April 2009

Walker Jones School

Washington, DC

Maria Piergallini

The Pennsylvania State University

AE Senior Thesis Final Report

Construction Management

Faculty Advisor: Dr. John Messner

Walker Jones Educational and Community Center

Washington, DC

Project Team

Owner:	Office of the Deputy Mayor for Planning and Economic Development
Architect:	Hord Coplan & Macht
Construction Manager:	Forrester Construction & Columbia Enterprises (joint venture)
Structural Engineer:	Simpson Gumpertz & Heger
MEP Engineer:	Burdette Koehler Murphy & Associates

Mechanical

•8 roof top air handling units ranging in size from 3,150 CFM to 20,200 CFM with energy recovery wheels

•AHU's work in conjunction with 2 boilers to serve the 2 pipe VAV system that ventilates the building

•Commissioning for all MEP systems

•Pre-occupancy building flush-out to increase indoor air quality

Building Statistics

Size:	125,000 SF
Function:	Pre-K – 8 school, public library, and community center
Building Cost:	$36 Million
Construction Dates:	March 2008-August 2009
Delivery Method:	Design-Bid-Build with GMP

Structural

•Concrete foundation walls sit on spread footing system supported by soil reinforced with impact piers and helical anchors ranging in length from 19' to 42'

•Steel superstructure with concrete composite slabs on metal deck supported by wide flange beams

•W shaped beams and columns with HSS in multi story spaces

Architecture

•Organized by grade based on floor level with shared spaces at circulation nodes

• "C" shape footprint designed to provide a safe area in the middle of the "C" for kids to play

•Seeking LEED certification upon completion

•29,000 SF of green roof with access for students

Electrical

•Building distribution is 480V, 3 phase, 4 wire from Pepco supply

•3000A main switchboard with 1000A, 400 A and 225A distribution panelboards

•275kW 480/277V emergency generator with 500 gallon fuel tank for 23 hours of operation at full load

Maria Piergallini

Construction Management

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Acknowledgements

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- Twin Valley Elementary
- Wrightsville Elementary

And most of all, my family and friends

Executive Summary

This senior thesis is an in depth analysis of Walker Jones School located on the block bound by New Jersey Avenue, Pierce Street, 1st Street, and K Street in Northwest Washington, DC. This report focuses on adding value and incorporating sustainable building methods in the school without significantly increasing the project cost or schedule. This report addresses sustainability and added value by analyzing existing sustainable schools to determine the greatest benefits to the students and staff. Daylighting and acoustical performance in the classrooms of Walker Jones are also addressed.

This first analysis focuses on the critical industry issue of LEED certified schools. With the new $787 billion American Recovery and Reinvestment Act of 2009, the concern for sustainable schools is more important than ever. This timely act will ensure that billions of dollars are spent on the construction and renovation of sustainable schools across the nation. To determine how to best utilize the money spent on sustainable schools, a survey was sent to teachers at schools that are currently LEED certified. In conjunction with this survey, standardized test results from three Pennsylvania schools that have already achieved LEED certification were studied. Both the survey and test results reflect that there is no direct correlation between LEED certified schools and student performance. Key findings of the survey include the lack of knowledge of LEED and awareness of its benefits, as well as the lack of sustainable teaching methods. 93.75% of the 36 respondents believe that a sustainable school improves the learning environment and 90.63% think that a sustainable school increases productivity. Finally, 69.44% of teachers surveyed said that natural light was the greatest educational benefit of a sustainable school. In addition, it was determined that the additional cost associated with Walker Jones pursuit of LEED certification is $7.41 per SF, which is above the national average premium of $3 per SF. If the green roof is removed, the additional cost would only be $2.52 per SF.

Because of the survey results, the lighting in Walker Jones classrooms was examined to ensure maximum daylighting. It was found that the current design is unsuitable for daylighting; however, after nearly doubling the window space, changing the glazing, and improving the quality of the lamps, the classrooms at Walker Jones are suitable for daylighting. Daylight sensors and on/off switches are recommended to maximize energy cost savings and to help teach students the importance of energy conservation. In addition to this analysis, an acoustical analysis was performed to ensure that the current design is suitable for a sustainable classroom. While the existing design is acceptable, improving the quality of the ceiling tile can greatly improve the sound quality in a typical classroom. The additional upfront cost of the suggested lighting design is $24,000 or $0.20 per SF with a payback period of just over six years. The acoustical improvements cost an additional $35,000, or $0.29 per SF. These additional costs are low enough that the added value is considered worth the investment.

Project Background

Project Summary

The new Walker Jones School is a 100,000 SF District of Columbia public school, 15,400 SF community center, and 7,000 SF public library designed to replace two existing schools. The existing Walker-Jones Elementary and Terrell Junior High School have been partially demolished to allow room for construction and will be completely demolished upon completion of the project. The new educational and community center has been designed as part of an effort to revitalize the area now known as the Northwest One neighborhood.

The facility includes classrooms for grades K – 8, dining and performance space, a gymnasium, outdoor athletic fields, and a public library. The school is organized by grade based on floor level, with shared spaces at circulation nodes. The most noticeable feature of the design is the building's "C" shape footprint. The facility was designed to provide a safe area in the middle of the "C" for kids to play outside away from the streets. The classrooms and library occupy the middle of the C while the gymnasium and cafeteria occupy each end of the C.

The fast-paced 15 month schedule, LEED certification, and tight budget provide many coordination and logistical challenges. A negotiated GMP of $36 million was agreed on between Forrester Construction (the general contractor) and The Office of the Deputy Mayor for Planning and Economic Development (the owner). The school will be complete in time for the start of the 2009-2010 school year. The steel structure and primarily brick façade are accented by strategically placed curtain wall and unique features such as 29,000 SF of green roof.

Project Team

Owner – Office for the Deputy Mayor for Planning and Economic Development
Architect – Hord Coplan Macht
Construction Manager (Joint Venture) - Forrester Construction Company & Columbia Enterprises
Project Manager (Joint Venture) - Regan Associates LLC & Banneker Ventures
Civil Engineer - Delon Hampton and Associates
Structural Engineer - Simpson Gumpertz & Heger
MEP Engineer - Burdette Koehler Murphy & Associates

Client Information

The owner of the project is the District of Columbia Office of the Deputy Mayor for Planning and Economic Development. When the current mayor, Mayor Fenty, assumed office in January of 2007, he immediately began the long-overdue transformation of the District of Columbia Public Schools (DCPS) by placing them under the authority of the Mayor. DCPS has begun a new era of high-quality education with a new management team, new personnel rules and an ambitious facilities modernization program. Mayor Fenty decided to start the transition from the bottom, so he chose the area now known as Northwest One. The Office of the Deputy Mayor for Planning and Economic Development worked with The Office of Planning's Neighborhood Planning & Development/Urban Design Division to develop a master plan for the Northwest One neighborhood which will revitalize it as a vibrant, mixed-use community fully integrated within the larger city of Washington.

Project Delivery

The project delivery method is a type of design-bid-build, with preconstruction services added. Forrester Construction Company offered paid preconstruction services, but was selected based on a competitive bid since it is a public project. Forrester's contract as a GC is a negotiated guaranteed maximum price. Due to the short schedule, this agreement accommodates for allowances for aspects of the design that were not 100% complete when the contract was signed. The remaining owner contracts are lump sum, as are Forrester's contracts with each subcontractor. This is a typical contract arrangement and allows for change orders to easily reimburse costs that exceed the project budget. Due to a 50% Certified Business Enterprises (CBE) requirement, there are several joint ventures to achieve the requirement for local, minority, or disadvantaged businesses. As can be seen in Figure 0.1, joint ventures include the owner's representative, general contractor, and the earthwork subcontractor.

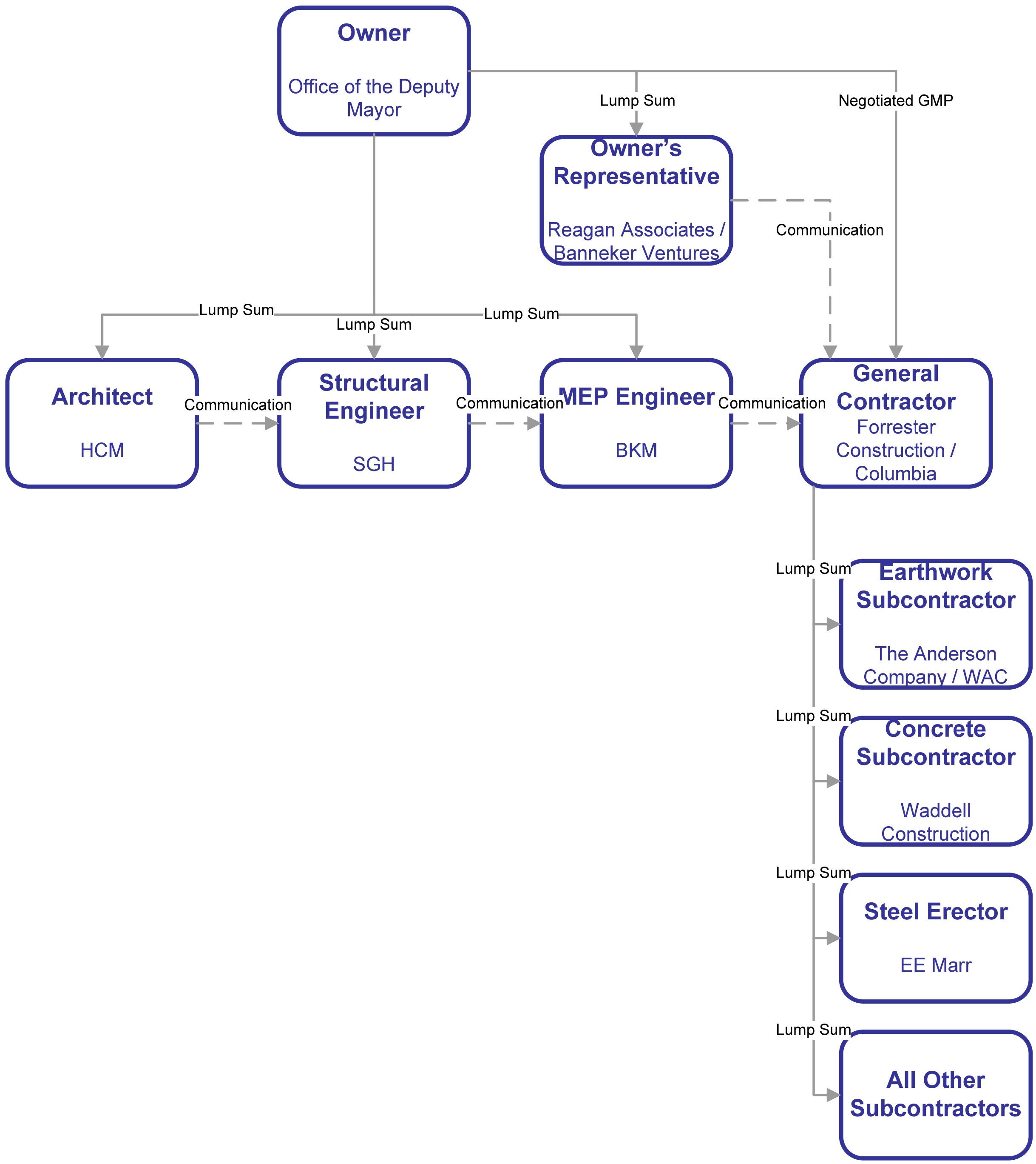

Figure 0.1 - Project Delivery Method

Site Plan and Existing Conditions

The site for Walker Jones is located on the block bound by New Jersey Avenue, Pierce Street, 1st Street, and K Street in Northwest Washington, DC. The site can be seen on the map in Figure 0.2.

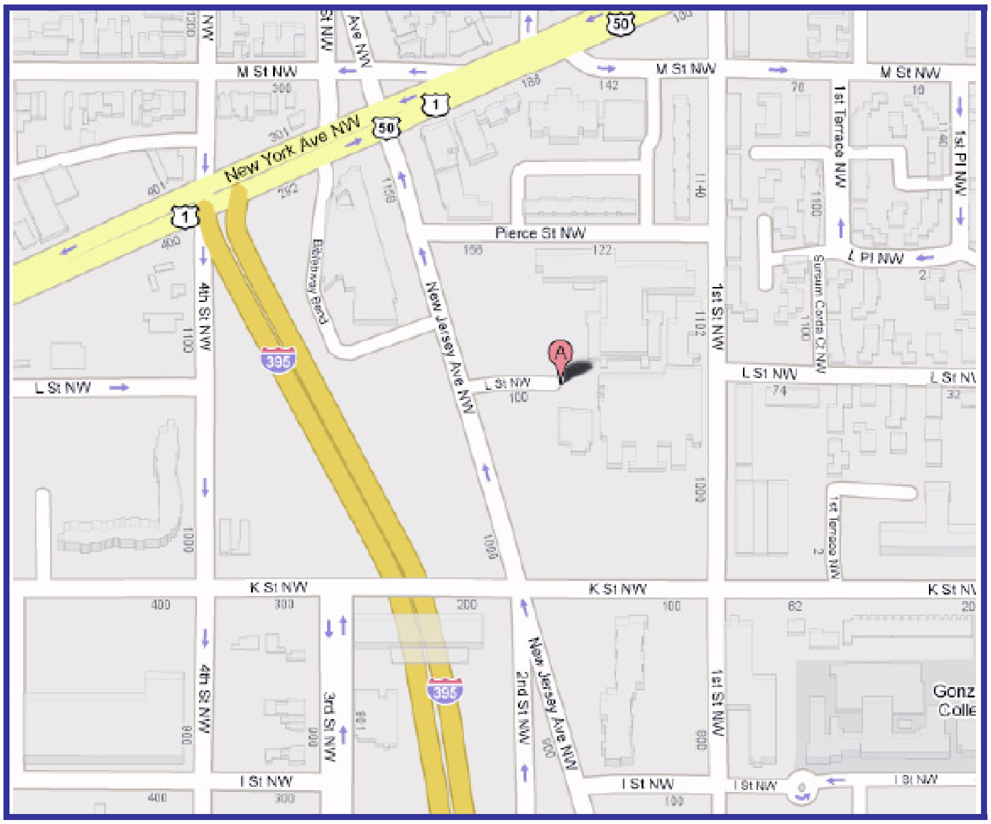

Figure 0.2 - Site Location

While there is nothing directly adjacent to the site, there are several buildings in the area which cause concern. Across Pierce Street, there is a residential neighborhood consisting of two-story row homes. Across New Jersey Avenue, there is an eight-story assisted living community. In both cases, scheduling is an issue as local ordinances limit construction time to 7 am - 7 pm. Additionally, pedestrian access and handicap accessibility around the site was an important issue. A covered walkway with handicap ramps was installed along New Jersey Avenue to ensure safety of pedestrians.

The relocation of utilities is minimal. Because there were two schools located on the site previously, gas, water, electric, and telephone lines are easily accessible. Most existing utilities will be cut and capped, then reconnected once the new facility is ready.

Building Systems Summary

Construction

The project delivery method is a type of design-bid-build, with preconstruction services added. Forrester Construction Company offered paid preconstruction services, but was selected based on a competitive bid since it is a public project. Forrester's contract as a GC is a negotiated guaranteed maximum price. Due to the short schedule, this agreement allowed for allowances for aspects of the design that were not 100% complete when the contract was signed. The general contracting services are offered as a joint venture between Forrester Construction and Columbia Enterprises.

Before construction could begin, demolition had to occur. Approximately 150,000 SF of demolition was required to build the new Walker Jones School. Terrell Junior High School was demolished to allow room for construction and the adjacent Walker Jones Elementary School will be completely demolished once the new school is complete. The majority of the demolition was concrete and masonry which was crushed onsite, as shown in Figure 0.3. This material was then used as backfill in several areas to save money.

Figure 0.3 - Demolition of Terrell Junior High

Several issues required an abatement crew to prepare the school prior to being wrecked. There was a small amount of asbestos used in Terrell Junior High. In addition, the fluorescent light fixtures had to be removed because of the hazardous materials contained in the older ballasts. Below the structure there were also two abandoned fuel tanks, 10,000 and 20,000 gallons which needed to be dealt with. The smaller tank was not a problem to remove; however, the larger tank was leaking. Due to schedule impacts, the larger tank was covered and removed at a later time. Special precautions had to be taken around the tank- the soil needed to be separated, removed, and treated properly. During demolition on the west side of the site, excavation work began on the portion of the site where the new school is located.

Lighting/Electrical

The main service feeder for the building enters from Pepco transformer vaults in the North-East corner of the building adjacent to the basement mechanical room. The service is 3 Phase, 4 Wire, 480/277 Volt with a 3000A Main Switchboard. Emergency power is supplied by a 275kW 480/277V generator with a 500 gallon fuel tank for 23 hours of operation at full load. The generator is located outside the building adjacent to the Pepco ductbank in a sound attenuated enclosure. All classrooms and labs are equipped with occupancy sensors to ensure lights are only on when the room is occupied.

Mechanical

The heating, ventilating and air conditioning system provides the facility with equipment that meets the long term energy efficiency and maintenance priorities as well as being a cost effective solution. The system provides flexibility and increased energy savings opportunities. Each air handling unit (AHU) zone is capable of an independent operating schedule. Each of the eight air handling units is responsible for an individual zone. Zones 1-8 are broken into east, west, north and south classroom blocks, cafeteria, library, gymnasium, and kitchen, respectively.

The mechanical rooms are located in Area C in a partial basement and on the third floor above the kitchen. The building's eight air handling units are located on the roof of the building. Each air handling unit will be provided with a DX cooling coil, hot water heating coil, 30% and 85% efficient filters as well as access sections for maintenance to all coils and filters. All fans will be provided with variable frequency drives (VFD's) and energy recovery wheels will be provided for AHU's 1, 2, 3, 4 and 7 to maximize energy efficiency.

The cafeteria, gymnasium and kitchen have constant air volume systems while the rest of the building has a variable air volume (VAV) system. Heating water will be generated from three (3) gas fired boilers located in the northeast mechanical room above the kitchen. Two (2) heating water pumps (primary and standby) will circulate heating water to the air handling units.

Controls

Automatic temperature controls are web-based, electrically actuated, direct digital control (DDC). The entire temperature control system as well as all associated control components and mechanical equipment (chiller, boilers, VFD's, etc.) are Bacnet compatible.

Each classroom is provided with a separate air terminal (VAV) to provide independent room temperature control. Offices where usage and exposure are similar are combined on common VAV terminals.

All major mechanical equipment items (chilled and heating water source equipment, air handling units, pumps, etc.), as well as all air terminals, temperature sensors, etc., will be capable of being controlled and/or monitored through the web-based energy management control system (EMCS).

Structural

Structurally, the building is divided into three sections, as shown in Figure 0.4.

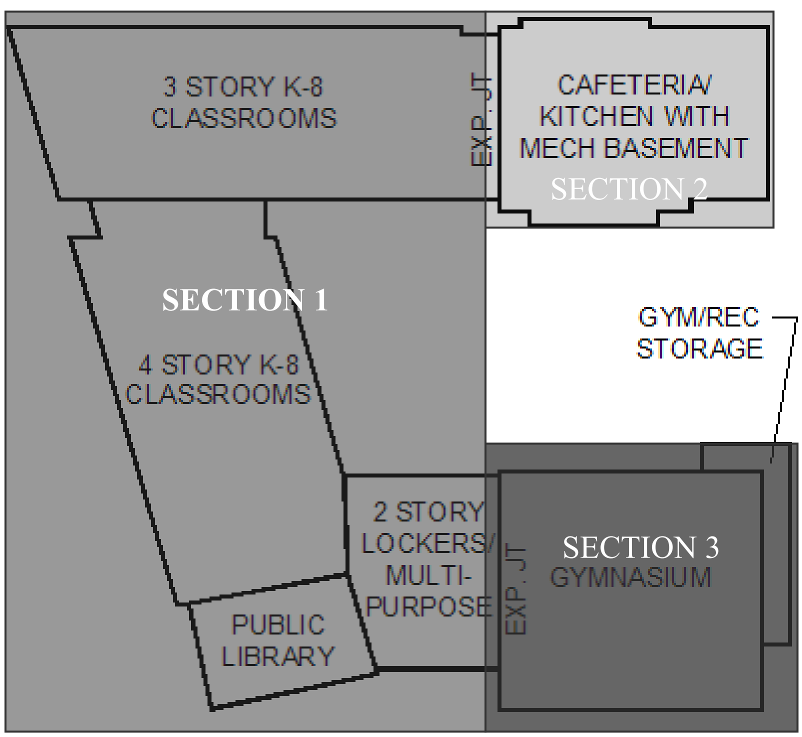

Figure 0.4 - Structural Sections of the Building

SECTION 1:

The 4 STORY K-8 CLASSROOMS, the PUBLIC LIBRARY, and the 2 STORY LOCKERS/ MULTI-PURPOSE are founded a story below the 3 STORY K-8 CLASSROOMS portion of SECTION 1 as grading drops an entire story across the site. The 3 STORY K-8 CLASSROOMS and the 4 STORY K-8 CLASSROOMS share the same roof. Typical floor to floor height is 14'.

Foundations and Slab on Grade:

The lower floor consists of 5" concrete (3500 psi) slab on grade reinforced with 6" x 6" W.21/W2.1 welded wire reinforcing over vapor barrier over 12" granular fill and an under-slab drainage system.

The foundation system is spread footings which bear on ground reinforced with impact piers, providing an allowable bearing strength of 6000 psf. The north, west, and south exterior walls of the structure are against the property line. The footings of these walls and the footings of columns along the perimeter at these walls may not cross the property line. For this reason, interior grade beams are utilized to accommodate the eccentric load.

The typical foundation walls are reinforced concrete (concrete masonry units). Approximately 700 feet of the foundation walls at the four story wing will be either fully or partially retaining earth. The walls which are retaining earth are 15" cast in place 4000 psi concrete.

Floor Framing:

The structural floor is a 5 ½" slab (3 ½" of lightweight 4000 psi concrete topping over 2" x 18 gauge composite metal deck) supported by wide flange steel beams (composite beams with ¾" diameter x 4" headed studs at 12" on center) at 8'-0" on center. The beams are supported by wide flange steel girders (composite beams with two ¾" diameter x 4" headed studs at 12" on center) along the perimeter and along either side of the corridor running the length of the classroom wings. The girders and beams are supported by wide flange steel columns. The columns are positioned at the perimeter and on either side of the corridor and spaced approximately 24' on center.

Roof Framing:

The typical structural roof supporting the green roof is a 5 ½" slab (3 ½" of light weight psi concrete topping over 2" x 18 gauge composite metal deck). The slab is supported by wide flange steel beams (composite beams with ¾" diameter x 4" headed studs at 12" on center) at 8'-0" on center. The roof is sloped ¼" per foot to interior drains.

Exterior Walls:
The brick exterior walls are backed up with 6" light gage metal stud. Typical window openings on the exterior wall are "punch" windows and loose angle lintels are provided to span the openings, in addition brick veneer are hung from the floor above with galvanized steel "shelf" angles.

Lateral Force Resisting System:
Steel moment frames and reinforced CMU shear walls resist wind and seismic lateral forces.

SECTION 2:
The CAFETERIA/ KITCHEN WITH PARTIAL MECH BASEMENT is located at the east end of the three story classroom wing. The roof of the cafeteria/ kitchen is approximately 30' above finished grade.

Foundation and Slab on Grade:
Same as SECTION 1 with the exception of the mechanical basement. The mechanical basement floor is 6" 3500 psi concrete slab on grade.

Floor Framing:
The structural floor over the mechanical basement is a 5 ½" slab (3 ½" of lightweight 4000 psi concrete topping over 2" x 18 gauge composite metal deck) supported by wide flange steel beams (composite beams with ¾" diameter x 4" headed studs at 12" on center) at 8'-0" on center.

Roof Framing:
The roof framing is 1-1/2" x 22 gauge metal deck in 3 spans supported by steel bar joists spaced from 4'-0" to 6'-0" on center, specially designed to accommodate equipment hung from the roof spanning between CMU bearing walls.

Exterior Walls:
The exterior walls are reinforced CMU bearing walls clad with a brick veneer separated by an air space cavity. The perimeter walls of the basement are 12" poured in place

concrete. The areaway retaining walls and basement walls retaining earth are poured in place concrete.

Lateral Force Resisting System:
The perimeter CMU bearing walls resist wind and seismic lateral forces.

SECTION 3:
The one story GYM/ REC STORAGE is located on the east side of the GYMNASIUM. The roof of the gymnasium is 34' above finished grade. The roof of the storage rooms is 13' above finished grade.

Foundations and Slab on Grade:
Same as SECTION 1 with the exception of the footings on the south wall. This wall is constructed against the property line so the footings will be increased in size to accommodate the eccentric load.

Roof Framing:
Same as SECTION 2.

Exterior Walls:
The exterior walls are reinforced CMU bearing walls clad with a brick veneer separated by an air space cavity. Earth retaining walls on the North side of the gymnasium are 12" poured in place concrete, with reinforced CMU bearing walls above grade.

Lateral Force Resisting System:
The perimeter CMU bearing walls resist wind and seismic lateral forces.

Fire Protection

The building is provided with a wet pipe fire protection sprinkler system in accordance with NFPA and the local authority. Standpipe risers are provided in each stairwell and sprinkler zone assemblies are provided (minimum one per floor) to provide sprinkler coverage throughout the facility. A fire pump is provided to meet the fire protection system flow and pressure required by the local authority.

Plumbing

Separate incoming water services are extended from Pierce St. to a 4-inch domestic water and an 8-inch fire protection service to the building. In addition, the building is connected to an existing 20 psi gas main located in Pierce St. located to the north of the building. A domestic water booster pump is provided to meet the pressure requirements of the fixtures within the building. Domestic hot water is generated from a gas-fired water heater located in the northeast mechanical room above the warming kitchen. Hot water distribution temperature is set for 140ºF to the warming kitchen and 110ºF for all other areas.

Master of Architectural Engineering Requirement

The course which inspired and enabled me to perform the chosen analyses is AE 597D: Sustainable Building Methods. Through this course, I gained a working vocabulary and familiarity with "green" technologies such as green roofs and daylighting. I was also familiarized with the LEED rating system by spending eight weeks discussing each point in the LEED for New Construction rating system. Additionally, the semester long team project opened my eyes to the concerns of LEED rated schools. My group was assigned to the State College Area School District, and through discussions with members of the school board and district staff, I learned the importance of understanding the educational benefits and economic impacts of pursuing LEED certification. At the time of the project, the school board was voting on a sustainable resolution which would require all new construction or major renovations to achieve at least LEED Silver certification. The resolution was adopted by the State College Area School District's Board of School Directors on October 13, 2008 after several months of discussion. The resolution states that the first priority area of focus is "Student performance and staff health through measures such as natural lighting, the use of non toxic-emitting materials, and sound insulation or isolation to minimize noise and enhance classroom acoustical quality[1]." This motivated me to focus my depth study on the perceived benefits to building occupants and to focus my breadth studies on the feasibility of daylighting as well as the acoustical performance in Walker Jones classrooms.

Several studies, such as "Daylighting in Schools: An Investigation into the Relationship between Daylighting and Human Performance," target improved test scores based on one aspect of design, such as daylighting. This report, performed by Hescgong Mahone Group of Fair Oaks, California studied over 2000 classrooms in three school districts to determine the correlation between natural light and student performance. The survey found that students with the most daylighting in their classrooms progressed 20% faster on math tests and 26% faster on reading tests in one year than those students in classrooms with the least daylighting[2]. Unlike specifically focused studies like the investigation performed by Hescgong Mahone Group, it is expected that there will be no direct correlation between LEED rated schools and student performance. The depth

[1] State College Area School District. "Resolution on Sustainability & the Design and Construction of High Performance Schools." Adopted 13 October, 2008. Accessed March 19, 2009 <http://www.scasd.org/249710063152311/lib/249710063152311/SCASD_Sustainability_FINAL.pdf)

[2] Hescgong, L. "Daylighting in Schools: An Investigation into the Relationship between Daylighting and Human Performance." Hescgong Mahone Group, 13 Aug 1999. Accessed February 2 2009 <http://eric.ed.gov/ERICDocs/data/ericdocs2sql/content_storage_01/0000019b/80/16/66/41.pdf>

study, “An Analysis of the Cost and Benefits of Walker Jones’ Pursuit of LEED Certification,” focuses on this hypothesis and strives to determine what the actual benefits of a sustainable school are, from the perspective of the building occupants. Additionally, a national study of 30 schools by Gregory Kats found that green schools cost less than 2% more than conventional schools - or about $3 per square foot[3]. Based on this number, I was curious to discover the additional cost to Walker Jones due to LEED certification. This accounts for the third aspect of my depth study.

My first breadth analysis, “The Feasibility of Daylighting in Walker Jones Classrooms,” is based partially on the Hescgong Mahone Group study described above, and partially on “Analysis of the Performance of Students in Daylit Schools,” a study performed by Innovative Design in Raleigh, NC. This study concluded that students who attend daylit schools outperform those that do not by five to fourteen percent[4]. Both studies in combination with my knowledge from AE 597D, prove that daylight is essential to a beneficial learning environment. Unfortunately, the existing Walker Jones design does not allow for daylighting. Because of this, I performed an analysis on the existing design, and suggested an improved layout to allow for more window space which is conducive to daylighting. In addition, I suggest the use of daylight sensors to maximize energy efficiency and reduce energy related costs. This analysis was based on extensive research; however, I first became aware of the importance of daylighting in classrooms through interaction with the State College Area School District during the semester project in AE 597D and through class discussions of sustainable building methods.

The final aspect of this report is the analysis of the acoustical performance in Walker Jones classrooms. My interest in this was spurred by the clause in the State College Area School District’s resolution requiring enhanced classroom acoustics quality. Acoustics is also essential to developing a sound educational environment, and fits nicely into my other two topics. Excessive background noises and poor reverberation can interfere with speech intelligibility, affect understanding, and reduce a child’s ability to learn. Many classrooms in the United States have speech intelligibility of 75 percent or less. Speech intelligibility tests consist of a list of words that are read, and the listener then lists the words to determine whether or not the words are correctly heard[5]. Understanding only

[3] Kats, G. “Greening America’s Schools: Cost and Benefits,” October 2006. Accessed January 10, 2009 <http://www.cap-e.com/ewebeditpro/items/O59F11233.pdf>
[4] Nicklas, M. and Bailey, G. “Analysis of the Performance of Students in Daylit Schools,” Prepared by Innovative Design, 1993. Accessed January 9, 2009 <http://www.innovativedesign.net/studentperformance.htm>

75 percent of spoken words is equivalent to reading a book with every fourth word missing. Acoustics is such an import aspect on the learning environment, and basic compliance with ANSI Standard is also a prerequisite for LEED certification.

The knowledge and insight gained in AE 597: Sustainable Building Methods, in combination with research performed through the semester made this thesis report possible. I was able to build on what I learned in AE 597 about LEED, daylighting, and sustainable design, to perform three separate analyses that were of interest to me and that provide valuable insight to the design and construction of LEED rated schools.

[5] Acoustical Society of America. “Classroom Acoustics: A Resource for Creating Learning Environments with Desirable listening Conditions,” The Technical Committee on Architectural Acoustics of the Acoustical Society of America, August 2000. Accessed March 10, 2009 <http://asa.aip.org/classroom/booklet.html>

LEED Certification Cost and Benefits

Introduction

According to the 2006 American Community Survey, there are 58.7 million students enrolled in elementary and secondary schools in the United States[6]. Based on this statistic, about 20% of the population spends their days in a classroom, and that does not include teachers and staff. Because of this, it is not surprising that there has been so much time spent determining the benefits of sustainable school buildings on the environment and the occupants. This research on the benefits of sustainable schools is multidisciplinary; the construction of green schools concerns the education industry as well as the architecture, engineering and construction (AEC) industries. Recently, the construction of sustainable schools has become a critical issue in the AEC industry. With the new $787 billion American Recovery and Reinvestment Act of 2009, the concern for sustainable schools is more important than ever. This act includes $90.9 billion dedicated to education and $48.7 billion devoted to energy[7]. This timely act will ensure that billions of dollars are spent on the construction and renovation of sustainable schools across the nation.

With all of this new construction, it is important to remember that a typical school is used for educational purposes for 30 years or longer. During this time, the investment made in operation, maintenance, and repair will be six to eight times greater than the cost of construction[8]. For this reason, it is imperative to focus on the overall quality and lifetime cost of a school rather than just the first cost of construction and design; however, an efficiently designed sustainable school does not always require a drastically higher up-front cost. The most common method of rating sustainable buildings is the United States Green Building Council (USGBC) LEED rating system. Since its inception in 1998, the LEED rating system has gained popularity and became a widely acceptable way of evaluating green buildings. Because of the numerous revisions to the LEED rating system and the respect that the system has gained, there is no need to investigate the

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[6] Davis, J, and Bauman, K. "School Enrollment in the United States: 2006." United States Census Bureau Aug 2008. Accessed 5 Mar 2009 <http://www.census.gov/prod/2008pubs/p20-559.pdf>

[7] Obey, D. "Summary: American Recovery and Reinvestment." Committee on Appropriations 13 Feb 2009. Accessed 5 Mar 2009 <http://appropriations.house.gov/pdf/PressSummary02-13-09.pdf>.

[8] Narional Research Council of the National Academies. "Green Schools: Attributes for Health and Learning." National Academy of Sciences, 2006. Accessed February 27, 2009 <http://www.nap.edu/catalog/11756.html>

credibility of the LEED system[9]. Therefore, the purpose of this analysis is not to gauge the environmental impact of a LEED certified school. This study is intended to assess the research-based evidence of the effects that a green building will have on the academic environment, the productivity of teachers and students, and the health impact on building occupants.

Research has established that sustainable schools are better for the environment, and that occupants are generally more satisfied in a sustainably designed structure; however, there is little information on the greatest benefits to the occupants in schools. This study focuses on the benefits to the students, teachers, and staff in a sustainable school. Four schools across the state of Pennsylvania have given permission to study their historical data and survey their teachers. Standardized test scores will be tracked to determine if student performance was enhanced when the new sustainable school was constructed. To analyze the benefits of LEED from the perspective of the buildings occupants, a survey was distributed to the four LEED rated schools. Thirty six teachers responded to the survey to offer their perceived benefits to occupant health, productivity and comfort as well as the positives and negatives of the everyday function of a sustainable school.

In addition to studying the first hand benefits of sustainable schools, a cost study is being performed based on the LEED points that Walker Jones is currently pursuing. Because LEED certification is required by the District of Columbia, the project team did not perform any LEED comparison cost analysis. This cost analysis goes through the thirty-six LEED points that Walker Jones is pursuing and determines which points are required by codes or local jurisdictions, and which points required additional money to be spent to earn the credit. This information is useful in determining how much additional money was spent to achieve LEED certification for Walker Jones.

The three aspects of this analysis will come together to portray the additional up-front cost to the school as well as the benefits to the occupants. The cost analysis can be used to determine which areas of LEED certification are the most costly and what alternatives could be implemented to lower the cost while still satisfying the requirements. The survey of teachers will show what the true benefits of a sustainable school are and the insight will be useful to teachers at the new Walker Jones School and to design teams striving to achieve LEED for Schools certification in the future.

[9] United States Green Building Council. Accessed February 26, 2009 <http://www.usgbc.org/DisplayPage.aspx?CategoryID=19>

Problem Statement

Despite the growing respect for the LEED rating system, there is still much doubt concerning the direct cost and benefit observed by LEED rated schools. Studies have been performed to determine the benefits of certain aspects of sustainable design, such as *Student Performance in Daylit Schools: Analysis of the Performance of Students in Daylit Schools,* a study performed by Innovative Design in Raleigh, North Carolina[10]; however, these studies do not take into account standardized test scores in combination with insight from the building occupants concerning all aspects of sustainable design.

In addition to the lack of clarity concerning the direct benefits of LEED rated schools, many school districts are hesitant to pursue LEED ratings because of the perceived additional cost. This study will determine the actual additional cost associated with Walker Jones' LEED certification.

Goals

The goal of this analysis is to determine the greatest strengths and weaknesses of the LEED for Schools rating system, and to determine the additional upfront cost to the District of Columbia Public School System as a result of pursuing LEED certification.

Methodology

1. Research LEED rated and sustainably designed schools
2. Contact LEED rated schools in the state of Pennsylvania
3. Track standardized test scores over the past seven years at each school compared to the state average
4. Create a survey to distribute to teachers to gain their insight
5. Compile survey results
6. Perform a cost analysis of each LEED point that Walker Jones is pursuing
7. Analyze the results
8. Make recommendations

[10] Nicklas, M. and Bailey, G. "Student Performance in Daylit Schools: Analysis of the Performance of Students in Daylit Schools." Innovative Design, Raleigh, North Carolina. Accessed February 12, 2009 <http://www.innovativedesign.net/studentperformance.htm>

Tools / Resources

1. USGBC
2. Clearview Elementary School (Hanover Public School District)
3. St. Stephen's Episcopal School (National Association of Episcopal Schools)
4. Twin Valley Elementary School (Twin Valley School District)
5. Wrightsville Elementary School (Eastern York School District)
6. Student survey
7. Dave Obey. "Summary: American Recovery and Reinvestment." Committee on Appropriations 13 Feb 2009. 5 Mar 2009 <http://appropriations.house.gov/pdf/PressSummary02-13-09.pdf>.
8. Jessica W. Davis, and Kurt J. Bauman. "School Enrollment in the United States: 2006." United States Census Bureau Aug 2008. 5 Mar 2009 <http://www.census.gov/prod/2008pubs/p20-559.pdf>.
9. The National Academies: Advisers to the Nation on Science, Engineering and Medicine. Green Schools: Attributes for Health and Learning. Washington, DC: National Academies Press, 2006. 21 Feb 2009 <http://www.nap.edu/catalog/11756.html>.
10. The Walker Jones team

Expectations

Unlike studies which target improved test scores based on one aspect of design, such as daylighting, it is expected that there will be no direct correlation between LEED rating and student performance. Instead, it is anticipated that the survey results will show a perceived improvement in the learning environment and in student and staff productivity levels.

It is suspected that the cost analysis will result in an increased upfront cost. According to *Greening America's Schools: Project Cost and Benefits*, a study by Gregory Katz, the average premium for a LEED certified school is 1.52%, or about $3 per SF[11]. The increase in cost for Walker Jones should be within this range.

[11] Katz, G. "Greening America's Schools: Cost and Benefits." A Capital E Report, October 2006. Accessed February 11, 2009 < http://www.cap-e.com/spotlight/index.cfm?Page=1&NewsID=34196>

Teacher Survey

A survey titled "Benefits of Green Schools" was sent to teachers and staff at the four K-8 LEED rated schools listed above to determine the perceived benefits and opportunities for improvement at each school. A total of thirty-six of the eighty-seven teachers surveyed responded, offering their insight on the perceived benefits and opportunities for improvement at their schools. The four schools that participated in the survey are 1) Clearview Elementary in Hanover, PA, 2) Wrightsville Elementary in Eastern York, PA, 3) Twin Valley Elementary in Twin Valley, PA and 4) St. Stephen's Episcopal in Harrisburg, PA. To view a blank version of the survey, please see **Appendix A.**

Survey Result Summary and Discussion

A summary of results can be seen in Table 1.1. As these results show, thirty-two of the respondents have previously taught at a school that was not sustainably designed. The responses to the following six questions are based on responses only from those 32 respondents. Only one teacher believes that there is an increase in student test scores as a result of attending a sustainable school, and only two teachers, or 6.25% believe that student performance is enhanced by sustainable schools. These results support the information that was found from the standardized test results. As was anticipated, a higher percentage of teachers believe student productivity is improved by sustainable schools. Ninety percent of the teachers who responded believe that their productivity has increased as a result of working in a LEED rated school. The difference between perceived improvements in student performance versus teacher performance is likely accounted for by a lack of ability to perceive student productivity.

Table 1.1 - Summary of Teacher Survey Results

Survey Results		
Question	**Yes**	**No**
Have you taught at a traditional (not sustainable) school?	88.89%	11.11%
Have you noticed an improvement in:		
Student performance?	6.25%	**93.75%**
Student test scores?	3.13%	**96.87%**
Student productivity?	**62.50%**	37.50%
Student attendance?	31.25%	**68.75%**
Learning environment?	**93.75%**	6.25%
Your productivity?	**90.63%**	9.38%
Does a sustainable school improve the school's image in the community?	**69.44%**	30.56%
Are you happier working at a sustainable school than one that is not?	**72.22%**	27.78%
Are you more likely to stay at your current school because it is sustainable?	30.56%	**69.44%**
Do you incorporate sustainability into your lesson plans?	19.44%	**80.56%**

Additionally, over ninety percent of respondents believe that a LEED rated school improves the learning environment. The learning environment is a significant contribution to student learning, and is a very valuable benefit of LEED rated schools. While over seventy percent of teachers responded that they are happier at a sustainable school, only thirty percent said that this is likely to keep them at their current school. This difference is due to the fact that teachers enjoy their sustainable schools but ultimately, their career choices depend more on factors such as their personal lives, pay, and benefits. According to the survey results, there is no teacher retention benefit to LEED rated schools. The most surprising result of the survey is that eighty percent of teachers stated that they do not incorporate sustainability into their lesson plans.
This statistic is especially disturbing because teachers have a great tool – the school building – at their disposal every day around which to base a lesson plan on. Only seven of the thirty-six respondents teach sustainability on a regular basis. Perhaps the greatest benefit of LEED rated schools is the ability to teach students about the environment and the importance of being conscious of their impact on the earth's resources. This is a

valuable lesson, which when implemented early in a student's life, has the potential to greatly reduce wasteful behaviors and encourage a more sustainable lifestyle.

When asked what the greatest benefit in the classroom is, an overwhelming majority of teachers responded that natural light or abundant windows were their favorite feature. The responses can be seen in Table 1.2.

Table 1.2 - Greatest Sustainable Design Benefit in the Classroom

Greatest Percieved Design Benefit			
Question	Daylight	IAQ	Energy Efficiency
What is the most beneficial "green" aspect of the school's design?	69.44%	22.22%	8.33%

Daylight in a classroom has proven to be important through studies and research and has been confirmed by teachers in elementary classrooms. Analysis Two takes a look at daylighting in the Walker Jones classrooms.

Test Score Analysis

Test scores from the Pennsylvania System of School Assessment (PSSA) standardized test were compiled for the 2001-2002 school year through the 2007-2008 school year[12]. The average of the reading and math components of the PSSA test were used to compare performance. The analysis compares the test results for one school for one year to the state average for that same year. Because it is impossible to account for the differences in the student and teacher make-up at each school, the relative improvement within each year is the significant comparison. By graphing the results for each school individually with the results for the state average, the rate of improvement (or lack of improvement) can be seen. St. Stephen's Episcopal is not included in this comparison because students there do not take the PSSA test.

Test Score Comparison

A detailed breakdown for each school can be found in Table 1.3.

[12] Pennsylvania Department of Education. "Pennsylvania System of School Assessment" Results based on PDE PSSA records. Accessed January 27, 2009
<<http://www.pde.state.pa.us/a_and_t/cwp/browse.asp?a=3&bc=0&c=27525>

Table 1.3 - A Detailed Breakdown of Test Results

Wrightsville Elementary School Eastern York School District (Completed in 2003)									
% Proficient or Higher									
Grade	**Wrightsville / State**	**01/02**	**02/03**	**03/04**	**04/05**	**05/06**	**06/07**	**07/08**	**% Increase 2004-2008**
5th	Wrightsville	39.05	50.95	54.6	75.5	67	60	76.5	40.11%
5th	State Average	55.05	57.15	62.25	66.6	63.75	65.5	62.4	0.24%
Twin Valley Elementary School Eastern York School District (Completed in 2003)									
% Proficient or Higher									
Grade	**Twin Valley / State**	**01/02**	**02/03**	**03/04**	**04/05**	**05/06**	**06/07**	**07/08**	**% Increase 2004-2008**
5th	Twin Valley	88.75	78.85	82.65	88.2	82.85	72.15	85.3	3.21%
5th	State Average	55.05	57.15	62.25	66.6	63.75	65.5	62.4	0.24%
Clearview Elementary School Hanover Public School District (Completed in 2003)									
% Proficient or Higher									
Grade	**Clearview / State**	**01/02**	**02/03**	**03/04**	**04/05**	**05/06**	**06/07**	**07/08**	**% Increase 2004-2008**
3rd	Clearview	-	63.4	70.5	71	71.5	63.55	69	-2.82%
3rd	State Average	-	69.6	73	74.5	76	75.5	79.5	6.71%

As can be seen in Figure 1.1, in the time since the new LEED Silver school has opened, Wrightsville Elementary improved from 54.6% of fifth grade students scoring proficient or higher to 76.5% of students. This is an improvement of 40.1% from the 2003-2004 school year to the 2007-2008 school year. The state average increased only from 62.25 to 62.4, an increase of less than 0.24%. Although Wrightsville Elementary showed a significant increase of 40.1% of students moving to the proficient or above category, this is likely due to the fact that they were so far below the state average in 2004. According to Don Gillett, the school's principal, changes were made in the staff and curriculum in an attempt to improve test scores. For this reason, the improvement is not being considered a direct result of the sustainable school.

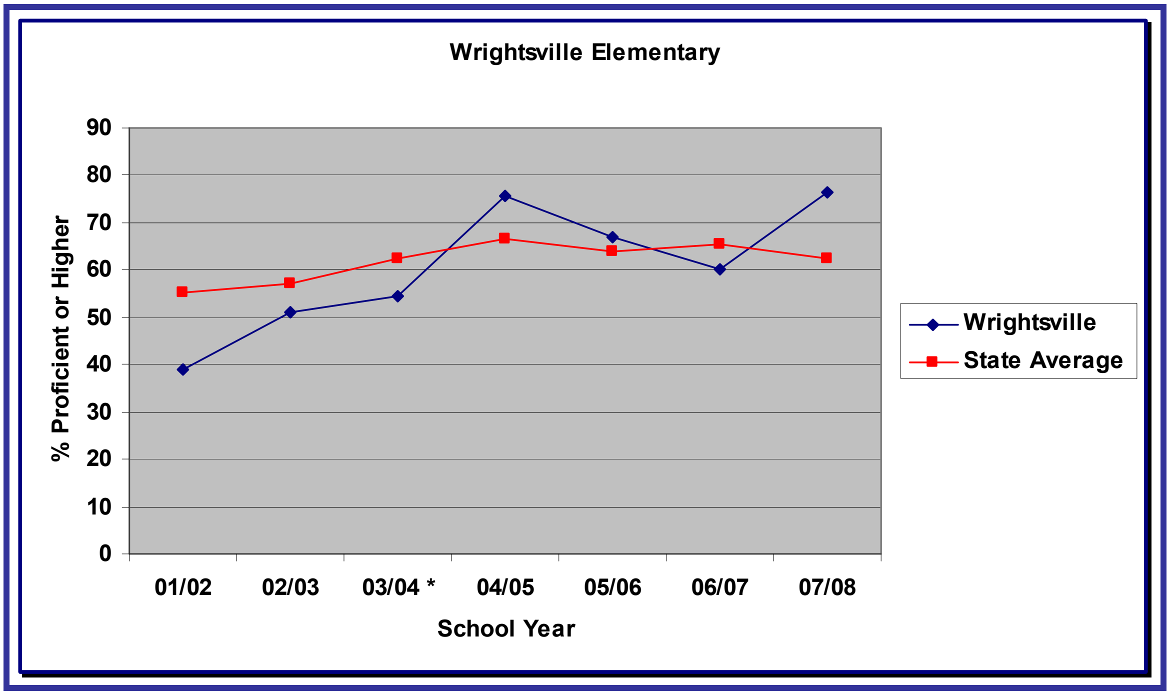

Figure 1.1 - Wrightsville Elementary Test Scores

Figure 1.2 displays the PSSA results from fifth graders at Twin Valley Elementary versus the state average. At the end of the 2003-2004 school year, the first year the LEED Silver school was complete, 82.7% of fifth graders tested proficient or higher on their PSSA test. By 2007-2008, 85.3% of fifth graders were at least proficient. This is an overall improvement of 3.21% versus the state average improvement of less than 1%.

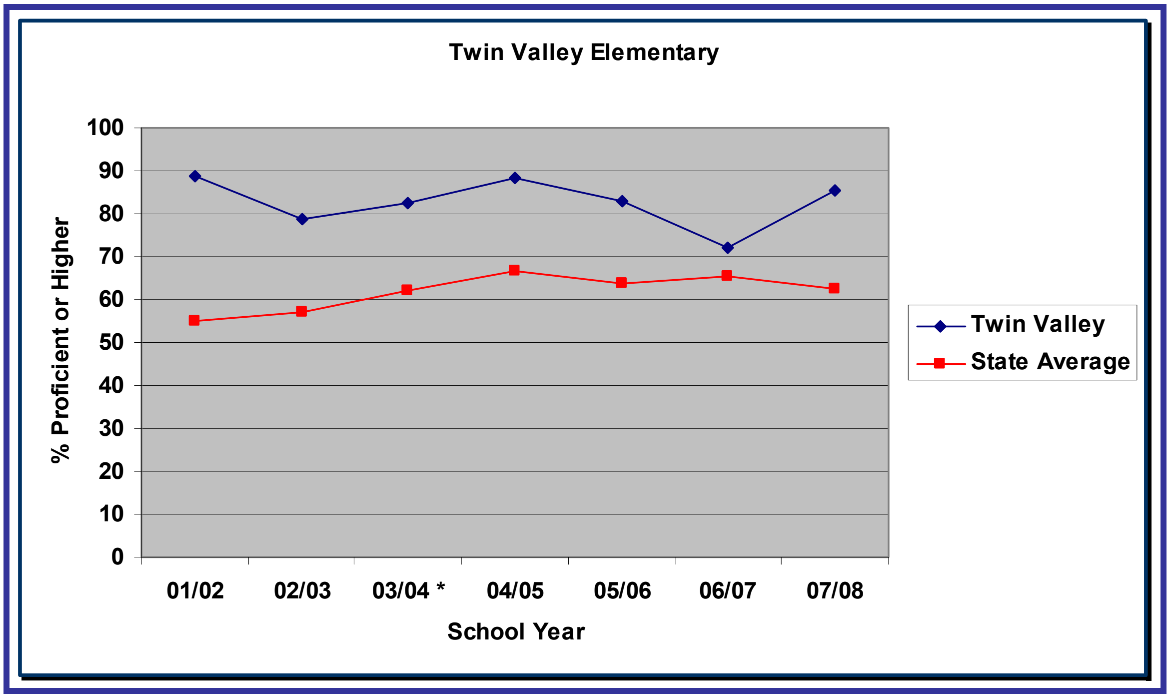

Figure 1.2 - Twin Valley Elementary Test Scores

Figure 1.3 illustrates the test results for Clearview Elementary. Clearview Elementary serves only grades K-4, so test results from third grade PSSA tests were used for comparison. From 2003-2004 to 2007-2008, third graders at Clearview Elementary declined from 70.5% proficient or higher to 69% proficient or higher. The state average test scores during this time increased from 73% to 79.5%, an increase of 6.71%. In this case, the average state school made more improvement than Clearview Elementary, despite Clearview Elementary being a LEED Gold school.

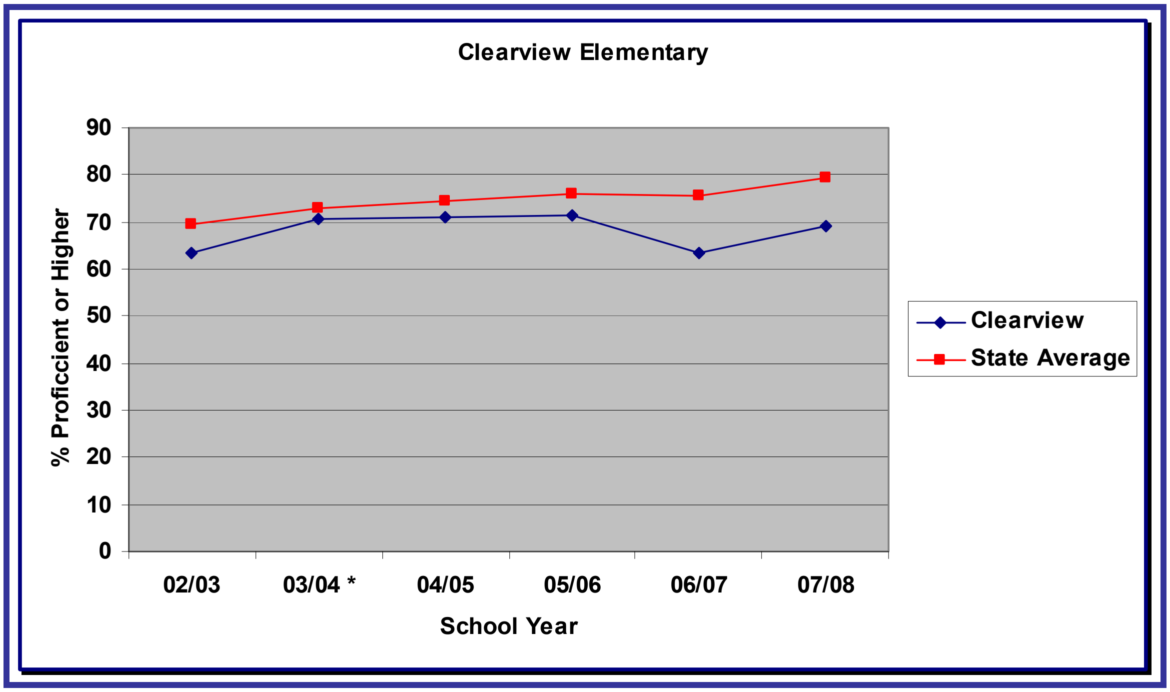

Figure 1.3 - Clearview Elementary Test Scores

Test Score Discussion

Although it is a state standardized test, the PSSA test results appear to be rather inconsistent. Based on the PSSA test results, there is no evidence that a LEED rated school improves student performance. It is worth noting that the teacher survey supported this finding. Although Wrightsville showed significant improvements, it is hard to prove that they were a direct result of the sustainable school. The other two schools do not show convincing data that supports the idea that sustainable schools increase student performance either. While Twin Valley improved 3.21%, Clearview actually decreased 2.82%. Additionally, as can be seen in Figure 1, the PSSA results are rather sporadic and the data does not appear to be reliable. Because this data is inconclusive, the teacher survey results will either prove the belief that there is no direct correlation between a LEED rated school and student performance.

Additional Up Front Cost

This portion of the analysis considers each of the thirty-five LEED points and nine prerequisites that Walker Jones is pursuing for LEED certification. It aims to estimate the additional upfront cost associated with each point or prerequisite. If a point or prerequisite would have been satisfied regardless of LEED certification, then additional costs are not considered. For example, local codes require a stringent erosion and sediment control plan, so extra costs for Prerequisite 1: Construction Activity Pollution Prevention are not taken into account.

Point Cost Breakdown

Sustainable Sites

Prerequisite 1: Construction Activity Pollution Prevention

The Walker Jones team created a detailed erosion and sediment control plan prior to the start of construction. They utilized silt fence, temporary seeding, sediment traps, and windscreen fences to minimize dust. The District of Columbia required that these criteria be met, regardless of LEED certification, so no additional cost was incurred.

Additional Cost: $0

Prerequisite 2: Environmental Site Assessment

The site of Walker Jones was previously a school, so there was little concern about contamination. There was a site assessment performed to ensure that there was no contamination onsite which could harm students or add unexpected costs to the project. This assessment would have been performed regardless of LEED certification.

Additional Cost: $0

Credit 1: Site Selection

The school is located in an urban environment and is replacing an existing school; therefore the site does not include sensitive site elements or restrictive land types.

Additional Cost: $0

Credit 2: Development Density & Community Connectivity

Because the site is in a heavily populated urban environment, both Option 1 – Development Density and Option 2 – Community Connectivity are satisfied by building on the current site. No extra time or money was required to achieve this point.

Additional Cost: $0

Credit 4.1: Alternative Transportation, Public Transportation Access

Due to the location of the project, Option 2 is satisfied. The school is located one block away from a bus stop servicing several bus lines. In addition, there will be a school bus system.

Additional Cost: $0

Credit 4.3: Alternative Transportation, Low-Emitting & Fuel Efficient Vehicles

Walker Jones satisfies this requirement by providing two spots, or 5% of the total parking, for preferred parking spots. A designated drop-off area is also included, but would be regardless of LEED certification. The only additional cost comes from two signs designating preferred parking. An example of the sign can be seen in Figure 1.4. The sign itself only costs $19 each, but installation must be taken into account.

Additional Cost: $350.00

Figure 1.4 - Preferred Parking Sign

Credit 4.4: Alternative Transportation, Parking Capacity

Walker Jones satisfies Option 1 by not exceeding the minimum local zoning requirements and provided preferred parking for 5% of total spaces. DC zoning requirements for an elementary school mandate two spots for every three staff members. For Walker Jones, about thirty spots are required by DC regulation and two are required for carpool preference parking. The signs are similar to the one shown in Figure 1.4.

Additional Cost: $350.00

Credit 5.2: Site Development, Maximize Open Space

The school was designed as a multi-level school to efficiently use space and to allow for open spaces for recreational use and sports fields. The school would have been designed as is, regardless, but the design allows for 47,700 ft^2 of sodded open space used for play areas and fields. The cost to sod the open space is about forty cents per square foot, or about $19,000.

Additional Cost: $19,000

Credit 6.1: Stormwater Design, Quantity Control

The existing site had imperviousness greater than 50%, so for Walker Jones to satisfy Credit 6.1, the requirement is to reduce the volume of stormwater runoff by 25%. The existing site consisted of two sprawling schools and pavement. The new design has one compact school with open space (accounted for in Credit 5.2), and a green roof (accounted for in Credit 7.2) to increase permeability and reduce stormwater runoff.

Additional Cost: $0

Credit 7.1: Heat Island Effect, Non-Roof

Walker Jones uses Option 1, using paving materials with a Solar Reflectance Index (SRI) of at least 29 for greater than 50% of the site hardscape. Because most of the site is covered with sod, the only hardscaping onsite is 6000 ft² of basketball courts and 7600 ft² of parking. The basketball court is paved with asphalt, and does not satisfy the SRI requirement; however, the parking lot and sidewalks are all concrete. Regardless of mix, all 45 concretes tested according to ASTM C 1549 have an SRI of at least 29, so the concrete parking and sidewalks will satisfy the LEED criteria. Because of its durability and life-cycle cost benefits, the parking lot would have been concrete regardless of LEED certification.

Additional Cost: $0

Credit 7.2: Heat Island Effect, Roof

Walker Jones' roof satisfies Option 2 of this credit, with greater than 50% of the roof being vegetated. Walker Jones has 29,200 ft² of green roof at $30/ft² and 9,700 ft² of built up EPDM roof, costing $9.50/ft². The total additional cost due to the green roof is $598,600.

Additional Cost: $598,600

Credit 8: Light Pollution Reduction

The interior lighting requirements for this point are met because the building will not be in use from 11 p.m. to 5 a.m., and so all non-emergency interior lighting will be off. The school is located in an LZ3, high-density residential zone with medium exterior lighting requirements. Minimizing outdoor lighting will only reduce costs, and requires no additional money.

Additional Cost: $0

Credit 10: Joint Use of Facilities

This credit is satisfied because of the buildings use as a school, community center, and public library. The auditorium, cafeteria. gymnasium, library, and a portion of classrooms are available for public use when school is not in session. Because of the desire to revive the Northwest One district of DC, the school was designed this way regardless of LEED certification.

Additional Cost: $0

Water Efficiency

Credit 1.1: Water Efficient Landscaping, Reduce by 50%

The landscape design for Walker Jones uses a variety of grasses which are durable and require little water once established. These plants can be purchased and installed for less than $10 each, which is cheaper than many more decorative and time-demanding plants. No extra cost was incurred due to this requirement.

Additional Cost: $0

Credit 1.2: Water Efficient Landscaping, No Potable Use or No Irrigation

As was mentioned above, Fountain Grasses and Switchgrasses do not require permanent irrigation systems and are very durable species. There is no additional cost associated with this credit.

Additional Cost: $0

Credit 3.1: Water Use Reduction, 20% Reduction

Walker Jones satisfies this requirement by using low-flow toilets. DC regulations do not allow waterless urinals in this school. There are two types of low-flow toilets used. They are American Standard Afwall FloWise Elongated Toilet, of which there are sixteen, and the ADA compliant version, of which there are 29. These toilets cost $293 and $642, respectively. The American Standard Afwall Elongated Toilets without the FloWise feature cost $279 and $612. Using the FloWise toilets rather than standard toilets adds $1,094 to the cost.

Additional Cost: $1,094

Credit 3.2: Water Use Reduction, 30% Reduction

This point is achieved in the same way as Credit 3.1. No additional cost is incurred.

Additional Cost: $0

Energy & Atmosphere

Prerequisite 1: Fundamental Commissioning of the Building Energy Systems

Commissioning is being handled by the owner with assistance from the mechanical contractor. The total additional cost to the project is $153,650; however, the owner recognizes the importance of ensuring proper functioning of the building systems.

Additional Cost: $153,650

Prerequisite 2: Minimum Energy Performance

Regardless of LEED certification, the building would be designed to comply with ASHRAE standards and local codes. No additional cost is incurred.

Additional Cost: $0

Prerequisite 3: Fundamental Refrigerant Management

The mechanical engineer would not specify CFC-based refrigerants, regardless of LEED certification. There is no additional cost associated.

Additional Cost: $0

Credit 1: Optimize Energy Performance (2 points)

The building envelope and systems were designed to maximize energy efficiency, regardless of LEED certification. The energy model confirmed that the school is designed to provide about a 15% energy cost savings compared to a baseline ASHRAE compliant design. These points were achieved using standard design practices.

Additional Cost: $0

Materials and Resources

Prerequisite 1: Storage & Collection of Recyclables

By law, recycling is required in all commercial establishments in DC, including public schools.

Additional Cost: $0

Credit 2.1: Construction Waste Management, Divert 50% from Disposal

LSI, the waste management service used by the Walker Jones team offers a sorting and recycling service. All construction waste is deposited in the same dumpster and LSI sorts, tracks, and recycles the recyclable waste. LSI then forms a report and reports back to Forrester, the general contractor on the project. The fee for this service is a mere $27 per dumpster. Assuming a conservative four dumpsters a week for the duration of the fifteen month schedule, the additional cost is $6,480.

Additional Cost: $6,480

Credit 2.2: Construction Waste Management, Divert 75% from Disposal

The additional cost to achieve this point is accounted for in Credit 2.1.

Additional Cost: $0

Credit 4.1: Recycled Content, 10%

Typical materials were used to satisfy this requirement. Carpets, shelving materials, concrete, furniture, and even windows help satisfy this credit without adding additional cost.

Additional Cost: $0

Credit 5.1: Regional Materials, 10%

This credit was satisfied using primarily masonry, which accounted for about $2.7 million of the project. There was no additional cost associated with this credit.

Additional Cost: $0

Indoor Environmental Quality

Prerequisite 1: Minimum IAQ Performance

The building is designed to exceed ASHRAE standards. There is no additional cost associated with this, as it is standard design procedure.

Additional Cost: $0

Prerequisite 2: Environmental Tobacco Smoke Control

Smoking is prohibited in DC public schools, so no additional action was required.

Additional Cost: $0

Prerequisite 3: Minimum Acoustical Performance

More information on the acoustical design can be found in analysis three. Common design practices for an elementary school were used to satisfy the minimum acoustical requirements to achieve this credit.

Additional Cost: $0

Credit 1: Outdoor Air Delivery Monitoring

Carbon dioxide monitors were installed in all densely occupied areas such as classrooms, the cafeteria, auditorium and gymnasium. The GE Telaire Ventostat 8000 Series Carbon Dioxide Detector is intended for use in schools and retails for $298. After installation, the cost per detector is about $650. There are fifty-four required detectors, adding a total cost of $35,100.

Additional Cost: $35,100

Credit 3.1: Construction IAQ Management Plan, During Construction

The construction team used cautious practices during construction such as covering and elevating absorptive materials to protect them from moisture damage. Permanently installed AHU's were not used during construction, and smoking on site is prohibited. Although this credit required extra thought and planning, no additional costs were added.

Additional Cost: $0

Credit 3.2: Construction IAQ Management Plan, Before Occupancy

Option 1, a flush-out of the building prior to occupancy is being used on Walker Jones. Although no new equipment is required, the process is costing the project $75,000 for planning and assistance costs.

Additional Cost: $74,700

Credit 4: Low-Emitting Materials (4 points)

To satisfy this requirement, the four categories used are adhesives and sealants, paints & coatings, flooring and ceiling. The paint is Olympic Premium Interior Latex Flat, which sells for $70/ 5 gallon container. There is approximately 239,572 ft² of painted surfaces, resulting in a cost of $9,590 using a 350 ft² per gallon coverage rate. A similar quality brand that does not offer low-emitting materials compliance is Valspar Ultra Premium Interior Latex, which sells for $57.40 per 5 gallon container. This comes to a total of $7,863.80. The total added expense for paints and sealants is $1,726.20. The ceiling tiles are manufactured by Armstrong, a common manufacturer. These tiles satisfy the low volatile organic compound (VOC) requirements. The carpet is manufactured by Shaw Contract Group, which the architect commonly specifies regardless of LEED certification. Shaw Contract Group uses 100% eco-solution materials in their carpets.

Additional Cost: $1,726

Credit 5: Indoor Chemical & Pollutant Source Control

Cleaning and maintenance areas of Walker Jones have isolated exhaust systems for contaminants. According to the mechanical engineer, this is common design practice. Likewise, there are entryway systems such as architectural louvers and grilles to prevent contaminants from entering the building. Additionally, there are high-level filtration systems in air handling units processing both return air and outside supply air. The mechanical engineer typically designs systems in such a way that would satisfy this credit.

Additional Cost: $0

Credit 6.1: Lighting System Design & Controllability

It is common practice to design classrooms to have individual switching which can be adjusted for general illumination or for A/V conditions. In addition to this design, Walker Jones classrooms are equipped with occupancy sensors to ensure efficient energy use. These sensors are Watt Stopper DT200 Dual Technology Ceiling Sensors, which sell for $116.10 each. Forty-one classrooms in Walker Jones are equipped with occupancy sensors. When installation is taken into account, this results in a total additional cost of $13,726.

Additional Cost: $13,726

Credit 6.2: Thermal Comfort Controllability

The thermal controls are designed to meet ASHRAE standards with individual controls in each classroom, as well as multi-purpose areas such as the gymnasium and cafeteria. According to the mechanical engineer, this is a typical control schematic.

Additional Cost: $0

Credit 7.1: Thermal Comfort, Design

The building's HVAC system was designed in compliance with ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy. This standard would have been met and exceeded even if the project was not pursuing LEED certification.

Additional Cost: $0

Innovation & Design Process

Credit 1.2: Innovation in Design: Exemplary Performance SS5.2 – Open Space

Because of the vast amount of open space used as fields and play space, Walker Jones is applying for this additional credit. All additional costs are discussed under SS5.2: Open Space.

Additional Cost: $0

Credit 1.3: Innovation in Design: Exemplary Performance SS10 – Joint Use

Due to the status of Walker Jones as an elementary school, public library and community center, it is eligible to apply for exemplary performance. All additional costs are accounted for under SS10: Joint Use.

Additional Cost: $0

Credit 2: LEED Accredited Professional

The architect, Jeff Hagan, of Hord Coplan and Macht is the LEED Accredited Profession (AP) on Walker Jones. The costs associated with becoming LEED Accredited are the cost of the USGBC LEED Reference Book and the cost of taking the LEED exam. For USGBC members, the cost is $150 for the reference book and $300 for the exam.

Additional Cost: $450

Additional Costs Associated with LEED Certification

Anticipated Certification Costs

The team anticipates a cost of about $1750 for applying for LEED certification in addition to the $450 registration fee. This fee covers the design and construction review which is performed by the USGBC.

In Table 1.4, a breakdown of the points that contribute to additional building costs is presented. More than half of the additional cost, or $598,600 comes from the addition of the green roof. Another $153,650 is added due to the cost of fundamental commissioning. The total added cost is $907,426.00 or about $7.41 per ft². This is significantly higher than the average premium of $3 per ft², mostly due to the cost of the green roof.

Table 1.4 - Summary of LEED Points with Added Cost

LEED Points Requiring Additional Up-Front Cost	
Category / Credit	**Additional Cost**
Sustainable Sites	
Credit 4.3: Alternative Transportation, Low-Emitting & Fuel Efficient Vehicles	$350.00
Credit 4.4: Alternative Transportation, Parking Capacity	$350.00
Credit 5.2: Site Development, Maximize Open Space	$19,000.00
Credit 7.2: Heat Island Effect, Roof	$598,600.00
Water Efficiency	
Credit 3.1: Water Use Reduction, 20% Reduction	$1,094.00
Energy & Atmosphere	
Prerequisite 1: Fundamental Commissioning of the Building Energy Systems	$153,650.00
Materials and Resources	
Credit 2.1: Construction Waste Management, Divert 50% from Disposal	$6,480.00
Indoor Environmental Quality	
Credit 1: Outdoor Air Delivery Monitoring	$35,100.00
Credit 3.2: Construction IAQ Management Plan, Before Occupancy	$74,700.00
Credit 4: Low-Emitting Materials (4 points)	$1,726.00
Credit 6.1: Lighting System Design & Controllability	$13,726.00
Innovation & Design Process	
Credit 2: LEED Accredited Professional	$450.00
Anticipated Certification Costs	
Registration	$450.00
Design and Construction Review	$1,750.00
Total Additional Cost	**$907,426.00**
Total Cost per Square Foot	**$7.41**
Total Additional Cost Without Green Roof	**$308,826.00**
Total cost/sf without green roof	**$2.52**

The additional cost without the green roof is only $2.52/ft². This amount is less than 1% of the total project cost ($294/ ft²), and is a reasonable amount to pay for a sustainable and healthy school. Because the students have access to the green roof, it can serve as a valuable learning tool for them. It will also be a prominent feature in the neighborhood, drawing attention to the school and commanding attention for sustainability. Because of this, it is a worthwhile investment even though it causes the additional LEED related costs to contribute 2.50% of the total building cost.

Conclusion

From the standardized test score comparison and the teacher survey, it is reasonable to assume that there is no correlation between student performance and a LEED rated building. There are, however, many other benefits. The greatest of these benefits are the enhancement of the learning environment, improvement in student and staff productivity, and the improved image of the school in the community. Sixty-nine percent of teachers surveyed believe that the greatest perceived benefit for educational purposes is daylighting in the classroom. Because of the immeasurable benefits to the learning environment, no price can be put on building a sustainable and healthy school. Although the additional cost per square foot of $7.34, or about 2.5% of the building cost, is high, the school could have been designed to achieve LEED Certification without the green roof. Although it is not recommended because of the added benefits of the green roof on this particular project, this would result in a less than 1% increase in the total cost of the building, which is a worthwhile long-term investment for the students and staff, and for the environment.

Daylighting in Walker Jones Classrooms

Introduction

As the teacher survey and research have proven, classrooms with ample daylighting are both a perceived and proven benefit to schools. Teachers who responded to the survey said that they enjoyed daylighting and believed that it added to the positive learning environment in their classrooms. This experimental evidence is backed up by many scientific studies, including "Daylighting in Schools: An Investigation into the Relationship between Daylighting and Human Performance[13]." This report, performed by Hescgong Mahone Group of Fair Oaks, California studied over 2000 classrooms in three school districts to determine the correlation between natural light and student performance. The survey found that students with the most daylighting in their classrooms progressed 20% faster on math tests and 26% faster on reading tests in one year than those students in classrooms with the least daylighting. The results found in this survey are supported by similar results in thousands of other surveys across the country, including "Student Performance in Daylit Schools: Analysis of the Performance of Students in Daylit Schools," performed by Innovative Design in Raleigh, North Carolina[14]. This study found both improvements and performance and attendance as a result of attending a daylit school.

Not only are classrooms with natural light beneficial to students and staff, but they can also provide significant financial and environmental benefits if designed correctly. Another study by Innovative Design, titled "Energy Performance of Daylit Schools in North Carolina," compared the energy costs of fifteen schools and found that daylit schools in the study benefitted from energy cost reductions from 22% to 64% over typical schools. All daylit schools in the study experienced paybacks within the first three years.

Problem Statement

The current design for a typical Walker Jones classroom has one 8' x 8' window. Because the windows are spaced evenly on the exterior wall of the school, their location

[13] Hescgong, L. "Daylighting in Schools: An Investigation into the Relationship Between Daylighting and Human Performance" *Hescgong Mahone Group* 13 Aug 1999. Accessed February 27 2009 <http://eric.ed.gov/ERICDocs/data/ericdocs2sql/content_storage_01/0000019b/80/16/66/41.pdf>

[14] Nicklas, M. and Bailey, G. "Student Performance in Daylit Schools: Analysis of the Performance of Students in Daylit Schools." Innovative Design, Raleigh, North Carolina. Accessed February 12, 2009 <http://www.innovativedesign.net/studentperformance.htm>

within each classroom varies; most windows are located off-center towards the corner of each room. The layout used for this analysis has the window located 3' from the center of the room and 3' from the wall. It is expected that this design will provide illuminance levels too high for optimal student performance in one corner of the room, while the other side of the room will experience no benefits of natural light.

In addition to the issue of one large floor-to-ceiling window in each classroom, the second design issue is the use of occupant sensors in each classroom. Because a typical elementary school classroom is used by the same teacher all day, it is easy for him or her to turn the lights off when the room is no longer in use. Additionally, many teachers complained in the survey about occupancy sensors that turn the lights off during silent reading times or when the teacher is working alone in the room.

This analysis seeks to address both these issues by determining a suitable window design to allow for adequate natural light in the classrooms while incorporating a daylight sensor in replace of the occupancy sensor. These changes aim to improve the learning environment while cutting energy costs for the school.

Goal

This analysis will aim to improve the design of a typical Walker Jones classroom to incorporate daylighting to maximize student performance and reduce the school's energy costs and impact on the environment. If the current design is deemed inadequate to provide natural light, a new design will be proposed and illuminance levels in the new classroom will be analyzed to determine if daylighting is feasible in a typical Walker Jones classroom.

Methodology

1. Research daylighting.
2. Meet with AE lighting faculty to obtain advice and guidance.
3. Use AGi to run calculations on the current classroom design.
4. Suggest improvements to the lighting design and room layout.
5. Run calculations on the new room design.
6. Compare the results to determine if daylighting is possible.
7. Determine energy cost savings.
8. Determine cost and schedule impacts.
9. Make a recommendation and conclusions.

Tools / Resources

1. Walker Jones construction documents
2. The Walker Jones Team
3. AGi32 Lighting Design Software
4. AutoCAD 2009 for 3D modeling
5. Penn State Architectural Engineering faculty
6. 5th year AE lighting students
7. Brian Leach at Penn Lighting Associates
8. "Daylighting in Schools: An Investigation into the Relationship Between Daylighting and Human Performance" Hescgong Mahone Group (1999).
9. Student Performance in Daylit Schools: Analysis of the Performance of Students in Daylit Schools," performed by Innovative Design in Raleigh, North Carolina. (1995)
10. The National Fenestration Rating Council (NFRC)

Expectations

It is anticipated that the current design with one window will flood a portion of the room with too much daylight. In addition to uncomfortable conditions in one corner of the room, the current design does not account for any energy saving due to the use of natural light. It can be expected that a design with more evenly spaced windows will provide much more useful natural light that can be used to offset energy costs.

Current Lighting Design

The current design of a typical Walker Jones Classroom is 28' x 32' and has one large 8' x 8' window located somewhere along the exterior wall. This design can be seen in Figure 2.1.

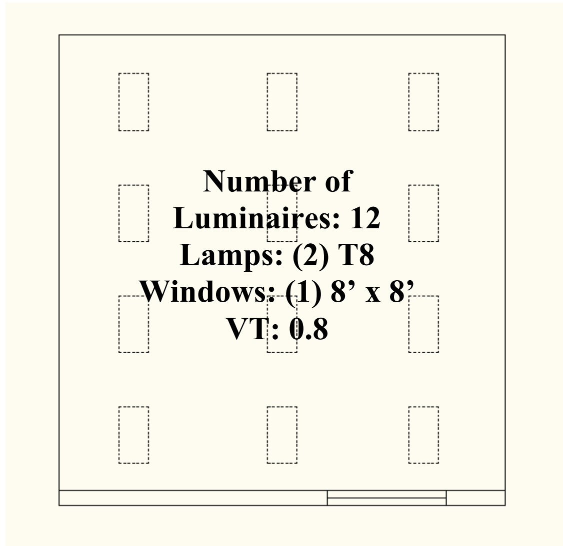

Figure 2.1 - Current Room Layout

The following information concerns the current design:

- 2' x 4' recessed flourescent light fixtures
- (2) T-8 lamps per fixture
- Windows are double 3 mm: 1/8" clear glass, .3" air space, 1/8" clear glass
- Ballasts are Lithonia ¼ GEB10IS
- According to NFRC, Center-of-Glazing Values, visible transmittance (VT) = 0.814 and solar heat gain coefficient (SHGC)= 0.761[15]

The following assumptions were used for AGi32 modeling purposes:

- Fixtures are Lithonia 2GT8 2 32 A12 MVOLT, 2 Lamp T-8 fixtures[16]
- Reflectance values are as follows:
  - Ceiling: 0.8
  - Walls: 0.5
  - Carpet: 0.2
- Work plane is 2'-6"

[15] National Fenestration Rating Council. "Center of Glazing Values." January 30, 2007. Accessed February 16, 2009 < http://www.nfrc.org/documents/FilmDatasubmissionprocess-final_000.pdf>
[16] Lithonia Lighting, an Acuity Brands Company. "General T8 Troffer." Accessed February 6, 2009 <http://www.lithonia.com/product/advSrch.aspx>

- Light Loss Factor is 0.75
- Targeting Illuminance is 50 foot candles + / - 10%

The current design also uses occupancy sensors to control unnecessary electricity usage. These occupancy sensors are relatively ineffective in a K-8 classroom, since one teacher is responsible for each classroom. Turning the lights off when no one is in the classroom is the responsibility of that one teacher. Many teachers also complained in the teacher survey that occupancy sensors do not sense them while they are working at their desk, and the lights frequently shut off, which can become an annoyance.

Current Design Calculations

Using the current room design, calculations were performed at noon on March 21 for both overcast and clear sky conditions. From these calculations, it appears that the current room design is not suitable for daylighting, and provides levels of light too high in a portion of the room closest to the window. For the current layout calculations, the fourth row of lights was shut off for both clear sky and overcast conditions. Table 2.1 shows the summary results of the calculation.

Table 2.1 - Current Layout Calculations

Current Layout Calculation				
Conditions	Average Illuminance (FC)	Maximum Illuminance (FC)	Minimum Illuminance	Suitable for Daylighting
ClearSkies	242	5880	29.8	No
Overcast	55.23	253	8.5	No

Table 2.1 shows that the illuminance levels due to daylight are far too high, and are not evenly distributed throughout the room. This will likely result in teachers using the blinds to block daylight all together. It can be hypothesized from this calculation that the current design is not suitable for daylighting.

New Room Design

The new room design can be seen in Figure 2.2. The following assumption differs from those listed for the current room design:

- Fixtures are Lithonia 2RT5 28 T5 MVOLT, 2 Lamp T-5 fixtures[17]

[17] Lithonia Lighting, an Acuity Brands Company. "Volumetric Recessed Lighting." Accessed February 6, 2009 < http://www.lithonia.com/product/advSrch.aspx>

- Visible transmittance of the windows = 0.40
- There are (2) 6' x 8' windows

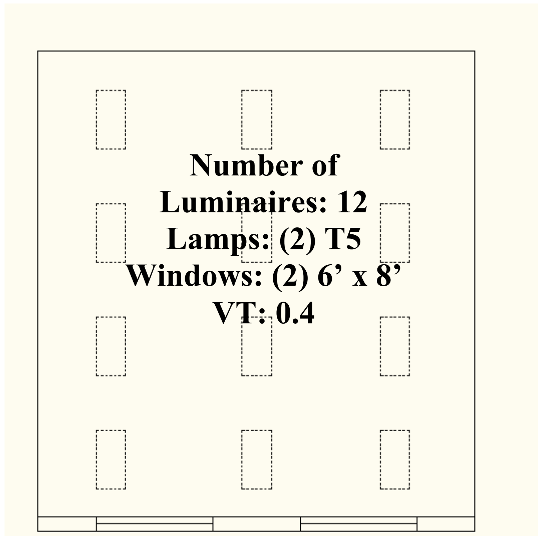

Figure 2.2 - New Room Layout

At a visible transmittance of 0.80, as the original design was modeled, the solar heat gain coefficient is 0.82. With a visible transmittance of 0.40, the solar heat gain coefficient is reduced to 0.35. This means that the size of the window in each classroom can be increased from 64 ft² to 125 ft² without impacting the mechanical system. To be conservative, the recommended window size in each classroom totals 96 ft². By adding additional window space and reducing visible transmittance, occupants will experience more uniform natural light with significantly less glare.

New Room Design Calculations

With the new window layout and switch in lamps, the lighting calculations must be recalculated. Again, AGi32 was used with the same assumptions (except the change in lamps and window transmittance). Calculations were run for both clear and overcast skies. The facility is designed to be used year round, and operating hours are assumed to be 8 AM to 6 PM. This is due to after school programs, summer school and camps, and community activities. Because of this, calculations were run on March 21, since that is a mid-point between December 21 and June 21. Calculations were performed for each two-hour period to determine how often daylight is able to provide enough light to shut off one row of luminaires. An image of the classroom with isolines showing the illuminance levels can be seen in Figure 2.3. This image is from a calculation run at 12 PM with clear sky conditions.

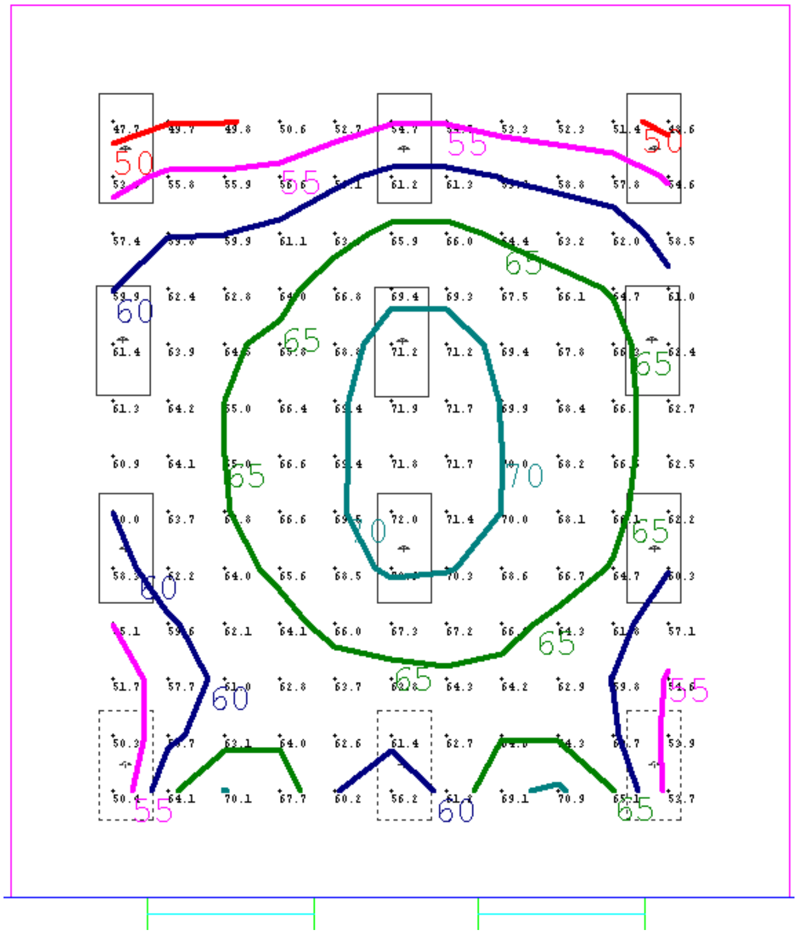

Figure 2.3 - Classroom Illuminance levels, Clear Sky Conditions

As can be seen in Figure 55, the workspace is assumed to be in the center of the room. Illuminance levels are at a suitable level and are fairly consistance throughout the room. For clear sky conditions, the fourth row of lights is completely off. For overcast conditions, one lamp in each of the luminaires in the fourth row is shut off. Table 2.2 shows a summary of the calculations.

Table 2.2 - Summary Calculation for New Room Design

New Layout Calculation - Overcast Skies				
Time	Average Illuminance (FC)	Maximum Illuminance (FC)	Minimum Illuminance	Suitable for Daylighting
8:00 AM	45.76	62.4	16.5	No
10:00 AM	52.56	64.4	34.2	No
12:00 PM	57.18	81.1	43.1	Yes
2:00 PM	58.31	86.9	44.7	Yes
4:00 PM	55.67	73.73	40.3	Yes
Total Hours Suitable for Daylighting				6 Hours

New Layout Calculation - Clear Skies				
Time	Average Illuminance (FC)	Maximum Illuminance (FC)	Minimum Illuminance	Suitable for Daylighting
8:00 AM	52.43	66.3	27.1	No
10:00 AM	66.53	77.1	48.8	Yes
12:00 PM	62.72	72	47.7	Yes
2:00 PM	61.4	91.5	46.8	Yes
4:00 PM	190.58	2144	49.8	No
Total Hours Suitable for Daylighting				6 Hours

Using this information, the total hours per year that each condition satisfies for daylighting can be calculated. To do this, data from The University of Utah's Department of Meteorology is used[18]. Researchers have tracked weather for the past 45 years in Washington, DC and compiled the average number of days a year that it is clear, partly cloudy and overcast. For a conservative estimate, all partly cloudy days will fall into the overcast catergory. According to this study, the following data is used:

- Clear Days: 97 days
- Overcast Days: 268 (105 partly cloudy days and 163 overcast days)

Table 2.3 displays the total hours for which each calculation satisfies the requirements to switch off (or switch half off) the fourth row of luminaires.

Table 2.3 - Hours Suitable for Daylighting

Total Hours Suitable for Daylighting per Year		
Overcast Conditions		
Hours per Day	Days per Year	Total Hours per Year
6	268	1608
Clear Sky Conditions		
Hours per Day	Days per Year	Total Hours per Year
6	97	582

The ability to shut off lamps will enable teachers to use the lighting design as a teaching tool and for the school to save a small amount of money on operating costs.

Daylight Sensor Selection

As mentioned above, it is not believed that occupancy sensors are the most effective lighting control sensor to use in K-8 classrooms. Daylight sensors have the ability to save Walker Jones money in operating cost and they also present a unique opportunity to

[18] The University of Utah, Department of Meteorology. "Historical Weather Data." Accessed February 26, 2009 < http://www.met.utah.edu/jhorel/html/wx/climate/cldy.html>

use the lighting change as a teaching tool so that children learn at a young age to only use electric light when it is necessary.

To select a daylight sensor, Watt Stopper was used[19]. Watt Stopper has two daylight sensors that would be viable to use on Walker Jones. One is the LightSaver LS101, which is a daylighting controller that provides on/off switching. The second option is the LightSaver LS-301 Dimming Photoensor. Penn Lighting Associates confirmed that the LightSaver LS101 is a discontinued sensor, so it is out of consideration.
Dimming, although it has the potential to save more energy in the long-term, will complicate installation, require different luminaires and ballasts, costs considerably more up from and can affect the schedule. For these reasons, an on/off sensor was chosen for Walker Jones. The LS102 can be seen in Figure 2.4.

Figure 2.4 - The Watt Stopper LightSaver LS 102

The sensor resembles a smoke detector and is virtually unnoticable. The LS 102 can sense light from 1 to 1400 footcandles and can be set to switch on or off at 25%, 50%, 75%, or 100%. This is useful since on overcast days, half of the light is still needed from the first row of lights. The LS 102 should be ceiling mounted between the window and the first row of fixtures. Figure 2.5 shows a typical mounting location from www.WattStopper.com.

[19] Watt Stopper. "Daylighting Sensors and Controls." Accessed February 26, 2009 <**www.wattstopper.com**>

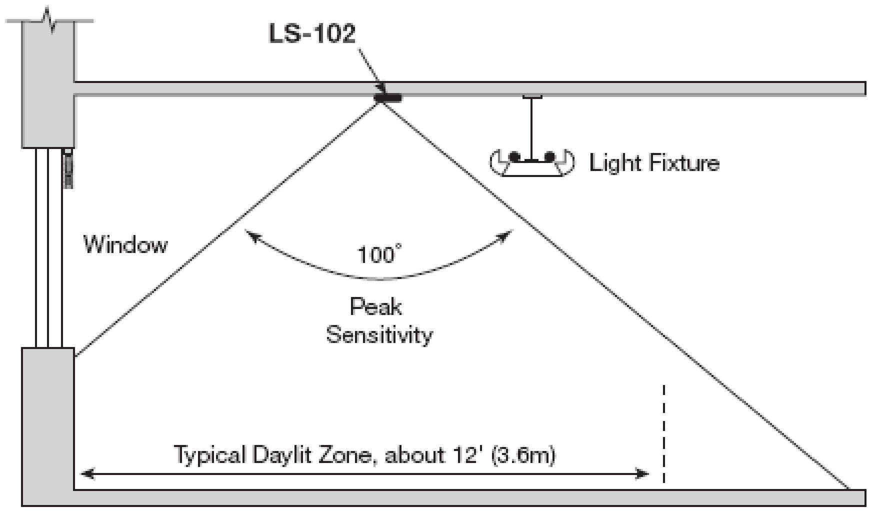

Figure 2.5 - A Typical Mounting Location for the LS 102

This device will allow the lighting design to utilize natural light. Although the switch between daylight and electric light may be noticable, that can be a positive lesson for young students.

Daylighting Technical Analysis Comparison

The first adjustment made was the switch from T8 lamps to T5 lamps. The initial cost difference can be seen in Table 2.4. Although the initial cost is considerably higher, the payback period is short when annual savings due to reduced wattage and daylighting are taken into account. The payback period calculation can be seen in Table 2.9 under the cost and schedule heading.

Table 2.4 - Initial Cost Comparison

Initial Cost Comparison			
T5		T8	
Number of Luminaires	492	Number of Luminaires	492
Initial Cost	$186.00	Initial Cost	$168.00
Total Cost	$91,512.00	Total Cost	$82,656.00
Additional Initial Cost: $8,856.00			

The cost comparison in savings due to energy cost each year can be seen in Table 2.5[20]. This cost savings is due to the reduction in watts when lamps are changed from T8 to T5 lamps. The specified T8 lamps use 32 watts of input power, while the recommended T5 lamps use 28 watts of input power.

Table 2.5 - Annual Savings using T5 Lamps

Annual Cost Savings			
T5		**T8**	
Number of Lamps	984	Number of Lamps	984
Hours per Year	3650	Hours per Year	3650
Input Power (Watts)	28	Input Power (Watts)	32
Energy Rate	$0.13	Energy Rate	$0.13
Energy Cost per Year	$13,073.42	Energy Cost per Year	$14,941.06
Savings per Year: $1,867.63			

The second change that was made is the incorporation of a daylight sensor to save on energy costs. The daylight sensors are actually cheaper than the specified occupancy sensors, so the initial savings can be seen in Table 2.6.

Table 2.6 - The Initial Cost Savings using On/Off Daylight Sensor

Initial Cost Comparison			
Type of Sensor	**Cost**	**Amount**	**Total Cost**
Watt Stopper DT 200 Occupancy Sensor	$113.10	41	$4,637.10
Watt Stopper LS 102 Daylighting Sensor	$83.70	41	$3,431.70
Total Initial Savings			**$1,205.40**

The cost savings per year due to the on/off switching can be seen in Table 2.7. This cost can be attributed to an average of six hours a day when daylight provides enough light to switch off one row of lights.

[20] Balboni, B. R.S. Means 2009 Interior Cost Data, 26th Annual Edition. R.S. Means Company, Inc., Construction Publishers and Consultants, Kingston, MA, 2009.

Table 2.7 - Annual Cost Savings Using On/Off Daylight Sensor

Clear Skies	
Number of Lamps Switching Off	246
Hours a Year Lamps are Off	582
Input Power (Watts)	28
Energy Rate ($ / KWH)	$0.13
Energy Saved per Year	**$521.15**
Overcast	
Number of Lamps Switching Off	246
Hours a Year Lamps are Off	1608
Input Power (Watts)	28
Energy Rate ($ / KWH)	$0.13
Energy Saved per Year	**$1,439.87**
Total Savings per Year	**$1,961.01**

The final change that must be taken into account is the addition of windows in each classroom. Total, there is an additional 1,312 ft² of windows added instead of brick. The initial cost impact of this change can be seen in Table 2.8.

Table 2.8 - The Added Cost of Installing Additional Windows

Initial Cost Comparison			
Material	**SF**	**Cost / SF**	**Total Cost**
Windows	1312	$55.00	$72,160.00
Brick	1312	$42.00	$55,104.00
Added Cost: $17,056.00			

Cost and Schedule

Overall, the schedule of the project will not be affected by the suggested changes. Switching the types of lamps will affect only the lamps and ballasts, which will not in any way change the schedule. According to Young Electric, the electrical contractor on the job, an on/off switch is just as simple to install as an occupancy sensor[21]. Finally, the windows can be installed in approximately the same time as the brick façade, if not slightly faster.

The overall cost comparison can be seen below in Table 2.9. Although the payback period is slightly high, it can be argued that it is a worthwhile investment. After six and a half years, the investment will pay for itself and after that, the savings will keep adding

[21] Young, D. Young Electric. Oral conversation, March 3, 2009.

up. Since the average school is in operation for over 30 years[22], this appears to be a worthwhile investment. Although the savings are not huge, they are still savings. It is also important to note that these estimates are conservative, and that the monetary amount cannot put a value on the educational benefits which are gained by additional daylight in the classrooms and through learning the valuable lesson of energy conservation.

Table 2.9 - Payback Period Calculation

Payback Period Calculation	
Switching to T5 Lamps	
Number of Luminaires	**Total Added Cost**
492	8,856.00
Additional Windows	
SF of Added Windows	**Total Added Cost**
1312	17,056.00
T5 Energy Savings	
kW per Year	**Total Savings**
14,366	(1,867.63)
Sensor Cost Savings	
Number of Sensors	**Total Savings**
41	(1,205.40)
Daylight Cost Savings	
kW per Year	**Total Savings**
15,085	(1,961.00)
Total Initial Difference	**24,706.60**
Total Yearly Savings	**(3,828.63)**
Payback Period	**6.45**
Savings over 30 Years	**($114,858.90)**

Conclusion

The above changes are all suggested based on the fact that these changes have no impact on the construction schedule and that the cost impact is minimal (0.066% of the total project cost or $0.20 per SF). The added benefits to the students and staff as well as the continued energy savings are well worth the investment.

For specifications of existing and suggested lamps and sensors, please see **Appendix B**.

[22] The National Academies: Advisers to the Nation on Science, Engineering and Medicine. Green Schools: Attributes for Health and Learning. Washington, DC: National Academies Press, 2006. Accessed Feb 21, 2009 <http://www.nap.edu/catalog/11756.html>.

Acoustical Analysis of Walker Jones Classrooms

Introduction

The United States is about to partake in the largest campaign of school construction and renovation in recent American history. With the increased emphasis on education, energy and the environment, it is time to end a longstanding practice of building classrooms with inferior acoustics. This easily correctable problem has far-reaching implications for learning. Excessive background noises and poor reverberation can interfere with speech intelligibility, affect understanding, and reduce a child's ability to learn. According to The Acoustical Society of America, many classrooms in the United States have speech intelligibility of 75 percent or less[23]. Speech intelligibility tests consist of a list of words that are read, and the listener then lists the words to determine whether or not the words are correctly heard. Understanding only 75 percent of spoken words is equivalent to reading a book with every fourth word missing.

Inadequate acoustical designs are unacceptable in classroom settings. Students under the age of 15 are still developing mature language and need appropriate listening environments to understand what is being dictated. Young children are especially dependent on good acoustics because with their limited vocabulary and experience, they are unable to predict from context what is being said.

The best way to solve problems with acoustics is to solve the problems during the design phase, rather than renovate poorly designed systems. The cost of ensuring proper acoustical designs prior to construction is small compared to the cost to renovate, or the cost of poor acoustics that impair the learning of millions of students.

In the case of Walker Jones, widely accepted design practices were used when designing the classrooms; however, special attention was not invested to ensure the learning environment provides the best acoustics possible.

Problem Statement

Because detailed attention was not spent ensuring the best possible listening environment in a typical Walker Jones classroom, this analysis will verify that the conditions are in

[23] The Acoustical Society of America, "Classroom Acoustics: A Resource for creating learning environments with desirable listening conditions." August, 2000. Accessed March 10, 2009 <http://asa.aip.org/classroom/booklet.html>

fact acceptable. Reverberations, reflections, interior and exterior noise sources and mechanical equipment will be considered.

Goal

The goal of this analysis is to ensure that the current acoustical design provides a favorable learning environment. If any aspect of the current design is found to be less than favorable, suggestions for improvement will be made. The criteria used for the analysis are based on guidelines from Classroom Acoustics: A Resource for Creating Learning Environments with Desirable Listening Conditions from the Acoustical Society of America. The following guidelines are used:

- Reverberation – Reverberation time will be less than 0.60 seconds.
- Undesirable Reflections – Absorptive materials will be used to prevent echoes
- Mechanical Equipment Noise – Locate mechanical equipment away from critical listening spaces. Also, select equipment with low sound-level ratings, size ducts large enough to permit low air velocities and select diffusers with NC ratings below 25. Finally, pay special attention to duct runs.
- Interior Noise Sources – All interior assemblies will have an STC rating of 50 or higher. Also, consider layout of the building to optimize listening spaces.
- Exterior Noise Sources – Exterior Walls will have an STC rating of 50 or higher.

Methodology

1. Research classroom acoustics

2. Analyze current classroom design.

3. Suggest improvements to current design.

4. Reanalyze classroom with suggested improvements.

5. Determine the cost and schedule implications of the suggested improvements.

Tools / Resources

1. ANSI S12.60-2002, “Acoustical Performance Criteria, Design Requirements and Guidelines for Schools

2. M. David Egan. *Architectural Acoustics*. New York: J. Ross Publishing, 2007.

3. Marshall Long. *Architectural Acoustics.* Burlington, MA: Elsevier Academic Press, 2006.

4. Acoustical Society of America

5. Armstrong Acoustical Systems

6. Walker Jones construction documents

7. Penn State Architectural Engineering faculty

8. Microsoft Office Excel, for calculations

Expectations

Because Walker Jones was designed by respected professionals, it is expected that the current acoustics are acceptable; however, there is always room for improvement. During the design process, time and money are often not readily available and so certain aspects may have been overlooked. This analysis will seek to find those opportunities for improvement, make suggestions, and re-evaluate the typical classroom's acoustical performance.

Current Acoustics Design

Classroom Layout

The current design of a typical Walker Jones classroom meets all the requirements for good acoustics based on design. Ceiling height is nine feet, which eliminates the problem of echoes due to high ceilings. Ceilings higher than ten feet are usually a concern. In addition to being a desirable height, the current ceiling is composed of acoustical tiles; however, the tiles are not the most absorptive tiles that are available.

The layout of Walker Jones is thoughtful in that it separates classrooms from potential louder spaces such as the music room, equipment rooms, cafeteria, and gymnasium. A typical classroom is surrounded by a classroom on each side, the exterior on the third side, and a corridor on the final side. Corridors are not considered especially loud areas since they will be empty during class time. Classroom doors are staggered so that there is not a direct path for noise to travel from room to room. Classrooms that would be subjected to potentially louder areas such as restrooms or stairwells are buffered by storage areas and offices. An example of thoughtful layout can be seen in Figure 3.1.

The entrances to classrooms 331, 332 and 354 all have doors located as far away from each other as possible to minimize noise travel between classrooms. Additionally, this image shows the use of storage space and offices to separate classrooms from a stairwell and potentially louder laboratory spaces.

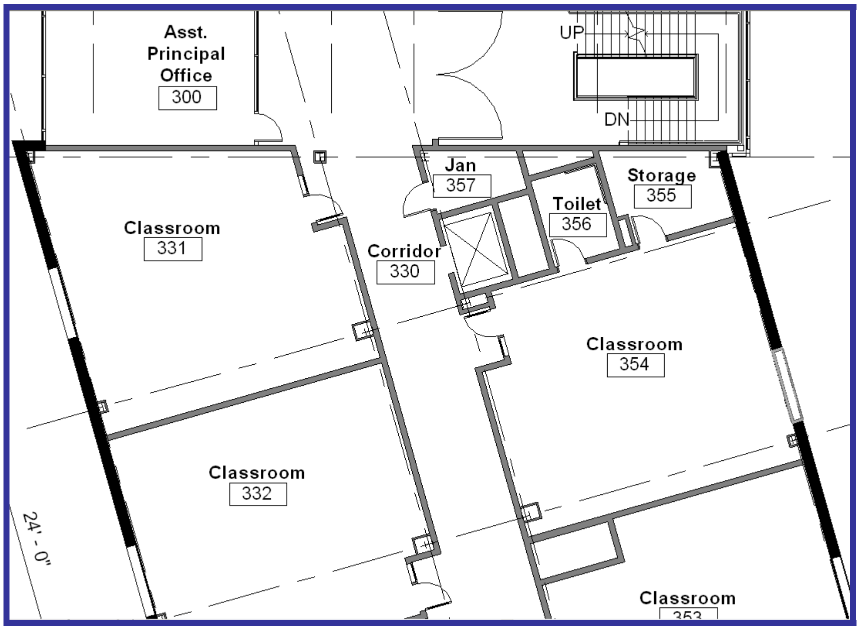

Figure 3.1 - The Careful Placement of Classroom Doors

Interior Noise Sources

Although it was established that the layout of classrooms is pretty ideal, it still must be taken into account that noise can penetrate from one especially noisy classroom through the interior walls and disturb students in an adjacent classroom. Another positive aspect of the current design relative to interior noise is that the interior walls extend from the structural floor to the structural ceiling, making them more effective sound barriers. To evaluate if sound transfer will be an issue prior to construction is difficult; however, sound transmission class (STC) can be used to estimate whether or not sound transmission will be a problem.

STC is a single-number rating system used to characterize the transmission loss values of a particular construction element. The higher the STC, the better the partition attenuates airborne sound. According to ANSI S12.60-2002[24], classrooms adjacent to other

[24] ANSI S12.60-2002, "Acoustical Performance Criteria, Design Requirements and Guidelines for Schools

classrooms should have walls and floor and ceiling assemblies with an STC rating of 50. Doors should have an STC rating of at least 30.

To calculate STC, the known transmission loss of a material is listed at each of sixteen one-third octave bands. Standard three segment STC curves are then compared to the data until the following criteria is met: no single transmission loss is more than 8 dB below the STC curve, and the sum of all differences between the curve and the transmission loss falling below it may not exceed 32 dB. Once the highest STC curve is found that meets these criteria, the STC rating is the value at the point where the curve crosses the 500 Hz frequency line[25].

Table 3.1 shows a summary of the STC calculations for interior walls. Some interior walls are concrete block, while others are metal stud with gypsum wall board (GWB). The concrete block walls do not meet the required STC rating of 50; however the difference between an STC rating of 49 and an STC rating of 50 is not a perceivable change.

Table 3.1 – Interior Wall STC Calculations

Interior Wall Sound Transmission Class							
Building Construction	Transmission Loss (dB)						
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	STC Rating
8" LW Concrete Block, Painted (38 lb/ft²)	34	40	44	49	59	64	49
3 5/8" Steel Channel Studs with two layers 5/8" GWB, 3" insulation	38	52	59	60	56	62	57
1 3/4" Hollow Core Steel Door	23	28	36	41	39	44	38

Table 3.2 shows a summary of the transmission loss and STC rating of the floor-ceiling assembly. The floor – ceiling system is an acoustical ceiling tile with a 16" airspace and 5" concrete slab on metal deck. The concrete is topped with a 41 oz carpet laid on pad. As can be seen in Table 3.2, the STC rating of this floor assembly is 55.

Table 3.2 – Floor-Ceiling STC Calculations

Floor and Ceiling Sound Transmission Class							
Building Construction	Transmission Loss (dB)						
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	STC Rating
Floor-Ceiling	38	44	52	55	60	65	55

25 Egan, M.D. *Architectural Acoustics*. New York, NY: J. Ross Publishing, 2007.

The STC rating of 55 for the floor-ceiling assembly is suitable for noise control between floors. Detailed STC calculations can be seen in charts and graphs on the following pages.

Table 3.3 illustrates the STC rating calculations of each of the interior building materials.

Table 3.3 - Interior Building Materials STC Calculations

Concrete Block Interior Wall Sound Transmission Class																	
	Transmission Loss (dB)																
	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1000 Hz	1250 Hz	1600 Hz	2000 Hz	2500 Hz	3150 Hz	4000 Hz	STC Rating
Concrete Block	34	37	42	40	38	41	44	48	52	49	54	57	59	63	67	64	**49**
STC Curve	21	27	33	39	45	47	49	51	53	55	57	57	57	57	57	57	**Total**
Difference	0	0	0	0	7	6	5	3	1	6	3	0	0	0	0	0	**31**
Steel Stud and Gypsum Wall Board Interior Wall Sound Transmission Class																	
	Transmission Loss (dB)																
	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1000 Hz	1250 Hz	1600 Hz	2000 Hz	2500 Hz	3150 Hz	4000 Hz	STC Rating
Concrete Block	38	45	57	52	54	58	59	54	58	60	62	67	58	62	65	62	**57**
STC Curve	29	35	41	47	53	55	57	59	61	63	65	65	65	65	65	65	**Total**
Difference	0	0	0	0	0	0	0	5	3	3	3	0	7	3	0	3	**27**
Hollow Steel Door Sound Transmission Class																	
	Transmission Loss (dB)																
	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1000 Hz	1250 Hz	1600 Hz	2000 Hz	2500 Hz	3150 Hz	4000 Hz	STC Rating
Door	23	20	18	28	31	34	36	42	40	41	43	47	50	47	48	44	**38**
STC Curve	10	16	22	28	34	36	38	40	42	46	48	48	48	48	48	48	**Total**
Difference	0	0	4	0	3	2	2	0	2	5	5	1	0	1	0	4	**29**
Floor-Ceiling Sound Transmission Class																	
	Transmission Loss (dB)																
	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1000 Hz	1250 Hz	1600 Hz	2000 Hz	2500 Hz	3150 Hz	4000 Hz	STC Rating
Floor-Ceiling	38	46	48	44	46	48	52	60	61	55	58	62	60	66	68	65	**55**
STC Curve	27	33	39	45	51	53	55	57	59	61	63	63	63	63	63	63	**Total**
Difference	0	0	0	1	5	5	3	0	0	6	5	1	3	0	0	0	**29**

Figure 3.2 displays the STC curve for the concrete block interior walls.

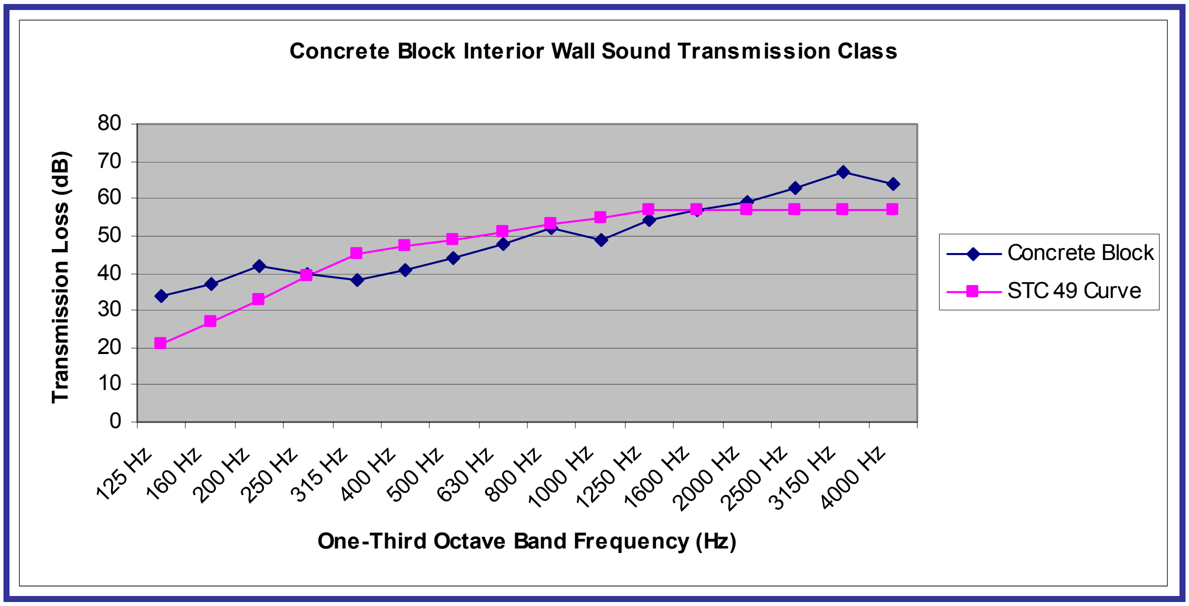

Figure 3.2 - Concrete Block STC Curve

Figure 3.3 shows the STC curve for the steel stud and GWB interior walls.

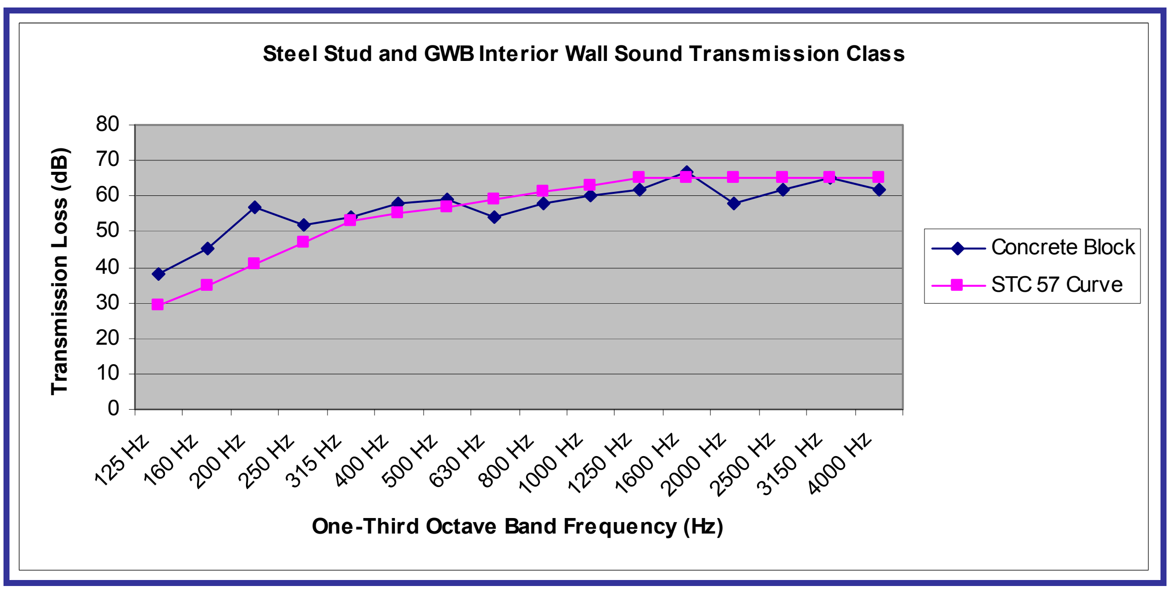

Figure 3.3 - Steel Stud and GWB STC Curve

Figure 3.4 shows the STC curve for hollow steel doors used in classrooms.

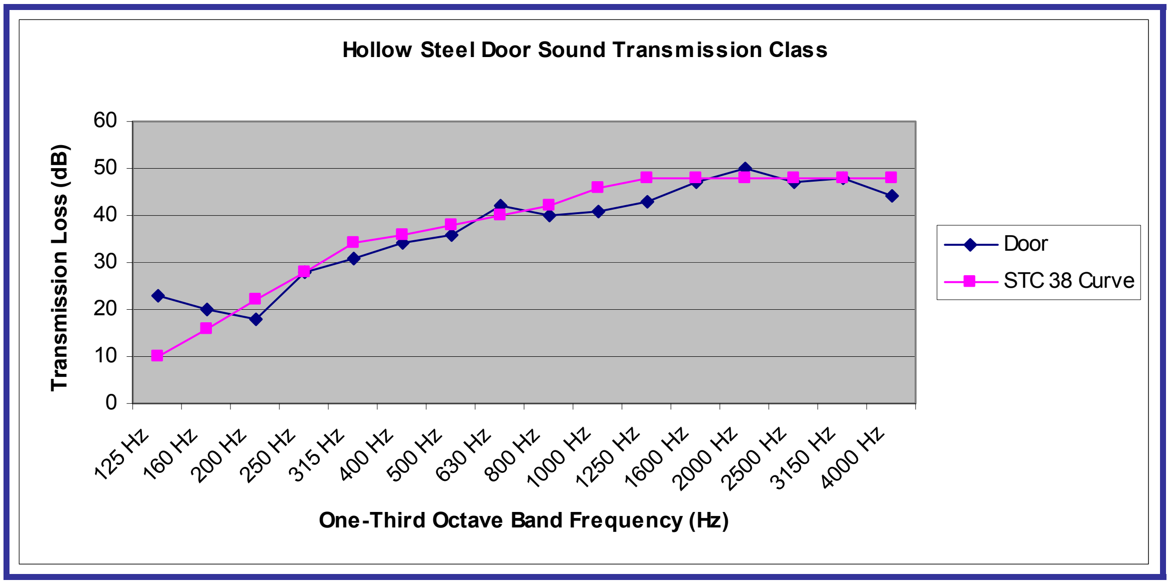

Figure 3.4 - Door STC Curve

Figure 3.5 shows the STC curve for the floor-ceiling assembly.

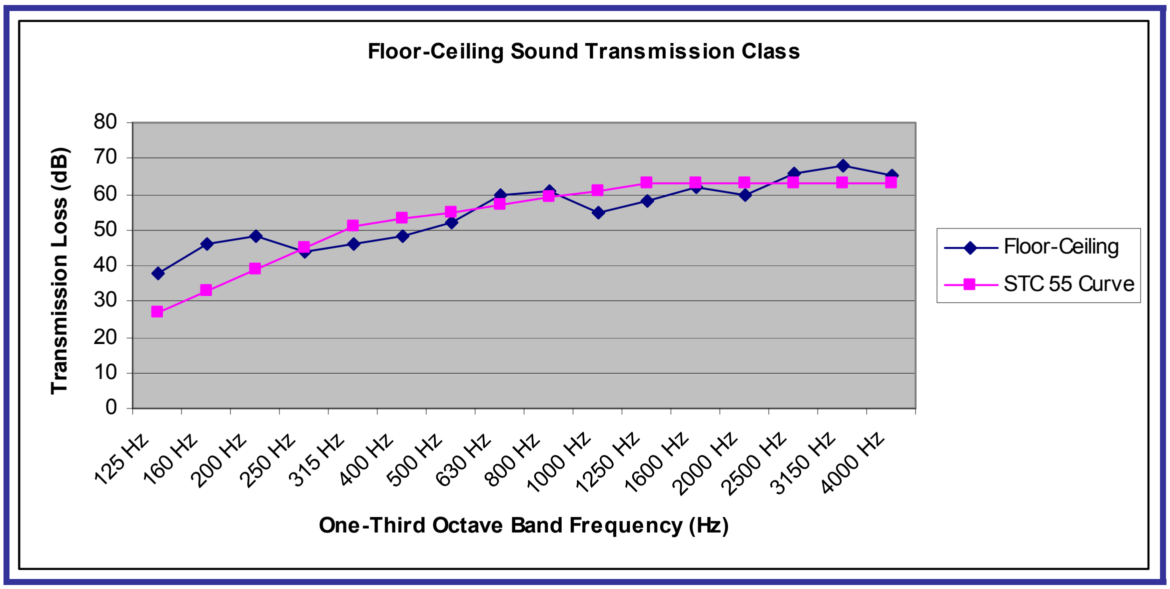

Figure 3.5 - Floor-Ceiling STC Curve

Exterior Noise Sources

Exterior walls should also have an STC rating of 50 or higher. The exterior walls of Walker Jones consist of face brick, a 1" air space, 2" of rigid insulation, sheathing, a 6" metal stud, and 5/8" gypsum wall board.

Windows should have an STC rating of at least 35. The windows specified for Walker Jones area manufactured by EFCO, a division of Pella Windows, and have an STC of 42[26]. As can be seen in TABLE 3.4, the exterior wall assembly has an STC value of 53, which exceeds the requirement of 50.

Table 3.4 - Exterior Wall STC

Exterior Wall Sound Transmission Class							
Building Construction	Transmission Loss (dB)						
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	STC Rating
Exterior Wall	43	50	52	61	73	78	59
Windows	21	30	40	44	46	57	42
Exterior Wall Assembly	35.17778	42.88889	47.73333	54.95556	63.4	70.53333	53

The resulting wall assembly, consisting of 174 ft² of wall and 96 ft² of windows has an STC rating of 53, which makes the exterior wall assembly suitable to eliminate outside noise. Detailed calculations and graphs for exterior noise control can be seen below. Table 3.5 illustrates the calculations for STC ratings of the exterior walls.

Table 3.5 - Exterior Wall STC Calculations

Exterior Wall Sound Transmission Class																	
	Transmission Loss (dB)																
	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1000 Hz	1250 Hz	1600 Hz	2000 Hz	2500 Hz	3150 Hz	4000 Hz	STC Rating
Exterior Wall	43	40	43	50	51	53	52	55	61	61	63	68	73	75	76	78	59
STC	29	35	41	47	53	57	59	61	63	65	67	67	67	67	67	67	Total
Difference	0	0	0	0	2	4	7	6	2	4	4	0	0	0	0	0	29
Window Sound Transmission Class																	
	Transmission Loss (dB)																
	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1000 Hz	1250 Hz	1600 Hz	2000 Hz	2500 Hz	3150 Hz	4000 Hz	STC Rating
Window	21	24	27	37	39	37	40	38	41	44	45	48	46	50	51	57	42
STC	14	20	26	32	38	40	42	44	46	48	50	50	50	50	50	50	Total
Difference	0	0	0	0	0	3	2	6	5	4	5	2	4	0	0	0	31
Exterior Wall Assembly Sound Transmission Class																	
	Transmission Loss (dB)																
	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1000 Hz	1250 Hz	1600 Hz	2000 Hz	2500 Hz	3150 Hz	4000 Hz	STC Rating
Exterior Wall Assembly	35	38	45	43	43	44	48	57	64	62	56	57	64	68	73	71	53
STC	25	31	37	43	49	51	53	55	57	59	61	61	61	61	61	61	Total
Difference	0	0	0	0	6	7	5	0	0	0	5	4	0	0	0	0	27

[26] Efco, a Pella Company. Accessed March 11, 2009 <http://www.efcocorp.com/products/arm/default.asp?L=1>

Figure 3.6 shows the STC curve of the exterior walls. The exterior walls exceed the minimum requirement of an STC rating of 50.

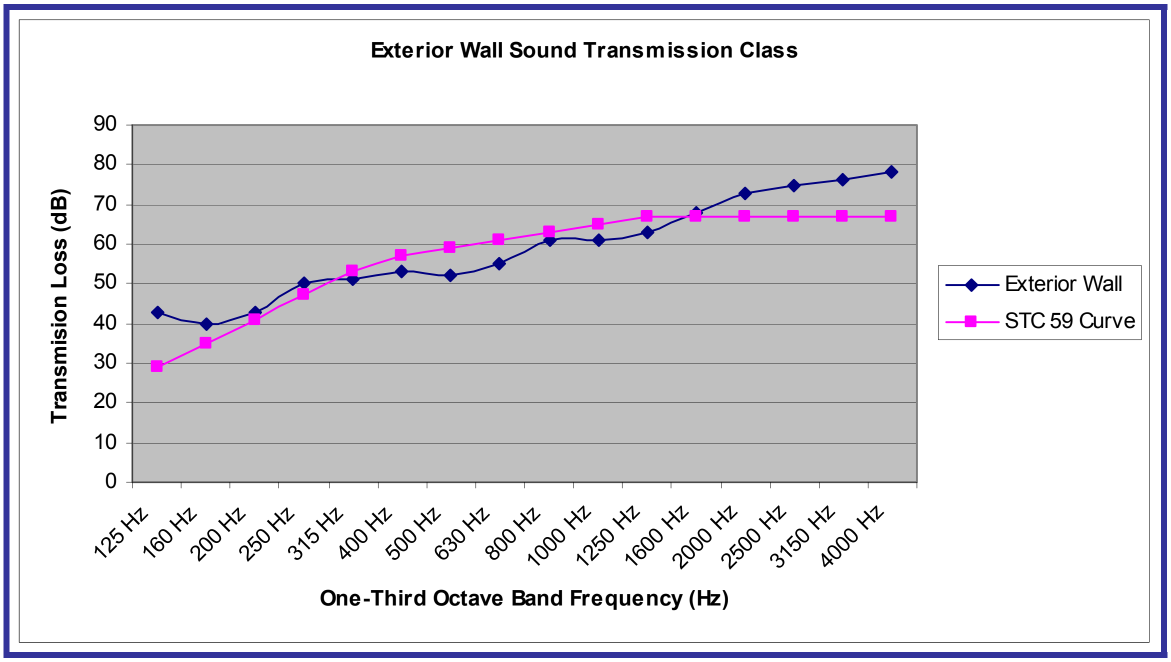

Figure 3.6 - Exterior Wall STC Curve

Figure 3.7 shows the STC curve of the Windows. The STC rating of 42 surpasses the required rating of 35.

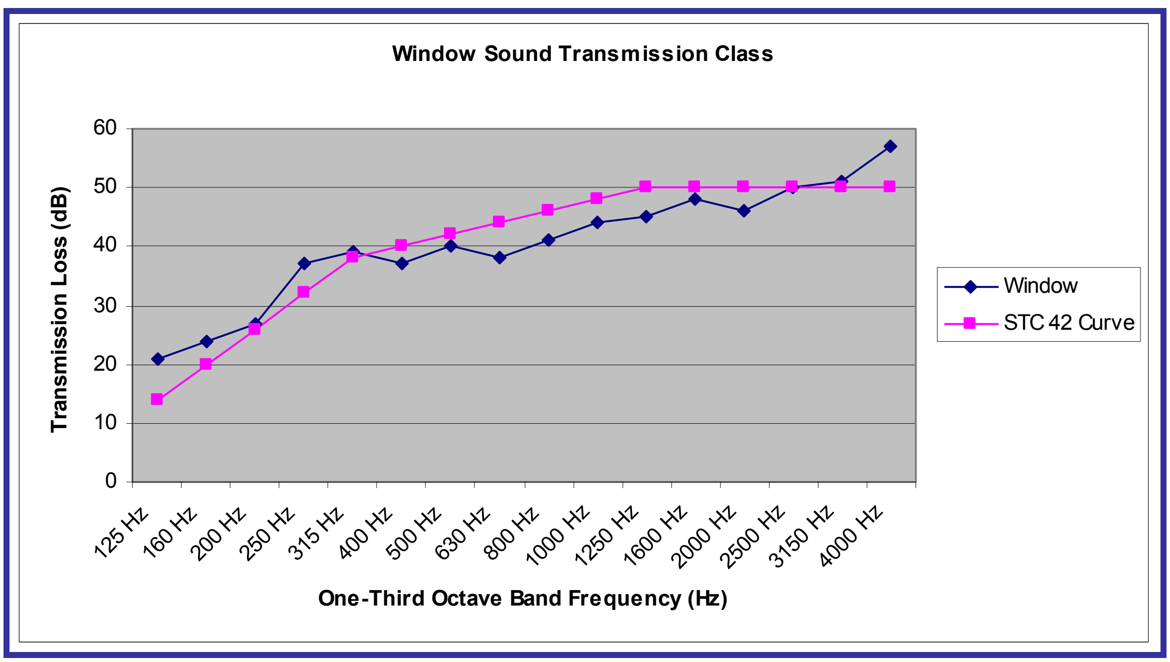

Figure 3.7 - Window STC Curve

Figure 3.8 shows the STC curve for the exterior wall assembly. The wall system has an STC rating of 53, which exceeds the required rating of 50.

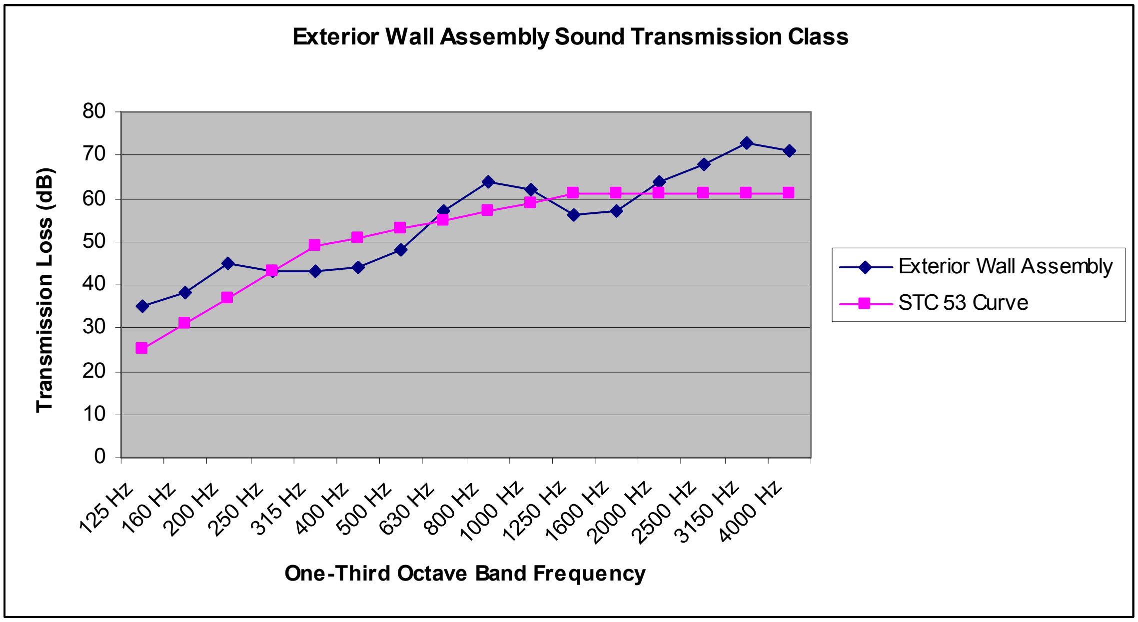

Figure 3.8 - Exterior Wall Assembly STC Curve

Reverberations

Classrooms are generally noisy places and modern elementary education methods often require students to be more active than in past decades. The combination of excessive noise and too many reflective surfaces can result in undesirable reverberation times. Long reverberation times are the most common acoustical problem in classrooms. Ideally, a classroom's reverberation time should be between 0.30 – 0.60 seconds[27].

Reverberation times can be calculated using the Sabine Equation. The variables are the volume of the room, the areas of different surface materials, and the absorption coefficients of these materials. The absorption coefficient is a measure of how much of the energy of a sound wave a material will absorb. The equation is:

$$T(60) = 0.05 \times \frac{V}{a} = 0.05 \times \frac{V}{\sum Sa}.$$

The reverberation time in a typical classroom was calculated based on the current design. The analysis was performed for an unoccupied classroom, since this is the worst case

[27] Long, M. *Architectural Acoustics.* Burlington, MA: Elsevier Academic Press, 2006.

scenario. The calculation can be seen in Table 3.6. The carpet is heavy weight on concrete. The concrete block is 8" painted block and the areas of the side walls do not include the area of any subtracted doors or windows.

Table 3.6 - Unoccupied Classroom Reverberation Calculation

Reverberation Time Calculation for Classroom, Unoccupied										
Surface	**Material**	**Area (sf)**	**Absorption Coefficient**				**Sα**			
			500 Hz	**1000 Hz**	**2000 Hz**	**4000 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
Floor	Carpet	960	0.14	0.37	0.6	0.65	134.4	355.2	576	624
Front Wall	Concrete Block	288	0.06	0.07	0.09	0.08	17.28	20.16	25.92	23.04
Back Wall	Concrete Block	288	0.06	0.07	0.09	0.08	17.28	20.16	25.92	23.04
Side Wall	Concrete Block	174	0.06	0.07	0.09	0.08	10.44	12.18	15.66	13.92
Side Wall	Concrete Block	226	0.06	0.07	0.09	0.08	13.56	15.82	20.34	18.08
Door	Hollow Metal	28	0.05	0.04	0.04	0.04	1.4	1.12	1.12	1.12
Windows	Glass	112	0.18	0.12	0.07	0.04	20.16	13.44	7.84	4.48
Ceiling Tile	**Armstrong Tegular Fine Fissured**	864	**0.5**	**0.7**	**0.6**	**0.4**	**432**	**604.8**	**518.4**	**345.6**
Lights	Lithonia RT5	96	0.03	0.03	0.02	0.02	2.88	2.88	1.92	1.92
Volume: 8,640 ft³						a=∑Sα	649.4	1045.76	1193.12	1055.2
		T(60) = .05(V/a)=.05(V / ∑Sα) (seconds)					**0.66523**	**0.4131**	**0.36208**	**0.4094**

As can be seen in Table 3.6, the current design is out of range at 500 Hz for the criteria which requires the reverberation time to be less than 0.60 seconds in a classroom smaller than 10,000 ft³.

Reflections

Another significant cause of echoes is rooms with parallel, reflective wall surfaces. The floor and ceiling in a typical classroom at Walker Jones are not susceptible to echoes due to the carpet and ceiling tile; however, the four classroom walls are of concern. There is currently nothing in the design to improve echoes from reflections off the wall surfaces.

Mechanical Equipment Noises

Mechanical equipment noise can be one of the greatest sources of unwanted noise in a quiet classroom setting. Measuring the mechanical noise in an un-built classroom is difficult; however, there are certain standards that should be met. In the case of Walker Jones, mechanical equipment noise was dealt with during the design process by using good design practices.

Large mechanical equipment is located on the roof, away from critical listening spaces such as classrooms. Air handlers are positioned over the gymnasium and cafeteria, or where that is not possible, the AHU's are placed above corridors rather than classroom spaces. All VAV terminals are specified for maximum NC of 30 to avoid noisy equipment. Where this requirement is not met, there are sound attenuators at the VAV terminal discharge to reduce the NC to 30 or lower. Air devices are all between NC 20 to NC 25. Because multiple air devices have a cumulative sound influence, the more devices that are used, the quieter each device must be. Air devices do not have opposed blade dampers (OBD) for balancing. The use of OBD's at the neck of a device creates a noise condition that is difficult to modify, so instead, Walker Jones is designed to use balance dampers in the ductwork as close to the branch duct as possible. This keeps the balance dampers as far from the air device as possible, and creates significantly less noise.

Ductwork, if not sized properly or arranged correctly can cause distracting noise, so all low pressure ductwork between the VAV terminal and the supply air devices is specified to be lined with fiberglass liner to reduce sound transmission. Some agencies have concerns with fiberglass liner; however, the liner specified for Walker Jones is an Environmental Protection Agency approved anti-microbial lining to resist the growth of bacteria and fungi. Additionally, special precautions are taken with ductwork that runs from low pressure duct to the air devices. Flexible ductwork is used on Walker Jones because of its excellent sound reduction qualities. Flex duct length is limited to five foot lengths to reduce excess noise. Finally, at the air handling unit level, there are sound attenuators specified to mitigate sound at the source and reduce noise before it reaches occupied spaces.

Suggested Improvements

In the current design for Walker Jones, there are only two areas of acoustical concern. The first area is where there are CMU interior walls. The interior CMU walls provide an STC rating of only 49 rather than the suggested 50. Switching the wall assembly is not an option because the CMU walls act as shear walls. Similarly, adding materials to the outside of the wall is not possible because the CMU walls are used in high traffic areas for their durability. The best solution would be to use sand or mortar to fill the cells of the blocks; however, it is probably not worth the time and cost impact since there is no perceivable difference from an STC rating of 49 to one of 50.

The area that is of the most concern, and is in need of improvement is the reverberation time in a typical classroom at a frequency of 500 Hz. A reverberation time of 0.66523 is not acceptable and can interfere with speech intelligibility in a small classroom. To improve this condition, a more absorbent ceiling tile should be specified. It is possible to use the same manufacturer's product with a higher noise reduction coefficient (NRC). The selected ceiling tile is Armstrong's *Ultima*, which provides an NRC of 0.70 which is much higher than the current design, Armstrong's Tegular with an NRC of 0.55[28]. In addition to switching the ceiling tile, acoustical wall panels can also lower the reverberation time and help prevent echoes. Acoustical wall panels can be seen in Figure 3.9 as applied to an educational setting. These panels, in combination with the cubbies which are currently located along one wall should be sufficient to prevent unwanted echoes.

Figure 3.9 - School with Acoustical Wall Panels

The calculations for the improved conditions can be seen in Table 3.7.

Another possible area for improvement is the mechanical system. Many sound consultants recommend locating the VAV terminals outside classroom to reduce sound. While this is a nice idea, it is typically not practical to locate the VAV terminals in the corridors as there is not enough room to accommodate the main ductwork as well as the VAV's. In the case of Walker Jones, this technique was not used. It would require a redesign of the entire mechanical system, but it is an idea which may be worth further looking into.

[28] Armstrong Commercial Ceilings. "Ultima." Accessed March 11, 2009 <http://www.armstrong.com/commceilingsna/ceiling_family_detail.jsp?productLineId=47&typeId=1>

Table 3.7 - Reverberation Calculation with Improved Conditions

Reverberation Time Calculation for Classroom, Unoccupied with Improvements										
Surface	Material	Area (sf)	Absorption Coefficient				Sα			
			500 Hz	1000 Hz	2000 Hz	4000 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Floor	Carpet	960	0.14	0.37	0.6	0.65	134.4	355.2	576	624
Front Wall	Concrete Block	288	0.06	0.07	0.09	0.08	17.28	20.16	25.92	23.04
Back Wall	Concrete Block	288	0.06	0.07	0.09	0.08	17.28	20.16	25.92	23.04
Side Wall	Concrete Block	174	0.06	0.07	0.09	0.08	10.44	12.18	15.66	13.92
Side Wall	Concrete Block	226	0.06	0.07	0.09	0.08	13.56	15.82	20.34	18.08
Acoustical Wall Panels	**Fabric Wrapped Sound Panels**	**50**	**0.8**	**1.11**	**1.14**	**1.14**	40	55.5	57	57
Door	Hollow Metal	28	0.05	0.04	0.04	0.04	1.4	1.12	1.12	1.12
Windows	Glass	112	0.18	0.12	0.07	0.04	20.16	13.44	7.84	4.48
Ceiling Tile	**Armstrong Ultima**	864	**0.6**	**0.85**	**0.75**	**0.6**	518.4	734.4	648	518.4
Lights	Lithonia RT5	96	0.03	0.03	0.02	0.02	2.88	2.88	1.92	1.92
						a=∑Sα	775.8	1230.86	1379.72	1285
	Volume: 8,640 ft³	T(60) = .05(V/a)=.05(V / ∑Sα) (seconds)					**0.55684**	**0.35097**	**0.31311**	**0.33619**

Table 3.8 shows the reverberation time with only the change in the acoustical ceiling tile. Changing the ceiling tile to a more absorptive panel lowers the reverberation time at 500 Hz from 0.665 seconds to 0.587 seconds, which is within the acceptable range.

Table 3.8 - Reverberation Calculation with Suggested Ceiling Tile

Reverberation Time Calculation for Classroom, Unoccupied with Suggested Ceiling Tile										
Surface	Material	Area (sf)	Absorption Coefficient				Sα			
			500 Hz	1000 Hz	2000 Hz	4000 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Floor	Carpet	960	0.14	0.37	0.6	0.65	134.4	355.2	576	624
Front Wall	Concrete Block	288	0.06	0.07	0.09	0.08	17.28	20.16	25.92	23.04
Back Wall	Concrete Block	288	0.06	0.07	0.09	0.08	17.28	20.16	25.92	23.04
Side Wall	Concrete Block	174	0.06	0.07	0.09	0.08	10.44	12.18	15.66	13.92
Side Wall	Concrete Block	226	0.06	0.07	0.09	0.08	13.56	15.82	20.34	18.08
Door	Hollow Metal	28	0.05	0.04	0.04	0.04	1.4	1.12	1.12	1.12
Windows	Glass	112	0.18	0.12	0.07	0.04	20.16	13.44	7.84	4.48
Ceiling Tile	**Armstrong Ultima**	864	**0.6**	**0.85**	**0.75**	**0.6**	518.4	734.4	648	518.4
Lights	Lithonia RT5	96	0.03	0.03	0.02	0.02	2.88	2.88	1.92	1.92
						a=∑Sα	735.8	1175.36	1322.72	1228
	Volume: 8,640 ft³	T(60) = .05(V/a)=.05(V / ∑Sα) (seconds)					**0.58712**	**0.36755**	**0.3266**	**0.35179**

Cost Comparison

The only change that is necessary to make is the switch in the acoustical ceiling tile. If acoustical wall panels are also installed, an additional cost would be incurred. A cost comparison can be seen in Table 3.9. For $35,242 or $0.29 per square foot, the suggested improvement in the acoustical ceiling tile is a beneficial investment.

Table 3.9 - Cost Comparison

Additional Cost Associated with Acoustical Improvements				
Material	Number of Classrooms	SF per Classroom	Cost Per SF	Total Cost
Acoustical Wall Panels	41	80	$18.00	$59,040.00
Suggested Acoustical Ceiling Tile	41	864	$5.00	$177,120.00
Existing Acoustical Ceiling Tile	41	864	$4.00	$141,696.00
	Difference For Suggested ACT			**$35,424.00**
	Difference For Wall Panels			**$59,040.00**

Schedule Comparison

The required modification to the acoustical ceiling tiles would not cause any change in the schedule. Because they are both products of Armstrong, they have similar installation procedures and require no additional time.

Conclusion

As designed, the classroom acoustics are acceptable, but there is room for improvement. The wall panels in the classrooms are probably an unnecessary addition, and they would add both cost and time to the project. The switch in ceiling tiles from the Armstrong Tegular Fine Fissured to the Armstrong Ultima is a worthwhile investment, adding only $35,424 and no time to the schedule. Additionally, this change will qualify the project to apply for the LEED Indoor Environmental Quality Credit 9: Enhanced Acoustical Performance. This credit requires that classrooms be designed to meet ANSI Standard S12.60-2002, meet STC requirements of 50 (except windows, which must meet an STC rating of at least 35), and achieve an NC rating of 32 in core learning spaces. As outlined above, the design will meet both the ANSI Standard and satisfy the STC requirements as well as achieve an NC rating of 30.

Conclusion

By building Walker Jones, the District of Columbia is seeking to create a high quality educational environment that promotes the health and well-being of students and staff. A new, sustainable school has the potential to revive the surrounding community, improve the learning environment, and the capability to teach students crucial life lessons concerning the importance of a sustainable lifestyle. To determine the greatest benefits and opportunities for improvement of sustainable schools, an analysis was performed on existing LEED certified schools. In addition, natural light and classroom acoustics were taken into account in an attempt to improve the learning environment in Walker Jones classrooms.

In LEED Certification Costs and Benefits, it was determined that the added cost to Walker Jones due to LEED certification is $7.41 per SF. Over half of this cost is due to the addition of a green roof which helps to achieve several LEED credits and can be a valuable learning tool for students. The greatest benefits of a LEED school, according to 36 teachers at existing LEED certified schools, are: an improved learning environment, increase in productivity and happiness of occupants, and an improved image in the school community. It was found that there is no correlation between a sustainably designed school and student test scores. The opportunities for improvement in LEED certified schools involve educating teachers and staff and incorporating sustainability, with the building as a tool, into daily lesson plans.

According to the survey, the greatest perceived benefit of sustainable design is natural light in classrooms and an opportunity for improvement is classroom acoustics. Because of this, the next two analyses involve the current lighting and acoustical designs of Walker Jones classrooms. It was found that the current design is unsuitable for daylighting; however, after adding extra window area, the classrooms at Walker Jones can be suitable for daylighting. On/off switches are recommended to maximize energy cost savings and to help teach students the importance of energy conservation. In addition to this analysis, an acoustical analysis was performed to ensure that the current design is suitable for a sustainable classroom. While the existing design is acceptable, improving the quality of the ceiling tile can greatly improve the sound quality in a typical classroom and avoid future acoustical complications. The additional upfront cost of the suggested lighting design is $24,000 or $0.20 per SF with a payback period of just over six years. The acoustical improvements cost an additional $35,000, or $0.29 per SF. The additional cost associated with enabling daylighting and improving classroom acoustics are low enough that the value added outweighs the upfront cost. No price can be put on an exceptional learning environment, and with careful consideration during the design process, a high cost does not have to be associated with sustainable design.

Resources

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Appendix A: Teacher Survey

Senior Thesis Critical Industry Issue Research Survey

Benefits of Green Schools

This survey was created for the sole purpose of Maria Piergallini's senior thesis research. All responses will be kept confidential and any results or conclusions from this survey are for academic research purposes only. Participant name and contact information are optional, and will only be used if Maria needs to contact the individual for more questions or clarifications. If you wish to remain anonymous, please fill out the remainder of the survey for research purposes. Thank you in advance to all participants.

1. Name:
2. Email:
3. May Maria contact you with further questions? Y N
4. Your Position:
5. Approximately how many years have you been teaching?
6. Have you taught at a school that was not sustainably designed? Y N

If you answered "Yes" to # 6, please complete the following section. If not, please skip to # 13.

Have you noticed an improvement in the following areas since moving to your current school?

7. Student performance? Y N
8. Student test scores? Y N
9. Student productivity? Y N
10. Student attendance? Y N
11. Learning Environment? Y N
12. Your productivity? Y N

13. Do you think a sustainable school improves the school's image in the community? Y N
14. Are you happier working at a sustainable school than at one that is not? Y N
15. Are you more likely to stay at your current school because it is sustainable? Y N N

16. Do you incorporate sustainability into your lesson plans? Y N
17. If so, do you use the building as a tool? How?

18. What do you think is the most beneficial "green" design aspect of the school (examples: daylighting, water conservation, energy efficiency, indoor air quality, green roof, or any other item you like)?

19. Are there any "green" aspects of the school that you feel are wasted or not used to their fullest potential? If so, what?

Please share any additional information or comments concerning the benefits of green schools below:

Thank you for participating in this survey. Please send the completed survey as an email attachment to:
mkp5000@psu.edu.
Confidential results will be made available in April through Maria Piergallini's Penn State Architectural Engineering Senior Thesis E-Portfolio at http://www.engr.psu.edu/ae/thesis/portfolios/2009/mkp5000/. Please contact Maria with any inquiries or information at mkp5000@psu.edu/

Appendix B: Lighting Specifications

![LITHONIA LIGHTING]

Catalog Number	
Notes	Type

FEATURES & SPECIFICATIONS

INTENDED USE

Low-profile static luminaire provides general illumination for recessed applications; ideal for restricted plenum spaces.

ATTRIBUTES

Designed exclusively for use with T8 lamps, electronic ballasts and sockets.

CONSTRUCTION

Smooth hemmed sides and smooth, inward formed end flanges for safe handling. Lighter weight fixture allows for safe, easy installation.

Standard steel door frame has superior structural integrity with premium extruded appearance and precision flush mitered corners. Steel door allows easy lens replacement without frame disassembly (for lenses up to .156" think). Powder painted, steel latches provide easy, secure door closure.

Superior mechanical light seal requires no foam gasketing. Integral T-bar clips secure fixture to T-bar system. Housing formed from cold-rolled steel. Acrylic shielding material 100% UV stabilized. No asbestos is used in this product.

FINISH

Five-stage iron-phosphate pretreatment ensures superior paint adhesion and rust resistance. Painted parts finished with high-gloss, baked white enamel.

ELECTRICAL SYSTEM

Standard ballast is electronic, thermally protected, resetting, Class P, HPF, non-PCB, UL Listed, CSA certified ballast, universal voltage and sound rated A.

Luminaire is suitable for damp locations. AWM, TFN or THHN wire used throughout, rated for required temperatures.

LISTING

Standard: UL. Optional: Canada — CSA or cUL; Mexico — NOM.

WARRANTY

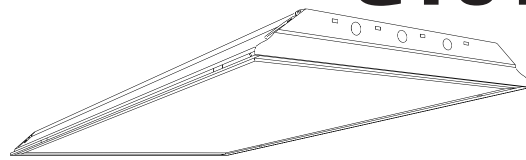
Guaranteed for one year against mechanical defects in manufacture.

US patents: 6,210,025; 6,231,213; 2,288,471.

Specifications subject to change without notice.

General Purpose T8 Troffer

GT8 2'x4'



2, 3 or 4 Lamps

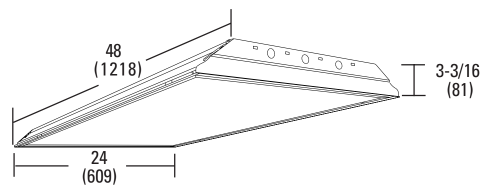
Specifications

Length: 48 (1218)

Width: 24 (609)

Depth: 3-3/16 (81)

Weight: 22 lbs (9.9 kg)



All dimensions are inches (millimeters).

ORDERING INFORMATION

For shortest lead times, configure product using **standard options (shown in bold).**

Example: 2GT8 4 32 A12 MVOLT 1/4 GEB10IS

2GT8 ___ ___ ___ ___ ___ ___ ___

Series

2GT8 2' wide

Trim type

(blank) **Grid**

F Overlapping flanged

Number of lamps

2

3

4

Not included.

Lamp type

32 32W T8 (48")

Door frame

(blank) **Flush steel, white**

FN Flush aluminum, natural

FM Flush aluminum, matte black

FW Flush aluminum, white

RN Regressed aluminum, natural

RM Regressed aluminum, matte black

RW Regressed aluminum, white

Diffuser type

A12 #12 pattern acrylic

A12125 #12 pattern acrylic, .125" thick

A19 #19 pattern acrylic, .156" thick

A15 #15 pattern acrylic, .2" thick

PC1S 1/2" x 1/2" x 1/2" plastic cube louver, silver

PC2S 1-1/2" x 1-1/2" x 1" plastic cube louver, silver w/ flange[1]

PC3S 3/4" x 3/4" x 1/2" plastic cube louver, silver

Voltage

120

277

347

MVOLT

Others available.

Options[2]

1/4 One 4-lamp ballast

1/3 One 3-lamp ballast

GEB10IS Electronic ballast, ≤10% THD, instant start

GEB10RS Electronic ballast, ≤10% THD, rapid start

EL Emergency battery pack (nominal 300 lumens

EL14 Emergency battery pack (nominal 1400 lumens)

GLR Internal fast-blow fuse

GMF Internal slow-blow fuse

LST Tandem-wired fixture pairs (shared ballasts)

PWS1836 6' prewire, 3/8" dia., 18-gauge, 1 circuit

LP_ Lamped, specify lamp type and color

LP735 Lamped; 700-series, 3500K

LP741 Lamped; 700-series, 4100K

JP Palletized and stretch-wrapped without individual cartons; grid trim

CSA CSA Certified

NOM NOM Certified

NOTES:

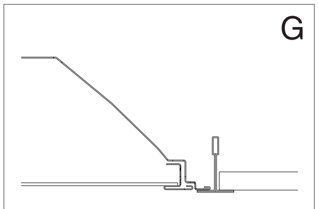
1 Available with flush door frames only.

2 MVOLT standard for 120-277V applications, 50-60 hz operation. Some options require voltage specified.

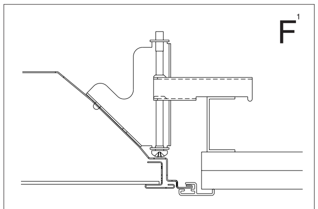
GT8 2'x4' Static T8 Troffer

MOUNTING DATA

Continuous row mounting of flanged units requires CRE and CRM trim options (see Options).



Lay-in Grid
(exposed or concealed grid)

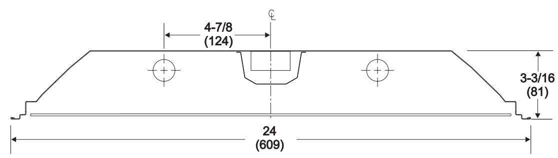


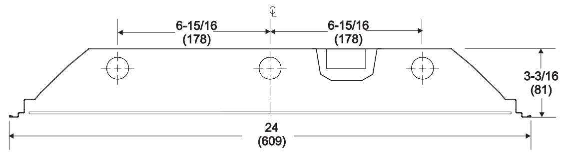
Overlapping Flanged Trim
with swing-gate hangers

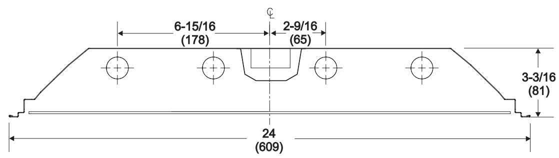
NOTE:

1 Recommended rough-in dimensions for F-trim fixtures 24"x48" (Tolerance is +1/4"-0"). Swing-gate range 1-3/16" to 3-15/16". Swing-gate span 23-3/8" to 26-11/16". Fixture swing-gate points require additional 1-1/16" over nominal fixture height.

DIMENSIONS







PHOTOMETRICS

Calculated using the zonal cavity method in accordance with IESNA LM41 procedure. Floor reflectances are 20%.
Lamp configurations shown are typical. Full photometric data on these and other configurations available upon request.

2GT8 2 32 A12

Report LTL 7424
Lumens per lamp - 2850 – Lum. eff. - 81.7%
S/MH (along) 1.2 (across) 1.4
Coefficient of Utilization

Ceiling	80%			70%			50%		
Wall	70%	50%	30%	70%	50%	30%	50%	30%	10%
0	97	97	97	95	95	95	91	91	91
1	89	86	82	87	84	81	80	78	76
2	82	75	70	80	74	69	71	67	63
3	75	67	60	73	65	59	63	58	54
4	69	59	52	67	58	52	56	51	46
5	63	53	46	62	52	46	51	45	40
6	59	48	41	47	47	40	46	40	35
7	54	44	37	53	43	36	42	36	31
8	51	40	33	49	39	33	38	32	28
9	47	37	30	46	36	30	35	29	25
10	44	34	27	43	33	27	32	27	23

Zonal Lumens Summary

Zone	Lumens	%Lamp	%Fixture
0-30	1372	24.1	29.4
0-40	2277	39.9	48.9
0-60	3907	68.5	83.9
0-90	4658	81.7	100.0
90-180	0	0	0
0-180	4658	81.7	100.0

2GT8 3 32 A12 1/3

Report LTL 7421
Lumens per lamp - 2850 – Lum. eff. - 80.1%
S/MH (along) 1.2 (across) 1.4
Coefficient of Utilization

Ceiling	80%			70%			50%		
Wall	70%	50%	30%	70%	50%	30%	50%	30%	10%
0	95	95	95	93	93	93	89	89	89
1	88	84	81	85	82	79	79	76	74
2	80	74	69	78	72	68	70	66	62
3	74	66	59	72	64	58	62	57	53
4	68	58	52	66	57	51	55	50	46
5	62	52	45	61	52	45	50	44	40
6	58	47	40	56	47	40	45	39	35
7	54	43	36	52	42	36	41	35	31
8	50	39	33	49	39	32	38	32	28
9	47	36	30	45	36	29	35	29	25
10	44	33	27	43	33	27	32	27	23

Zonal Lumens Summary

Zone	Lumens	%Lamp	%Fixture
0-30	2066	24.2	30.2
0-40	3412	39.9	49.8
0-60	5768	67.5	84.2
0-90	6851	80.1	100.0
90-180	0	0	0
0-180	6851	80.1	100.0

2GT8 4 32 A12 1/4

Report LTL 7425
Lumens per lamp - 2850 – Lum. eff. - 78.6%
S/MH (along) 1.2 (across) 1.4
Coefficient of Utilization

Ceiling	80%			70%			50%		
Wall	70%	50%	30%	70%	50%	30%	50%	30%	10%
0	94	94	94	91	91	91	87	87	87
1	86	82	79	84	81	78	77	75	73
2	79	73	68	77	71	67	68	64	61
3	72	64	58	70	63	57	61	56	52
4	66	57	51	65	56	50	54	49	45
5	61	51	45	60	51	44	49	43	39
6	57	47	40	55	46	39	44	39	34
7	53	42	36	51	42	35	40	35	31
8	49	39	32	48	38	32	37	31	27
9	46	35	29	45	35	29	34	29	25
10	43	33	27	42	32	27	32	26	22

Zonal Lumens Summary

Zone	Lumens	%Lamp	%Fixture
0-30	2718	23.8	30.3
0-40	4481	39.3	50.0
0-60	7553	66.3	84.2
0-90	8965	78.6	100.0
90-180	0	0	0
0-180	8965	78.6	100.0

Energy (Calculated in accordance with NEMA standard LE-5)

LER.FL	ANNUAL ENERGY COST*	LAMP DESCRIPTION	LAMP LUMENS	BALLAST FACTOR	WATTS
73	$3.29	(2) 32WT8	2850	.90	58
70	$3.43	(3) 32WT8	2850	.87	85
73	$3.29	(4) 32WT8	2850	.88	109

* Comparative yearly lighting energy cost per 1000 lumens

LITHONIA LIGHTING®
An Acuity Brands Company

Lithonia Lighting
Fluorescent
One Lithonia Way, Conyers, GA 30012
Phone: 800-858-7763 Fax: 770-929-8789
www.lithonia.com

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DT-300 Series Dual Technology Ceiling Sensors

PROJECT
LOCATION/TYPE

Product Overview

Description

The DT-300 Series Dual Technology Ceiling Sensors combine the benefits of passive infrared (PIR) and ultrasonic technologies to detect occupancy. Sensors have a flat, unobtrusive appearance and provide 360 degrees of coverage.

Operation

Low voltage DT-300 Series sensors utilize a Watt Stopper/Legrand power pack to turn lights on when both PIR and ultrasonic technologies detect occupancy. They can also work with a low voltage switch for manual-on operation. PIR technology senses motion via a change in infrared energy within the controlled area, whereas ultrasonic uses the Doppler Principle and 40KHz high frequency ultrasound. Once lights are on, detection by either technology holds them on. When no occupancy is detected for the length of the time delay, lights turns off. DT-300 Series Sensors can also be set to trigger lights on when either technology or both detect occupancy, or to require both technologies to hold lighting on.

SmartSet™

DT-300 Series Sensors require no adjustment at installation, as SmartSet technology continuously monitors the controlled space to identify usage patterns. Based on these patterns, the unit automatically adjusts time delay and sensitivity settings for optimal performance and energy efficiency. Sensors assigns short delays (as low as five minutes) for times when the space is usually vacant, and longer delays (up to 30 minutes) for busier times.

Application

DT-300 Series Dual Technology Sensors have the flexibility to work in a variety of applications, where one technology alone could cause false triggers. Ideal applications include classrooms, open office spaces, large offices and computer rooms. The DT-300 Series mounting system makes them easy to install in ceiling tiles or to junction boxes, providing the flexibility to be used in a wide range of spaces.

Features

- Advanced control logic based on RISC microcontroller provides:
  - Detection Signature Processing eliminates false triggers and provides immunity to RFI and EMI
  - SmartSet automatically adjusts sensitivity and time delay settings to fit occupant patterns
  - Walk-through mode turns lights off three minutes after the area is initially occupied – ideal for brief visits such as mail delivery
  - Available with built-in light level sensor featuring simple, one-step setup
- Sensors work with low-voltage momentary switches to provide manual control
- Patented ultrasonic diffusion technology spreads coverage to a wider area
- LEDs indicate occupancy detection
- Uses plug terminal wiring system for quick and easy installation
- Eight occupancy logic options provide the ability to customize control to meet application needs
- Available with isolated relay for integration with BAS or HVAC

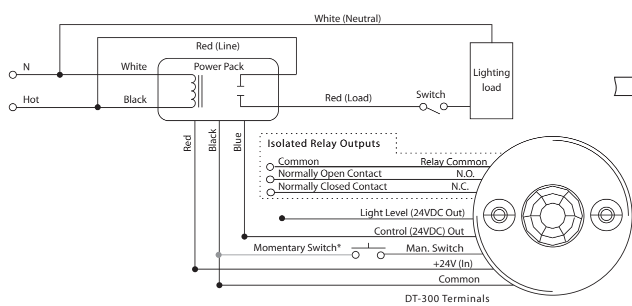
WattStopper | legrand
www.wattstopper.com
800.879.8585

Specifications

- 24 VDC/VAC
- Ultrasonic frequency: 40kHz
- Time delays: SmartSet (automatic), fixed (5, 10, 15, 20, or 30 minutes), Walk-through/Test Modes
- Sensitivity adjustment: SmartSet (automatic); reduced sensitivity (PIR); variable with trim pot (ultrasonic)
- Built-in light level sensor: 10 to 300 footcandles (107.6 to 3,229.2 lux)
- Low-voltage, momentary switch input for manual on or off operation
- DT-300 contains an isolated relay with N/O and N/C outputs; rated for 1 Amp @ 30 VDC/VAC
- Multilevel Fresnel lens provides 360° coverage for superior occupancy detection
- Mounting options: ceiling tile; 4" square junction box with double-gang mud ring
- Max DT-300s per power pack: B=2 , BZ=3
  Max DT-305s per power pack: B=3, BZ=4
- Dimensions: 4.50" diameter x 1.02" deep (114.3mm x 25.9mm)
- UL and CUL listed; five-year warranty

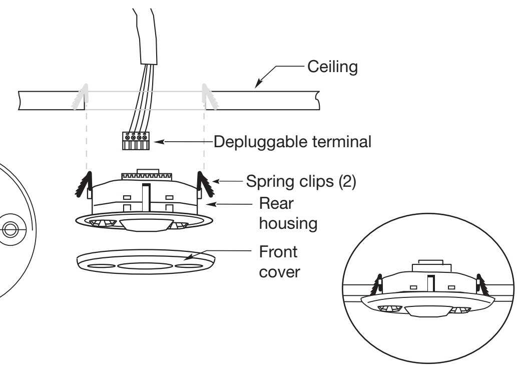
Wiring & Mounting

Wiring Diagram



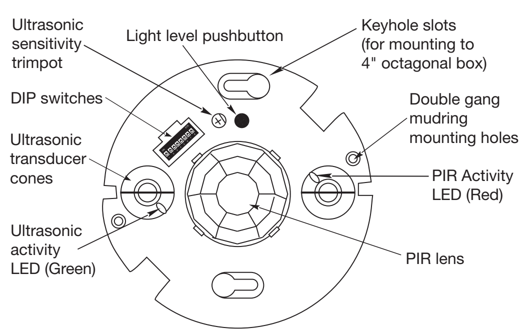
*Momentary switch connection is optional.
Connect only when momentary switch is installed.

Ceiling Mounting



Controls & Settings

Product Controls



DIP Switch Settings

◄ = Factory Setting
● = ON
– = OFF

Occupancy Logic	1	2	3	
Standard	–	–	–	◄
Option 1	●	–	–	
Option 2	–	●	–	
Option 3	●	●	–	
Option 4	–	–	●	
Option 5	●	–	●	
Option 6	–	●	●	
Option 7	●	●	●	

Occupancy Logic – Trigger	Initial Occupancy	Maintain Occupancy	Re-trigger (seconds duration)
Standard	Both	Either	Either(5)
Option 1	Either	Either	Either(5)
Option 2	PIR	Either	Either(5)
Option 3	Both	Both	Both(5)
Option 4	PIR	PIR	PIR(5)
Option 5	Ultra	Ultra	Ultra(5)
Option 6	Man.	Either	Either(30)
Option 7	Man.	Both	Both(30)

Time Delay	4	5	6	
5 sec/SmartSet 🚶	–	–	–	
5 minutes	–	–	●	
10 min. 🚶	–	●	–	
10 minutes	–	●	●	
15 min. 🚶	●	–	–	
15 minutes	●	–	●	
20 minutes	●	●	–	◄
30 min. 🚶	●	●	●	

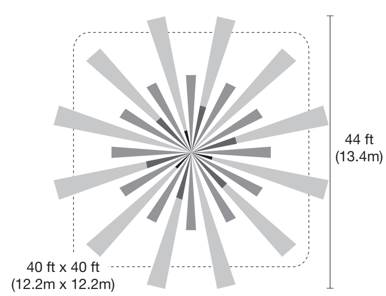
🚶 = walk-through mode

LEDs	7	
Disabled	–	
Enabled	●	◄

PIR Sensitivity	8	
Minimum	–	
Max./SmartSet	●	◄

The technology control (occupancy logic) options are adjustable by user. The standard setting recommended for most applications requires both technologies to trigger on, either to hold on.

Coverage



Coverage shown is maximum and represents half-step walking motion. Under ideal conditions, coverage for half-step walking motion can reach up to 1000 ft^2.

Ordering Information

Catalog No.	Voltage	Current	Coverage	Features
☐ DT-300	24 VDC/VAC	43 mA	up to 1000 ft^2 (92.9 m^2)	Isolated relay, light level
☐ DT-305	24 VDC/VAC	35 mA	up to 1000 ft^2 (92.9 m^2)	

Sensors are white and use Watt Stopper power packs. Current consumption can be slightly higher when only one sensor per power pack is used.

LITHONIA LIGHTING®

Catalog Number	
Notes	Type

FEATURES & SPECIFICATIONS

INTENDED USE

RT5 is designed for applications that require the extremely energy efficient delivery of comfortable volumetric light from a lay-in fixture that is appealing and shallow in depth. Ideal for offices, schools, hospitals, retail and numerous other commercial applications.

OPTICAL SYSTEM

Delivers volumetric lighting by filling the entire volume of space with light, delivering the ideal amount to walls, cubicles, work surfaces and people.

Luminous characteristics are carefully managed at high angles, providing just enough intensity to deliver the volumetric effect.

Regressed, two-piece refractive system obscures and softens the lamp and smoothly washes the reflector with light.

Linear faceted reflector softens and distributes light into the space and minimizes the luminance ratio between the fixture and the ceiling.

Mechanical cut-off across the reflector and fresnel refraction along the refractor provide high angle shielding and a quiet ceiling.

Sloped endplates provide a balanced fixture to ceiling ratio while enhancing the perception of fixture depth.

CONSTRUCTION

Impact modified acrylic prismatic refractor with polymer light-diffusing film.

Rugged, one-piece, cold-rolled steel reflector with embossed facets. Polyester powder paint after fabrication.

Rigid structure with ballast box and endplates with integral T-bar clips.

Fixtures may be mounted end-to-end.

ELECTRICAL SYSTEM

Highly efficient program-start electronic ballasts, Class P, thermally protected, resetting, HPF, non-PCB, UL Listed, CSA Certified, sound rated A. Premium T5 lamp with enhanced phosphors and 85 CRI. Ballast/lamp efficacy up to 100+ LPW. Lamp is TCLP compliant.

0.95 ballast factor standard for typical applications. 1.15 ballast factor or F54T5HO lamping available for higher ceiling height applications.

Bi-level dimming option allows system to be switched to 50% power for compliance with common energy codes while maintaining fixture appearance.

S5 option available for use with SIMPLY5™ Lighting Intelligence system with multi-level dimming. See SYNERGY® Lighting Controls specification sheets for more information.

MAINTENANCE

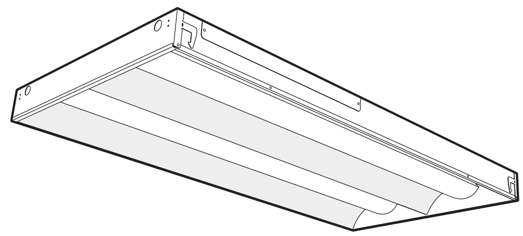
Side mounted ballast tray accessed by removing adjacent ceiling tile. Ballast tray may be removed from fixture during service.

Lamps accessed by squeezing refractor to release from retention tabs.

LISTING

UL Listed (standard). Optional: Canada CSA or cUL. Mexico NOM.

RT5™ VOLUMETRIC RECESSED LIGHTING



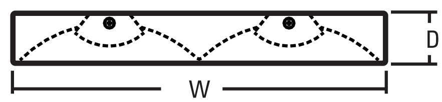
2RT5

2'x 4'
2 Lamps
Premier T5

SIMPLY5™ LIGHTING INTELLIGENCE

Specifications

Length: 48 (1218)
Width: 24 (610)
Depth: 3-1/8 (79)



All dimensions are inches (millimeters) unless otherwise specified.

WARRANTY

Fixture guaranteed for one year against mechanical defects in manufacture. Lamp and ballast system warranty (24 months for lamp, 60 months for ballast) by lamp and ballast manufacturer.

Protected by one or more of US Patents Nos. 7,229,192; D541,467; D541,468; D544,633; D544,634; D544,992; D544,933 and additional patent pending.

Specifications subject to change without notice.

ORDERING INFORMATION

For shortest lead times, configure product using **standard options (shown in bold).**

Example: 2RT5 28T5 MVOLT GEB95 LPM835P

2RT5

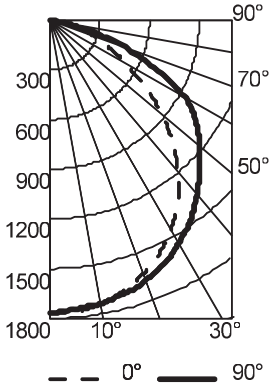
Series	Lamp type	Voltage	Ballast	Lamp[4]	Options
2RT5 Recessed T5	**28T5 28W T5 (46")** 54T5HO 54W T5 (46")[1]	**MVOLT**[2] 347[3]	**GEB95 0.95 ballast factor** **GEB95S 0.95 ballast factor, step dimming** GEB115 1.15 ballast factor GEB115S 1.15 ballast factor, step dimming GEB10PS 1.0 ballast factor, program start S5 0.95 ballast factor SIMPLY5 system[4] S5115 1.15 ballast factor SIMPLY5 system[4] GEB10PS 1.0 ballast factor, program start[1] GEB80 .80 ballast factor[1] GEB80S .80 ballast factor, step dimming[1]	**LPM835P Premier 3500°K 28W lamp** LPM830P Premier 3000°K 28W lamp LPM841P Premier 4100°K 28W lamp LP835 3500°K 54W lamp LP830 3000°K 54W lamp LP841 4100°K 54W lamp	GLR Internal fast-blow fuse[5] PWS1836 6' prewire, 3/8" diameter, 18-gauge, 3-wire (n/a with GEB95S)[6] PWS1846 6' prewire, 3/8" diameter, 18-gauge, 4-wire[7] **EL14 Emergency battery pack**[8] EL65 Emergency battery pack[8] HW Hardwire for S5 system; replaces RELOC® CSA Listed and labeled to comply with Canadian standards QFC_ Quick-flex cable[9] BDP Ballast disconnect plug (meets codes that require in-fixture disconnect)

NOTES:

1. For T5HO applications, use GEB10PS, GEB80 or GEB80S ballast.
2. MVOLT (120-277 volts), 50-60HZ.
3. For 347V, use GEB95S or GEB10PS.
4. SIMPLY5 includes 13' S5 SSC RELOC® wiring system, specify voltage unless HW (hardwire) or PWS is ordered.
5. Must specify voltage, 120 or 277.
6. For use with standard ballast.
7. For use with step dimming ballast.
8. See PS1400QD spec sheet for EL lumen output information.
9. Required. All fixtures shipped with lamps installed.

2RT5 Volumetric Recessed Lighting 2' x 4'

2RT5 28T5 GEB95 LPM835P, (2) FP28/835/PM/ECO lamps, 2730 lumens per lamp, s/m 1.2 (along) 1.3 (across), test no. LTL13260



CP Summary

	0°	90°
0°	1770	1770
5°	1766	1750
15°	1695	1707
25°	1555	1623
35°	1339	1473
45°	1044	1280
55°	695	1071
65°	393	715
75°	179	257
85°	30	21
90°	0	0

Coefficients of Utilization

pf	20%								
pc	80%			70%			50%		
pw	70%	50%	30%	50%	30%	10%	50%	30%	10%
RCR 0	107	107	107	105	105	105	100	100	100
1	98	94	91	92	89	86	88	86	83
2	89	82	76	81	75	70	77	73	69
3	82	72	65	71	64	59	68	63	58
4	75	64	56	63	56	50	61	54	49
5	69	57	49	56	49	43	54	48	43
6	63	52	44	51	43	38	49	42	37
7	59	47	39	46	39	33	45	38	33
8	55	43	35	42	35	30	41	34	30
9	51	39	32	39	32	27	38	31	27
10	48	36	29	36	29	24	35	28	24

Zonal Lumen Summary

Zone	Lumens	% Lamp	% Fix
0° - 30°	1383	25.3	28.
0° - 40°	2264	41.5	46.
0° - 60°	3976	72.8	81.
0° - 90°	4908	89.9	100
90° - 180°	0	0.0	0.(
0° - 180°	4908	89.9	100

Efficiency: 89.9%

LER: 80.4 lpw

*The LER (Luminaire Efficacy Rating) is the lumens per watt rating for this fixture. It is used to compare the energy efficiency of various products. This photometric report is based upon IES testing procedures, as stated in LM-41-1998. The reported lumen rating is based upon lamp manufacturer's published lumen output for the cold spot temperature measured during lamp calibration.

Ballast	Input Wattage 120/277
GEB95 GEB95S	60/58
GEB95S @50% power mode	28/28
GEB115 GEB115S	73/71
GEB115S @50% power mode	35/35
GEB80 GEB80S	96/93
GEB80S @50% power mode	52/51
S5	60/58

T5/T8 Energy Comparison

System	*Lamp Type*	*Ballast Factor*	*Input Watts*	Watts Saved Compared to T8
3-lamp T8	F32T8	0.88	–	–
2RT5 2-lamp T5	F28T5	0.95	58	30
2RT5 2-lamp T5	F28T5	1.15	71	17

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LightSaver® LS-102 Daylighting Controller

PROJECT
LOCATION/TYPE

Product Overview

Description

The LS-102 Daylighting Controller is a single zone, on/off switching device designed to be installed in a closed loop application. A self-contained 24 VDC device with an extended range of 1-1400 footcandles, the LS-102 requires a low voltage power pack to operate. The controller consists of an advanced digital multi-band photosensor, an on-board microcontroller, and an LCD display. This photosensor is positioned behind a 100° cone that cuts off unwanted light, preventing false triggers.

Operation

Setpoints can be selected either automatically or manually. When ambient light levels exceed the off setpoint, the controller turns lighting off. It will turn lighting systems back on when the on setpoint is triggered. Because of its automatic calibration feature, many applications require little or no adjustment of the settings. The LS-102 can be paired with a low voltage wall switch to enable manual override, or with an occupancy sensor to enable its 'Hold On While Occupied' feature.

Automatic Calibration

The LS-102 features automatic setpoint calculations. The device initiates a procedure to select an appropriate value for the on setpoint. As part of the process, the controlled load is first turned on for a brief interval to warm up the lamps, and then switched off. This process is repeated several times. At the completion of the calibration, a new value for the on setpoint will have been selected. Other adjustable settings include deadband and time delay settings. If desired, the deadband can be adjusted to a value of 25, 50, 75, or 100 percent above the setpoint. The time delay can be adjusted to 3, 10, 20 or 30 minutes.

Applications

The LS-102 Daylighting Controller can be used to control any type of lighting: incandescent, fluorescent, compact fluorescent (CFL) and HID . The devices work in peripheral offices, skylit areas, cafeterias, warehouses and any other indoor area with natural light contribution.

Features

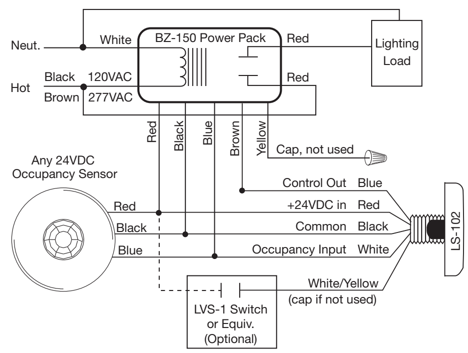
- Easy-to-read LCD display prompts installer through set-up
- Four user-adjustable parameters: on setpoint, off setpoint, off setpoint time delay, and 'Hold On While Occupied' Mode (if wired with an occupancy sensor)
- Test mode overrides programmed time delay, enabling installer to verify accuracy of settings
- Control load status verification allows testing and confirmation that wiring is correct
- Form factor designed to eliminate misalignment
- Meets California Title 24 Section 119 requirements for daylighting
- LED status indicator identifies when device is in override or test mode, or if device has switched lights on or off
- Mounting options for top-lit or side-lit applications
- One-hour manual override capability (when wired with low voltage, pushbutton wall switch)
- Programmable in most daylight conditions

Specifications

- Digital Multi-Band Photosensor Range: 1-1400 footcandles
- ON Setpoint Range: 1-850 footcandles
- Status Indicator: Multi-function green LED
- Power Requirements: 12/24 VDC; 7 mA typical
- Output Signal: 24VDC; maximum 120 mA
- Location: Suitable for dry interior locations
- Environment: 32 to 120°F, less than 90% rh
- Dimensions: 2.4" diameter x 0.7" deep (61mm x 17mm)
- Five-year warranty
- UL listed

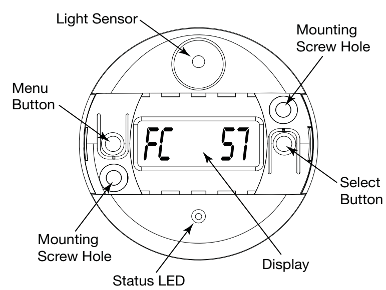
Wiring & Installation Location

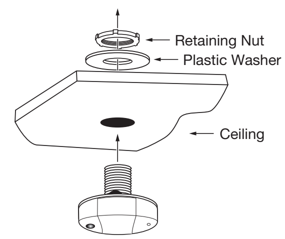
Wiring Diagram



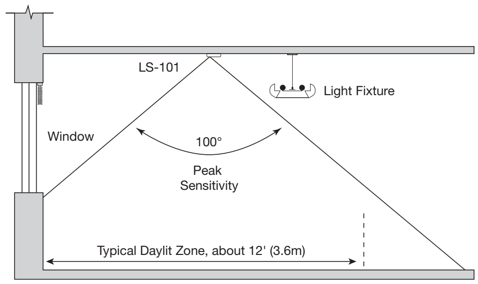
For other wiring diagrams, please visit the CAD Resource Center at www.wattstopper.com

Mounting and LED Display

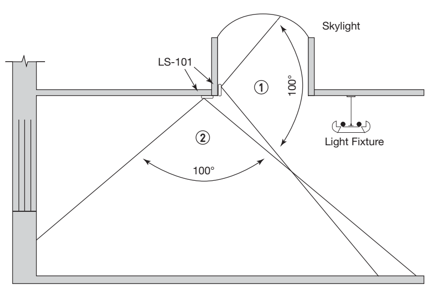




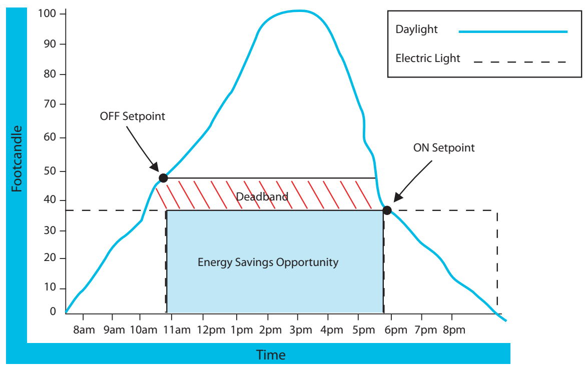
Side Lighting Application



Top Lighting Application



Deadband Level Chart



If the LS-102's photosensor lighting level drops below the on setpoint, the lights will remain on. If the sensor's lighting level rises above the off setpoint, the LS-102 will automatically turn the lights off. If the sensor's lighting level remains in the predetermined deadband range (25%, 50%, 75% or 100%) the lighting will be passive until the sensor's level reaches the high or low setpoints.

Ordering Information

Catalog No.	Voltage	Current	Photosensor Range	Deadband Adjustment Range
☐ LS-102	12/24 VDC	7 mA Typical	1-1400 footcandles	25%, 50%, 75% & 100% above the on setpoint

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