SECTION 5

APPENDICES

SCHOOL DISTRICT ENROLLMENT FROM 1999-2000 TO 2014-2015

YEAR	4K	E.C.	K	1	2	3	4	5	6	7	8	9	10	11	12	Total	Dif.	% Inc.
1999-00		11	67	91	82	81	100	113	87	109	105	119	114	104	106	1,289	-25	-1.9%
2000-01		12	79	70	91	86	80	102	118	90	115	106	122	113	103	1,287	-2	-.16%
2001-02		7	73	76	74	97	92	83	101	120	91	116	110	125	116	1,281	-6	-.47%
2002-03		13	82	79	78	76	93	96	82	108	124	93	121	115	122	1,282	+1	+.08%
2003-04		16	81	84	73	78	73	100	92	88	111	124	102	109	106	1,237	-45	-3.5%
2004-05		20	78	80	86	78	84	76	103	94	93	119	120	95	112	1,238	+1	+.08%
2005-06		18	89	71	78	87	80	87	78	111	97	99	124	109	91	1,219	-19	-1.5%
2006-07	60	11	92	85	79	86	92	86	95	89	104	110	96	116	115	1,316	+97	+7.9%
2007-08	87	7	82	89	86	83	90	90	84	94	94	120	106	91	115	1,318	+2	+.15%
2008-09	106	4	99	81	88	92	81	89	86	86	90	108	117	100	90	1,317	- 1	-.08%
2009-10	90	7	115	96	78	90	94	84	89	84	87	107	105	103	103	1,332	+15	+1.14%
2010-11	111	6	90	118	95	82	92	95	82	97	91	98	107	90	101	1,355	+23	+1.73%
2011-12	88	4	110	89	124	96	81	91	91	83	91	102	99	91	92	1,332	-23	-1.69%
2012-13	94	5	105	115	91	124	101	79	96	94	85	96	101	94	93	1,373	+41	+3.08%
2013-14	96	6	117	100	124	95	127	112	87	98	94	101	111	101	98	1,467	+94	+6.85%
*2014-15	82	5	106	113	104	120	99	129	116	89	101	97	104	101	108	1,474	+7	+.48%

*Estimate

Class	Total Difference from 8th to 9th Grade
2015	+11
2014	+11
2013	+17
2012	+14
2011	+16
2010	+13
2009	+6
2008	+8
2007	0
2006	+2
2005	+1
2004	+1
Average	+8.33
Average Since New Middle School was Opened in 2009	+12.57

Senior Class	Total Enrollment	Add Average of 12 students with addition to 9th grade
2015	410	
2016	403	415
2017	391	403
2018	403	427
2019	435	471
2020	430`	478
2021	464	512
2022	452	500
2023	436	484
2024	443	491

Do School Facilities Affect Academic Outcomes?

National Clearinghouse for Educational Facilities

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November 2002

On any given school day, about twenty percent of Americans spend time in a school building. The average age of our schools is close to fifty years, and studies by the U.S. General Accounting Office have documented widespread physical deficiencies in many of them. Faced with an aging building stock and growing, shifting student enrollments, states and communities are working hard to build and modernize K–12 facilities.

Those involved in school planning and design see this as an opportunity to enhance academic outcomes by creating better learning environments. Their logic is compelling—how can we expect students to perform at high levels in school buildings that are substandard?

We all know that clean, quiet, safe, comfortable, and healthy environments are an important component of successful teaching and learning. But which facility attributes affect academic outcomes the most and in what manner and degree?

A growing body of research addresses these questions. Some of it is good, some less so; much of it is inconclusive. The research is examined here in six categories: indoor air quality, ventilation, and thermal comfort; lighting; acoustics; building age and quality; school size; and class size.

Indoor Air Quality, Ventilation, and Thermal Comfort

There is a growing body of work linking educational achievement and student performance to the quality of air they breathe in schools. Some of this research is just beginning to make a cumulative mark, and some of the research, for example on thermal comfort, shows how much variation there is between individuals, making guidance for school construction somewhat difficult.

Indoor Air Quality

Poor indoor air quality (IAQ) is widespread, and its effects are too important to ignore. The U.S. General Accounting Office has found that fifteen thousand schools suffer from poor IAQ, affecting more than eight million children or one in five children in America's schools (General Accounting Office 1995). The IAQ symptoms identified—irritated eyes, nose and throat, upper respiratory infections, nausea, dizziness, headaches and fatigue, or sleepiness—have collectively been referred to as "sick building syndrome" (EPA 2000).

Ironically, the high incidence of symptoms stemming from poor IAQ seems to have emerged as an unintended consequence of the electric power brownouts, oil embargoes, and gas lines that characterized the 1970s energy crisis. In response to that national emergency, many buildings, including schools, were fitted with air handling systems and controls that delivered less fresh air than now is considered adequate. Most recommendations from the Occupational Safety and Health Administration (OSHA) and the National Institute of Occupational Safety and Health (NIOSH) now call for between fifteen and twenty cubic feet of air per minute per person. These enhanced ventilation rates not only deliver more adequate supplies of fresh air but also help dilute or remove contaminants, especially chemical (e.g., formaldehyde, toluene, and styrene) and biological (e.g., mold and bacteria) contaminants that have highly demonstrable negative health effects.

Linking IAQ to Student Performance

Most discussions linking IAQ to student performance depend on a series of simple logical links: poor indoor air quality makes teachers and students sick—and sick students and teachers can't perform as well as healthy ones (EPA 2000, Kennedy 2001, Leach 1997). This logic seems unassailable, and researchers are developing the scientific evidence to support it.

Most notably, poor IAQ has been associated with increased student absenteeism. For example, Smedje and Norback (1999) found a positive relationship between airborne bacteria and mold and asthma in children, which in turn increased absentee rates (also Rosen and Richardson 1999, EPA 2000). Further, the American Lung Association (ALA) found that American children miss more than ten million school days each year because of asthma exacerbated by poor IAQ (ALA 2002, EPA 2000).

Rosen and Richardson (1999) found that improving air quality through electrostatic air cleaning technology reduces absenteeism. Their experiment, conducted in two Swedish day-care centers, one old and the other modern, collected data on absenteeism and air quality over three years. The air cleaning technology was operational during only the second of the three test years, and absenteeism fell during that period in both schools. But only in the older school did the change reach statistical significance (absenteeism dropped from 8.31 percent in year one to 3.75 percent in year two, but upon removing the air cleaners, the rate increased to 7.94 percent in year three).

Temperature and Humidity

Temperature and humidity affect IAQ in many ways, perhaps most significantly because their levels can promote or inhibit the presence of bacteria and mold. For example, a study of Florida classrooms with relative humidity levels greater than seventy-two percent found visible mold growth on the ceilings and complaints of allergy symptoms associated with sick building syndrome (Bates 1996). At the other end of the humidity scale, Leach (1997) reported findings of a 1970 study done in Saskatoon, Saskatchewan, Canada, which found absenteeism was reduced in schools by twenty percent as relative humidity in the facilities was increased from twenty-two to thirty-five percent. Wyon (1991) showed that student performance at mental tasks is affected by changes in temperature, and Fang et al. (1998) found that office workers are most comfortable in the low end of temperature and humidity comfort zones. These findings support the idea that students will perform mental tasks best in rooms kept at moderate humidity levels (forty to seventy percent) and moderate temperatures in the range of sixty-eight to seventy-four degrees Fahrenheit (Harner 1974, Wyon, Andersen, and Lundqvist 1979).

Ventilation Effects on Performance

It seems obvious that in a sealed space, without the availability of fresh air from outside, the occupants of that space will die from asphyxiation. Yet despite this knowledge, deaths of workers in confined spaces constitute a recurring occupational tragedy (NIOSH 1986). While we certainly seek to avoid such extreme conditions in schools, a surprising number of classrooms lack adequate ventilation, and evidence is accumulating to support the common-sense notion that occupants of a classroom without good ventilation can't function normally and can't learn at their full capacity.

The purpose of ventilating classrooms and school buildings, at minimum, is to remove or otherwise dilute contaminants that can build up inside. Such contaminants come from people breathing, from their skin, clothes, perfumes, shampoos, deodorants, from building materials and cleaning agents, pathogens, and from a host of other agents that, in sufficient concentrations, are harmful.

Schools need especially good ventilation because children breathe a greater volume of air in proportion to their body weight than adults do (Kennedy 2001, McGovern 1998, Moore 1998) and because schools have much less floor space per person than found in most office buildings (Crawford 1998). But because of the high costs of conditioning the ventilation air in schools to comfortable temperatures before it is circulated, the designers and operators of school buildings can be the unwitting architects of learning spaces that impair learning and health by offering inadequate ventilation—whether this results from economic measures, ignorance, neglect, poor maintenance, or some combination of these factors.

One of the first symptoms of poor ventilation in a building is a buildup of carbon dioxide caused by human respiration. When carbon dioxide levels reach 1000 parts per million (about three times what is normally found in the atmosphere), headaches, drowsiness, and the inability to concentrate ensue. Myhrvold et al. (1996) found that increased carbon dioxide levels in classrooms owing to poor ventilation decreased student performance on concentration tests and increased students' complaints of health problems as compared to classes with lower carbon dioxide levels. The study was conducted at eight different European schools on more than 800 students with results that achieved statistical significance.

Despite the clear need for fresh air in schools, the systems that are the principal source of ventilation other than windows don't always deliver adequate supplies of fresh air. These include not just the ducted systems influenced by the 1970s energy crisis, which often delivered only about one third of the fresh air supplies now deemed adequate (ASHRAE 1989), but a whole variety of ventilation systems with their own unique problems. For example, the through-wall unit ventilators specified in school designs for decades, which connect directly through the wall to an outside air source and are fitted with a fan to draw outside air into the classroom (Strickland 2001), often become shelves for books and other classroom materials, which in turn restricts fresh air flow. The intake vents in these systems, through poor design, siting or neglect, can restrict airflow or can have their flows restricted by snow or debris at ground level, for example, which can result in an accumulation of mold, bacteria, and other contaminants (Crawford 1998). These unit ventilators, beyond creating excessive, sustained background noise that can hinder learning, also tend to filter out less air pollution than more modern ventilation systems, which can lead to higher levels of volatile organic compounds (VOC) in the air (Strickland 2001, 364).

Inadequate ventilation is often a cause of IAQ problems. A 1989 study by the National Institute for Occupational Safety and Health found that more than half of the IAQ problems in the workplace were caused by inadequate ventilation (NIOSH 1989). A 1992 study by Armstrong Laboratory found that the two greatest causes of poor IAQ were inadequate maintenance of heating, ventilation, and air conditioning (HVAC) systems and a lack of fresh air. A 1998 Cornell University study found that workers in poorly ventilated offices are twice as likely to report the symptoms of sick building syndrome as employees in well-ventilated environments. The study also found that a relatively small buildup of carbon dioxide from human respiration—an indicator of poor ventilation—is also related to sick building syndrome (Lang 1998).

In a recent study, twenty-six percent of Chicago public school teachers and more than thirty percent of Washington, D.C., teachers interviewed reported health-related problems caused by the school facility. Most of these problems were related to poor indoor air quality, with teachers reporting that asthma and other respiratory problems were the main adverse health effect (Schneider 2002).

As for scientific evidence for ventilation's effect on performance, two recent papers examining talk times for registered nurses in call centers found that ventilation levels had only a small negative effect on productivity (Federspiel et al. 2002, Fisk et al. 2002). However, Smedje and Norback (1999) and Wargocki et al. (1999) reported stronger links. Wargocki et al. found that ventilation levels in offices affected performance in logical reasoning, typing, and arithmetic (also EPA 2000). The researchers also found that higher carbon dioxide levels increased the incidence of headaches, which appeared “to affect human performance during office work by reducing the inclination to exert effort” (Wargocki et al. 1999, 136). Can we assume that this relationship might extend to students, perhaps even more so because they are growing, developing, and attempting to learn new things?

Smedje and Norback (1999) in a 1993 survey found that students with asthmatic symptoms were less likely to report them two years later if the school they attended had installed a new ventilation system in the meantime. Given that asthma is among the leading causes of absenteeism in American schools, we can assume that improved ventilation can bring about less asthma, better school attendance, and improved academic performance.

Walinder et al. (1997) found that schools in Sweden with the lowest ventilation rates had VOC concentrations two to eight times higher than schools with adequate ventilation, and students in these schools were more likely to have swelling of the nasal mucosa, a symptom associated with sick building syndrome that could lead to absenteeism.

Though we know that some specific components of indoor air quality will likely affect students, rigorous studies comparing the individual effects and the interactive effects of different aspects of air quality still are needed. As Woods et al. note, "Building managers and other fiscal decision-makers still tend to minimize the value of environmental control. This may be in part caused by the absence of scientific, quantifiable data to support decisions addressing health impacts." Woods also argues that most previous field studies have not had adequate control groups, and many studies have been anecdotal. Moreover, most studies have focused on single environmental media, leaving aside the critical issue of interaction effects between daylighting, air quality, noise, thermal comfort, or other factors that affect learning (Woods et al., no date, 1–2).

Given these problems, it is perhaps not surprising that the American Public Health Association (2000) has criticized the U.S. Department of Education for the lack of scientific research in this area.

There may be some improvements in the state of knowledge in the future. One promising study is a three-year research project launched in 2001 by the HP-Woods Research Institute. Based on a rigorous research design with treatment and control groups, the study is to focus on student performance, health, and productivity (improved performance compared to the cost of creating that performance) at differing levels of IAQ and with different mechanisms in place for solving IAQ problems. The study is intended to follow third and fourth graders in six schools from two areas in Montgomery County, Maryland.

The Center for the Built Environment (CBE) at the University of California at Berkeley has placed ventilation's effects on productivity on its research agenda, so perhaps it will find new scientific evidence that will yield better assessments of ventilation's effects on student performance.

The federal government may act as a catalyst for more research. The No Child Left Behind Act of 2001 calls for more research into IAQ and student performance. Specifically, Section 5414 of the bill calls for the Department of Education to conduct a "study regarding the health and learning impacts of environmentally unhealthy public school buildings on students and teachers" (U.S. Congress 2002). The bill goes further, requesting that the Department of Education make recommendations to Congress on how to bring schools into compliance with environmental health standards and the cost of such an effort. While no date exists determining when such a study takes place, it should eventually provide much needed guidance for policy makers.

The current lack of specific knowledge makes it difficult for policy makers to create definitive IAQ standards. However, while scientists, engineers, architects, and others seek to quantify more exactly the precise links between IAQ and student performance, some school districts are investing extra effort and resources to ensure that fresh air in schools is plentiful and readily available to students and teachers. Minneapolis schools—where the design and construction of school buildings is managed to maximize air quality—are a case in point (Leach 1997, 32). The list of such "demonstration" projects is expanding. Indeed, there is a growing movement to construct schools that provide not only good indoor air quality and thermal comfort but also utilize high-performance energy-saving HVAC systems coupled to other advanced building systems, including environmentally preferable building materials and products in order to produce quality schools that promote rather than detract from the health and productivity of occupants over their life (SBIC 2000).

IAQ and Environmental Justice

As with several other areas reported in this publication linking the quality of school facilities to student performance, some researchers are directly concerned about the disproportionate effect of poor air quality in schools on students from racial minority groups and from families having lower socio-economic status.

Most notably, the Children's Environmental Health Network's (CEHN) 1997 conference on the exposure of children to environmental hazards reported that children from racial minorities are more likely to encounter poor IAQ. The proceedings of the CEHN conference stated that Black and Hispanic neighborhoods have a disproportionate number of toxic waste facilities in their neighborhoods and that eighty percent of Hispanics live in neighborhoods where air quality does not meet EPA standards (CEHN 1997). While this finding does not specifically focus on schools, the existence of poor quality air in these neighborhoods may parallel poor quality air indoors in schools.

Statistics from the General Accounting Office report on school facilities in 1996 directly confirm that schools serving poor and minority students do suffer disproportionately from poor IAQ (General Accounting Office 1996). Of schools where less than forty percent of their students were eligible for free lunch, approximately sixteen percent reported unsatisfactory IAQ, but of schools where more than forty percent of students were eligible for free or reduced-cost lunch, almost twenty-three percent reported having unsatisfactory IAQ. Similarly, fewer than eighteen percent of schools with less than twenty and one-half percent minority students reported unsatisfactory IAQ. In contrast, more than twenty percent of schools with minority populations between twenty and one-half percent and fifty and one-half percent reported unsatisfactory IAQ, and almost twenty-three percent of schools with minority populations greater than fifty and one-half percent reported unsatisfactory IAQ.

"Teachers seemed to hold a basic expectation that they would be able to control light levels, sun penetration, acoustic conditions, temperature, and ventilation in their classrooms."

As with so many other issues linking school facilities to educational outcomes, the demands of environmental justice and social justice overlap to call attention to the disproportionate burden that poor and minority students carry in education.

Thermal Comfort

Researchers have been studying the temperature range associated with better learning for several decades. Harner (1974) found that the best temperature range for learning reading and math is sixty-eight to seventy-four degrees Fahrenheit and that the ability to learn these subjects is adversely affected by temperatures above seventy-four degrees Fahrenheit. As temperature and humidity increase, students report greater discomfort, and their achievement and task-performance deteriorate as attention spans decrease (King and Marans 1979). McGuffey (1982) was one of the first to synthesize existing work linking heating and air conditioning to learning conditions, and her work still is widely cited.

Research also shows that even within commonly acceptable temperature spans, there are specific ranges that increase individual performance. It is not feasible, however, to provide every student in a common space with the temperature or humidity that best suits him or her.

Thermal factors may seriously degrade teachers' abilities to teach and may also affect their morale. In the 2002 follow-up study to the school daylighting study completed in 1999 by the Heschong Mahone Group, environmental control was found to be an important issue for teachers, especially for those who lacked full environmental control:

> Teachers seemed to hold a basic expectation that they would be able to control light levels, sun penetration, acoustic conditions, temperature, and ventilation in their classrooms. They made passionate comments about the need for improvement if one or more of the environmental conditions could not be controlled in their classrooms (Heschong 2002).

Lowe (1990) found that the best teachers in the country emphasized their ability to control classroom temperature as central to the performance of teachers and students. Lackney (1999) showed that teachers believe thermal comfort affects both teaching quality and student achievement. Corcoran et al. (1988) focused on how school facilities' physical conditions affect teacher morale and effectiveness. They conclude that problems caused by working conditions may result in higher absenteeism, reduced effort, lower effectiveness in the classroom, low morale, and reduced job satisfaction.

Lighting

Classroom lighting plays a particularly critical role in student performance (Phillips 1997). Obviously, students cannot study unless lighting is adequate, and there have been many studies reporting optimal lighting levels (see Mayron et al. 1974, Dunn et al. 1985, 866). Jago and Tanner's review (1999) cites results of seventeen studies from the mid-1930s to 1997. The consensus of these studies is that appropriate lighting improves test scores, reduces off-task behavior, and plays a significant role in students' achievement.

Recently there has been renewed interest in increasing natural daylight in school buildings. Until the 1950s, natural light was the predominant means of illuminating most school spaces, but as electric power costs declined, so too did the amount of daylighting used in schools. According to Benya, a lighting designer and consultant, recent changes, including energy-efficient windows and skylights and a renewed recognition of the positive psychological and physiological effects of daylighting, have heightened interest in increasing natural daylight in schools (Benya 2001).

Lemasters' (1997) synthesis of fifty-three studies pertaining to school facilities, student achievement, and student behavior reports that daylight fosters higher student achievement. The study by the Heschong Mahone Group (1999), covering more than 2000 classrooms in three school districts, is perhaps the most cited evidence about the effects of daylight. The study indicated that students with the most classroom daylight progressed twenty percent faster in one year on math tests and twenty-six percent faster on reading tests than those students who learned in environments that received the least amount of natural light (also Plympton, Conway, and Epstein 2000). There were some questions that could not be answered by the original Heschong study, such as whether the higher performance was driven at least in part by better teachers being assigned to the classrooms that received more daylight. A follow-up study surveyed teachers in one of the districts and added information on teacher characteristics to the analysis. This new report found that the effect of daylighting remained both positive and significant. Other studies are currently in process to try to validate the results in another school district and determine more detail about a possible mechanism for such an effect.

While the scientific foundation linking daylighting to learning is accumulating, there have been distractions and fads that affect school lighting decisions. For example, there has been an ongoing controversy about so-called "full-spectrum" fluorescent lighting, and some schools have been re-lamped at considerable expense to offer this perceived benefit (the lamps themselves are several times more expensive than conventional lamps and produce significantly less light). But according to Gifford, research on the effects of full-spectrum lighting has been "inexpert" (Gifford 1994, 37), and the strong claims made about such lighting have been based on poor research that does not meet even rudimentary standards of scientific investigation. Indeed, in 1986, the U.S. Food and Drug Administration instructed the Duro Test Corporation, makers of Vita-lite and promoters of UV enhanced "full-spectrum" lamps, to cease and desist from making claims about any health benefits from non-clinical applications of this type of light source (Benya 2001, Gifford 1994).

While there are serious questions about the effects of full-spectrum fluorescent lighting, there is sufficient reason to believe that daylight provides the best lighting conditions.

There also have been studies attempting to correlate elements such as color and aesthetic appeal with student achievement. One example is Cash's report (1993) that student achievement improved when walls were painted pastel colors instead of white. The appeal of physical conditions such as color may vary considerably among individuals, and there is a good opportunity here for further work with definitive recommendations.

Acoustics

The research linking acoustics to learning is consistent and convincing: good acoustics are fundamental to good academic performance.

In one of their many syntheses of existing work, Earthman and Lemasters (1998) reported three key findings: that higher student achievement is associated with schools that have less external noise, that outside noise causes increased student dissatisfaction with their classrooms, and that excessive noise causes stress in students (1998, 18).

Crandell et al. (1995) and Nabelek and Nabelek (1994) reviewed the literature linking the acoustical environment in a classroom to the academic achievement of children and have linked levels of classroom noise and reverberation to reading and spelling ability, behavior, attention, concentration, and academic achievement in children (also ASHA 1995, Crandell 1991, Crandell and Bess 1986, and Crandell et al. 1995). Evans and Maxwell (1999) examined 100 students enrolled in two New York City schools, one of which was in the flight path of an airport. The students exposed to the air-traffic noise scored as much as twenty percent lower on a reading test than children in the other school.

There also is evidence of a cumulative effect of excessive classroom noise on a child's academic achievement level. These problems are more acute for children who may have hearing impediments and may affect the detection of such impediments (Nelson and Soli 2000). It also is generally agreed (Fisher 2000) that high noise levels cause stress. Noise levels influence verbal interaction, reading comprehension, blood pressure, and cognitive task success and may induce feelings of helplessness, inability to concentrate, and lack of extended application to learning tasks.

Teachers attach importance to noise levels in classrooms and schools. Lackney (1999) found that teachers believe that noise impairs academic performance. Indeed, it appears that external noise causes more discomfort and lowered efficiency for teachers than for students (Lucas 1981). This factor could lower the quality of teaching and, ultimately, learning.

Clearly, classroom acoustics matter, and yet Feth and Whitelaw (1999) found that the acoustics of many classrooms are poor enough to make listening and learning difficult for children. Their study of thirty-two classrooms in central Ohio primary schools found that only two met the standards recommended by the American Speech-Language-Hearing Association (ASHA).

Other studies cite acoustics problems in schools. For example, a third of the school systems cited in a 1995 General Accounting Office study reported that poor acoustics were their most serious environmental concern (General Accounting Office 1995). Studies of elementary and secondary school classrooms revealed that excessive background noise, which competes with the speech of teachers, aides, classmates, and audio-educational media, is common even in new classrooms (U.S. Architectural and Transportation Barriers Compliance Board 1999).

Acoustical performance is an important consideration in the design of classrooms, according to the U.S. Architectural and Transportation Barriers Compliance Board (2002), an independent federal agency devoted to accessibility for people with disabilities. The board writes:

> Research indicates that high levels of background noise, much of it from heating and cooling systems, adversely affect learning environments, particularly for young children, who require optimal conditions for hearing and comprehension. Poor acoustics are a particular barrier to children with a hearing loss. For the past several years, the Board has worked with the private sector in the development of classroom acoustics standards as an alternative to rulemaking of its own. In 1999, the Board partnered with the Acoustical Society of America (ASA) on the development of a new standard for acoustics in classrooms that takes into account children who are hard of hearing. The standard, completed in 2002, has been approved as ANSI/ASA S12.60-2002, Acoustical Performance Criteria, Design Requirements and Guidelines for Schools. It sets specific criteria for maximum background noise (thirty-five decibels) and reverberation (0.6 to 0.7 seconds for unoccupied classrooms). These and other specifications are consistent with long-standing recommendations for good practice in acoustical design.

When these standards are implemented, schools may face significant costs. For example, many existing HVAC systems, particularly room unit ventilators, will exceed these noise standards.

While science is clearly linking daylighting, acoustics, and indoor air quality to learning outcomes, it is harder to scientifically measure the effects on learning of such factors as building quality and size or the way that a building may be divided into different learning spaces and different-sized classrooms. Almost all the other research discussed here so far is fairly tightly focused on single environmental (or closely related) factors, and many of the conditions can be directly measured (including decibel levels, air flows, lumens, and so on). However, when we begin to look at the effects of more complex variables, such as the overall quality of school buildings, school size, or class size, we immediately see that these factors or "inputs" are multitudinous and multidimensional—making it much harder to identify and isolate precise measures and effects. The outcomes also are harder to isolate and measure accurately, although over the past twenty years, standardized test scores have been a principal measure of learning outcomes. And in much of this work discussed below, higher test scores have become the holy grail of facilities reform.

Building Age, Quality, and Aesthetics

McGuffey's 1982 synthesis of earlier studies correlated student achievement with better building quality, newer school buildings, better lighting, better thermal comfort and air quality, and more advanced laboratories and libraries. More recent reviews by Earthman and Lemasters (1996, 1998) report similar links between building quality and higher test scores. For example, researchers studying Georgia's primary schools found that fourth-grade students in non-modernized buildings scored lower in basic skills assessments than students in modernized or new buildings (Plumley 1978). Similarly, Chan (1979) found that eighth-grade students scored consistently higher across a range of standardized tests if housed in new or modernized buildings. Bowers and Burkett (1987) found that students in newer buildings outperformed students in older ones and posted better records for health, attendance, and discipline. The study attributed approximately three percent of the variance in achievement scores to facility age, after considering socio-economic differences in the student populations. In more recent work, Phillips (1997) found similar improvements in newer facilities, and Jago and Tanner (1999) also found links between building age and student achievement and behavior.

Clearly, there is consensus that newer and better school buildings contribute to higher student scores on standardized tests (Plumley 1978; Edwards 1992; Cash 1993; Earthman and Lemasters 1998; Hines 1996), but just how much varies depending on the study and the subject area. For example, Phillips (1997) found impressive gains in math scores, but Edwards (1992) found much lower gains in social sciences.

Isolating the independent effects of age and building condition is essential to studies such as these but may be difficult to do; a building's age can be ascertained from public records, but its condition is harder to gauge. Building quality actually may have less to do with age and more to do with the budget for that particular building. In older buildings, a lack of maintenance can ruin an otherwise high-quality building; in new buildings, funding limitations can result in a brand new building of inferior quality. Any careful study must account for these factors.

Indeed, some researchers have tried to rigorously identify the effect of building quality independent of building age. Andersen (1999) studied the relationship of thirty-eight middle-school design elements to student scores from twenty-two schools on the Iowa Test of Basic Skills and found positive correlations with twenty-seven elements. Maxwell (1999) found a correlation between newer facilities and student performance levels and a significant relationship between upgraded facilities and higher math scores. But her study also found lower student performance during the renovation process, since classes can be disrupted during renovation. In at least one case (Claus and Girrbach 1985), reading and math scores improved among the better students when buildings were renovated, but the scores fell among the lowest-performing students.

Lewis (2000) tried to identify the independent effects of school quality in a study of test scores from 139 schools in Milwaukee and found that good facilities had a major impact on learning.

Stricherz (2000) notes that student achievement lags in inadequate school buildings but suggests there is no hard evidence to prove that student performance rises when facilities improve well beyond the norm. "Research does show that student achievement lags in shabby school buildings—those with no science labs, inadequate ventilation, and faulty heating systems," Stricherz says. "But it does not show that student performance rises when facilities go from the equivalent of a Ford to a Ferrari—from decent buildings to those equipped with fancy classrooms, swimming pools, television-production studios, and the like."

While many studies link the effects of building quality to academic achievement, other studies tie building quality to student behavior. Vandalism, leaving early, absenteeism, suspensions, expulsions, disciplinary incidents, violence, disruption in class, tardiness, racial incidents, and smoking all have been used as variables in these studies.

More than sixteen studies collated by McGuffey (1982) found fewer disciplinary incidents as building quality improved. Discipline also was better in newer buildings. However, later reports (Edwards 1992; Cash 1993) found that disciplinary incidents actually increased in schools with newer and better buildings—perhaps caused by the stricter discipline standards in these newer schools, among other factors.

In studying how school quality relates to achievement and behavior, the criteria that Earthman et al. (1995) used included factors such as structural differences and open space as indicators of quality. They found that schools farther up the overall quality index had fewer disciplinary incidents, but schools that rated higher only on the structural component had more disciplinary incidents.

A recent study in Great Britain by Pricewaterhouse-Coopers (2001) linked capital investment to academic achievement and other outcomes such as teacher motivation, school leadership, and student time spent on learning. This study combined quantitative and qualitative analysis and was based on interviews with teachers and headmasters. Its quantitative analysis found weak and inconsistent relationships between capital expenditures and outcomes. However, the study's surveys found a stronger link between capital expenditures and motivation and leadership. The researchers concluded (p. 42):

- Good teaching takes place in schools with a good physical environment;
- Good school leadership can also be found in schools with a high-quality capital stock;
- The general attitudes, behavior, and relationships amongst pupils and staff are more conducive to learning in those schools which have had significant capital investments.

A careful look at the data reported by Pricewaterhouse-Coopers shows some weaknesses in the study. For example, most of the data collected by Pricewater-houseCoopers was used in an econometric production function analysis. As with virtually all such studies, the analysis found few, if any, relationships linking capital spending and academic achievement. The study's organizers then turned to interviews and other more impressionistic data upon which to base their findings. But the data they collected were not particularly useful in helping policy makers decide how to allocate monies across different categories of expenses. For example, no one would be able to know from the study whether it would be better to invest in improved air quality or to ensure that classrooms met certain acoustics standards.

While existing studies on school building quality basically point to improved student behavior and better teaching in higher-quality facilities, what is needed is more firm policy advice about the types of capital investments that would be most conducive to learning and to good teaching. This would help those who manage construction dollars better target and maximize the return on such investments.

School Size

Schools in the United States have grown larger and larger, but how this growth affects learning is still being explored. Buildings housing two or three thousand students are not uncommon; high schools in some large cities house five thousand students (Henderson and Raywid 1994). The trend toward large schools stems from several historical processes, including school district consolidation and the belief that large schools can deliver education with major economies of scale. As a result of rural school district consolidation and lack of available sites and population growth in central cities, large schools began appearing in this country as early as 1869. The post-WWII baby boom and concurrent population shift from city to suburbs made larger schools commonplace.

These trends accelerated as a result of the Cold War. When Sputnik was launched in 1957, so too was our nation's desire to quickly graduate scientists to meet that perceived challenge. Close on Sputnik's heels came Conant's 1959 book, *The American High School Today*, calling the small high school America's number one education problem and suggesting its elimination be a top priority (Conant 1959, 37–38).

Although what Conant considered an appropriate size for schools was not that large by today's standards, his book became part of a school facilities planning mentality that saw larger and larger schools constructed routinely. And these newer, larger schools often have been sited away from neighborhoods.

Today, ironically, despite the need for more classrooms because of renewed enrollment growth, many neighborhoods face losing their schools because of declining enrollments or school consolidation. According to estimates of the Building Education Success Together team (BEST), nearly 200 schools in Chicago, Cleveland, Columbus, Cincinnati, and Washington, D.C., may be closed or consolidated because they have smaller student populations than they were originally designed for (BEST 2002). Yet this decision is being made even while evidence accumulates that small schools may work better than large ones, especially for students with lower socio-economic status. Indeed, there's an impressive body of literature linking small school size to positive outcomes. This literature is worth studying—but with three caveats:

First, while the evidence affirms small is generally better, the definition of small varies across studies. At one level there is the question about whether or not policy makers should be aiming to create schools of some specific size. In contrast, many studies are looking at the effects of size as a "continuous" variable. There is some evidence that no matter the size distribution, the smaller schools in the distribution enhance achievement (Howley, Strange, and Bickel 1999). This finding implies that a policy of smaller size, no matter the starting point, and notwithstanding any absolute definition of smallness, is appropriate. And as shown below, this may be especially true in low-income communities. But despite the possibility that any reduction in size is good, the consensus seems to be that small-school benefits are achieved in the 300- to 400-student range for elementary schools and less than 1,000 students for high schools (Cotton 1996).

"A specific benefit associated with smaller schools is higher student achievement, an especially significant outcome given the importance now accorded to test scores."

Second, the evidence on various reforms to create small schools through mechanisms such as schools-within-schools, where large schools are subdivided into "houses" or "academies," is nowhere near as extensive or conclusive as the evidence on school size. This is partly because these reforms are relatively new and partly because arrangements that create schools within a school vary so widely. Cotton (2001) has produced perhaps the best review of what we currently know about these arrangements to create more intimate learning places.

Third, much of the work linking school size to education outcomes derives from case studies and other less quantitative evidence. While the evidence calls for small schools, specific findings will need to withstand stronger scrutiny.

With these caveats in mind, there is a growing body of research linking smaller school size to higher student achievement. In one of the earliest studies, Barker and Gump (1964) used sophisticated sociological concepts and measurements to link the size of a school as an "ecological environment" to the behavior of individual students.

> The large school has authority: its grand exterior dimensions, its long halls and myriad rooms, and its tides of students all carry an implication of power and rightness. The small school lacks such certainty: its modest building, its short halls and few rooms, and its students, who move more in trickles than in tides, give an impression of casual

> or not quite decisive educational environment (p. 195).

Barker and Gump conclude that these outside "views" are wrong and that there are strong forces within small schools that create, stimulate, and even compel students to become more active and involved with school events and learning than in large schools. The authors concentrated on extra-curricular activities and found that the proportion of students engaged in these activities was as much as twenty times higher in the four small schools they studied compared to the largest one. More students in the smaller schools were involved in a wider range of activities, and many more students held leadership positions than in the largest schools. And the students in the smaller schools were not only more involved but more satisfied with their experiences (ch. 12).

Barker and Gump were among the first to demonstrate diminishing returns to increasing school size. While they recognized that big schools may be able to provide some services that small schools cannot, ultimately they concluded that: "It may be easier to bring specialized and varied behavior settings to small schools than to raise the level of individual participation in large schools" (p. 201).

The soundness of these observations has withstood the test of many newer studies. In one recent and well-known study linking school size to beneficial outcomes, Wasley et al. (2000) argue that small schools can:

- improve education by creating small, intimate learning communities where students are well-known and can be encouraged by adults who care for them and about them,
- reduce isolation that adversely affects many students,
- reduce discrepancies in the achievement gap that plagues poor children, and
- encourage teachers to use their intelligence and skills.

In addition, small schools often encourage parental involvement, which benefits students and the entire community (Schneider et al. 2000).

Nathan and Febey (2001) identify similar beneficial outcomes. In their highly regarded study, "Smaller, Safer, Saner, Successful Schools," they argue that smaller schools, on average, can provide:

- a safer place for students,
- a more positive, challenging environment,
- higher achievement,
- higher graduation rates,
- fewer discipline problems, and
- greater satisfaction for families, students, and teachers.

Raywid (1999) aptly summarizes the value of small schools. She says that students in these schools "make more rapid progress toward graduation, are more satisfied with small schools, fewer of them drop out than from larger schools, and they behave better in small schools." Indeed, Raywid concludes that: "All of these things we have confirmed with a clarity and at a level of confidence rare in the annals of education research." (Also see Howley 1994, Irmsher 1997, and Cotton 1996, 2001.)

A specific benefit associated with smaller schools is higher student achievement, an especially significant outcome given the importance now accorded to test scores. Fowler and Walberg (1991) found that school size was the best predictor of higher test scores in 293 New Jersey secondary schools, even considering widely varying socio-economic factors. Lee and Smith (1997) using the National Educational Longitudinal Study linked school size with higher performance, and Keller (2000) showed that small schools consistently outperformed large ones, based on evidence from 13,000 schools in Georgia, Montana, Ohio, and Texas (also Duke and Trautvetter 2001). There is considerable evidence on this point contained in reviews by Howley, Cotton, and Raywid. Here's how Cotton (1996) summarizes her reading of existing studies:

> About half the student achievement research finds no difference between the achievement levels of students in large and small schools, including small alternative schools. The other half finds student achievement in small schools to be superior to that in large schools. None of the research finds large schools superior to small schools in

> their achievement effects. Consequently, we may safely say that student achievement in small schools is at least equal—and often superior—to student achievement in large schools.

Achievement measures used in the research include school grades, test scores, honor roll membership, subject area achievement, and assessment of higher-order thinking skills.

Perhaps there is even stronger evidence linking the effects of small school size and higher performance in communities having low socio-economic status. Pertinent findings often stem from the Matthew Project, inspired by the 1988 work of Friedkin and Necochea, who presented empirical evidence linking smaller schools with stronger academic performance in impoverished communities. Over time, Friedkin's and Necochea's findings have been replicated in studies conducted in school districts in Arkansas, Georgia, Ohio, Montana, Texas, and West Virginia, and in districts in California other than those Friedkin and Necochea studied (see Howley and Bickel 1999, Howley 1995). While specific effects vary from study to study, and while the definition of small varies across studies, the cumulative evidence in these works is that smaller school size leads to higher performance in poor communities.

In general, school size has been tied to other desirable outcomes besides better academic performance.

• **Small schools can reduce violence and disruptive behavior.** Smaller schools seem to reduce negative student behavior, especially among students of low socio-economic status (see especially Gregory 1992, Stockard and Mayberry 1992, and Kershaw and Blank 1993). The research here tends to be more anecdotal, however, based on case studies, and it lacks the quality of work that links school size to achievement.

• **Small schools can improve a wide range of student attitudes and behavior.** Smaller schools seem to reduce the anonymity and isolation that students sometimes experience (Barker and Gump 1964), and they may increase students' sense of belonging. Fowler and Walberg (1991) argue that both large school size and large district size were associated with reductions in participation in school activities, satisfaction, attendance, feelings of belonging, and other measures of school climate (see also Stockard and Mayberry 1992, Foster and Martinez 1985). Small schools also seem to have lower dropout rates (Toenjes 1989, Pittman and Haughwout 1987, Stockard and Mayberry 1992), higher attendance rates (Fowler 1995, Howley 1994), and higher graduation rates (Farber 1998).

• **Small schools can improve teacher attitudes.** There is less research on this point, but most of it links smaller schools to higher levels of cooperation between teachers, better relations with school administrators, and more positive attitudes toward teaching (see Hord 1997, Gottfredson 1985, Stockard and Mayberry 1992). Lee and Loeb (2000) found more positive teacher attitudes in the small schools that planners created in Chicago as part of a city-wide plan to reduce school size.

• **Small schools may be cost effective.** Many studies dispute the often-heard justification for consolidating smaller schools into larger ones based on economies of scale. These works document the absence of economies of scale in public organizations and especially in public organizations that are labor intensive, such as schools. The evidence is fairly conclusive that economies of scale quickly become dis-economies of scale as schools grow in size (Steifel et al. 2000, Gregory 1992, Walberg 1992, Robertson 1995). Indeed, Gregory (1992, 5) writes:

> The perceived limitations in the program that small high schools can deliver, and their presumed high cost, regularly have been cited as justifications for our steady march toward giantism. The research convincingly stamps both of these views as misconceptions.

Not only does the cost of education increase with larger schools, but related research shows that curricula do not improve with increased school size. Indeed, some research indicates that the supposed improvements in curricula associated with school size face rapidly diminishing marginal returns. Pittman and Haughwout (1987, 337) argue that "It takes a lot of bigness to add a little variety."

• **Public opinion data confirm a preference for small schools.** In February 2002, the public opinion research organization Public Agenda released a study endorsing small schools. Based on surveys of parents, teachers, and students, the report notes that more than two-thirds of the parents interviewed believed that smaller high schools offer a better sense of belonging and community, have administrations that would be more able and likely to identify poorly performing teachers, and would be better able to tailor instruction to individual needs. Conversely, two-thirds of the parents interviewed thought that larger schools were more likely to have discipline problems. Based on these findings, Public Agenda (2002, 1) concluded:

> The latest idea in America's ongoing debate on education reform has been a simple one: when it comes to schools, small is beautiful. A group of influential reformers says the U.S. trend toward larger and larger school buildings is creating schools that are difficult to manage in which students feel alienated and anonymous. These advocates call for high schools of around five hundred pupils, saying teenagers thrive in more personal settings. The kind of comfortable, informal communication that takes place readily in a small institution is simply not feasible, these advocates say, in a larger, more harried one.

In their study about what motivated parents to seek vouchers available through the Children's Scholarship Fund, a nationwide privately funded voucher program targeted at low income families, Peterson et al. (2001) argued that, among other reasons parents chose to participate in the program, “Parents applied for vouchers partly in order to shift from the larger schools in the public sector to the smaller schools generally available in the private sector” (p. 16).

Based on the cumulative findings on school size, Ayers et al. (2000) argue that making schools smaller is the “ultimate reform.” While this argument certainly would benefit from better research across all these issues and by a more precise definition of small, findings now indicate that reducing school size can produce considerable benefits across a range of outcomes—and there is little evidence showing that reducing school size will produce negative outcomes. This is especially true for children and communities ranked lower in socio-economic status.

Class Size

Class size is an important factor in school design and drives a host of costly facility-related issues that are part and parcel of the school building's planning, design, construction, cost, maintenance, and operation. Given that education is labor intensive, class size is a big factor in determining the number of teachers needed and, hence, how much education will cost. While social scientists are engaged in an intense debate over the effects of class size on educational outcomes, there is widespread popular belief that smaller classes are better.

Of the teachers surveyed by Public Agenda, seventy percent said that small class size is more important to student achievement than small school size. This preference for smaller classes is being codified in law: nearly half the states have enacted legislation and are spending hundreds of millions of dollars each year to reconfigure school buildings to reduce the student-teacher ratio to twenty or fewer students per teacher (National Association of Elementary School Principals 2000).

At the national level, the Clinton administration made class size reduction a centerpiece of its educational reform efforts, and the Bush administration has followed suit. Despite the popularity of small classes, the scientific evidence linking class size to achievement is mixed—and hotly contested.

The Debate Over Class Size

The debate in the literature over class size is often highly technical and focuses on fights over appropriate methods for using metanalysis to identify patterns in existing work. Much of this work has been done by economists focusing on the efficiency of education measured by the effects of different inputs, such as class size, to educational outputs, such as test scores.

One of the leading scholars in this field, Eric Hanushek, believes that educational inputs, including class size, are not associated with higher performance (Hanushek 1997, 1999). The outputs he gauges usually are test scores measured by the National Assessment of Educational Progress (NAEP), a long-term project administered by the National Center for Education Statistics.

(For more information on NAEP see http://nces.ed.gov/nationsreportcard/about/)

Hanushek has collected a set of studies that begin with the Coleman report and run through 1994, and each of these studies includes estimates of how some school factor (such as class size, for example) affects some desired academic output (such as test scores). Equations that link such inputs to outputs are called a production function, and Hanushek's original database consisted of 377 different production function estimates contained in ninety individual publications. According to Hanushek (1997), of these estimates, 277 include some measure of student/teacher ratios (not class size) and of these, only fifteen percent find statistically significant effects showing that lower student/teacher ratios increased performance, while an almost equal number (thirteen percent) report that lower student/teacher ratios reduced test scores. In the handful of studies that have actual measures of class size, the results also are mixed.

In a number of publications, Greenwald, Hedges, and Laine have attacked Hanushek's methodology and findings. A 1996 article in the *Review of Educational Research* sets forth their reasoning. They argue that, based on their analysis of a larger set of production functions than Hanushek used, "A broad range of school inputs are positively related to student outcomes, and that the magnitude of the effects are sufficiently large to suggest that moderate increases in spending may be associated with significant increases in achievement" (Greenwald, Hedges, and Laine 1996, 362).

Similarly, Krueger (2000) argues that Hanushek's findings are based on a flawed methodology. According to Krueger, Hanushek's reported findings are derived by weighting all the studies included in his database equally, thus placing a disproportionate weight on a small number of studies that use small samples and mis-specified models. Krueger argues further that Hanushek exercised "considerable discretion" in applying his own selection rules. According to Krueger, "Hanushek's procedure of extracting estimates assigns more weight to studies with unsystematic or negative results" (p. 10).

Using a different (and easily defended) weighting rule that corrects for the number of results reported in the same study, Krueger shows that studies with positive effects of class size are almost sixty percent more prevalent than studies with negative effects. In a second exploration of the effects of weighting schemes, Krueger weights the studies in Hanushek's database by the quality of the journal in which it appeared (utilizing impact scores calculated by the Institute for Scientific Information based on the average number of citations to articles published in the journals in 1998). Using this weighting method, positive findings again are twice as likely as negative findings.

"Collectively, the work of Krueger, Greenwald, Hedges, and Laine has undermined the strength of Hanushek's argument—but the issue is far from settled."

Hunt (1997, ch. 3) provides more detail on the rather intense arguments that greeted Hanushek's work. Collectively, the work of Krueger, Greenwald, Hedges, and Laine has undermined the strength of Hanushek's argument—but the issue is far from settled.

While Hanushek has been a driving force in staking out the "class size doesn't matter" position, other researchers using a range of data also have found that reducing class size has no effect on educational outcomes. For example, Hoxby (2000), using naturally occurring variation in class sizes in a set of 649 elementary schools, finds that class size has no effect on student achievement. An analysis of the relationship between class size and student achievement for Florida students using 1993–94 school level data found no relationship between smaller classes and student achievement (State of Florida 1998). Similarly, Johnson (2000) finds no effect of class size on 1998 NAEP reading scores, other things being equal. While many studies use student/teacher ratios, Johnson uses class size, and he compares students' performance in classes that have both more and less than twenty students and finds no difference. However, Johnson notes that the range of class sizes in his database may not be sufficient, since some researchers such as Mosteller (1995) and Slavin (1989) find effects only for very large declines in class size.

In contrast, Robinson and Wittebols (1986), using a related cluster analysis approach of more than one hundred relevant research studies (in which similar kinds of research studies are clustered or grouped together), concluded that the clearest evidence of positive effects of smaller class size is in the primary grades, particularly kindergarten through third grade, and that reducing class size is especially promising for disadvantaged and minority students.

More positive conclusions on the influence of class size have been drawn from an analysis of Texas schools. Using data from more than 800 districts containing more than 2.4 million students, Ferguson (1991) found significant relationships among teacher quality, class size, and student achievement. For first through seventh grades, using student/teacher ratio as a measure of class size, Ferguson found that district student achievement fell as the student/teacher ratio increased for every student above an eighteen to one (18:1) ratio.

Other studies find that class size affects test scores (Ferguson 1991, Folger and Breda 1989, Ferguson and Ladd 1996). Wenglinsky (1997) used data from fourth graders in more than 200 districts and eighth graders in 182 districts and found that smaller class size positively affected math scores for fourth graders and improved the social environment for eighth graders, which in turn produced higher achievement. These effects were greatest for students of lower socio-economic status.

None of these econometric studies, however, have shown very large effects, and many researchers caution about the high cost of implementing this reform relative to its expected benefits. While the econometric evidence has been inconclusive, there have been a series of experiments in which class sizes have been reduced, and the results of these experiments have been interpreted to support the benefits of smaller class size.

In Indiana, the Prime Time project reduced class size from approximately twenty-two to nineteen students in first grade and from twenty-one to twenty students in second grade. The study's design drew criticism, which cast doubt on its modest conclusions. Beginning in 1990, Burke County, North Carolina, phased in a class-size reduction project, with the goal of placing all first, second, and third grade students in classes limited to about fifteen students. This project offered a better design, improved experimental criteria, and results that, according to Egelson et al. (1996), increased time on task and decreased disciplinary problems substantially.

“Smaller classes allow more time for instruction and require less time for discipline.” This conclusion was reported by Molnar et al. (1999) in evaluating the first two years of the five-year Student Achievement Guarantee in Education (SAGE) program in Wisconsin, which was implemented in 1996. This study compared thirty schools that entered the SAGE program to a group of approximately fifteen comparison schools having similar demographics in order to gauge SAGE researchers' claims that reduced class sizes in early grades leads students to higher academic achievement. Targeted toward low-income schools, the SAGE class-size reduction was quite large, ranging from twelve to fifteen students per teacher compared with twenty-one to twenty-five students per teacher in the comparison group. This reduction was larger than in the better-known STAR (Student/Teacher Achievement Ratio) experiment in Tennessee. The gain in test scores was similar to gains attained with STAR, and also consistent with STAR. The greatest gains were posted by African-American students.

Of numerous experiments around the country to reduce class size, the STAR program authorized by the Tennessee legislature in 1985 has received the most attention. Even before the Hanushek, Hedges, and Krueger controversies, it was evident that the statistical evidence relating smaller class size to academic outcomes was uncertain. In turn, legislators in Tennessee launched the STAR project as a random-assignment experiment to more rigorously identify the effects of class size. The program established a class size of approximately fifteen students per teacher. It embraced seventy-nine schools, more than 300 classrooms, and 7,000 students, and followed their progress for four years. STAR compared classes containing thirteen to seventeen students to those containing twenty-two to twenty-six students. Teachers and students were randomly assigned to different-sized classes so that the independent effect of class size could be measured more precisely. The results were clear:

- students in small classes did better in math and reading tests at the end of kindergarten,
- the kindergartner achievement gap between the two class sizes remained the same in first, second, and third grades,
- students from smaller classes behaved better than students from larger classes, and these differences persisted through at least fourth grade,
- the effects were stronger for students of lower, rather than higher, socio-economic status, and
- the effects were stronger for African-American students.

These outcomes have been identified by several researchers (most notably Mosteller 1995 and in a series of papers by Krueger—for example, Krueger 2000 and Krueger and Whitmore 2000). While much of the early work based on STAR data sought to identify short-term effects, many researchers wondered how durable the effects were. Because the STAR experiment began in the 1980s, sufficient time has passed to allow researchers to begin identifying longer-term effects of small classes.

Nye et al. (1999) explored these longer-term effects using data from the Lasting Benefits Study (part of the STAR experiment) to show that the positive effects of small classes are evident in test scores for math, reading, and science at least through eighth grade. Controlling for a variety of confounding factors, such as attrition and variable time in small classes, the authors found that more time spent in small classes is positively related to higher achievement. This work clearly extends the time span for benefits attributed to small class size.

Krueger and Whitmore (2000) also examined STAR's long-term effects. Their main finding was that students who were assigned to small classes were more likely to take the ACT and SAT exams—and that this effect was substantially greater for Blacks than for Whites. Thus while the percentage of students who took the test increased for Whites from forty percent to almost forty-four percent, for Blacks, the increase was from thirty-two percent to more than forty percent. These results withstood a series of increasingly rigorous statistical tests. Moreover, minority students increased their test scores more than White students did, narrowing differences in performance between White and Black students. The time elapse between the STAR experiment and their study was still too short to allow Krueger and Whitmore to link enrollment in STAR's smaller classes to actual enrollment in college (or performance in college once enrolled). However, taking the SAT or ACT exams is the first step toward college, and the higher rate of students who were in small STAR classes taking these tests should ultimately translate into higher enrollment in college.

Conclusion

What is to be concluded from the research presented here?

- School facilities affect learning. Spatial configurations, noise, heat, cold, light, and air quality obviously bear on students' and teachers' ability to perform. Empirical studies will continue, focusing on fine-tuning the acceptable ranges of these variables for optimal academic outcomes. But we already know what is needed: clean air, good light, and a quiet, comfortable, and safe learning environment. This can be and generally has been achieved within the limits of existing knowledge, technology, and materials. It simply requires adequate funding and competent design, construction, and maintenance.
- Building age is an amorphous concept and should not itself be used as an indicator of a facility's impact on student performance. Many schools built as civic monuments in the 1920s and 1930s still provide, with some modernization, excellent learning environments; many newer schools built in the cost-conscious 1960s and 1970s do not.
- There is a definite consensus about the positive effects of small school size, and the effects seem to be the strongest with students from lower socio-economic groups. This is an area, however, where policy makers need the support of studies that better establish the tradeoffs between small schools and other community needs and resources.
- The class size debate is unresolved, although few would argue against smaller classes, where possi-

ble. This is an educational issue that has a serious impact on school planning and design, since smaller classes require more classrooms or more schools, a fact that may seem self-evident but often is lost in the debate.

- There is little standardization of facilities-related definitions. For example, the definition of small schools varies among studies, and overall student-teacher ratios are often (and wrongly) taken as a proxy for class size.
- The quality of facilities-related research ranges widely. Much of it is case-based and verges on the anecdotal, and many literature reviews use simple counts of articles, or they present undocumented summaries of findings. More rigorous approaches to summarizing large bodies of literature, such as metanalytic techniques, are few, and these studies often lead to disagreements over the methods themselves. Better research offering more definitive findings is needed.

Decisions about school facilities, once translated into brick-and-mortar, affect the daily performance of the generations of teachers and students who use them. These decisions are based on tradition, available technology, experience with "what works," and the changing needs of the times. Good facilities research allows us to productively sort through this mix and can help produce long-term, positive effects on academic outcomes.

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Acknowledgements

The author thanks Atri Battacharya and Adam McGlynn for their help in preparing this report. The author also thanks Jim Gardner of NCEF, who contributed a great deal to the work as editor.

The work reported in this publication is part of the Building Educational Success Together (BEST) initiative, which is working to make better urban school facilities a public priority at the national, state, and local levels. The mission is to secure the policy changes needed to improve conditions for students and teachers and to help make schools anchors of their communities. The initiative is led by the 21st Century School Fund (Washington, D.C.). Partners are the Education Law Center (New Jersey), the KnowledgeWorks Foundation (Cincinnati, Ohio), the National Clearinghouse for Educational Facilities (Washington, D.C.), the Neighborhood Capital Budget Group (Chicago), the National Trust for Historic Preservation (Washington, D.C.), and Mark Schneider (State University of New York at Stony Brook). Primary funding for the BEST initiative comes from the Ford Foundation.

For more information, contact the 21st Century School Fund at 202-745-3745, email BEST at info@21csf.org or check the BEST website at http://www.21csf.org/csf-home/BEST/best.htm

Additional Information

See the NCEF resource lists *Impact of Facilities on Learning, Classroom Acoustics, Classroom Color Theory, Daylighting, Healthy School Environments, High Performance School Buildings, Lighting, Indoor Air Quality, Mold in Schools, and School Size* online at http://www.edfacilities.org/rl/

Reviewers

Paul Abramson, William Brenner, Glen Earthman, Mary Filardo, Lisa Heschong, John Lyons, Joe Nathan, Henry Sanoff, Marty Strange.

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Educational Trends Shaping School Planning, Design, Construction, Funding and Operation

National Clearinghouse for Educational Facilities

Kenneth R. Stevenson
September 2010

What does the future hold for educators and facilities professionals when it comes to planning, building, funding, and operating school facilities? No one can absolutely know beforehand. However, there are many, many indicators of where public education in the United States may well be destined. These indicators take the form of already occurring trends that will change education dramatically in the next forty years. While that seems like a long way off, school facilities built today will likely still be in existence in 2050. This raises a critical question. What are the emerging major trends educators and facilities specialists need to be aware of to better insure that future school structures complement the coming evolution, and possibly revolution, in public education? This question serves as the framework for what is presented in the following pages.

First, though, why is it important to be aware of trends? As futurist Gary Marx (2006) points out, "Identifying, monitoring, and considering the implications of trends is one of the most basic processes for creating the future (p. 326)." Aldridge and Goldman (2007), authors of a book on issues and trends in education, reinforce the need to carefully study trends when they point out that, "People living in the 21st century will experience more rapid changes than in any other period of human history (p. 94)." And, Gene Glass (2008), writing on the possible fate of public education in America, reminds us that the events of today often reshape the future in dramatic ways not now imagined. He states, for example, "The invention of technologies shapes culture in ways that are often unpredictable at the birth of the invention. Television killed dance bands; the Internet is killing book stores (p. 11)."

Will technology, or a yet to be identified phenomenon, "kill" public education as it now exists? If so, what may take its place? If not, what adjustments will be needed to insure that the public education system has a vital and vibrant future? And, what does all of this mean to educators and facilities professionals who are responsible for planning, design, construction, funding, and operation of schools? Not all of these questions can or will be answered here. However, the intent is to provide sufficient information about trends in America to assist educators and facilities professionals to be prepared for an increasingly diverse, conflicted, and constantly evolving world of education.

Presented are fifteen trends that are redefining education in the United States -- and how each relates to the field of school facilities. Some trends are broader, such as those dealing with general population changes impacting on education. Others are specific to education, including trend information on changes in the teaching corps, school size, and organizational structure of schools.

In the concluding section, the cumulative effects of the trends on the brick and mortar place called school are discussed, as well as ways educators and facilities professionals can work in concert to prepare for and to address the trends as they emerge and become full-blown.

Before presenting the updated trends, a note of forewarning is extended to the reader. The first two editions of this NCEF "Trends" work (2002 and 2007) tended to envision a relatively rosy, almost idealistic future for public education. The new version does not. A continuing recession, escalating political polarization, risiing racial/ethnic tensions, a growing national debt, and a widening divide between the haves and the have nots portend a future fraught with unprecedented challenges to and clashes over the form and substance of public education in America. However, while the likely picture that the new "Trends" paints is relatively bleak, the future is not pre-determined. The intent is that this edition serve first and foremost as a vehicle for careful study, reflection, discussion, and thoughtful action by those who will affect and be affected by changing educational conditions and circumstances. As a result, the hope is that the fate of public education may be more positive than trends, if left unattended, appear to indicate. In essence, this work reflects the belief that, as an old adage suggests:

We can't control the future, but we can help shape it.

Prepared under a grant from the U.S. Department of Education, Office of Safe and Drug-Free Schools

Trend 1: The Numbers of U.S. Youth Increase Dramatically

The school-age population in the United States will grow from less than 60 million in 2010 to nearly 80 million in 2050. (U.S. Census Bureau, 2008a)

Synopsis

The number of school-age children in the United States will increase by about 20 million, or nearly 35%, in the next forty years (U.S. Census Bureau, 2008a). On average approximately ninety percent of America's children historically have attended public schools (National Center for Education Statistics, 2009j). Therefore, public education could need space for about 18,000,000 more students than in 2010. Using 600 as the average size for a school, this increase equates to about 30,000 new school facilities between 2010 and 2050. On average, over 750 new public schools per year could be needed over the next four decades just to address the population growth. That number does not include construction required to replace or modernize currently existing schools as they age and deteriorate over this time period. Assuming that education as we know it continues to exist over the coming decades, the need for new schools will be significant.

Consequences

On the surface it appears that educators and facilities professionals can expect a significant amount of work in the area of school construction in the coming decades. However, many confounding variables need to be considered in looking to the future of school facilities construction. First, current depressed economic conditions are not expected to improve for some time (Kennedy, 2010). Even when they do, psychological scars of high unemployment and lost homes will remain for many years afterward. While student enrollments will undoubtedly increase, it is less clear that capital funding will be readily available to meet the certain growth. Overcrowding and continued use of school buildings beyond their useful life may well occur. Significant efforts will be needed to convince taxpayers and politicians to adequately fund school construction over the next forty years.

Second, no one is sure what the ultimate impact of the "virtual" school movement will be on the need for a physical place called school. What is known is that more and more students are opting to take web-based courses (and, in some cases, full degrees) in their homes (Gray & Lewis, 2009). And, many states are beginning to set up and administer their own publicly financed virtual schools as an alternative for requiring students to attend a brick and mortar facility. It is not unrealistic to think that many states will look more and more to technology and virtual schooling in hopes of reducing the tax burden for school construction. Educators and facilities professionals will need to work together to monitor technological and funding trends and be prepared to incorporate their effects into school facilities planning, design, construction, funding, and operation.

Trend 2: The U.S. Student Population Becomes More and More Diverse

The percentage of non-Hispanic white students in schools will decline from 52% in 2010 to 35% in 2050. (U.S. Census Bureau, 2008b)

Synopsis

Forty years ago a vast majority of children (4 out of every 5) in America's public schools were white, non-Hispanic. That percentage has dropped precipitously, with slightly over half of the students in schools today falling into that category. And, projections indicate that within the next forty years white, non-Hispanic children will comprise slightly over one-third of the school-age population. In effect, over the next several decades, America's public schools will become institutions serving multiple minorities, with no single racial/ethnic group being a majority (U.S. Census Bureau, 2008b). The Hispanic school-age population (all races) will grow significantly during the foreseeable future. By 2050 the number of school-age Hispanic children will increase 120% over 2010 numbers. At the same time, as birth rates continue to decline among the white, non-Hispanic population, the actual number of school-age white children in 2050 will be about three million fewer than that of 2010. The black school-age population (non-Hispanic) will show some increase over the coming decades, growing about 15 percent in number, but becoming a smaller percent of the total. Other racial/ethnic school-age populations (i.e. Asian, American Indian), though relatively small individually in terms of total student enrollments, will increase as well, growing from 13% of the whole today to 18% in 2050.

Consequences

Diversity itself will not be the issue that confronts educators and school facilities professionals. Instead, the real challenge will come from what that diversity represents in this country. In the United States as of 2010, about 8 percent of white, non-Hispanic people were living in poverty. While that is a large number, approaching one out of every ten, it pales in comparison with the two other major racial/ethnic groups comprising the population. Nearly 1 in 4 (23%) of blacks and Hispanics (all races) now live below the poverty line (U.S. Census Bureau, 2008c).

Unless conditions change, what this means for public education in the future is that, as the school population becomes more diverse, an ever increasing number of children in poverty will be entering America's schools. This is important because of the profile of families in poverty. Families living in poverty often have much higher incidences of: a) parents being under-educated; b) only one parent living at home; c) few informal educational resources or opportunities for learning available at home; d) limited health care, with little or none being preventive; and e) low expectations regarding school completion (Moore, Redd, Brukhauser, Mbwana, & Collins, 2009). Living in such contexts, children of poverty often struggle with schooling from the time they enter until dropping out before finishing high school. As a result, they often end up either unemployed or in low paying jobs, perpetuating the cycle (U.S. Department of Labor, 2010).

The growing number of high-risk children coming to school in the future will call for a curriculum and teaching approaches that overcome the negative environmental factors these young people will have lived with from before birth. In turn, educators and facilities professionals will be challenged to provide school structures designed to facilitate such new teaching/learning approaches as they are developed to better assure that children of poverty succeed in the educational process.

Trend 3: The Country Experiences an Ever Growing Number of Older Citizens

> **The number of people 65 or older living in the United States will increase from about 40 million in 2010 to nearly 90 million in 2050. (U.S. Census Bureau, 2008a)**

Synopsis

In just 40 years the senior population in this country will increase by 120%. For comparison purposes, the total population will grow by about 56% (U.S. Census Bureau, 2008a). And, as noted in Trend 1, the numbers of school age children will increase by only around 35%. In 2050, one in every five people in the United States will be 65 or older -- compared to a little over one in nine in 2010. Why this trend is so important to educators and school facilities professionals is that the aging "baby boomer" population will be a political and economic force that must be reckoned with for decades to come (Age Wave, 2009). These seniors will cast ballots in great numbers, carefully voting for initiatives that enhance their quality of life and against proposals and candidates that negatively affect their fixed retirement incomes. On the surface it appears that the country faces a most daunting challenge – a significant need for new school facilities versus an aging population likely to be unwilling to pay for such construction.

Consequences

Educators and school facilities professionals can promote the "buy-in" of the older generation to expending large amounts on school facilities if those seniors see direct benefit to themselves. Schools traditionally have been closed systems, focused almost exclusively on serving children. Baby boomers and future aging generations in growing numbers will have no personal relationship with the schools in their neighborhoods. Because of this, they will see little value in supporting tax increases to build or modernize schools. Educators and school facilities professionals who recognize this, and make a paradigm shift in their thinking as to who schools should serve, are much more likely to be successful in getting construction projects funded. Schools can become wonderful places for both children and seniors, with seniors having access to everything from library materials, to health room services, to dining facilities, to recreational facilities, to the companionship of young people (Bingler, Quinn, & Sullivan, 2003).

Educators and school facilities professionals can also improve the perceptions of the older generation about schools by highlighting the benefits of a quality education for the nation's youth. The youth of today literally are the workforce of tomorrow (Society for Human Resource Management, 2010). Their success in the educational process eventually equates to the quality of life of seniors. The services the older generation receives in retail establishments, the availability of first-class doctors and other professionals, and the economic well-being of the country as a whole are tied to young people. If the younger generations are well educated, they are much more likely to become productive workers, raise their standard of living, and support social security and Medicare through taxes they pay. For educators and school facilities professionals, the issue and challenge will be convincing the senior generation that expenditures on America's youth are both directly and indirectly beneficial to the older members of society as well.

Trend 4: An Increasing Number of Special Needs Children Receive A Majority of Their Instruction and Services in Regular Classroom Settings

> **The number of children classified with some type of disability has grown nearly 45% since 1990. (National Center for Education Statistics, 2009a)**

Synopsis

Growing numbers of school-age children are being formally diagnosed with some type of disability requiring service under the Individuals with Learning Disabilities Act (IDEA). In the last thirty years the percentage of students with disabilities has grown from about 10% of the total school population to approximately 13% (National Center for Education Statistics, 2009a). With the school-age population expected to grow to nearly 80,000,000 students by 2050, the estimated special education population could approach 11,000,000 children, or over 4 million more than in 2010. Assuming that current averages continue, ninety percent of the special needs school-age population, or about 10 million, will be served by public schools. This assumes that the percent of the total population identified as disabled remains near the 13% mark. However, since the composition of students is expected to change during the same 40 years, with more and more children of poverty being served, the percentage of disabled students in schools could be much higher.

While the numbers of special needs students have been increasing, how they are served in schools has undergone a dramatic shift as well. Twenty years ago less than one-third of these students received their instruction primarily within the regular classroom setting. However, well over half the special needs children in schools today are served chiefly in a regular classroom, and that percentage has been steadily rising over the past two decades (National Center for Education Statistics, 2009b).

Consequences

The era in which a school was built often can be determined by how and where special education programs are located. In the oldest schools no basic mobility accommodations for special needs children or adults have been provided, much less spaces designed to specifically serve students with disabilities. Eventually attempts were made to serve the disabled through specific program offerings in designated, separate spaces. This generation of schools can be readily recognized because "special education" is a distinct part of the building, often away from the main activities of the school. More recently, educators and facilities professionals have made great strides in providing instructional programs and physical design considerations that accommodate the disabled seamlessly into the mainstream of the school (Greville, 2009).

The demand to provide instruction to special needs children in the least restrictive environment likely will continue to grow. With the special needs population increasing but an aging population fighting taxation, it will be a ordeal for educators and facilities professionals to stretch limited capital budgets to design schools and deliver programs that provide a mainstream learning experience for these children. But, it is a challenge that must be met if all children are to be treated as "first-class citizens" in the educational process (Hutchings and Olson, 2008). Educators and facilities professionals can expect growing numbers of special needs students over the coming forty years. These children will not only require special services, they likely will receive such services predominantly via the regular classroom.

Trend 5: More and More Early Childhood Students Come to School

> **In 1965 only 27% of children ages 3 through 5 in the United States attended preprimary programs. Forty years later, the percentage has risen to approximately 65%. (National Center for Education Statistics, 2009c)**

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Synopsis

The number of children under five years old is expected to grow from 21 million in 2010 to over 28 million in 2050, an increase of 33% (U.S. Census Bureau, 2008a). Thus, the pool of potential students for early childhood programs (preprimary, ages 3 through 5) will be large. Exactly how many of these children may eventually attend school as 3 through 5 year olds depends on whether current enrollment trends stabilize or continue to grow. Since the 1960s the percentage of preprimary-age youngsters going to school has increased each decade. About two-thirds of all 3 through 5 year olds in the United States now participate in a preprimary schooling experience (National Center for Education Statistics, 2009c). And, that percentage is likely to increase over time (National Center for Education Statistics, 2009d). Therefore, educators and facilities professionals will have to prepare for growth in early childhood numbers for two reasons: 1) the raw numbers of preprimary age students in this country will grow substantially over time; and 2) more of these students proportionally probably will participate in early childhood programs.

The growing numbers of early childhood children will not be the only issue. How these 3 to 5 year olds are housed is likely to continue to change as well, putting even more pressure on the need for school facilities for this population. For the past three decades the percentage of 3 through 5 year olds housed in full-day programs has increased by ten percent per decade (National Center for Education Statistics, 2009c). In 1975 about three-fourths of preprimary students attended school for only part of a school day, usually a morning or afternoon session. Now, approximately 60% of all early childhood students attend school all day. If universal education for 3 to 5 year olds becomes the norm in the next forty years, and most of these students attend full day, the need for early preprimary facilities will grow greatly.

Consequences

Analyzing data specific to preprimary children, the 12 million 3 through 5 year olds in 2010 will become 16 million by 2050 (U.S. Census Bureau, 2008a). Assuming twenty students per classroom and assuming 90% of these children will attend public schools, that growth alone may require 200,000 new preprimary classrooms over the coming four decades. Further, another 120,000 new early childhood instructional spaces could be needed to provide full-day facilities for the equivalent of today's preprimary enrollments now housed in half-day settings.

With challenging economic times across the country, and with a growing taxpayer resistance to levies of any kind, the movement to universal 3 and 4-year-old education has slowed. However, during the next forty years preprimary education likely will become a critical part of meeting the needs of the growing number of children of poverty entering schools. The timely intervention that early childhood programs are designed to provide, especially for high risk children, is expected to prove highly cost effective, reducing the need for later remediation, keeping children in school, and generally better assuring they become productive members of society (Coleman, Buysse, & Neitzel, 2006).

Educators and facilities professionals will want to begin considering now how to provide sufficient and adequate future early childhood spaces. A burgeoning 3 through 5 year old cohort of youngsters – more and more of whom will attend school full day – mandate this.

Trend 6: The Likelihood of Smaller Schools Diminishes

Since 1995 the average enrollment of public secondary schools has risen about 5% to 816. The mean enrollment of elementary schools has remained relatively constant, averaging fewer than 500 students. (National Center for Education Statistics, 2009e)

Synopsis

The size of secondary schools has continued to slowly climb over time. A half century ago the average size secondary school was less than 500. By the 1970s that figure had increased to over 700 (Lindsay, 1982). Today the average, as noted above, is slightly over 800 (National Center for Education Statistics, 2009e). Though secondary schools have grown in enrollments in previous decades, since 2000, their average size has remained fairly constant year after year. This raises the question of whether this leveling off is a temporary phenomenon, or if secondary schools will grow bigger or become smaller in the coming decades. At the elementary level schools on average have not really varied that much in size over the last twenty years (National Center for Education Statistics, 2009e). In general, though pulled to build bigger schools to take advantage of economy of scale and pushed for smaller schools for better outcomes, districts have tended on

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average to construct schools comparable in size to what they already have.

Consequences

Data from the most recent ten years do not portend larger or smaller schools in the near future. With this in mind, for the short term elementary schools likely will remain on average in the 475 to 500 pupil range. Secondary schools will not grow greatly in size, if at all, remaining on average around 800 to 850 in student population.

However, as the press of student population growth continues to manifest itself over the next forty years, school size may be dramatically affected. First, as noted before, by 2050 18 million more children are expected in U.S. public schools than currently enrolled. And, at current average school sizes, this could create a need for 30,000 new K-12 facilities within four decades. At the same time a growing senior population will likely fight for lower taxes instead of higher ones.

As a result, districts and states will struggle to find adequate funding to support the mammoth amount of construction anticipated. Consequently, efforts will have to be made to stretch limited capital funds. One approach that will be considered is construction of larger facilities that provide an economy of scale in both capital costs and operational expenses. To accommodate the strong desire of parents and communities for smaller schools, districts and states will utilize "small-within-large" or "school-within-school" approaches (Duke, DeRoberto, & Trautvetter, 2009). In general, over the longer term, average school size may well increase.

Two caveats to this prediction relate to technology and school choice. Schools may become smaller as virtual learning opportunities become more and more common. It is easy to envision a day when most students take a course or two online at home or at their parent's work site. If schools take into account such off-campus learning experiences as part of their master course schedules, the total number of students physically on a campus at any one time might never exceed 50% to 75% of its total enrollment. As to choice, if schooling moves primarily to a model of personal/family elected educational options with vouchers/tax credits, schools may become boutique in nature, with various providers carving out a specialized niche to attract a particular clientele. In any event, educators and facilities professionals will want not only to explore issues of school size in general as part of the long-range planning process, but particularly discuss how to at least provide "smaller" within larger school structures.

Trend 7: Reductions in Teacher-Pupil Ratios Slow

In the 1950s the average teacher/pupil ratio in U.S. public schools was 26.9 to 1. Near the end of the 2000s this ratio had dropped to about 15.3 to 1. (National Center for Education Statistics, 2009f)

Synopsis

In a little over half a century, the average public school teacher/pupil ratio in this country has been cut nearly in half (44% lower today than in 1955). Projections are that the teacher/pupil ratio nationally will continue to drop in the coming decade, reaching a record low of about 14.5 to 1 by 2018 (National Center for Education Statistics, 2009f).

Until 1980, the average teacher/pupil ratio was falling at a rate of about 2 students every five years. More recently the decrease in the number of students per teacher has slowed, with the average ratio dropping by only about one student every decade (National Center for Education Statistics, 2009g).

Consequences

The question becomes: Will teacher/pupil ratios continue to decline over the next forty years? The answer is that it is unlikely, at least to any appreciable amount. A major reason for this is economic. As noted in other trends, school enrollments will grow significantly in the coming decades, requiring large increases in expenditures to build and operate needed new schools. At the same time, great numbers of baby boomers will have disdain for taxes, particularly increasing taxes. Educators will find themselves pressed to find adequate funding for all the different priorities that must be addressed in the future: more teachers and school facilities for higher enrollments; more intervention programs and personnel for a greater and greater number of disadvantaged, high-risk students; lower teacher/pupil ratios; etc.

While smaller teacher/pupil ratios are something almost everyone favors, the reality is that reducing classroom enrollments is extremely expensive. In an elementary school of 500, with 20 students on average in a class, 25 regular classrooms are needed to house the student

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population. Reduce that number to 15 students per regular classroom teacher and 33 classrooms are required. The added cost of reducing the average number of students by five per class is not just the expense of eight more classrooms, but also the compensation for eight additional teachers for the life of the school.

As with school size, teacher/pupil ratios may well be stable or even drop slightly over the next few years. But, the long term trends suggest that teacher/pupil ratios may actually increase – offset by more technology and/or a different staffing model, which are discussed in later trends. In any event, educators and facilities professionals will want to monitor over time what is occurring regarding teacher/pupil ratios and discuss both what a decrease and an increase might mean in planning, designing, constructing, funding, and operating school facilities.

It should be noted that for this trend the numbers of students per instructor are presented and discussed largely as teacher/pupil ratio data. Teacher/pupil ratio data include most certified professional instructors in a school, whether they are regular classroom teachers or instructional specialists. Therefore, the teacher/pupil ratio tends to be lower than actual pupils per teacher in regular classrooms. Teacher/pupil ratio data were used because they are available nationally and historically. The trend issues raised are applicable with either method, though students per regular classroom would be consistently higher.

Trend 8: Grade Span Configurations Continue to Evolve

> **The number of public schools housing grades PK/K/1 to grade 12 doubled between 1993/94 and 2007/08, from 1,514 to 3,113. (National Center for Education Statistics, 1995 & 2009h)**

Synopsis

During the past decade and a half the school grade span configurations of K/PK-5, 6-8, and 9-12 have continued to be the most popular across the nation's public school systems, growing thirty to forty percent in number. Grade span configurations that have lost favor are: a) the elementary span of PK/K/1 to grade 6 (-30%); b) the middle level grade structures of 7 to 8 and 7 to 9 (-23%); and the high school grade span of 10 to 12 (-21%). Interestingly, two older grade span configurations have gained new life. The numbers of PK/K to 8 grade schools have increased by 32% in fifteen years, from 4,566 to 6,049. And, as noted above, the "all grades under one roof" PK/K/1 to 12 configuration has doubled in number during the same period. (National Center for Education Statistics, 1995 & 2000h).

Consequences

One reason for the re-emergence of the K-8 and K-12 grade span models is the interest parents and communities have in children being in environments that provide quality learning, and that promote feelings of physical and emotional safety (Bushaw & McNee, 2009). By staying in the same educational facility for more grades, students do not have to experience the trauma of going off to a bigger, more impersonal school -- either after the elementary years or, in the case of K-12, at all. However, while this trend likely will continue to garner attention, it will not overtake the much more prevalent K-5, 6-8, 9-12 configuration in the foreseeable future.

Part of the reason for this relates to the basic logistics of using existing facilities. The cost of remodeling and adding to existing schools to restructure them to house a different grade configuration may be extremely high (i.e., converting an elementary school to also house secondary programs). As noted earlier, in the coming era of limited resources and reluctant taxpayers, budgets likely are going to be committed to first priority initiatives such as building more public schools to address the influx of 18 million additional students expected over the next four decades. This will leave little in terms of resources to reconfigure a large number of schools to such spans as K-8 or K-12.

This is not to propose that K-8 or K-12 configurations will not continue to get attention as society seeks to return to neighborhood schools directly within communities. But, these configurations are more likely to prosper in smaller public charter school and public school choice settings, as opposed to becoming mainstream for the greater school population. Nonetheless, as educators and facilities professionals look to the future, long range planning topics should include how best to configure grades to promote optimum learning (Hill, 2008).

Trend 9: Time in School Remains Relatively Unchanged

> **During the 2000s, five states increased the minimum number of days in a school year. Four others reduced the minimum mandated. On average, the range remains 170 to 180 days. (National Center for Education Statistics, 2009i)**

Synopsis

To provide more and/or better quality of time for learning, districts and states have explored: a) adding more school days; b) making school days longer; c) and spreading school days more evenly across the calendar year. Though the concept of extending the time children are in school has been a point of discussion for many years, the reality is that things have remained relatively constant for the past several decades. No state as of 2008 required more than 180 days of annual schooling (National Center for Education Statistics, 2009i). Fewer than 3,000 of the 91,000 public schools across the country were on a year-round schedule (National Association of Year-Round Schooling, 2007). And, several states and districts had explored reducing school weeks by a day, with some actually implementing this approach (Kingsbury, 2008).

Consequences

With continuing concern about controlling school operating costs in rough economic times, the likelihood of extended school days or years is relatively remote. More probable over the coming decades is that "learning time" will be extended through virtual educational experiences. And, this approach may well be combined with reduced number of school days in brick and mortar facilities. By 2050 it is not hard to imagine a state of affairs in which students attend the physical place called school for 3 or 4 days a week, with the remainder of their educational activities occurring at home, parents' places of work, or local community centers via some form of telecommunications. The benefits are twofold. Districts save significant operating costs since support service expenses such as heating and cooling and bus transportation may be reduced by twenty percent or more. And, actual "learning time" might in fact be increased since students could be provided a variety of virtual self-paced enrichment and remediation instructional modules beyond the standard curriculum. Such modules might be completed in the evenings, on weekends, or even in the "off-summer," without increasing operating costs.

As to year-round schooling, the concept has not really caught on as many imagined it would. A major reason is that the concept conflicts with what has become standard social/cultural practice. While year-round education may have unique benefits, a majority of parents and communities still want their children free for summer vacation, off the streets during the days of a traditional school year, and available as teenagers for summer employment. In forty years, year-round education may become the accepted delivery model for schooling. However, if so, the process will be long and slow, as it has been to date.

In any event, educators and facilities professionals will find that school facilities continue to have large periods of "down time" in terms of children not present. What will be a critical consideration is how such time could be best used to the advantage of the whole community (Daily, 2007). As noted earlier, educators and facilities professionals who find ways to integrate schools and communities will have greater success in convincing those communities to support the schooling process, including funding of school construction and remodeling.

Trend 10: School Attendance Lines Continue to Blur and Disappear

> **In 1993 about 80 percent of students attending public schools did so through assignment (prescribed attendance zones). Now, over 25 percent choose the school they attend. (Grady & Bielick, 2010)**

Synopsis

Public school choice continues to grow. More and more districts are instituting programs that allow students and parents to select a school that best meets the interests, needs, and goals of a child. Not only are fewer public school children now required to attend a specific school, many are given multiple options including magnet school and charter school alternatives. These options are being exercised. For example, in 1999/2000 about 350,000 children were attending charter schools. Near the end of the decade of the 2000s that number has risen to 1.3 million students. Related survey data indicate that noticeably more parents (62%) who choose their child's school are happy with that school than are parents (52%) whose children are assigned to a school (prescribed attendance zones). In general, the numbers of public options are growing steadily and parents with those options are more satisfied with the schools their children attend (Grady, & Bielick, 2010).

Consequences

Public school districts and schools continue to serve the vast majority (approximately 90%) of school-age children in the United States (National Center for Education Statistics, 2009j). But, how this is done is changing. Educators are beginning to realize that satisfied

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customers (students and their parents) may make all the difference in whether public education continues to exist. As a result, attendance lines are slowly but surely becoming things of the past as parents and their children are given public education options, not only to meet their needs, but to keep them participating in public schooling.

As this unfolds, real care must be exercised that the transition is inclusive. To date, available data indicate that those more likely to make choices (particularly private vs. public) tend to be white, well-educated, socio-economically comfortable, and located in more suburban settings (Grady & Bielick, 2010). Educators and facilities professionals must work closely together to develop master plans for public choice that geographically, economically, racially/ethnically, and politically extend choice to all constituents. Through proper location of schools of choice, and the types of choices available, this can be a reality. But, careful thought and planning, as well as commitment, will be keys.

Trend 11: Technology Becomes the Future: The Future Becomes Technology

> **Ninety-seven percent of the U.S. public schools report they have instructional computers in their classrooms. And, two out of three teachers are integrating technology into instruction at least moderately. (Gray, L. & Lewis, L., 2008)**

Synopsis

Technology is now incorporated into all aspects of instructional delivery and school operations (Gray & Lewis, 2008). Technology in support of instruction is used for everything from student assessments, to individualized instruction, to grading, and to reporting student progress (Gray, Thomas, & Lewis, 2010). Operationally, schools have embraced technology for such functions as accounting and bookkeeping, staff development, security, bus routing, energy conservation, and maintenance scheduling. While almost all schools are now wired for technology, the next generation of connectivity is rapidly taking hold. About 40% of public schools now report having wireless access. As to variety of instructional equipment available, most schools report having such items as LCD/DLP projectors, electronic whiteboards, and digital cameras. Rapidly emerging trends include: a) increasing numbers of virtual learning experiences (distance courses and fully online schools), b) less and less reliance on paper instructional products (texts, workbooks, and paper are disappearing), c) greater use of hand-held learning devises (smart phones and iPods), and d) individually prescribed curricula generated from technology-based assessments and prescriptions (Johnson, Smith, Levine, and Haywood, 2010).

Consequences

For educators and facilities professionals the challenge of technology over the next forty years is, to say the least, daunting. Technology is advancing at such a rapid rate that it is nearly impossible to plan school structures that remain "cutting-edge" for very long after opening. However, schools planned with the greatest flexibility in terms of adding (and removing) technology will best support continuously emerging technology-based instructional methodologies and operational management approaches.

One note of caution must be added to all of this. While technology will become ubiquitous, it is not to that point as yet, either in America or across the world (Newcastle University, 2009). A great disparity as to the amount of technology, the quality of technology, and the preparedness of instructional personnel to use the technology now exists across America's schools (Gray, L. & Lewis. L., 2008). Similar to the unevenness related to who makes school choices noted in a previous trend, schools with the most current and comprehensive technologies (and teachers well-trained in their use) tend to serve higher income, well-educated, white, suburban populations. As the student population of the United States becomes more diverse, quality instructional technology will need to be readily available to all children, regardless of economic status, race/ethnicity, or geographic location. Educators and facilities professionals will want to keep this in mind as new schools are constructed, but also in monitoring and upgrading technology in existing, older schools.

Trend 12: Larger Amounts of Instructional Time Continue to be Allocated to Core Subjects

> **Since 2001 nearly 60 percent of U.S. school districts have increased instructional time for English/language arts, and 45% for mathematics. Sixteen to thirty-six percent reported decreasing time for social studies, art, music, and/or science. (McMurrer, 2007)**

Synopsis

Since the No Child Left Behind legislation was put in place, schools and districts have steadily increased instructional time allocated to curricular areas where state and national testing is focused. Not only are elementary schools increasing the amount of time students participate in English/language arts and math, so are many middle and high schools. For example, over twenty-five percent of high schools report requiring students who do not do well on state academic performance tests to take additional course work in English/language arts and math (McMurrer, 2007).

Further, a recent national movement, the Common Core State Standards Initiative (2010), has proposed that common standards and benchmarks in English/ language arts and mathematics be adopted across the country. While the proposal has caused considerable consternation among strong states rights advocates, many educators and policy makers support the idea that a child, regardless of where he or she lives in the United States, should receive an education that is adequate for successful job or college entry.

Consequences

Educators and facilities professionals have the intimidating task over the next forty years of not only building tens of thousands of new schools, but doing so in such a way that the structures themselves fully and adequately support the instructional programs to be offered. This is not an easy assignment since what should be taught, to what extent, and by whom are evolving in this country. Strong advocates continue to press for a broad curriculum that educates the "whole child" (Association of Supervision and Curriculum Development, 2007). However, the reality is that over the next many years educational resources in this country will be focused on basic subjects and content – with a particular emphasis continuing to be on English/language arts and mathematics (Common Core State Standards Initiative, 2010).

One reason for this is that these two subjects are considered by many as the building blocks for others. Another is that industrialized countries, competing for their share of the world marketplace, consider basic worker language/communication skills and mathematical knowledge essential to economic survival. Third, as noted earlier, continued challenging economic times, combined with increasing percentages of at-risk children in schools over the next forty years, means that education in the main will have to channel limited resources into the basics first, leaving less and less for other areas of the curriculum.

With the strong push now beginning for national standards in mathematics and English/language arts, these areas will continue to garner the greatest interest and consideration of policy makers and citizens in general for years to come. This is not to imply that the arts will no longer be offered in schools of the future, nor that science and social studies/history will be abandoned. In fact, a growing body of research is beginning to indicate that subjects like the arts can improve academic outcomes (Hardiman, Magsamen, McKhann, & Eilber, 2009). But, it does mean that larger portions of school time and school spaces likely will be committed to the "essential" knowledge and skills areas. Educators and facilities professionals will want to plan new schools and remodeling of existing structures accordingly.

Trend 13: Schools Grow Greener and Greener

As of 2010 over 300 schools across the United States had been LEED certified, with another 1,700 seeking certification. LEED is a third party voluntary verification process focused on environmental sustainability of structures and sites. (U.S. Green Building Council, 2010)

Synopsis

Schools are being viewed more and more as a key component of creating and maintaining a sustainable environment (Kats, 2006). In this role schools are expected to accomplish three different tasks: a) to teach children the importance of and how to protect the earth's environment; b) to model environmental best practice in the construction and operation of school facilities, and c) to improve operational efficiency, (thus, saving tax dollars) through green practices that reduce energy costs, control water and wastewater use, and reduce personnel expenditures by creating healthier work environments. While estimates vary, the general rule of thumb is that building environmentally friendly schools costs about 2% to 3% more than would be the case without doing so. However, proponents of green schools argue that when life cycle costs are taken into account, green schools more than pay for themselves (Kats, 2006).

Consequences

Some local education policy makers are yet to be convinced that green schools are worth the added expense (Hui, 2010). The argument is made that, particularly considering the current economic crunch, spending more to build green schools in effect reduces the total number of building projects that school districts can fund. However, the idea of "going green" has taken firm hold in America. Businesses tout green products, towns and cities boast of green living conditions that promote health and well-being, and various governmental entities from the federal to the local level reward green activities via grants and incentives. As green building materials and construction practices become more common, the cost of erecting green structures, including schools, likely will fall noticeably. And, if longitudinal studies consistently verify substantial life cycle cost savings as a result of building environmentally friendly schools, the movement will not only continue, but become expected and/or required throughout the United States.

In a sense, the concept of building green schools is in its infancy, much like where technology was twenty years ago (Steele-Saccio, 2007). And, as with technology, the likelihood is that "green" practices will be omnipresent in all aspects of the lives of Americans within twenty years. Educators and facilities professionals have a unique opportunity to both educate and model for the country green practices through careful planning and design of both new schools and retrofitted ones. The challenge will be reminding constituents and policy makers to think long term as it relates to upfront costs versus cost savings gained over the life cycle of a structure – not to mention a healthier plant.

Trend 14: Who Teaches Becomes a Critical Question

Currently approximately 3.7 million public school teachers are employed in the United States. In ten years that figure could exceed 4.2 million. (National Center for Education Statistics, 2009k)

Synopsis

If student populations grow as expected over the next forty years, America will actually need nearly 5.5 million teachers, using today's teacher/pupil ratios. That is, by 2050 public school enrollments could call for almost two million more teachers than now employed. Not only will higher education institutions need to recruit and train larger and larger cohorts of would-be teachers, that whole corps will have to be more diverse than it is today. Latest figures for the country indicate that over 80% of public school teachers are white, non-Hispanic (National Center for Education Statistics, 2009l). Hispanic (all races) and black teachers (non-Hispanic) each account for 7% of the total instructional staff. As noted earlier, by 2050, only 35% of the student population is expected to be white, non-Hispanic. If teacher race/ethnic cohort ratios do not change within forty years, public schools will be populated by a diversity of students - but a largely homogeneous teaching corps. A further challenge will be encouraging males to enter teaching. Among public school faculty today, only about 25% of staff members are male (National Center for Education Statistics, 2009m).

Consequences

Recruiting and retaining qualified teachers is a growing challenge in the United States (Alt & Henke, 2007). With the increased range of career opportunities for women today compared to their mothers and grandmothers, universities and schools are finding the potential teacher pool diminishing. Further exacerbating the problem is that relatively low wages and esteem issues have curtailed the number of males who make a profession of education. And, those who do so often enter administration as quickly as possible because of increased pay and prestige. Attracting replacement teachers for the 3.7 million current ones who will retire over the next forty years will require a Herculean effort in and of itself. To also add another two million teachers because of expected enrollment growth may be an impossible task. Further intensifying the problem is the need to greatly diversify the teacher corps as part of the process.

Over time limited resources in general and difficulty in attracting and retaining a qualified teaching corps may combine to be the impetus for a change in the delivery structure in schools (Coggshall, Lasagna, & Laine, 2009). Many expenditures related to operating schools are fixed (utilities, etc.), with educators having few options other than reducing personnel costs to cut or control budgets. As current hard economic times and their memories continue, and taxpayer reluctance grows, policy makers and administrators will seek economies through personnel reductions – with the most obvious target being teaching positions because of their relative abundance.

As a result, the function of the remaining teachers could be transformed. In one futuristic vision of what may happen, a smaller cohort of professional teachers assumes a new role of "facilitator of learning," operating much like doctors - diagnosing, prescribing, and coordinating treatment (Coggshall, Lasagana, & Laine, 2009). In this approach, a highly trained and elite corps of professional educators oversees an increasing number of technicians - both instructional and technical. In effect, teachers would diagnose and prescribe while technicians would administer "treatment" through an array of delivery systems.

Whether schools will adopt a "doctor's office" model is not clear at this instant. However, the indicators that some type of major structural change in public education will occur are strong, and growing. Educators and facilities professionals will want to formally include the ramifications of such potential changes in developing and reviewing long-range building programs.

Trend 15: By Necessity Learning Evolves to an Asynchronous and Ubiquitous Process

> **About a million students currently are enrolled in some form of online learning, and 24 states have virtual schools that serve multiple districts. Virtual learning is growing at an estimated rate of over 20% annually. (Watson, Ryan, & Wicks, 2009)**

Synopsis

The Alliance for Excellent Education recently highlighted three education crises facing this country in the coming years. These include: a) an insufficient capacity to prepare students for and to provide post-secondary learning experiences to compete in a global market; b) an impending "funding cliff" that is and will continue to change the organization and structure of education; and c) a looming teacher shortage (Wise, 2010). In general, the argument is made that education as it has been structured and delivered for decades and decades cannot continue to survive, much less flourish.

The underlying problem across all three crises is money, or lack thereof. And, the future does not seem bright in terms of that changing. A winner of the Nobel Prize in Economics, Paul Krugman (2010), lately has suggested that the recession of the first decade of the 21st century is not over and even hypothesizes that the country could yet be headed to another depression. As noted earlier, even if economic conditions improve in the next several years, the memory of the effects of the current unemployment and job woes will drive how many Americans feel about any kind of taxation, much less tax increases. In sum, the funding picture for education, not only in the near term, but for the foreseeable future, is dreary.

Consequences

How does a country provide a quality education to an increasing number of children, more and more of whom will be at-risk learners, while dollars budgeted to education continue to remain stagnant, or even diminish? How can effective learning experiences be delivered when the expectation is that the nation may well have fewer and fewer qualified teachers in the decades to come? And, how will districts address increasing enrollments when adequate funding is not available to construct or update school facilities?
The emerging answer is: Through virtual learning experiences – experiences that occur at any location, at any time, and focus on the topic of choice of the learner (Moe and Chubb, 2009). In this scenario, content materials are developed by the best educators in their respective fields. Highly trained distance delivery experts package the materials for effective use via multi-media devices. Student learning styles, as well as developmental stages and bio-rhythms, are considered as instructional packets are assembled. Learning opportunities become ubiquitous and asynchronous - literally available everyplace and all the time either through handheld devices or via electronic "learning stations" located in homes, at parents' work sites, in local libraries, or within community centers. The argument is made that the result is a delivery system that provides: a) the best of educational materials; b) instructional delivery tied to the uniqueness of the learner; and c) endless choices as to when, where, and how to learn. And, all of this occurs despite diminishing education budgets since personnel, operating, and facilities-related costs are reduced significantly when schooling is largely virtual.

This does not necessarily foreshadow the disappearance of schools within 40 years. In fact, it is more likely in 2050 that some hybrid or blended educational delivery model, involving on-site and online learning, will be prevalent (Means, Toyama, Murphy, Bakia, & Jones, K., 2009). It does, however, strongly suggest that educators and facilities professionals face a different future from what has always been. Thinking differently, particularly in terms of what school facilities will look like and the roles they will fulfill, must become a very necessary part of the long range facilities planning process.

The Message the Trends Send to Educators and Facilities Professionals

The author Ursala K. Le Guin may have said it best. "Morning comes whether you set the alarm or not." The same is true of the future. Regardless of how much we may dislike what the coming decades could bring, time will not stand still. Though the picture of the future painted by most of the trends is less than bright, educators and facilities professionals will have to deal with whatever transformations eventually manifest themselves in society and in education. The critical consideration is not "if" but "how" to deal with the issues the trends put forth. One way is to try to react as they occur. However, as mammoth and fast-moving as many of the trends are, this approach may well put educators and facilities professionals in an untenable position – one where today's solutions become tomorrow's problems.

The other option in dealing with the potential effects of the trends is to be pro-active. Instead of waiting for the shifts and their resultant impact to happen, educators and facilities professionals, as noted previously, who thrive and prosper likely will be those who uncompromisingly anticipate and prepare for varying potential futures (National Center for Education and the Economy, 2008). Necessary questions that must be part of this approach include:

a) What are the likely but alternative scenarios that could emerge regarding the framework and configuration of public education in the next several decades (mission, structure, clientele, funding, delivery system, etc.)?
b) What issues, challenges, and hurdles does each scenario present in terms of planning for, designing, constructing, funding, and operating public school facilities?
c) What opportunities, innovations, and advances does each scenario potentially offer for effectively and efficiently creating an optimum learning environment?
d) How can educators and facilities professionals work together not only to meet the consequences of the trends, but to influence the future itself?
e) What adjustments to both the planning process and the actual physical structure of schools need to be made now in anticipation of alternative futures?

Aggressively exploring possible future scenarios and creating contingency plans of action may not assure success. On the other hand, investigating the possibilities could lead to yet unimagined, creative, and innovative facilities-related solutions for everything from potential overcrowding to Baby Boomer reluctance to support schools financially. Though it's not a new tool, planning will continue to be the critical factor in providing school structures that complement and harmonize with the educational system of tomorrow.

Final Thoughts

This edition of "Trends" has painted an uncertain future for public education and, thus, of school facilities planning, design, construction, funding, and operation. However, it is critically important not to ignore or deny the possibilities the trends encompass. Instead, it is hoped that this "Trends" will serve as a starting point around which educators and facilities professionals come together to "think outside of the box," to ask "what if," to wonder "why can't we," and to "consider the unconsidered." Out of shared frank, open discussions of the potential impact of the trends on public education and its school structures will surely emerge new and exciting ideas -- ideas of how to best adapt to and, in some cases, ameliorate the effects of the trends in the best interests of America's children (Chen, 2010).

No doubt the roles of educators and facilities specialists will be affected by a changing future. But, it is also true that educators and educational specialists can help shape that future. The key is to be proactive, beginning now. As an old African proverb reminds us:

> *Tomorrow belongs to the people who prepare for it today.*

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School Facility Conditions and Student Academic Achievement

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October 2002

Williams Watch Series: Investigating the Claims of *Williams v. State of California*

(Document wws-rr008-1002)

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I. INTRODUCTION: SUMMARY OF FINDINGS

Based on my own studies, my review of pertinent research st1udies, and my background and experience in the field, my conclusion is that school facility conditions do affect student academic achievement. In particular, I reach the following conclusions:

a. School building design features and components have been proven to have a measurable influence upon student learning. Among the influential features and components are those impacting temperature, lighting, acoustics and age. Researchers have found a negative impact upon student performance in buildings where deficiencies in any of these features exist. In addition, overcrowded school buildings and classrooms have been found to be a negative influence upon student performance, especially for minority/poverty students. Section III describes studies that used a particular building feature or component such as air conditioning, lighting, or presence of windows to serve as variables with which to compare student achievement.

b. The overall impact a school building has on students can be either positive or negative, depending upon the condition of the building. In cases where students attend school in substandard buildings they are definitely handicapped in their academic achievement. Correlation studies show a strong positive relationship between overall building conditions and student achievement. Researchers have repeatedly found a difference of between 5-17 percentile points difference between achievement of students in poor buildings and those students in standard buildings, when the socioeconomic status of students is controlled. Section IV deals with those studies that used some form of assessment to determine the total condition of the school building and then compared the results with student performance.

c. Ethnographic and perception studies indicate that poor school facilities negatively impact teacher effectiveness and performance, and therefore have a negative impact on student performance. Section V of the report describes ethnographic studies related to the influence the physical environment has upon teacher performance.

d. Recent studies regarding the number of students in schools as compared with its capacity provide ample evidence that overcrowding conditions are a negative influence upon students and teachers. Section VI describes studies dealing with the relationship between overcrowding and student achievement.

All of the studies cited in this report demonstrate a positive relationship between student performance and various factors or components of the built environment. The strength of that relationship varies according to the particular study completed; nevertheless, the weight of evidence supports the premise that a school building has a measurable influence on student achievement.

II. THE STATE OF AMERICA'S SCHOOL BUILDINGS

During this past decade, there have been a number of studies that have demonstrated the deplorable condition of some of the school buildings throughout the country. The U.S. General Accounting Office has identified every state in the union, including California, as having school buildings that are in poor condition (1995). In many school systems, particularly in urban and high-poverty areas, students attend school in buildings that threaten their health, safety, and learning opportunities (U.S. Department of Education, NCES, June, 2000).

The GAO (1995) estimates that over half of the 42 million public school students attend school in a building that needs at least one or more major building component or feature extensively repaired. As a result of this situation, research exploring the relationship between building condition and student performance is critical.

In addition, many school districts throughout the country have a large number of old, worn-out buildings in which to educate students. The National Center for Educational Statistics stated the average age of school buildings in the United States was 40 years old. This would mean that half of the existing school buildings were completed before 1959 (NCES, 2000).

Many old buildings simply do not have the features, such as control of the thermal environment, adequate lighting, good roofs, and adequate space that are necessary for a good learning environment. Or if older buildings have such components, oftentimes they are not functioning because of poor maintenance practices. School buildings that can adequately provide a good learning environment are essential for student success (USDOE, 2000). The bridge between good physical environment and effective student learning is quite important.

III. BUILDING COMPONENTS AND STUDENT PERFORMANCE

A. Thermal Quality

Good thermal environment of a classroom is very important to efficient student performance. Various researchers have provided a long history of research on thermal conditions in the business and industrial workplace. McGuffey (1982) lists such researchers as Vernon, Bedford, and Warner (1927), Osborne and Vernon (1922), McConnell and Yaglou (1926), Mackworth (1926), Winslow and Herrington (1949), Herrington (1952), and Karpovich (1959). The conclusion of these researchers was that increases in temperatures in the workplace tends to decrease worker efficiency and increases the risk of work related accidents. As a result, proper control of the thermal environment is needed in the workplace.

These studies have provided some of the motivation for research efforts on the influence the thermal quality of the classroom has upon students. Specific research studies cited by McGuffey (1982) regarding the influence the thermal quality of the classroom has upon students have been completed by Mayo (1955), Nolan (1960), Peccolo (1962), Stuart and Curtis (1964), McCardle (1966), Harner (1974). Lemasters (1997) also cited Chan (1980). In almost all of these studies, the importance of a controlled thermal environment was stressed as necessary for satisfactory student performance.

Harner (1974) concluded based upon an analysis of existing research that temperatures above 74°F adversely affected reading and mathematics skills. A significant reduction in reading speed and comprehension occurred between 73.4º F and 80.6º F. According to his analysis, the ideal temperature range for effective learning in reading and mathematics is between 68º and 74º F. Lanham (1999) reported that after the socioeconomic status of the students, the most influential building condition variable that influenced student achievement was air conditioning.

In all of the above cases, the researchers presented convincing data that supports the seminal work done 61 years ago by the New York Commission on Ventilation (1931). The Commission endeavored to determine optimal air temperatures in classrooms for the healthiest environment for students. The experiments were conducted in regular city and rural classrooms as well as experimental laboratories at a local college. Students were subjected to varying temperatures while in the classroom and measures of the number of reported illnesses were taken to compare with the temperatures. The Commission reported that when classrooms are not maintained within the narrow band of temperature and humidity tolerances of 67° - 73°F and 50 percent relative humidity, there were more reported cases of student illnesses than students in a properly controlled thermal environment.

The results of the Commission Study confirmed earlier studies conducted in the workplace that found excessively high temperatures tends to produce harmful physiological effects on workers. That part of the study that dealt with overheating showed that 15 percent less physical work was performed at 75° F than at 68° F with humidity at 50 percent; while at 86° F with 80 percent humidity, the decrease was 28 percent as compared to that performed at 68° F with humidity at 50 percent. In spite of the age of this research, these findings are just as germane today as they were three quarters of a century ago.

B. Acoustic Quality

Proper and accurate hearing is essential to student's ability to learn in the classroom. Many studies have determined the level of noise in the classroom that interferes with student learning. As far back as 1917, Morgan concluded that noise distraction interfered with learning and that students reported being tense in noisy classrooms (McGuffey, 1982). Laird (1930) concluded that students learn more when the classroom noise level is reduced to 40 decibels (Ibid). McGuffey identified more recent researchers that have found similar results. Cohen, Evans, Krantz, and Stokols (1980), Zentall and Shaw (1980), Cohen, et al (1981), Hyatt (1982), and Duffy (1992) have completed research studies conducted in public schools that investigated relationships between noise level and various student behavioral and performance variables. The methodology used by these researchers is appropriately controlled for other factors, thereby isolating the relationship between acoustic conditions and student health and achievement.

An excellent study completed by the Department of Health Services in California (1981) investigated the relationship between student performance and classroom and community noise. The study was well conceptualized and executed, using exacting measurements, and appropriate statistical analysis. Students in grades three and six in schools that were near highways and expressways were compared with similar students in schools in quiet neighborhoods. A very rigorous methodology and analysis were used for the comparison of scores on the California Test of Basic Skills. The mean grade equivalent achievement scores of all students in socioeconomically matched noisy and quiet schools were compared. Students in grades three and six in the quiet schools scored considerably higher in reading scores than students in noisy schools. In mathematics, the researchers found a measurable impact upon student test scores, but not as large as that found in reading. Based upon these results, the conclusion was reached that a negative relationship exists between classroom noise levels and reading achievement.

The results of the California study support the findings of Bronzaft and McCarthy (1975) who measured students in schools near elevated train tracks in New York City and found that students in classrooms nearest the trains scored below those students in classrooms on the opposite side of the school building in reading scores. In a follow-up study, Bronzaft (1981) compared the California Achievement Test scores of student in classrooms on the noisy side of the building with those students on the quiet side of the building after certain noise abatement measures were installed. In three of the classrooms on the noisy side of the building, acoustical treatment was applied to the ceilings. In addition resilient rubber pads were installed on the elevated rail track. These measures effectively reduced the extraneous noise level for students. In comparing the test scores, she found no differences between the scores of students in the noisy and quiet side of the building, whereas before there had been differences..

All of these studies are seminal works that aptly demonstrate the devastating effect of unwanted noise in the classroom. The findings of these studies are important and can be relied upon because appropriate methodology was used and the researchers were able to control the student population. The ability to clearly hear and understand what is being spoken is a prerequisite for effective learning. When this ability is impaired through unwanted noise students do not perform well.

C. School Building Age

The age of the school building has been tested as a factor in relationship to student achievement. Age of building in and of itself is usually not an important factor in influencing student performance, but the building components that are necessary for good student learning (e.g. thermal quality and acoustical control) are usually absent in older buildings. If older buildings do have some of the important components, these components may well be compromised because of poor maintenance or retrofitting practices. In my own survey of the research, a clear conclusion follows that older buildings usually do not have the main attributes of a modern building that are associated with a positive physical environment conducive to student learning (Earthman & Lemaster October, 1996). Normally such buildings do not have positive thermal control in the classrooms where the temperature can be controlled. Even when an older building has classroom control of the heating/cooling/ventilation, the old shell of the building is not sound enough to eliminate drafts of air coming into the space. Likewise, older structures characteristically do not have proper illumination. In most modern buildings acoustical control measures have been installed, but older buildings do not have such measures to control noise. Many of the building factors that are necessary for proper learning environments are simply absent in older buildings, but are present and functioning in new buildings.

As a result, many researchers have used age of the building as a variable that might help explain student achievement. McGuffey & Brown (1978), Plumley, (1978), Chan, (1979), Garrett (1981), Bowers and Burkett (1988), and Phillips (1997) have all found age of school building to explain a percentage of the variance of student learning. For example, Plumley found that building age accounted for 3.3 percent to 6.4 percent of the variance on 3 of the 5 subtests and 5.3 percent of the variance of student learning when age of building is correlated with the composite score of students on the Iowa Test of Basic Skills. In other words, these percentages represent how much the building age accounts for in the difference between the scores of students in new and old buildings. Phillips found a difference between the mean test scores of fifth grade students in old and modern buildings to be 2.55 points for reading and 7.67 points for mathematics. In the third grade, the differences in mean test scores were 3.25 points for reading and 5.7 points for mathematics. All things being equal, students in modern buildings perform better on achievement tests than students in older buildings.

IV. OVERALL BUILDING CONDITION AND STUDENT PERFORMANCE

Some of the more recent studies, including my own, compare the building condition obtained through an assessment of certain components or features that have a direct influence on student achievement. These studies are very similar to those that used the age of the building as a variable in correlating student achievement, but in these studies the evaluative instrument provides a more complete assessment of the condition of the building. These correlation studies are very focussed in their approach and use measurable data for statistical analysis. As a result, the data from these types of studies document in rather precise terms the amount of differences in academic achievement of students in substandard buildings and those students in functional buildings.

Four well-designed studies have used a composite building condition to measure the relationship it has upon student achievement. Berner (1993) compared the condition of elementary schools in Washington, DC to student standardized achievement scores. She used data from the survey of school buildings conducted by the D.C. Committee on Public Education (COPE). The Committee organized several groups of maintenance workers, engineers, and architects who were charged with the responsibility of assessing the building condition and determining whether the building was in overall poor, fair, or excellent condition. Based upon this classification, she correlated that building rating with student achievement scores. The percent of students participating in the free/reduced lunch program, mean income in the census tract, and percentage of white students in the census tract were used as a control for the socioeconomic status of the school. She found a significant difference of 5 percentile points in the achievement scores of students in poor buildings compared with scores of students in excellent buildings. She also stated that based upon the parameter estimate that if a school were to improve its conditions from poor to excellent, the achievement scores would increase by an average of 10.9 points. Cash (1993) developed an instrument to measure the condition of school buildings. To construct her evaluative instrument, she used previous research studies to identify building components or features that had measurable influence upon student achievement. She combined these components into the instrument used to determine building condition. Her population consisted of all rural high schools and students in Virginia. Socioeconomic differences were controlled by using the percent of student participation in the free/reduced lunch program as a variable. She found the achievement scores of students in substandard buildings to be from 2 to 5 percentile points below the scores of students in above standard buildings. I conducted a replication of the Cash study along with several colleagues using all of the high schools in North Dakota (Earthman, et al, 1996). The results of this study confirmed the findings by Cash. Hines (1996) completed a similar study using basically the same instrument and methodology as Cash, but with a population consisting of large urban high schools in Virginia. All of these researchers found the same range of differences in achievement scores of students in substandard verses above standard buildings when controlling for socioeconomic differences between the various school districts. The North Dakota study produced a difference of 5 percentile rank points on the composite or total achievement scores for students in substandard buildings versus students in above standard buildings and differences of 7 and 9 percentile rank points on the reading vocabulary and spelling sub-tests. Hines found higher differences in his study of urban high schools. These differences between students in substandard buildings and students in above standard buildings were 14 percentile rank points on the composite achievement scores and as high as 15 and 17 percentile rank points on reading and mathematics sub-tests respectively.

Subsequent research studies (Andersen, 1999; Ayres, 1999, O'Neill, 2000) have provided some support for the results of previously cited researchers who found the average difference between students in old or substandard buildings and those students in modern or above standard buildings to be from 5-17 percentile points. Taken together, the research studies cited above, along with the studies dealing with age of buildings, presents a formidable body of research findings that demonstrate that the condition of the school building has a sizeable and measurable influence upon the achievement of students (Earthman, 1998).

V. BUILDING CONDITION AND TEACHER EFFECTIVENESS

The condition of a school building not only influences student achievement, but can also influence the work and effectiveness of a teacher. Although it is very difficult to measure teacher effectiveness quantifiably, perception studies of teachers in good and poor school buildings provide a rich source of data relative to the effect the physical environment has upon these professionals. Such ethnographic studies are an important source of findings regarding the influence the physical environment has upon teachers and students.

Lowe (1990) investigated the relationship between learning climate and physical conditions in three elementary schools in Texas. The learning climate was defined as the ethos of expectations and perceptions of teachers, students, parents about self, student achievement, organizational rules and policies and the facility itself. A researcher designed perception questionnaire was used to obtain data from teachers regarding the effect the building condition had upon their performance. Teachers in buildings in poor condition stated that the design and appearance of the facility had a negative impact upon the learning climate. Conversely, teachers in building in good condition reported the building had a positive influence upon the learning climate. The size and organization of instructional space was reported as having an influence upon learning climate. The maintenance of the building, according to the teachers, seemed to impact the learning climate, as did the design and appearance of the building.

Corcoran, Walker, and White (1988) described the working conditions of teachers in urban schools. The teachers stated that the physical environment was sub-standard even in the newer buildings primarily because of the lack of proper maintenance and repair. The researchers reported that the working condition of urban teachers is marginal and would not be tolerated by any other profession. Good working conditions in the "best" schools in the study included an adequately maintained physical plant.

Dawson and Parker (1998) provide a descriptive analysis of the feelings of teachers about the building before, during, and after a renovation project is done on their schools. Teachers reported that there were many aspects of the renovation project they did not like and they had negative feelings about their work before and during that period of time. After the renovation, however, teachers reported that morale among the faculty was high and their frustration level was much lower than during the renovation. The faculty reported that the changes and improvements to the physical environment greatly enhanced the teaching and learning environment and in a way compensated for the inconveniences the renovation work caused.

The studies cited above have amply documented the fact that poor schools do reduce the effectiveness of the teachers and subsequently have a negative influence upon the ability of the students to learn.

VI. OVERCROWDED SCHOOLS AND STUDENT ACHIEVEMENT

Overcrowding of school buildings occurs for many reasons. Whatever the reasons, the result is very troublesome for both the students and teachers, as well as the organization itself. An overcrowded building is normally defined in terms of there being more students assigned to the building than it is designed to accommodate. The type and kind of educational program offered in a school also has relevance for the capacity of the building. When the capacity of the building is exceeded extreme pressure is exerted upon all of the facilities and areas that teachers, administrators, and students need to use for an effective educational program.

Although there are not as many research studies on the effect overcrowding has on student learning as there are with other physical environmental factors, nevertheless available research shows that overcrowding causes a variety of problems and the findings indicate that students in overcrowded schools and classrooms do not score as high on achievement tests as students in non-overcrowded schools and classrooms. Corcoran et al. (1988) reported that overcrowding resulted in a high rate of absenteeism among teachers and students. Teachers reported that overcrowding resulted in stressful and unpleasant working conditions. The population Corcoran used consisted of the teachers in 31 elementary, middle, and high school buildings in 5 major cities across the nation. The authors of the study observed that the working conditions of the teachers in these schools would be considered intolerable in another profession.

During the period of time between 1990 and 1996, the New York City Public Schools experienced severe overcrowding throughout the city. Three major studies were conducted to determine the effect of overcrowding on the student population and the city school organization. The first study dealt with the causes of overcrowding conditions and offered some remedies to alleviate the condition (Fernandez and Timpane, 1995). This report focussed on school crowding, physical conditions of buildings, and class sizes. Also included in this report was a discussion of the impact overcrowded conditions had upon student achievement and teachers efficiency. According to the report, “Teachers say that overcrowded schools are noisier, that they create more non-instructional duties and paperwork, and that, without question, they inhibit teaching and learning.” (p.6).

Rivera-Batiz and Marti (1995) completed the other report dealing with the consequences of overcrowding. They surveyed 599 students and 213 teachers in overcrowded schools to obtain their reactions to the overcrowded conditions. More then 75 percent of the teachers reported that overcrowding negatively affected both classroom activities and instructional techniques. Close to 40 percent of the students reported they had problems concentrating in their classes when learning something new. The researchers also reported that teacher burnout was much more common in overcrowded buildings than in underutilized buildings. They also stated that in overcrowded schools teachers reported they had only time to cover the basic material and could not have any time for further exploration.

Rivera-Batiz and Marti used data from the Board of Education school profile on elementary and high schools to examine the linkage between overcrowded conditions and student achievement. The influence of overcrowding on student achievement was analyzed by multiple regression statistical analysis. Student achievement was measured by the percentage of students passing the Degrees of Reading Power Test and the Pupil Evaluation Program Test for mathematics. The reading test is given to all students in the city in grades 2-10. The mathematics test is administered to students in grades 3 and 6. To control for the socioeconomic background, separate analyses were conducted for: (1) schools with a high proportion of students from families with high socioeconomic status, and (2) schools with a high proportion of students from families with low socioeconomic status. The analysis for the schools with a high percentage of low socioeconomic students indicated that….”the proportion of sixth graders in overutilized facilities passing the minimum standard for the DRP reading examination was between 4 to 9 percentage points *below* that in schools that were not overcrowded, holding other things constant”(p. 10, emphasis in original). For the mathematics test, “the proportion of sixth graders who passed the exam was between 2 to 6 percentage points *below* that in schools that were not overcrowded, other things held constant” (p.10, emphasis in original). The analysis for the schools that had higher socioeconomic families indicated students passing the minimum standard was approximately 2-4 percentage points above the schools that were not overcrowded, other things held constant. Overcrowding in these schools resulted because areas of high socioeconomic status and high academic achievement attract more students to these schools and cause overcrowding. The results of the analysis indicate that among schools with a high proportion of students from low socioeconomic status families, overcrowding has a definitely negative impact on student achievement.

Contrasted to these findings are those of the class-size study in Tennessee (Finn and Achilles, 1999). These researchers studied the effect small class size (15-17 students per classroom) has upon primary grade student achievement. Over 12,000 students participated in the study over the four years. Incoming kindergarten students were randomly assigned to one of three types of classrooms: small classes (13-17 students), regular classes (22-26 students), or regular classes with a teacher's aide. The researchers compared the achievement scores of students using results of the Stanford Achievement Test, the Comprehensive Tests of Basic Skills, and the Tennessee Basic Skills First Tests. The findings relating to achievement test scores indicated statistically significant differences were found among the three classroom types on all achievement measures. Students in the small classes evidenced superior academic performance compared to those students in the regular classrooms, both with and without a teacher's aide. Further, they found that the differences in test scores were higher for minority students and those in urban areas. They also found there was a long-term improvement of those students in small classes in the primary grades when they returned to regular-sized classrooms. Additional benefits of the class reduction program was that smaller classes can enhance the student/teacher interaction, the amount of attention available to any student, the amount of individualized instruction, as well as the level of disruptive behavior that can be tolerated. Obviously, from the research findings above concerning overcrowded classrooms the above activities would be severely curtailed or would not even occur.

The Public Advocate for the City of New York investigated the effect overcrowding had upon the school district organization (December, 2000). He stated that in smaller classes students receive more individual attention, ask more questions, and participate more fully in discussions. Teachers reported they spend more time maintaining order and keeping the noise level down. The author of the Public Advocate Report quoted from a US Department of Education press release (USDOE, September 2000) which stated: "Evidence continues to accumulate that shows that reducing class size improves student achievement, reduces discipline problems, and provides a lasting benefit to both students and teachers."(Public Advocate, p.1).

In spite of the fact that some of the results of studies dealing with overcrowded conditions are limited, excellent studies conducted in the New York City Public Schools and other states provide ample evidence that overcrowding conditions are a negative influence upon students and teachers. The United States Department of Education (USDOE, 2/14/02) completed a review of several major analyses and concluded that the research results indicate that class size reduction in the primary grades leads to higher student achievement and that if class sizes are reduced below 20 students, the related increase in student achievement moves the average student from the 50^{th} percentile up to somewhere above the 60^{th} percentile. Achievement results for disadvantaged and minority students are somewhat larger.

'Flipped classrooms' spreading in Wisconsin

Students watch online lectures

Updated: Wednesday, 27 Feb 2013, 2:18 PM CST
Published : Saturday, 02 Mar 2013, 4:00 AM CST

- MATTHEW DEFOUR, Wisconsin State Journal

MADISON (AP) - On a typical school night, while most chemistry students are solving homework problems, Verona High School junior Alison Ford is watching her teacher lecture on her iPod Touch.

The next day in class she huddles with two classmates to work on equilibrium equations based on the recorded lecture while her teacher moves between groups of students to answer questions about the assignment.

"It's a lot nicer because instead of tying up class time trying to explain everything, it really allows you to learn at your own pace," Ford said.

Welcome to the "flipped classroom," a learning model that is going viral across Wisconsin and the nation, the Wisconsin State Journal reported. It's being employed not only in local elementary and high schools, but also at Madison Area Technical College, UW-Madison and even the Madison Fire Department.

The method is appealing for several reasons: it employs high-tech gadgets and online social networking popular among young people; students can pause and review parts of lectures they don't understand without stopping an entire class; and teachers can spend more classroom time on individualized instruction.

It also has some limitations, such as ensuring that low-income students have access to computers and the Internet. Some students accustomed to completing homework assignments without learning the material might resist. And the process of creating original videos can be time-consuming for teachers at first, but once created they can be reused and added to a growing online library of educational materials that teachers can share for free on websites such as YouTube.

The education institutions that develop curriculum and write textbooks also might resist the shift of learning material to the Internet, where quality and accuracy can be more questionable, said Richard Halverson, a UW-Madison education professor who studies school technology and new media.

But many students are already looking up information online and solving homework problems while texting with friends, an indication that the "flipped classroom" will soon be the regular classroom of the 21st century.

"It's catching on like crazy," Halverson said. "It has been a dream of many educators for a long time, to use your time with students to help them understand meaning rather than deliver information."

It's hard to gauge how many teachers in the country are using the flipped model, but the national Flipped Learning Network has seen participation in its online community more than quadruple in the past year, from 2,500 to about 11,000 today, executive director Kari Afrstrom said.

In Wisconsin, the Department of Public Instruction is strongly advocating for innovations such as the flipped classroom, spokesman John Johnson said. The state's Digital Learning Strategic Plan released a year ago called the flipped classroom a "low-cost idea that should be explored," but warned that it would only be possible if schools invested in digital resources.

Arfstrom said her organization has conducted six trainings in Wisconsin in the past six months, more than most other states. "The Midwest is really embracing this," she said.

Teachers using the flipped model report seeing improvements in student test scores, Arfstrom said, though no studies have been done to verify that.

Ann Moffat, a teacher for 29 years, including 19 in Verona, said she was originally skeptical about switching to the flipped classroom model. Her Socratic lecture style involves quizzing students as she writes out chemistry equations on the board; under the new model she records her lectures in five- to 12-minute snippets without an audience to react.

But it wasn't long before Moffat embraced the new method. Not only can she offer more individualized attention during class, but she also no longer has students seeking assistance before school starts.

The peer collaboration also simulates what they'll experience in the work world, Moffat said. "They're learning how to work off each other and solve problems independently, which is the whole goal."

Matt McLaughlin, a physics teacher at Sun Prairie High School who began converting to a flipped classroom last spring, said some students resisted the change.

"When I first started, they looked at this as, 'Oh, you mean I don't have any homework,'" McLaughlin said. At one point McLaughlin switched back to normal lectures, but found more students asking that he continue to provide the online lectures.

The model isn't limited to area high schools. Madison Area Technical College offers classes, such as robotics and dentistry, where instructors use online lectures to make more time for hands-on experience in the classroom.

Faculty instructors Tina Rettler-Pagel and Nancy Woodward are offering a class in April for MATC teachers to learn how to employ the flipped model.

"The flipped model speaks to so many types of students: the student who is busy, the student who is struggling with content," Rettler-Pagel

said.

UW-Madison has set up two classrooms on campus where students can take business, engineering and math courses using the flipped model.

Chris Olsen, vice provost for teaching and learning, said the courses have proven so popular the university is looking to create more flipped classroom space.

"There is growing data from the higher education world that the flipped classroom approach is as efficacious as the traditional approach," Olsen said.

The Madison Fire Department has been training both new recruits and veteran firefighters with elements of the flipped model for more than a decade, assistant chief of operations Jim Keiken said.

By reviewing ahead of time a lesson about a high-rise fire or how to dismantle a car, trainees have more time for the hands-on component. They also are able to review the lecture at their own convenience, which can be especially important for firefighters who are constantly called into action and have limited time for sitting in class.

"Not only has it made them more available, it's made them better at the skills that we're looking to give someone," Keiken said.

Table 2 Initial Cost Checklist

Energy and Fuel Service Costs
Fuel service, storage, handling, piping, and distribution costs
Electrical service entrance and distribution equipment costs
Total energy plant
Heat-Producing Equipment
Boilers and furnaces
Steam-water converters
Heat pumps or resistance heaters
Makeup air heaters
Heat-producing equipment auxiliaries
Refrigeration Equipment
Compressors, chillers, or absorption units
Cooling towers, condensers, well water supplies
Refrigeration equipment auxiliaries
Heat Distribution Equipment
Pumps, reducing valves, piping, piping insulation, etc.
Terminal units or devices
Cooling Distribution Equipment
Pumps, piping, piping insulation, condensate drains, etc.
Terminal units, mixing boxes, diffusers, grilles, etc.
Air Treatment and Distribution Equipment
Air heaters, humidifiers, dehumidifiers, filters, etc.
Fans, ducts, duct insulation, dampers, etc.
Exhaust and return systems
Heat recovery systems
System and Controls Automation
Terminal or zone controls
System program control
Alarms and indicator system
Energy management system
Building Construction and Alteration
Mechanical and electric space
Chimneys and flues
Building insulation
Solar radiation controls
Acoustical and vibration treatment
Distribution shafts, machinery foundations, furring

consulting commercially available cost-estimating guides and software. Table 2 shows a representative checklist for initial costs.

Analysis Period

The time frame over which an economic analysis is performed greatly affects the results. The analysis period is usually determined by specific objectives, such as length of planned ownership or loan repayment period. However, as the length of time in the analysis period increases, there is a diminishing effect on net present-value calculations. The chosen analysis period is often unrelated to the equipment depreciation period or service life, although these factors may be important in the analysis.

Service Life

For many years, this chapter included estimates of service lives for various HVAC system components, based on a survey conducted in 1976 under ASHRAE research project RP-186 (Akalin 1978). These estimates have been useful to a generation of practitioners, but changes in technology, materials, manufacturing techniques, and maintenance practices now call into question the continued validity of the original estimates. Consequently, ASHRAE research project TRP-1237 developed an Internet-based data collection tool and database on HVAC equipment service life and maintenance costs, to allow equipment owning and operating cost data to be continually updated and current. The database was seeded with information gathered from a sample of 163 commercial office buildings located in major metropolitan areas across the United States. Abramson et al. (2005) provide details on the distribution of building size, age, and other characteristics. Table 3 presents estimates of median service life for various HVAC components in this sample.

Table 3 Median Service Life

Equipment Type	Median Service Life, Years	Total No. of Units	No. of Units Replaced
DX air distribution equipment	>24	1907	284
Chillers, centrifugal	>25	234	34
Cooling towers, metal	>22	170	24
Boilers, hot-water, steel gas-fired	>22	117	24
Controls, pneumatic	>18	101	25
electronic	>7	68	6
Potable hot-water heaters, electric	>21	304	36

Median service life in Table 3 is based on analysis of survival curves, which take into account the units still in service and the units replaced at each age (Hiller 2000). Conditional and total survival rates are calculated for each age, and the percent survival over time is plotted. Units still in service are included up to the point where the age is equal to their current age at the time of the study. After that point, these units are censored (removed from the population). Median service life in this table indicates the highest age at which the survival rate remains at or above 50% while the sample size is 30 or more. There is no hard-and-fast rule about the number of units needed in a sample before it is considered statistically large enough to be representative, but usually the number should be larger than 25 to 30 (Lovvorn and Hiller 2002). This rule-of-thumb is used because each unit removal represents greater than a 3% change in survival rate as the sample size drops below 30, and that percentage increases rapidly as the sample size gets even smaller.

The database initially developed and seeded under research project TRP-1237 (Abramson et al. 2005) is now available online, providing engineers with equipment service life and annual maintenance costs for a variety of building types and HVAC systems. The database can be accessed at www.ashrae.org/database.

As of the end of 2009 this database contained more than 300 building types, with service life data on more than 38,000 pieces of equipment.

The database allows users to access up-to-date information to determine a range of statistical values for equipment owning and operating costs. Users are encouraged to contribute their own service life and maintenance cost data, further expanding the utility of this tool. Over time, this input will provide sufficient service life and maintenance cost data to allow comparative analysis of many different HVAC systems types in a broad variety of applications. Data can be entered by logging into the database and registering, which is free. With this, ASHRAE is providing the necessary methods and information to assist in using life-cycle analysis techniques to help select the most appropriate HVAC system for a specific application. This system of collecting data also greatly reduces the time between data collection and when users can access the information.

Figure 1 presents the survival curve for centrifugal chillers, based on data in Abramson et al. (2005). The point at which survival rate drops to 50% based on all data in the survey is 31 years. However, because the sample size drops below the statistically relevant number of 30 units at 25 years, the median service life of centrifugal chillers can only be stated with confidence as >25 years.

Table 4 compares the estimates of median service life in Abramson et al. (2005) with those developed with those in Akalin (1978). Most differences are on the order of one to five years.

Estimated service life of new equipment or components of systems not listed in Table 3 or 4 may be obtained from manufacturers,

Table 4 Comparison of Service Life Estimates

Equipment Item	Median Service Life, Years: Abramson et al. (2005)	Median Service Life, Years: Akalin (1978)	Equipment Item	Median Service Life, Years: Abramson et al. (2005)	Median Service Life, Years: Akalin (1978)	Equipment Item	Median Service Life, Years: Abramson et al. (2005)	Median Service Life, Years: Akalin (1978)
Air Conditioners			**Air Terminals**			**Condensers**		
Window unit	N/A*	10	Diffusers, grilles, and registers	N/A*	27	Air-cooled	N/A	20
Residential single or split package	N/A*	15	Induction and fan-coil units	N/A*	20	Evaporative	N/A*	20
Commercial through-the-wall	N/A*	15	VAV and double-duct boxes	N/A*	20	**Insulation**		
Water-cooled package	>24	15	**Air washers**	N/A*	17	Molded	N/A*	20
Heat pumps			**Ductwork**	N/A*	30	Blanket	N/A*	24
Residential air-to-air	N/A*	15[b]	**Dampers**	N/A*	20	**Pumps**		
Commercial air-to-air	N/A*	15	**Fans**	N/A*		Base-mounted	N/A*	20
Commercial water-to-air	>24	19	Centrifugal	N/A*	25	Pipe-mounted	N/A*	10
Roof-top air conditioners			Axial	N/A*	20	Sump and well	N/A*	10
Single-zone	N/A*	15	Propeller	N/A*	15	Condensate	N/A*	15
Multizone	N/A*	15	Ventilating roof-mounted	N/A*	20	**Reciprocating engines**	N/A*	20
Boilers, Hot-Water (Steam)			**Coils**			**Steam turbines**	N/A*	30
Steel water-tube	>22	24 (30)	DX, water, or steam	N/A*	20	**Electric motors**	N/A*	18
Steel fire-tube		25 (25)	Electric	N/A*	15	**Motor starters**	N/A*	17
Cast iron	N/A*	35 (30)	**Heat Exchangers**			**Electric transformers**	N/A*	30
Electric	N/A*	15	Shell-and-tube	N/A*	24	**Controls**		
Burners	N/A*	21	**Reciprocating compressors**	N/A*	20	Pneumatic	N/A*	20
Furnaces			**Packaged Chillers**			Electric	N/A*	16
Gas- or oil-fired	N/A*	18	Reciprocating	N/A*	20	Electronic	N/A*	15
Unit heaters			Centrifugal	>25	23	**Valve actuators**		
Gas or electric	N/A*	13	Absorption	N/A*	23	Hydraulic	N/A*	15
Hot-water or steam	N/A*	20	**Cooling Towers**			Pneumatic	N/A*	20
Radiant heaters			Galvanized metal	>22	20	Self-contained		10
Electric	N/A*	10	Wood	N/A*	20			
Hot-water or steam	N/A*	25	Ceramic	N/A*	34			

*N/A: Not enough data yet in Abramson et al. (2005). Note that data from Akalin (1978) for these categories may be outdated and not statistically relevant. Use these data with caution until enough updated data are accumulated in Abramson et al.

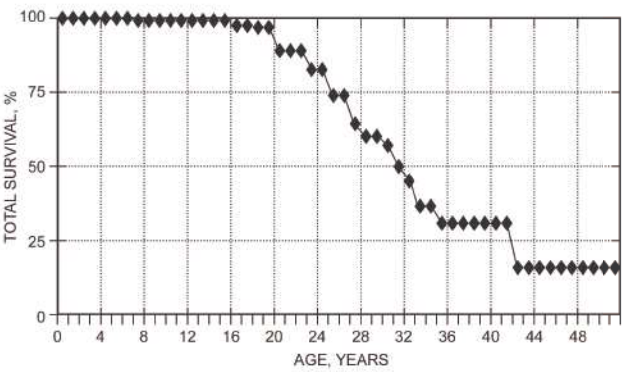

Fig. 1 Survival Curve for Centrifugal Chillers
[Based on data in Abramson et al. (2005)]

associations, consortia, or governmental agencies. Because of the proprietary nature of information from some of these sources, the variety of criteria used in compiling the data, and the diverse objectives in disseminating them, extreme care is necessary in comparing service life from different sources. Designs, materials, and components of equipment listed in Tables 3 and 4 have changed over time and may have altered the estimated service lives of those equipment categories. Therefore, establishing equivalent comparisons of service life is important.

As noted, service life is a function of the time when equipment is replaced. Replacement may be for any reason, including, but not limited to, failure, general obsolescence, reduced reliability, excessive maintenance cost, and changed system requirements (e.g., building characteristics, energy prices, environmental considerations). Service lives shown in the tables are based on the age of the equipment when it was replaced, regardless of the reason it was replaced.

Locations in potentially corrosive environments and unique maintenance variables affect service life. Examples include the following:

- **Coastal and marine environments**, especially in tropical locations, are characterized by abundant sodium chloride (salt) that is carried by sea spray, mist, or fog.

  Many owners require equipment specifications stating that HVAC equipment located along coastal waters will have corrosion-resistant materials or coatings. Design criteria for systems installed under these conditions should be carefully considered.
- **Industrial** applications provide many challenges to the HVAC designer. It is very important to know if emissions from the industrial plant contain products of combustion from coal, fuel oils, or releases of sulfur oxides (SO_2, SO_3) and nitrogen oxides (NO_x) into the atmosphere. These gases typically accumulate and return to the ground in the form of acid rain or dew.

  Not only is it important to know the products being emitted from the industrial plant being designed, but also the adjacent upwind or downwind facilities. HVAC system design for a plant located downwind from a paper mill requires extraordinary corrosion protection or recognition of a reduced service life of the HVAC equipment.
- **Urban** areas generally have high levels of automotive emissions as well as abundant combustion by-products. Both of these contain elevated sulfur oxide and nitrogen oxide concentrations.
- **Maintenance** factors also affect life expectancy. The HVAC designer should temper the service life expectancy of equipment with a **maintenance factor**. To achieve the estimated service life values in Table 3, HVAC equipment must be maintained properly,