, different sensitivities for pupils and adults, and among adults of different ages may be an issue. Another type of glare is termed 'discomfort glare,' which appears to have a psychological origin such that in one context glare from a flash of bright light might be distracting (the classroom) but in another setting (at a party) it might be desirable (Boyce 2003). The issue of glare is increasingly significant as classrooms accumulate more computer-associated display technologies such as monitor screens and interactive whiteboards (see, for example, Barnitt 2003), but the more general issue of how glare impacts on children in a classroom context has yet to be examined in detail.

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[4] The notion of the 'temperature' of light can be confusing: what is perceived as being 'cool' – light with a high proportion of the blue end of the spectrum in its output – is actually indicative of a higher physical temperature ~4000 K. 'Warmer' perceived light is actually generated at lower physical temperatures, ~ 3000K (Knez 1995).

4.2.4 *Light and colour in the environment*

Related to the colour spectrum of background illumination is the perceived colour of the environment that it illuminates. UK guidance indicates that the accurate rendering of the real colour of objects supports colour appreciation. To achieve this, lamps with a colour-rendering index of not less than 80 are recommended (DfES: Building Bulletin 87, 2003b; DfEE: Building Bulletin 90, 1999). Interviews with pre-school and young children indicate that young children are sensitive to the colour of their classrooms (Read, Sugawara & Brandt 1999) and that it is an important issue for them, even if adults in the same setting are less conscious of it (Maxwell 2000).

Improvements in achievement were identified by Cash (1993) when pastel colours were used on walls instead of white and for the same background illumination. Age is a relevant factor, with younger children preferring bright colours and older children more subdued colours (Engelbrecht 2003). In contrast, Pile (1997) advocates using strong but warm colours (and not intense primary colours) for younger children. Colour preferences also exist for older students (Rosenstein 1985), and may be gender and age related among adults. Khouw (1995) and Radeloff (1990) claim differences exist between adult males and females in colour preferences (but see Ou, Luo, Woodcock & Wright (2004) for an opposing view).

Many of the studies looking at the impact of colour use brief exposure to limited areas of colour as part of their methodology. This may lack face validity given the large scale and more sustained exposure experienced by teachers and pupils in their classrooms. As a result people's apparent preferences should be interpreted with caution (Sundstrom 1986). A similar caution should inform the interpretation of claims linking the effect of colour on perceptions of room space (light colours appearing to expand a space) and room temperature (warm colours, such as orange, being associated with a 'warmer' room – Sundstrom 1987).

Ceiling height may have additional effects not directly linked to light levels. One such effect is that they may affect teachers' and pupils' sense of space. However the evidence is contradictory, with Ahrentzen and Evans (1984) claiming higher ceilings lead to a greater sense of space and wellbeing for younger children. In contrast, Read *et al.* (1999) suggest that lower ceilings support group work and higher ceilings hinder it among pre-school children. As noted earlier, ceiling height may affect overall illumination levels for the same amount of available light. This in turn may affect perceived colour intensity and shade.

4.3 Teachers and Pupils

For adults in the age range of 18-65, relationships between background luminance, target contrast, target size and age exist and can be calculated (Rea & Ouelette 1991). For adults, large classroom objects (such as desks) are quickly processed visually, even when light levels are low and contrast with the background is poor. However, for smaller targets, greater discrimination is required. Visual processing declines markedly if light levels are low. Poor contrast between target (some print, for example) and background (the page containing the print) also makes visual processing more difficult. The importance of appropriate light levels is recognised in current UK guidance on light levels (DfES: Building Bulletin 87, 2003b). A need for high background light levels and high contrast increases with age for adults (Rea 2000). No such visual performance calculations currently exist for evaluating school children's needs. Partly this is a result of the fact that, for young children in particular, the visual system is still maturing as they enter school.

However, adults and young people routinely overcome inadequate background lighting levels by changing their behaviour. They may hold a text nearer to them for reading or move the target closer to a bright source of light. They may also alter how they hold the target material or its position on the work surface (Rea, Ouellete & Kennedy 1985). Teachers should attend to such behaviours, as they may indicate that background light levels for the child concerned (or a colleague) are inadequate.

Poor lighting levels in the classroom may also compound the effect of poorly corrected eyesight in children and adults and will create varying degrees of difficulty for teachers and other adults depending on their age. A significant proportion of English school children use corrective lenses for everyday use on the basis of redeemed spectacle vouchers – 27.1 per cent for 2005-2006 (NHS 2006). This is consistent with estimates in other countries such as the USA, where spectacle use is at 25.4 per cent among 6-18 year olds (Kemper, Bruckman & Freed 2004). However, many more may need to use spectacles as current use in the UK is regarded as an underestimate of need – a further 12 per cent of 5-16 year olds may need spectacles (Taylor Nelson Sofras 2002). The lenses prescribed for children's use may need to be supported by appropriate background lighting levels such as those associated with reading and working with classroom materials, and the use of materials with high contrast levels. Light distribution may be a further factor as even distribution of light reduces potentially distracting shadows. The effect of increasing the availability of natural light in this respect has not been investigated.

For teachers and other adults in the classroom, loss of refractive power in the eyes and the ability to accommodate to targets (such as books held close to the viewer) declines naturally with age (presbyopia), from about the age of 20 through to 65 years, with a marked decline more noticeable at approximately age 45 (Weale 1992). Lighting may therefore have differential effects on classroom adults of different ages, which may in turn impact on their access to task materials and task activity.

Full spectrum lamps are usually free of flicker and produce little or no glare, both factors identified as possible distracters in classrooms; Karpen (1993) has suggested that use of these lamps might lead to reduced levels of headaches, eyestrain and tiredness. Bad lighting has been identified by American teachers as one of the factors affecting their general classroom health (Schneider 2003). More general effects on health are not established however: pupil absenteeism has been examined with some researchers claiming a link with lighting (for example Hathaway 1994; Jago & Tanner 1999), and with others claiming the reverse (for example Heschong-Mahone Group 2001, 2003b).

Light further affects human activity by influencing an individual's underlying circadian rhythm, which cycles on an approximately 24-hour basis (NRCNA 2007). Natural light level and spectral composition are detected in the retina of the eye. Circadian effects occur at higher light levels than those needed for visual processing (McIntrye *et al.* 1989a, b) and need a longer period of exposure to be activated (Rea, Figueiro & Bullough 2002). Circadian processes are also more sensitive to the short wavelength component of the spectrum (Brainard *et al.* 2001). The sensitivity of the retina to these effects also varies during the day (Jewett *et al.* 1997). Seasonal variation in daylight exposure is associated with altered productivity and personal health (for example in the case of Seasonal Affective Disorder (SAD)), and has been linked to depression in various populations (Rosenthal *et al*. 1985).

Adults showing SAD symptoms report having had them as children (Rosnethal 1998), although there is little specific research relating to primary age children. Light/dark balance is also linked to altered sleep patterns (Reid & Zee 2004), and inadequate sleep is known to impact on adults learning activity (Heuer, Kleinsorge, Klein & Kohlisch 2004) and to affect older teenagers' school attendance patterns (Carskadon *et al*. 1998). As a result it may be hypothesised that access to daylight is important for adults and children across the age range, and that increasing this access in the classroom is desirable. It also indicates another area where further research is urgently needed.

4.4 Critical evaluation

The literature reviewed here indicates that light appears to have underlying physiological effects on the human body and specific effects on visual processing that may inform learning. These include the effects of background lighting level, contrast and colour. It may also have psychological effects through the perception of colour in relation to mood, and the impact of having a 'view' to look at and a person's sense of wellbeing.

Whether physiological or psychological, a person's health and productivity may be affected. These effects vary according to the age of the person in question, with most research having been conducted with young people and older adults. Where work has focused on young children and their classrooms, general effects have been noted and associations claimed between the amount and extent of exposure to daylight (and the balance of daylight to artificial light) and its impact on concentration and performance. The effects of glare as a potential source of distraction, of light spectrum and perceptions of comfort in the classroom have also been identified as important.

It has also been noted that there is conflicting evidence for saying that light has an effect on absenteeism and that colour preferences in the immediate environment are significant. The ways in which light is distributed in the classroom, and the impact of ceiling height and lighting design, may also be important. Overall it is not clear that light and its several characteristics have *direct* links to pupil performance. However, it is clear that, like the issue of heating and related factors discussed in section 3, lighting may interact with a range of factors which will preclude the identification of clear-cut causal effects. Similarly, associational links may need to be sufficient.

5 DISCUSSION

5.1 Minimal standards?

The review has drawn on and examined a broad range of literatures, including contemporary research from the educational, built environment and health literatures as well as publicly available national data where relevant. The built environment for primary school children and their teachers has the potential to enhance wellbeing and attainments. The current evidence for individual environmental variables suggests that in a range of different classroom contexts minimal standards are not actually achieved. The extent to which physical variables impact on children and adults, beyond a set of minimal standards, is more contentious (Higgins *et al*. 2005).

To a large extent drawing reliable and valid conclusions is limited by the paucity of large scale, systematic and rigorously controlled empirical studies that show a direct relationship between specific single environmental variables, pupil learning and pupil and teacher health. Much of the larger scale research informing this review has been carried out in the United States, and less frequently in Europe and Scandinavia, with the possible exception of noise research. Much of the other research is small scale, often case study-based and seldom comparative. Comparable measures across studies have generally not been used so it is very difficult to compare different studies, particularly to allow for different settings and contexts.

5.2 Diversity

Minimum standards are derived from a range of different methodologies and are typically the subject of debate between the relevant building professionals (BCSE 2007). The extent to which minimum standards meet the needs of all classroom users has been the focus of limited research. There is a need to think of those using primary school buildings not as groups (all the pupils of a school; all the staff at a school) but rather as a series of age-defined developmental groups, with each group having different needs and using the facilities in different ways. The same may apply to adults using particular facilities, such that what is appropriate visually for a young teacher may well be less so for older teachers. This necessarily involves a consideration of the range of pupils' learning needs and the range of teachers' needs, and how they are supported by environmental variables.

It is also apparent in the research to date that little account has been taken of the diversity of different forms of learning activity that can take place in primary school buildings, and their impact in relation to environmental factors. The diversity of geographical locations of the primary school buildings in this country has not been related to the question of whether or not minimum standards, if met in practice, are equally applicable to the diverse sites in question, or to the activities they play host to. These issues raise a range of methodological problems.

5.3 Methodology and practice

As we have argued, the current data sets are limited in their focus and consideration of the key variables. The absence of agreed standards and investigative practices, and the apparent lack of use of common definitions across researchers, makes the sharing and development of research more difficult and the application of research findings more complicated. Many of the sources examined were not drawn from a primary school context, and conclusions are drawn on generalisations for other relevant data. Moreover, it is important to establish not only that there is a significant effect of a key parameter but also the size of its effect – the variance accounted for. The data are also limited in their failure to calculate the effect sizes of various modifications. Thus it is currently unclear, for example, what effect a reduction of sound level might have on test success (but see Shield & Dockrell 2008).

5.4 Interconnectedness and modelling

Current research does not address the way in which primary school spaces are interconnected and influence each other, how they are used pedagogically, or how they are managed and maintained. This has meant that a particular learning space has tended to be examined in isolation rather than in the context of the learning environment. Contemporary pedagogical priorities and perspectives, affecting how those spaces are used and managed for learning, also affect environmental variables. For example, having the whole school together in one space may affect local air quality and heating, and may modify the acoustic properties of the space being used. This may in turn affect the attention of pupils, their ability to distinguish what is being said and constrain their overall behaviour. Thus the spaces available may affect their pedagogical use and influence the environmental variables of the space. These relationships have yet to be examined from a research perspective.

5.5 User health and learning

The materials reviewed strongly suggest that the nature of school environments impacts on the health and wellbeing of pupils and staff. Interactions between health and learning exist if only because ill health often means non-attendance at school, and this has been used – in various forms – as a key outcome indicator. Previous work has focused on whether particular environmental factors, such as heating, affect learning in a direct manner. An alternative and potentially more productive approach would be to note that many small effects might, in the aggregate, have substantial effects on pupil and teacher health. The focus would then shift to the impact of multiple factors working together.

Where more than one factor has been examined, small effects can be combined and the wider impact, in terms of broader outcome indicators, evaluated. This allows a focus on learning to be explicit as learning opportunities that are missed inhibit and dissipate pupil-learning progress. It may also impact on the development of social relationships with other pupils through the missing of shared learning experiences and events. Re-integration into the school's broader learning activity as a community, on returning to school after illness, may also impose learning losses on the returning child as they seek to 'catch-up' with their peers.

At the same time, staff absence through illness has impacts on children's learning opportunities; for example, the effect of a cover teacher on class learning. Teacher health may be compromised by infections arising outside of school but may also be influenced by the health environment of the school, in the form of more generalised stress, as indicated in the current review. Reduced physical (and arguably, mental) wellbeing is also, as has been shown here, itself exacerbated by poor air quality, over- or under-heating and inadequate ventilation, poor acoustics, limited access to natural light and the opportunity to take in 'a view'.

High humidity levels may create the conditions in which airborne infections can be exchanged more readily, affecting the health of pupils and staff alike. If pupil behaviour is adverse this can impact on teacher stress, and precipitate increased teacher tiredness and absenteeism from school. For pupils with particular learning and behavioural needs and for those teaching them, additional and specific effects have been identified.

Current research has restricted itself to mainstream schools with a small amount of research focusing on special school environments. Learning in pupil-offsite units or pupil-referral units where pupils would, by the nature of their needs and behaviour, be more sensitive to managed environmental factors has not been considered.

5.6 Decision makers

Those responsible for specifying the nature and detail of school building designs (for example at the individual school governor or headteacher level) need access to the limited but detailed information identified in this review. A 'one-stop shop' could inform those making school design decisions. It is therefore suggested that one priority should be the dissemination of existing knowledge through a range of accessible outlets, both on paper and electronically based. There is an equal need to examine the ways in which architects and those advising school projects are trained and informed about links between physical environment variables, school design, teacher and pupil health and pupil learning. Where the design task is the redevelopment of an existing school, close attention to collaboration with those involved in using the new school or refurbishment is clearly of paramount importance.

This review has suggested that single variables may contribute relatively small amounts towards an overall impact of the built environment on learning and health. However it may be at the level of interactions between, say, light levels, acoustic properties and pupil attention and learning progress that significant environmental impacts occur. Current research has not explored these interactive effects in primary school environments. Researchers and policy makers should be wary of drawing conclusions derived from adult studies or studies in different environments and then relating them to educational settings: the needs of young children are different and they do not respond to key variables in the same way as adults. While it may be easier to access the impact of environmental variables on young pupils' learning and wellbeing, the research leading to such understandings has yet to be conducted and suggests another agenda for future research.

5.7 Research implications

The review has highlighted the need for further research in a wide number of areas. In summary it suggests the following requirements for future research:

In relation to multiple variables

- Research should focus on the learning impacts of more than one physical variable at a time (and their interactions) on pupil learning and teacher teaching activity.

In relation to school users

- Research should be informed by a developmental perspective, which acknowledges that children of different ages in the same school may be affected differently by the same physical variables.
- Research should note that adults of different ages working in the same school may also be affected in different ways by key environmental variables.

In relation to teacher practice

- Research should take account of how pedagogic practices involving this age group relate to aspects of the physical environment.
- Research should examine teacher practices in controlling the physical characteristics of the classroom space and how these may affect pupil learning and teachers' sense of being able to influence learning.

In relation to building management

- Research should examine the relationship between the management and maintenance of physical environmental variables and how users experience that environment.

In relation to research methodologies

- Research should report effect sizes for the results they obtain and use these to assess the implication of their results.
- Research should clarify and state the definition and extent of particular variables it uses and their relation to other measures of the same variable.
- Research should, with both children and adults, including teachers, use a broader range of explicitly defined outcome variables as indicators of environmental impact. These should include: concentration in class; tiredness; respiratory unease; dehydration; time off task; time off school; absenteeism.
- Research should seek to undertake multi-site, multi-season and longitudinal research rather than single case study research.
- Research should consider and work towards the needs of establishing more sophisticated modelling procedures for the way real learning environments function and vary during the school day, school term and school year.
- Research should model the alternative uses to which school buildings are actually put in relation to the management of a school site and its impact on the learning use of the same site.

In relation to the consultation for, design and construction of, new schools and upgrading work

- Research should focus on the process of *how* schools are designed interactively through working with the communities who use them and have an interest in what goes on in them.

- Research should examine the extent that post-occupancy evaluations (and other forms of user evaluation, after completion of building) inform design, particularly in schools of a similar design or in schools in a particular locality.

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FURTHER INFORMATION

www.primaryreview.org.uk

General enquiries: enquiries@primaryreview.org.uk

Media enquiries: richard@margrave.co.uk

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