AE SENIOR THESIS

Final Paper
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Construction Management
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Integrated Science Center
College of William & Mary
Williamsburg, Virginia

INTEGRATED SCIENCE CENTER | COLLEGE OF WILLIAM & MARY
WILLIAMSBURG, VIRGINIA

BUILDING STATISTICS

- Building Occupant: Biology, chemistry, and psychology departments
- Size: Expansion - 120,000 GSF
  Renovation - 41,000 GSF
- Number of Stories: 3 stories plus a mechanical penthouse story above grade and one story vivarium below grade
- CM: Gilbane Building Company
- Design Team: Moseley Architects, Payette Architects, SST Planners
- Dates of Construction: January 2006 - March 2009
- Project Cost: $42 million
- Project Delivery Method: Design-Bid-Build for a CM at risk

ARCHITECTURE

- 2 phase project: the addition of the 120,000 s.f. ISC building to existing Roger's Hall followed by the renovation of Roger's Hall
- Both buildings contain classrooms, teaching and research laboratories, and faculty offices
- Vivarium located on ground floor of ISC includes animal holding and testing rooms
- Auditorium at East end of Roger's Hall
- ISC building's appearance and façade designed to match the brick style and color seen throughout campus
- Brick veneer/metal stud exterior walls
- Stimulated slate roofing

STRUCTURAL

- Steel structure provides long spans and column free spaces
- 14" thick concrete perimeter wall continuous around perimeter
- Various sized footings from 4'-0" x 4'-0" to 8'-0"x 8'-0"
- 6" concrete slab-on-grade
- Supported floor system consists of a 5" lightweight concrete slab on 1-1/2" 22 gauge composite deck
- W18x35 and W12x16 are the most typical transfer beams
- Columns vary from W10x33 to W12x65

MEP SYSTEMS

- 4th floor penthouse of the ISC building contains 5 AHUs with up to 40,700 max cfm
- Roger's mechanical room holds 2 AHUs with a max of 29,900 cfm
- Two 480V boilers located in boiler room along with an expansion tank and various heat pump
- Specialized laboratory features including a lab waste neutralization system and lab/acid waste piping
- Different sized fluorescent and HID lamps for various lighting fixtures
- 2000 kVa transformer is located on the ground floor of the ISC building

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2| Acknowledgements

The last five years have been both a challenging and rewarding experience for me. I have learned a lot since my freshman year and I feel a great sense of accomplishment as I wrap up my final year at Penn State and present my final senior thesis project. I could not have made it to this point without the help and support of the following people:

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- Dr. David Riley
- Dr. Michael Horman
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- Professor Moses Ling

Gilbane Building Company

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- Wayne Boy
- Randy Strickland
- Ronald Russell

Industry members from PACE who inspired my research topic

All my family and friends for their love and encouragement especially

- Mom and Dad
- My sisters Kristen and Kaitlyn
- My best friend and roommate of 3 years Samantha D'Agostino

My fellow AE Students

I cannot thank you all enough!

3| Executive Summary

At the PACE Roundtable event last fall, one of the topics discussed was the current energy and economic impacts on construction. There has been increasing interest in incorporating the principles of sustainable design and energy efficiency into building projects. These practices would lead to lower-than-industry-standard operational costs, occupant productivity gain, and they are environmentally beneficial. The following analyses are intended to not only offer reduced operating costs through energy saving opportunities but also to provide a high quality working environment for students and faculty.

The first study focuses on energy conservation through retrofitting. William and Mary's Rogers Hall will be undergoing a major renovation to upgrade its research facilities. This is an idal opportunity to apply retrofitting techniques that would result in reduced energy consumption. In this analysis, the existing lamps were compared to the installation of more energy efficient ones. Initially, the College of William and Mary would have to invest $34,567.30 for the new bulbs and ballasts plus an additional $21,044.13 for their installation. However, changing the bulbs to T8s would conserve 28,245 watts of electricity a year and result in the college saving over $9,000 a year, an annual savings of 34.2% compared to the existing lamps. The new system would not add time to the construction schedule and would pay for itself after 6.15 years.

The second study analyzes the current lighting layout and proposes an alternative design to implement daylighting techniques and reduce electrical costs. Natural light can result in energy and cost savings only if the lights are shut off or dimmed when sufficient illuminance levels are met. Installing light level sensors in the lab spaces would result in lower energy consumptions and costs as well as reduced maintenance (shorter burn hours). When lights are remained on during daylight hours (no sensors) 326,700 W of energy are consumed in the laboratories. If daylight sensors are used, only 245,025 W of electricity is used, a savings of 81,675 W. This is a 25% energy reduction for the lab spaces. After a few assumptions were made, natural light could reduce the annual electricity costs by approximately $1,247.82.

The final analysis investigates the feasibility of reducing cooling loads through the use of window overhangs on the south façade of Rogers Hall. During the daytime, solar radiation through the large windows causes significant heat gains in the smaller office spaces and results in increased cooling loads. By installing a window shading devices, solar heat gains decrease and results in lower cooling loads and increased energy cost savings. The overhang reduced the daily total cooling load by 2249.13 Btu. This is a 9.6% reduction. The overhang also resulted in lowering the peak cooling load. The peak cooling load required dropped from 2308.8 Btu/hr for an office containing a window without a shading device to 1750.4 Btu/hr with a shaded window, a difference of 558.4 Btu/hr.

4| Project Introduction

The College of William and Mary is interested in upgrading its out-of-date chemistry, biology, and psychology departments by replacing buildings over 30 years old with top-of-the-line facilities. This joint project includes the addition of a new, high tech laboratory building as well as the renovation of the existing Rogers and Millington Halls. The entire addition/renovation project is broken into five phases. Phases I and II were bid on together and awarded to Gilbane Construction Company. The remaining three phases (Phases III-V) are still in the schematic design stage.

Phase I includes the addition of the 3 story, 116,500 SF Integrated Science Center. This building has a mechanical penthouse located on the 4th floor and an animal holding area in the basement. Once the new addition is complete, Gilbane will work with the college to transition people and equipment out of the existing building into their new home. Once vacant, the existing buildings will be gutted and renovated. Phase II includes the renovation of the exiting, 2 story, 42,500 SF Rogers Hall only. Careful attention is required to move expensive equipment and hazardous materials, and meet certain academic dates. This $42 million project was started in May 2006 and is targeted to be completed in April 2009.

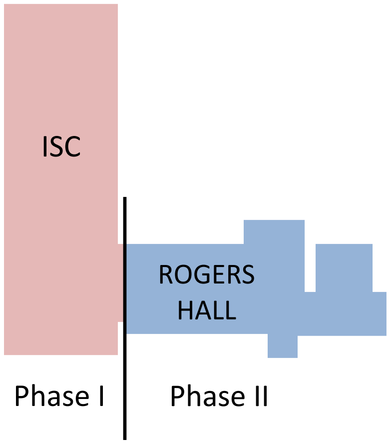


Figure 4.1 – Phase Designations

5| Project Team Overview

5.1 Client Information

College of William and Mary is a public university located in Williamsburg, Virginia. It is the United States second oldest institution of higher education and is one of the eight Public Ivies. To keep its reputation as being a cutting-edge research university, the college has decided to upgrade the outdated departments of Chemistry, Biology, and Psychology. Replacing facilities that are over 30 years old, the addition of the Integrated Science Center and the newly renovated Rogers Hall will include up to date mechanical systems, improved technological capacity and capability, upgraded electrical capacity, and modernization of laboratory spaces and equipment. William and Mary's intent is to become a national leader in research and teaching facilities in these departments.

During the construction process, the owner was represented by the College of William and Mary's Facilities Management Committee. This group, consisting of four members, made most of the decisions regarding the construction of the building and they all attended meetings to deal directly with the construction manager. After talking to Wayne Boy, director of Facilities Planning Design & Construction, the following are concerns or expectations for the Integrated Science Center project.

Owner Expectations and Keys to Success:

- **Cost** – Some of the funding for this project is provided by the Virginia College Building Authority and the rest is paid for by sponsors and the college. The College of William and Mary Board of Trustees sincerely desires to keep the project on budget without sacrificing the end product.

  Keys to Success: No one likes to pay more than they expect. Both the contractor and owner benefit if construction costs are within budget. It is the contractors' responsibility to keep up with the expenditures and budget. This should be updated regularly and the owner should be informed if unexpected changes affect project costs.

- **Quality** – The owner demands a high quality product. By aesthetically appealing and efficient facilities, the college will be able to attract the best faculty and students in these departments.

  Keys to Success: Quality work must be emphasized at all levels of the project staff. It is necessary to stress the importance of quality to workers when they first get on the project. If poor workmanship is allowed, workers may cut cornere and quality could be sacrificed. Gilbane checks daily to make sure the work performed meets the project specifications.

- **Schedule** – The college has requested certain deadlines to be met so as to not interrupt their academic schedule.

  Keys to Success: The academic calendar was taken into consideration when developing the project schedule. To keep the owner satisfied, it is critical to meet as many benchmarks as possible. Gilbane has developed 2-week look-ahead schedules for its contractors so they are fully aware of their expectations.

- **Safety** – Preventing workplace injuries is not only important for the project workers, it is simply good business. Accidents are costly, in both human and financial terms. Furthermore, it is crucial for W&M to keep their students and faculty unharmed.

  Keys to Success: It is inevitable that construction will take place during the school year. Gilbane intends to keep everyone injury and accident free by providing overhead protection where necessary, additional lighting and signs, full and easy access around the site, and fencing for security.

5.2 Project Delivery Method

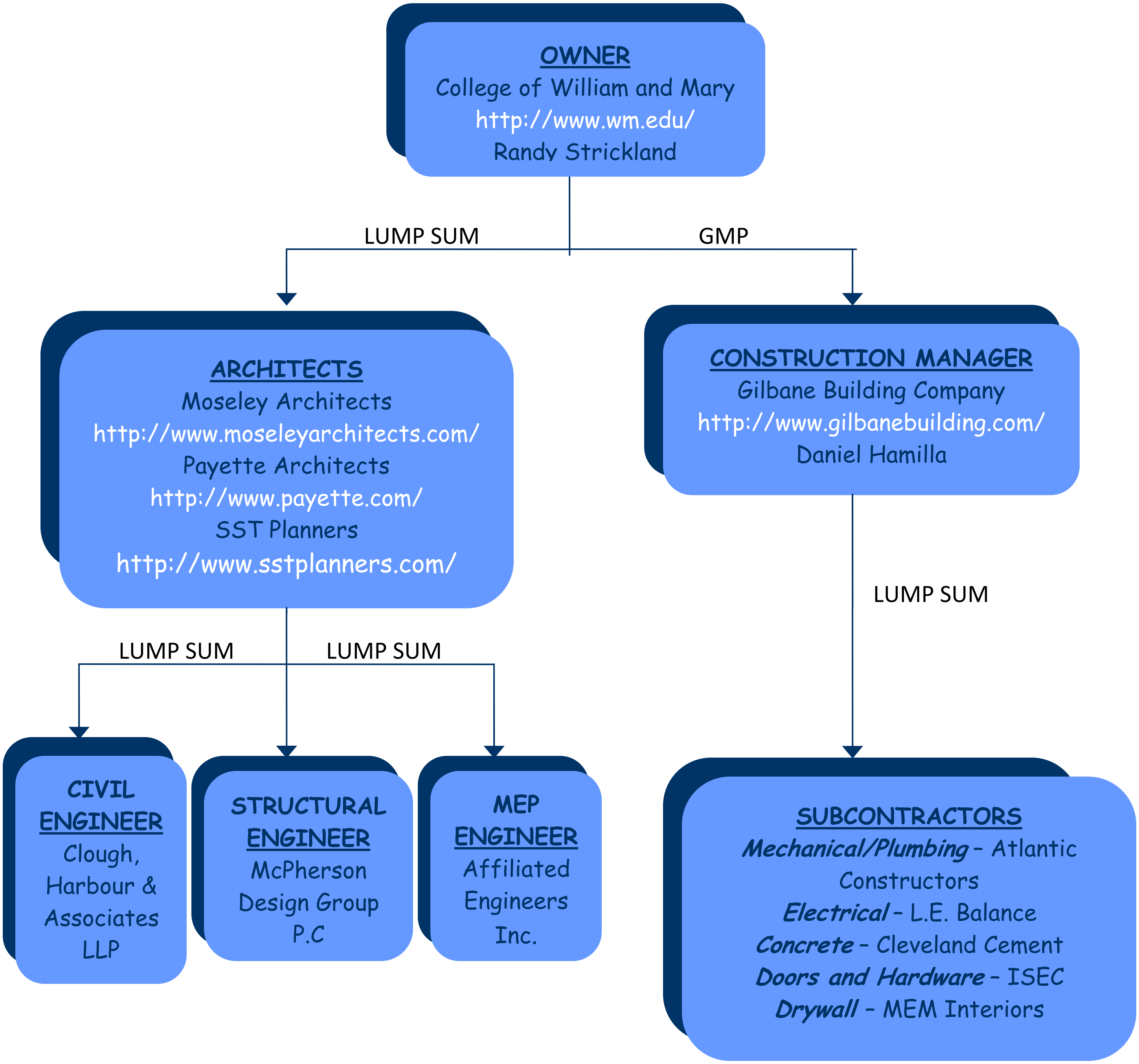
Gilbane Building Company was selected by the College of William and Mary to provide pre-construction and construction management services for their Chemistry/Biology/Psychology project on their campus. Gilbane serves as the construction manager at risk for this project. This assignment was chosen by the owner to enable the construction manager to get involved on the project early and to help alleviate some of the responsibilities and decisions from the W&M project staff. A guaranteed maximum price (GMP) contract was offered by Gilbane, which is a typical contact type for them. The proposal was agreed to by the college. Under this arrangement, the construction manager will be acting in the owner's interest. The contract between the College of William and Mary and Gilbane was a GMP of nearly $42 million and a project schedule duration of 3.5 years.

The lump sum contracts that Gilbane holds with the subcontractors were developed for the individual parties. These contracts specified the list of contract documents, scope of work, work inclusions and exclusions, bid breakdown, unit rates, construction milestones, termination conditions, change order process, bonds and insurance, payment conditions, etc.

Gilbane was awarded this job through a design-bid-build process and was chosen over a select number of other qualified firms. Although this was the first project for Gilbane at the College of William and Mary campus, the original project manager for the job had a prior relationship with one of the W&M team members.

The builder's risk insurance was held by the owner. Gilbane carried general liability, automobile, and worker's compensation insurance. Each subcontractor was to provide general and excess liability insurances, automobile insurance, and worker's compensation insurance. Gilbane also required each subcontractor to have a performance and payment bond.

Figure 5.2.1 - Project Organizational Chart



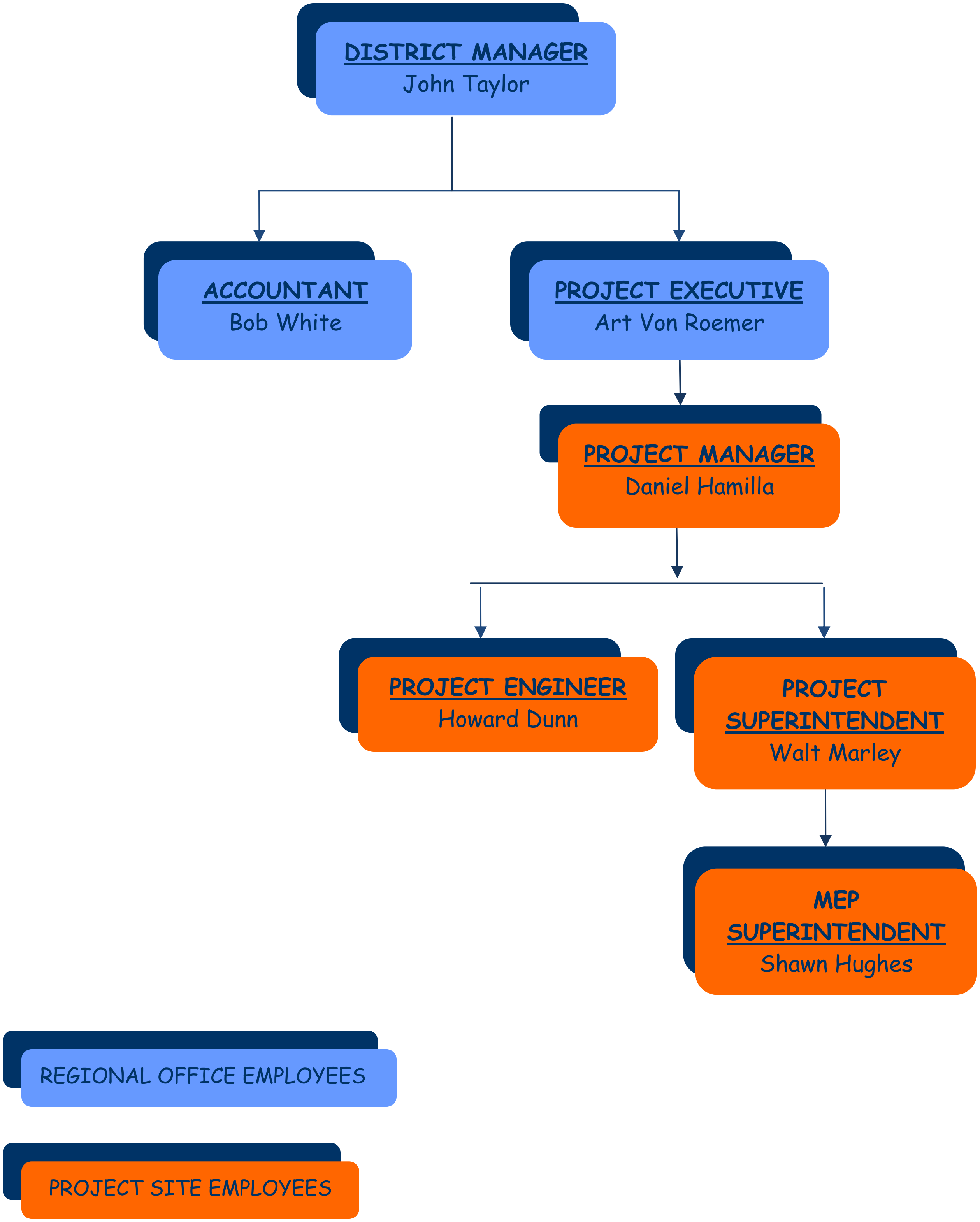
5.3 Project Staffing Plan

Gilbane Building Company was initially hired onto the project early on to act as a consultant to the owner in the development and design phases. Gilbane's preconstruction department provided estimating, purchasing, and budget control services. The preconstruction team consisted of the Richmond district manager, the accountant, and the project executive.

Once the project reached the construction phase, the project executive was head of the construction team. The ISC project executive oversees the construction progress primarily from the Richmond office and reports to the site once every two weeks. The project manager is in charge of the daily activities onsite. He is mainly responsible for the cost reports, owner correspondence, and schedule updating. The project executive and project manager work together with an accountant (in the Richmond office) for cost reporting. There was no assistant project manager assigned to this job so the project engineer stepped up to help the project manager in his responsibilities. The project engineer is also involved with any resource and engineering related activities relating to the project. There were two superintendents who shared duties in the field. They supervise the subcontractor's workers, inspect construction, oversee the MEP coordination, and enforce safety. The full time Integrated Science Center employees included the project manager, project engineer, and the two superintendents.

Gilbane has gone through numerous staffing changes on this project but the organization has remained the same. None of the original Gilbane team members remain on the William & Mary project, but despite the obvious challenges, the company has managed to keep the project under control.

Figure 5.3.1 - Gilbane Organizational Chart



6| Existing Conditions

6.1 Design Overview

Architecture:

This project includes the construction of a new, high-tech laboratory building as well as the renovation of existing spaces. The addition contains research and teaching laboratories, lecture halls, classrooms, instrument rooms, and office spaces. William and Mary's intent is to upgrade the outdated departments of chemistry, biology, and psychology, replacing facilities over 30 years old. The college aims to become a national leader in research and teaching facilities in these departments.

Figure 6.1.1 - Integrated Science Center North Facade

Founded in 1693, the College of William and Mary is the second oldest institution of higher learning. In order to preserve the historic atmosphere, the college has developed a "vision plan" as guidelines for the insertion of new structures. This stresses the importance of preserving the architectural configuration and character of the Old Campus. Therefore, the ISC building's appearance and facade was designed to match the brick style and color seen throughout the campus.

Building Envelope:

The brick exterior wall system is comprised of 6" batt insulation that lines the space between two 5/8" gypsum board. The continuous air and vapor barrier is followed by 2" R-10 rigid insulation. A cavity drainage material is located between the insulation and the flemish bond face brick. Masonry ties fasten the brick to the facade, and continuous flashing with weeps extends 1/8" beyond the face of the brick for proper drainage.

The roof system consists of a metal roof deck followed by 5" of nailable vented R-20 insulation. An ice and water protection underlayment was placed before the stimulated slate roofing.

Figure 6.1.2 - Stimulated Slate Roofing

6.2 Building Systems Summary

The following table and written information summarizes the main building systems in the Integrated Science Center and Rogers Hall buildings. The information describes the key design and construction aspects of the project.

Yes	No	Work Scope
X		Demolition
X		Structural Steel Frame
X		Cast-In-Place Concrete
	X	Precast Concrete
X		Mechanical System
X		Electrical System
X		Masonry
	X	Curtain Wall
X		Support of Excavation

Table 6.2.1 – Building Systems Summary Table

Demolition:

The demolition of interior partitions, ceiling assemblies, casework, and flooring materials in the existing Roger's Hall (except in the auditorium area) is required without jeopardizing the structural integrity of the building. Coordination between demolition work and the new work is necessary for the structural, plumbing, mechanical, and electrical systems. Asbestos was detected in samples of vinyl floor tile, black duct mastic, panels of a laboratory fume hood, white pipe mastic, and corrugated cementitious panels from the rooftop HVAC cooling tower therefore abatement was required before commencing work.

Figure 6.2.1 - Demolition

Structural Steel Frame:

The structural system for the Integrated Science Center consists of structural steel. This steel structure provides the building with long spans and column free spaces. W18x35s and W12x16s are the most typical transfer beams. Column sizes vary from W10x33s to W12x65s. The supported floor system consists of a 5" lightweight concrete slab on a 1-1/2" 22 gauge composite deck. Braced frames and moment resisting connections resist lateral forces on the building.

Figure 6.2.2 - Steel Framing

Cast-In-Place Concrete

Cast in place concrete was used for building footings, foundation walls, slabs-on-grade, suspended slabs, and concrete toppings. All the previously mentioned structures utilized normal weight concrete except for the suspended slabs in which used structural lightweight concrete was poured. The formwork (all horizontal for this project) was fabricated on site using typical wood framing. Undamaged formwork was reuseable once they were cleaned and their surfaces repaired. A concrete pump truck was used for all major pours.

Mechanical System:

A mechanical penthouse is located on the fourth floor of the ISC addition. It contains five (5) AHUs with a max of 40,700 cfm. The existing Roger's Hall has its own mechanical room located on the 1st floor of the east end of the building. The original room was gutted, reconstructed, and new equipment was installed. It contains two (2) AHUs with a max of 29,900 cfm. The constant volume AHUs distribute through galvanized sheet metal duct and supplied to rooms through registers and grilles. Two 480 V boilers are located in the boiler room (ground floor of ISC building) along with an expansion tank and various heat pumps. This specialized laboratory building features a lab waste neutralization system, compressed air system, vacuum piping system and lab/acid waste piping.

Electrical System:

A 2000 kVA transformer (35KV/480V/277V) is located on the ground floor of the ISC building. There are ten (10) dry type transformers (25kVA-300kVA) throughout the building and they are NEMA TP-1 rated. These three phase transformers are 60 Hz with a 480 V delta primary and 208Y/120 V secondary. There is one switchboard rated to withstand fault current of 100,000 amperes. Redundancy is provided by emergency power generation. Emergency/standby power will be supplied by a 1250 kW diesel engine generator. The demand load estimate for this project is 4,253.9 kVA.

Different sized fluorescent, incandescent, and HID lamps are used for various types of lighting fixtures. The majority of the labs, classrooms and offices are illuminated by recessed, ceiling grid mounted, fluorescent lights. Suspended mounted fluorescent lights are used in the bathrooms. The corridors contain wall mounted fixtures and recessed incandescent lighting is located in the lobbies.

Masonry:

This building has brick veneer/metal stud exterior walls. Galvanized steel shelf angles transfers the weight of the masonry back to the structural frame. Masonry ties at 1'-4" O.C. secure the brick veneer to the backup system.

Figure 6.2.3 - Exterior Brick

The brick for the Phase I addition is a Flemish Bond pattern to match the adjacent dorm construction. The brick for the Phase II renovation is also a Flemish Bond pattern to match the existing Roger's Hall. The ISC's ground floor vivarium contains 6" CMU interior partitions.

Figure 6.2.4 - CMU Partitions

Support of Excavation:

Permanent steel sheet piles and tie-back anchors were installed at the interface with the existing structures to facilitate the required excavation of the new addition. This system would potentially eliminate any surcharge loads from the existing building foundations on the basement walls of the new structure. Although the basement elevations are above the current ground levels, it is likely that some soils may transport water during wet seasonal conditions. The basement walls were waterproofed and a geocomposite drainage medium was applied to the outside of the walls. The wall drainage material is connected to a storm sewer system.

Fire Protection:

ISC and Rogers Hall will be equipped with a fire alarm and sprinkler system. Standard Orifice quick response sprinklers will be installed throughout the entire building. This is a wet sprinkler system. Basket guards will be provided on all exposed on all exposed sprinklers in equipment rooms, electrical rooms, and telecom rooms. Wall mounted pull boxes, audible alarms, and strobe lights are located in the corridors and easy to see spaces.

Transportation:

There are two hydraulic passenger elevators in the ISC building. The one located at the north end of the ISC is a 4,500 lb capacity, 4 stop elevator which services the ground through third floors. The south end one is a 3,500 lb capacity, 5 stop elevator which services the ground through fourth floors. The fourth floor is where the penthouse is located. Both cars have a 150 fpm speed capability.

Telecommunication:

There are data/communication outlets located in all the laboratories and classrooms. They are located on the floor, in the casework, or wall mounted. Faculty offices contain wall telephone outlets. Wireless LAN antennas and junction boxes are located in the ceiling for internet connection throughout the building.

6.3 Local Conditions

Williamsburg, Virginia

The project is located on the campus of the College of William and Mary in Williamsburg, Virginia. The following provides information regarding the city of Williamsburg and its surrounding area.

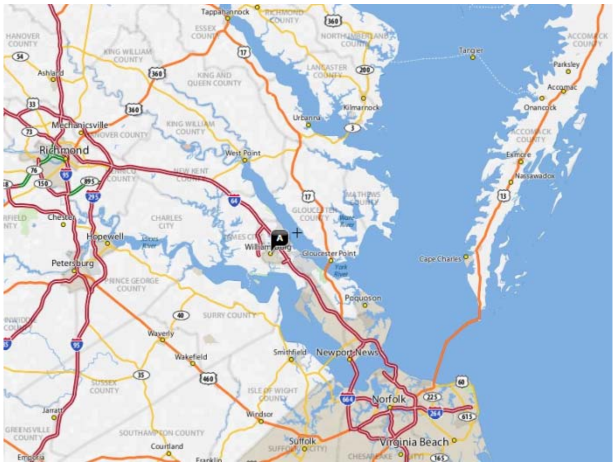


Figure 6.3.1[1] – Road Map of Williamsburg

- **Location** – Williamsburg is located on the I-64 corridor on the Virginia Peninsula, 45 miles southeast of Richmond and 37 miles northwest of Norfolk.

- **Williamsburg's Claim to Fame** – The city is well-known for Colonial Williamsburg, the restored Historic Area of the city, and for the adjacent College of William and Mary. Williamsburg is also part of the Historic Triangle of Virginia, along with Jamestown and Yorktown, which is one of the most popular tourist destinations in the world.

- **Preferred Methods of Construction** – To match the Colonial and Historic Williamsburg areas, most structures are masonry, cast-in-place concrete and light steel.

- **Construction Recycling** – Services are available locally for most materials.

- **Tipping Fee** – In 2008, the tipping fee was $49.95/ton but is expected to rise to $53.95 in 2009 (Solid Waste Management Program Overview)

- **Regional Soil Types** – The regional geology is very complex and generally consists of interbedded layers of varying mixtures of sands, silts, and clays.

Project Site

The subsurface exploration program and geotechnical engineering analyses for this project were performed by Froehling & Robertson Inc. The subsurface exploration program consisted of the installation of one 20-foot deep piezometer and 13 Standard Penetration Test borings that were performed January 31, 2005 through February 3, 2005. The following information regards the existing site conditions.

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[1] Maps from mapquest - mapquest.com

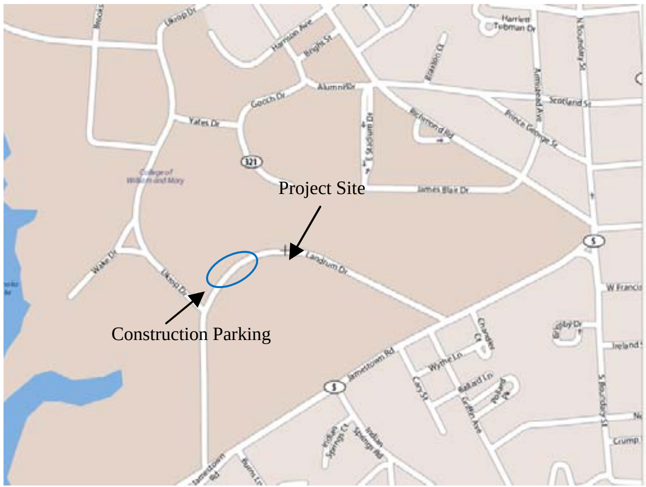

Figure 6.3.2[2] – Site Map of Roads

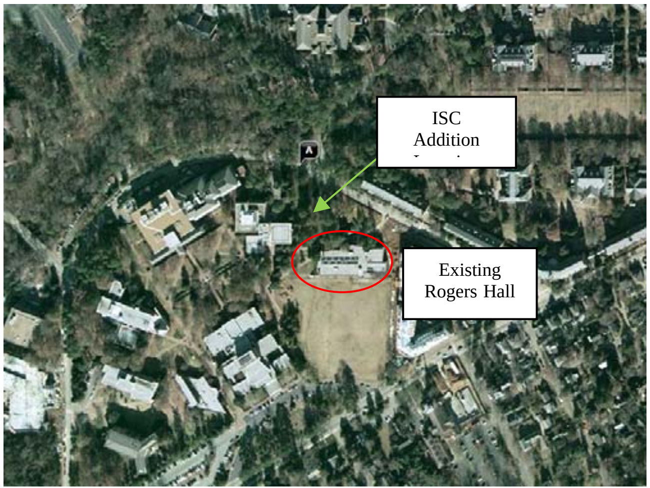

Figure 6.3.3[2] – Arial view of Existing Site

- **General Boundaries** - The site is generally bounded by Landrum Drive to the north, Jamestown Road to the south, Rogers Hall to the east and Millington Hall to the west.

- **Surface Conditions** – The project site was sparsely wooded and contains pedestrian walkways. An existing ravine is present along the north side of the site.

- **Site Soil Types** – The borings showed layers of varying mixtures of sands, silts, and clays.

- **Subsurface Conditions** – Groundwater level was below the bottom of the piezometer at the time of the study. This level was therefore evaluated by visually judging the moisture content of the spilt-spoon samples and determined to be at a depth of 14 feet to 23 feet below existing ground surface. The contractor was prepared to possibly encounter subsurface water if construction extended below the planned basement subgrade elevation.

- **Construction Parking** – Parking near the site was rather limited. Landrum Drive was restricted to W&M students and staff parking only. It was agreed on to close a portion of Landrum road (see figure above) for convenient parking. This closed the current Landrum Drive loop but did not prevent access to any part of campus.

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[2] Maps searched for on google earth - http://earth.google.com/

6.4 Site Plan of Existing Conditions

The site plan on the following page depicts the general conditions and site layout for this project. The ISC addition is bound to the east and west by existing buildings and to the north by Landrum Road. The larger staging areas were located at the north end of the building; therefore, most deliveries were made from Landrum Road. The site was occasionally accessed from the south but was limited in order to preserve the conditions of the nearby soccer field. Landrum Road is a through street but was blocked for contractor trailers and parking. Two mobile cranes were used on this project and their locations are displayed on the site plan. Existing underground utilities are also shown.

6.5 Site Layout Planning

Site plans for the following phases were developed to better visualize the changes in the site as construction progressed. Please refer to **Appendix A** for the excavation, superstructure, and closeout site plans for the College of William and Mary's Integrated Science Center.

Excavation Phase

The excavation plan depicts the site set up during the earliest construction phase of the new building. Excavation moved from the South end of the building to the North end (Area B to Area A). Once necessary, ramps were constructed at both ends. This provided more flexible access around the site in such a limited area. Most of the soil was removed by trucks at the both ends of the proposed building but a small soil storage area was located in the southwest corner.

Figure 6.5.1- Preparation for Excavation

Figure 6.5.2 – Excavation Hole

Figure 6.5.3- Steel Erection Started

Superstructure Phase

The site plan for the superstructure phase of the building shows the location of the crawler cranes, concrete pumps and pump trucks, material staging areas, and a material hoist. The site where the ISC addition is located was rather constricted. The structure is adjoining the existing Rogers Hall to the East and is in close proximity to Millington Hall to the West. Therefore, two crawler cranes were necessary to cover both ends of the building. Floors one through four were erected on in Area B followed by floors one through four in Area A. Steel layout areas were located on both the North and South ends of the building. Delivery and pump trucks had the same site access as the excavation site plan.

Closeout Phase I and Startup Phase II

The final site plan, the Closeout of Phase I and Startup of Phase II, was set up much differently than the two previous phases. The fences were relocated to surround Rogers Hall, which is now the new focus of construction. The Integrated Science Center was partially opened for the 2008 summer school session. All temporary roads and walkways were removed and replaced with new sod. Construction deliveries are now made only from Landrum Rd to the northeast. A small part of the North wall was demolished so equipment had easier access and materials could be removed. Dumpsters were then conveniently located near the opening.

Safety is the number one priority for Gilbane. Each of the above site plans were designed with the intent to keep workers and pedestrians unharmed. During both the excavation and superstructure phases, a large number of deliveries were made to the site. A flag person was provided to help direct construction and pedestrian traffic. Overhead protection was provided near Millington Hall during the superstructure phase to protect individuals from any falling debris. Fences and signage were used in all phases of the project to keep people out of the site.

7| Project Logistics Details

7.1 Project Schedule Summary

Appendix B depicts a summary schedule for Phases I and II of the Integrated Science Center project. It includes the design phase and procurement of construction services. Major phases of construction and milestone dates are illustrated.

7.2 Detailed Project Schedule

Appendix B also contains a detailed schedule of the construction process and key milestones for the Integrated Science Center project. Due to the limit on the number of items, this report focuses solely on the Phase I addition, enabling a greater detail of each trade sequence. Phase II is smaller and less complex than Phase I. A general schedule for Phase II is provided following the detailed schedule.

Key Element Sequences

Foundation

The ISC addition is supported by a shallow foundation system (spread footings) in conjunction with ground reinforcement measures. The Geopier Intermediate Foundations System is used to reinforce the foundation soils on this site. This process first involves drilling a cavity. Layers of aggregate are then placed into the drilled cavity in thin lifts of one-foot compacted thickness. A patented beveled tamper rams each layer of aggregate using vertical impact ramming energy. The tamper forces aggregate laterally into the cavity sidewalls resulting in exceptional union with surrounding soils. Following installation, this system can support the designed spread footings. The figure shown above depicts this process. The Geopier elements provide bearing support, settlement control, significantly higher resistance to sliding and uplift.

The construction of the foundation system started in the basement from the south end of the building to the north end. The basement walls are reinforced cast-in-place concrete.

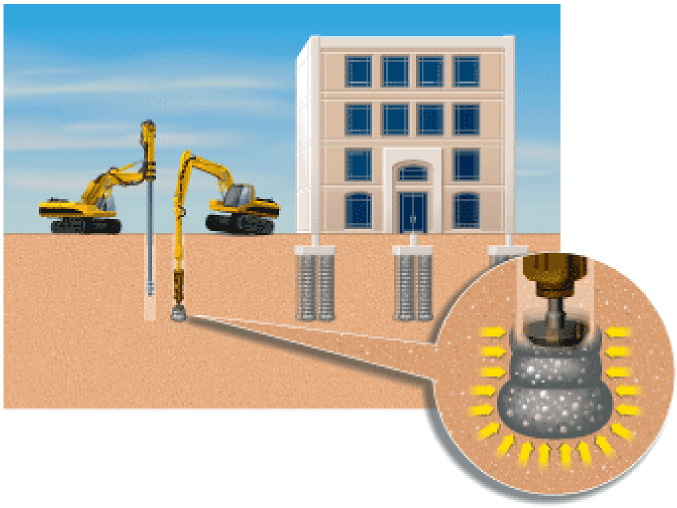

Figure 7.1.1[3] – Geopier Foundation System

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[3] Geopier foundation information - http://www.geopier.com/index.asp?id=71

Structural

For the steel erection of the Integrated Science Center, the building was broken into two areas. The north end of the building is considered Area A and the south end is considered Area B. Floors one through four were erected in Area B, followed by floors one through four in Area A. Construction again moved from south to north foundation just as the foundation system had.

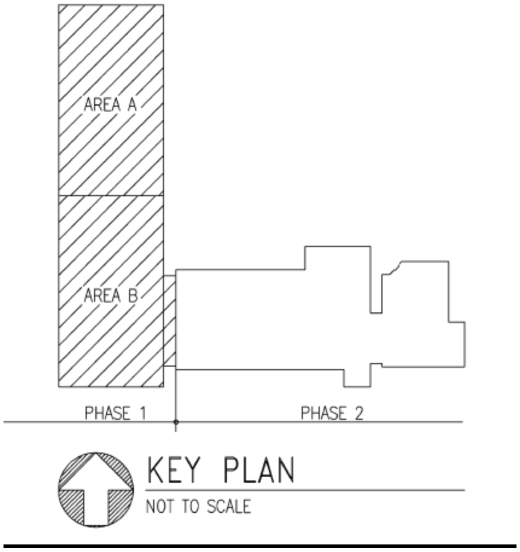

Figure 7.1.2 – ISC Area Designations

Finishes

Team meeting were held weekly to help with MEP coordination. Once all the major systems were in, the finishes began. The finishes are sequenced by floor in the same south to north fashion as the foundation system. Installation will occur in the following order:

- Metal Studs
- MEP Rough-In
- Gypsum Board
- Ceiling Grid and Tiles
- Floor Finishes (Carpet, VCT, Ceramic Tile, Epoxy, and Terrazzo)
- Painting
- Lighting Fixtures
- Furniture

Phase II

After the new addition is complete, Gilbane will work with the college to transition people and equipment out of the existing building into their new home. Once vacant, the existing building will be gutted and renovated. The abatement of asbestos was required before demolition could resume in full swing. While construction on the first floor focused on underground utilities, ductwork and piping were started on the second floor. In most cases, trades started on the second floor and moved down to the first. The contractors will complete their trades in the same order listed above.

7.3 Project Cost Evaluation

Actual Cost

The following is a cost breakdown of the major building systems for Phase I and II of the Integrated Science Center job. This information was provided by Gilbane from their September 2005 Design Development Estimate on this project.

Major Building System Costs

SYSTEMS COST	SITEWORK	PHASE I	COST/ 116,426 SF	PHASE II	COST/ 42,340 SF	TOTAL
Foundations	$0	$807,917	$6.94	$4,464	$0.11	$812,381
Slab-On-Grade	$0	$209,454	$1.80	$9,924	$0.23	$219,378
Structural Frame	$0	$1,590,469	$13.66	$40,292	$0.95	$1,630,761
Supported Floor	$0	$975,186	$8.38	$37,058	$0.88	$1,012,244
Roof Structure	$0	$189,270	$1.63	$99,916	$2.36	$289,186
Roof Coverings	$0	$529,957	$4.55	$56,332	$1.33	$586,289
Stairs	$0	$139,457	$1.20	$18,756	$0.44	$158,213
Conveying Systems	$0	$261,026	$2.24	$0	$0.00	$261,026
Exterior Walls	$0	$2,607,681	$22.40	$40,672	$0.96	$2,648,353
Interior Walls	$0	$1,496,407	$12.85	$509,149	$12.03	$2,005,556
Interior Finishes	$0	$1,226,871	$10.54	$496,170	$11.72	$1,723,041
Doors & Hardware	$0	$483,607	$4.15	$151,334	$3.57	$634,941
Windows & Glazed Walls	$0	$666,800	$5.73	$122,053	$2.88	$788,853
Specialties	$0	$167,331	$1.44	$56,023	$1.32	$223,354
Plumbing	$0	$2,366,361	$20.33	$538,495	$12.72	$2,904,856
HVAC System	$0	$8,092,726	$69.51	$2,379,154	$56.19	$10,471,880
Fire Protection	$0	$430,364	$3.70	$150,776	$3.56	$581,140
Power	$0	$2,245,369	$19.29	$621,904	$14.69	$2,867,273
Lighting	$0	$928,037	$7.97	$364,333	$8.60	$1,292,370
Special Electrical	$0	$333,594	$2.87	$130,995	$3.09	$464,589
Special Systems	$0	$491,951	$4.23	$165,157	$3.90	$657,108
Interior Demolition	$0	$135,756	$1.17	$262,910	$6.21	$398,666
Area Lighting	$30,461	$0	$0.00	$0	$0.00	$30,461
Exterior Mechanical Distribution	$11,184	$0	$0.00	$0	$0.00	$11,184
Water Distribution System	$64,831	$0	$0.00	$0	$0.00	$64,831
Sanitary Sewer	$142,388	$0	$0.00	$0	$0.00	$142,388
Storm Drainage	$150,596	$0	$0.00	$0	$0.00	$150,596
Roads	$42,084	$0	$0.00	$0	$0.00	$42,084
Earthwork	$538,851	$0	$0.00	$0	$0.00	$538,851
Landscaping	$98,782	$0	$0.00	$0	$0.00	$98,782
Site Improvements	$122,031	$0	$0.00	$0	$0.00	$122,031
Fencing	$11,400	$0	$0.00	$0	$0.00	$11,400
Special Building Foundations	$0	$572,300	$4.92	$0	$0.00	$572,300
Site Demolition	$69,790	$0	$0.00	$0	$0.00	$69,790
TOTAL	**$1,282,398**	**$26,947,891**	**$231.46**	**$6,255,867**	**$147.75**	**$34,486,156**

Table 7.3.1 – Major Building Systems Costs

Construction Cost

Table 7.3.2 below shows the actual construction costs and construction costs per square foot. This estimate does not include land costs, sitework, or permitting. The total construction cost for Phases I and II of the Integrated Science Center is **$33,203,758**.

Building	Cost per SF (CC/SF)	Size (SF)	Total Cost (CC)
Phase I	$231.46	116,426	$26,947,891
Phase II	$147.75	42,340	$6,255,867
		TOTAL	**$33,203,758**

Table 7.3.2 – Building Construction Costs and Construction Costs per SF

Total Project Cost

The following table illustrates the total project cost and total cost per square foot. The Total project cost includes the building costs for Phases I and II as well as the site work.

Building	Cost per SF (TC/SF)	Size (SF)	Total Cost (TC)
Phase I & II CC	$209.14	158,766	$33,203,758
Sitework	$8.08	158,766	$1,282,398
TOTAL	**$217.24**	**158,766**	**$34,486,156**

Table 7.3.3 – Total Project Cost and Total Cost per SF

The actual cost estimate above does not include jobsite overhead, contingency, or contractor fees. If these were factored in, the total project cost is almost **$42 million**.

RS Means 2008 Cost Estimate

The following RS Means estimate was performed using the information for a Commercial/Residential/Institutional college laboratory. The reference page from RS Means 2008 can be found in **Appendix C**. If the square footage of the Integrated Science Center and Rogers Hall were combined, the floor area would go beyond the RS Means chart. Therefore, the estimate was split into Phase I, the ISC building, and Phase II, Rogers Hall. The exterior wall system was assumed to be face brick with concrete block back-up. The common wall where the two buildings are connected was excluded from the building perimeters. Common additives were included for a more accurate estimate.

ISC Building – Phase I

- Floor area = 71,970 SF
- Perimeter = 695 feet
- Story Height = 11 feet

Rogers Hall – Phase II

- Floor Area = 40,520 SF
- Perimeter = 905 feet
- Story Height = 11 feet

The next two pages show the calculations and additions used to develop a square foot estimate.

SQUARE FOOTAGE ESTIMATE – Phase I

RS Means Source Year 2008 **Model #** M.150

Pages(s) 108-109 **Ext. Wall Type** Face Brick with Concrete Brick Back-up

Area 71,970 SF **Frame** Steel Frame

The Area falls between: 68,000 SF and 80,000 SF

*Base cost per Square Foot is: 152.41

Cost Adjustment Type: (11-12) x 0.733* Per SF Adjustment -0.733
(Story Height)
Cost Adjustment Type: (695-1151.15*)/100 x 1.6* Per SF Adjustment -7.30
(Perimeter)

Adjusted Base Cost per Square Foot: 144.38

Base Building Cost	144.38	x	71,9870	=	10,391,028.60
Basement Cost	28.60	x	23,320	=	666,952.00

Total Cost 11,057,980.60

RS Means Additions:

Addition:	(1) 3,500 lb hydraulic elevator at 150 fpm	Amount:	59,975.00
Addition:	(1) 4,500 lb hydraulic elevator at 150 fpm	Amount:	63,100.00
Addition:	(121) Fume Hood, included ductwork	Amount:	595,925.00
Addition:	(21) Safety Equipment, eye wash, hand held	Amount:	9,345.00
Addition:	(10) Deluge Showers	Amount:	8,050.00

Multiplier Type	Location	Value:	0.87
Multiplier Type	Time	Value:	-

Total SF Estimate for Building **$10,261,107.00**

*** After interpolation**

SQUARE FOOTAGE ESTIMATE – Phase II

RS Means Source Year 2008 **Model #** M.150

Pages(s) 108-109 **Ext. Wall Type** Face Brick with Concrete Brick Back-up

Area 40,520 SF **Frame** Steel Frame

The Area falls between: 37,000 SF and 45,000 SF

*Base cost per Square Foot is: 168.99

Cost Adjustment Type: (11-12) x 0.928* Per SF Adjustment -0.928
(Story Height)

Cost Adjustment Type: (905-840.08*)/100 x 2.858* Per SF Adjustment -3.86
(Perimeter)

Adjusted Base Cost per Square Foot: 164.20

Base Building Cost 164.20 x 40,520 = 6,653,465.04

Basement Cost x = -

Total Cost 11,057,980.60

RS Means Additions:

Addition: (9) Fume Hood, included ductwork Amount: 44,325.00

Addition: (4) Safety Equipment, eye wash, hand held Amount: 1,780.00

Addition: (2) Deluge Showers Amount: 1,610.00

Multiplier Type Location Value: 0.87

Multiplier Type Time Value: -

Total SF Estimate for Building **$9,661,956.00**

*** After interpolation**

D4 Cost 2002 Estimate

Due to the fact that the ISC building and Rogers Hall are different in terms of size and number of floors, the building was again broken into the two construction phases to estimate the cost of this project. For Phase I, the Integrated Science Center, the following four buildings were selected to use in the D4Cost2002 averaging analysis. The D4Cost estimate can be found in **Appendix C**.

Project Name	Size (SF)	Use	Floors	Cost
College Science Center	127,700	Educational	4	$27,133,551
Ezra Taft Benson Science Building	191,310	Educational	4	$24,388,293
Engineering Building VA State University	108,288	Educational	4	$11,769,200
Science & Technology Hall	73,406	Educational	3	$10,640,503

Table 7.3.4 – Projects Chosen for Phase I D4 Cost Analysis

For Phase II, Rogers Hall, the following two buildings were selected for the averaging estimate.

Project Name	Size (SF)	Use	Floors	Cost
Biopsychological Sciences Building Addition	30,000	Educational	2	$7,660,300
Science Lecture/Lab Building	25,563	Educational	2	$2,746,552

Table 7.3.5 – Projects Chosen for Phase II D4 Cost Analysis

These were relatively easy to pick out from the rest because they are all higher education buildings and fell within about the same square footage and number of floors as the ISC and Rogers Hall buildings. These were also chosen based on the building descriptions. I looked for facilities that contained office, class, and laboratory spaces as well as ones that used structural steel and brick masonry.

For each phase, the True Averaging function was used to compare the selected buildings with a target information date (project start date) of June 2006. D4 produced an estimate of **$25,088,412** for Phase I and **$10,589,177** for Phase II.

Cost Comparison

	Phase I		Phase II		Total Cost (Phase 1+II)
	Cost	***Cost/SF***	***Cost***	***Cost/SF***	
Actual Cost	$26,947,891	$231.46	$6,255,867	$141.75	**$34,486,156**
RS Means 2008	$10,261,107	$144.38	$9,661,956	$168.99	**$19,923,063**
D4Cost2002	$25,088,412	$215.49	$10,589,177	$250.10	**$35,677,589**

Table 7.3.6 – Cost and Cost per Square Foot Comparison of Estimates

The RS Means estimate turned out extremely low compared to the actual project cost. This is because the 4th floor penthouse and the general conditions were excluded. The ground floor of the ISC is much more sophisticated than just a basement. This could have also contributed to such a low estimate. The additives helped bring the estimate closer, but not significantly. Cabinets, hardware, and countertops were excluded from the estimate because they were not part of the actual cost. These were paid for and installed separately by the owner. The square foot estimate was higher than the actual cost for Phase II. This is because RS Means does not take into consideration that Roger's Hall is a renovation project, not a new building.

The D4 estimate was surprisingly close to the actual cost, just slightly higher. Despite the fact that the software has a limited database, I was able to find a few buildings of similar area, purpose, and structure. Again the Phase II cost was higher than the actual because the program treated Rogers Hall as a newly constructed building as opposed to a renovation.

7.4 General Conditions Estimate

Please refer to **Appendix D** for the detailed general conditions estimate.

Assumptions:

- Location factor for Newport News = 0.87
- Project duration = 46.5 months or 200 weeks (May 15, 2005 – March 31, 2009)
- All Gilbane employees were on the job from the start - the team on this project was rather small to begin with so they took on various positions and shared responsibilities to cover all the start-up tasks
- Maximum commissioning – laboratories have more systems and controls than normal higher education buildings
- Minimum or average unit costs were selected for all other items

The unit costs for the general conditions estimate were taken from the first division of R.S. Means 2008. The general conditions for the Integrated Science Center came out to be around **$3,351,000**. Contingency, as well as overhead and profit, were not included in this figure. Table 7.4.1 on the following page summarizes the breakdown of the general conditions for this project.

Item	Cost	% of GC
Staff	$1,109,250	0.331
Temporary Utilities	$127,287	0.038
Site Office & Expenses	$52,228	0.016
Site Security & Protection	$42,533	0.013
Fee, Insurance, Permits and Bonds	$1,419,394	0.423
Commissioning	$277,225	0.083
Miscellaneous	$323,044	0.096
Total	**$3,350,961**	**1.000**

Table 7.4.1 – General Conditions Estimate Breakdown

	General Conditions Estimate
Actual Budget	$4,286,057
RS Means	$3,350,961
Difference	**-$935,096**

Table 7.4.2 – General Conditions Estimate Comparison

As seen in Table 7.4.2, the estimate varied quite a bit from the actual general conditions budget. This could be contributed to the low project staff estimate for this project. The cost for employees can be difficult to estimate because it depends on the company. All the unit costs for the estimate were taken from R.S. Means rather than from Gilbane's data. The general conditions make up **9%** of the total project cost.

8| Introduction to Thesis Analyses

The College of William and Mary decided to spend millions of dollars on the addition of the Integrated Science Center and the renovation of Rogers Hall with the intent of becoming a national leader in research and teaching facilities in the departments of biology, chemistry, and psychology. With this in mind, this thesis focuses on incorporating the most recent concepts and technology to provide an even more higher performance facility than originally designed.

8.1 Labs for the 21st Century

Designing Energy Efficient Research Labs

Labs for the 21st century (Labs21) is a voluntary partnership program dedicated to improving the environmental performance of U.S. laboratories. Co-sponsored by the U.S. Environmental Protection Agency (EPA) and U.S. Department of Energy (DOE), Labs21 offers professionals worldwide an opportunity for continuous learning and to exchange information through interactive programs.

The objective of Labs 21 is to pursuit sustainable, high performance, and low-energy laboratories that will:

- Minimize overall environmental impacts.
- Protect occupant safety.
- Optimize whole building efficiency on a life-cycle basis.
- Establish goals, track performance, and share results for continuous improvement[4].

This group focuses on laboratories and high performance facilities because they represent a continuous opportunity for advanced, environmentally preferred, building technologies. The Labs21 approach to improving the energy efficiency and environmental performance of these facilities is to examine the entire building from a “whole building” perspective. This approach allows owners to pursue integrated energy and water conservation measures with significantly higher efficiencies and cost savings than the traditional approach of addressing components individually. This encourages laboratory owners and designers to make capital investment decisions based on the life cycle cost savings, pursue energy-efficient HVAC technologies, design systems that recover and exchange waste heat and other forms of free energy, and incorporate renewable energy systems.

The Labs21 approach was the driving inspiration for the topics selected in this thesis. Each analysis incorporates an energy-saving technique applied to the Integrated Science Center project.

[4] Labs for the 21st Century - http://www.labs21century.gov/about/approach.htm

9| Energy Conservation through Retrofitting

AE Construction Management Critical Industry Research Issue

9.1 Introduction

The PACE roundtable event covered a number of current issues facing the construction industry. One of the technical topics discussed was the recent energy and economic impacts on construction. Today's economic situation has made retrofitting existing buildings more appealing to some owners than new construction. The concept of retrofitting can be applied to Phase II of the Integrated Science Center project. While Rogers Hall undergoes interior renovations, updating old or outdated assemblies could lead to reduced operating costs for the owner.

9.2 Problem Statement

The College of William and Mary is interested in upgrading its chemistry, biology, and psychology department's image by replacing buildings over 30 years old with state-of-the-art facilities. This renovation project includes the addition of a new, high tech laboratory building as well as improvements to the existing Rogers Hall. During these times of economic uncertainty though, cost is one of the owner's top concerns. Retrofitting MEP features could lead to significant savings.

9.3 Goal

The purpose of this analysis is to identify MEP system upgrades or improvements to the existing Rogers Hall that would provide energy savings and reduced operating costs. One feature of building retrofit is that it pays off slowly and modestly. Owners are often hesitant to consider these options because it is difficult for them to pay more upfront even though it will almost certainly pay itself back in the long run. It is imperative to provide annual saving figures and an estimated payoff time in order to prove the value of my retrofit options.

9.4 Methodology

1. In order to identify areas of energy savings, extensive study on possible retrofit ideas is needed by researching literature focused on this topic.
2. Examine previously retrofitted laboratories or buildings similar to Rogers Hall by consulting related articles. Gilbane's building database may be a valuable research tool.
3. Study the existing Rogers Hall plans, the newly proposed plans, and determine possible retrofit considerations.
4. Determine the most feasible options and apply them to Rogers Hall.

5. Calculate the initial costs.
6. Calculate the annual cost and energy savings.
7. Determine the pay off duration.
8. Based on the research and calculations, draw conclusions and make recommendations regarding the proposed retrofit ideas.

9.5 Tools and Resources

1. College of William and Mary's owner representative
2. Gilbane Building Company
3. Penn State AE faculty
4. Internet and online resources
5. Magazine articles

9.6 Expectations

I expect to find ways in which the 35 year old Rogers Hall that could be improved or upgraded. When considering possible energy and cost saving possibilities, the electrical system tends to be overshadowed by the mechanical system. However, significant operating costs can be saved by addressing the electrical system as well. I expect to focus on electrical retrofitting because the majority of the mechanical and plumbing upgrades have been previously addressed or are included in the proposed renovation.

9.7 Research on Building Retrofits

Building retrofitting involves substituting older equipment with new or modernized parts or systems that was not existing or available at the time of the original construction. With today's technology, we know how to retrofit existing buildings to reduce their energy consumption by well over 50%, in some cases even 90-95%. An investment in retrofit has three basic features:

1. *It is cost intensive up front.* Energy saving materials and techniques usually cost more at the start than building with cheaper, more common materials and methods. Retrofitting buildings is also labor intensive, labor being a cost that most construction managers seek to reduce.
2. *It pays off slowly and moderately.* It takes time for the extra money invested into retrofits to pay off. Only in the long term do these investments offer a significant dividend.
3. *Its benefits are certain.* Money spent reducing the energy consumption costs of a building will almost undoubtedly pay for itself, given proper maintenance and a reasonable duration of time.

Upgrades and improvements can be applied to any of the building systems to provide various benefits to the owner. Seismic retrofitting involves modifications to existing structures to make them more resistant to ground motion or soil failure due to earthquakes. The incorporation of today's fire protection technology into existing structures helps reduce the loss of property and life due to a fire. Mechanical, electrical, and plumbing retrofits integrate more efficient components into a facility to provide energy and operation cost savings. Due to the recent rise in energy costs, this analysis will focus on MEP enhancements that could reduce energy consumption and therefore decrease operation costs. Building retrofit projects include some of the following elements:

Mechanical and plumbing systems can be upgraded by:
- Replacing inefficient boilers and cooling systems with high efficiency units
- Installing variable speed motors and drives on pumps and fans that consume less energy than their constant speed counterpart
- Converting air and water distribution systems to variable volume (this reduces energy consumption compared to a constant volume arrangement)
- Installing renewable energy technologies
- Installing low-flow and flow-control devices to reduce the use of water
- Installing modern digital control systems to more accurately monitor the operation of all systems

Electrical system improvements can include:
- Converting lighting systems to high-efficiency technology
- Installing motion sensors to ensure equipment is only used when required
- Installing digital lighting control systems
- Converting electric heating to natural gas or solar power
- Installing power factor correction capacitors to reduce utility charges

9.8 Applying Retrofits to Rogers Hall

Rogers Hall is currently undergoing interior renovations. New partition walls are being constructed; worn flooring and aged furnishings are being replaced by new tiles and the latest laboratory casework; and original plumbing fixtures are being replaced with low-flow devices. This renovation period is the perfect time to consider and apply retrofit components.

After extensive research and reference to the construction drawings, possible electrical retrofit options became apparent. Converting to high-efficiency lighting components would be the most feasible option which could save a considerable amount of energy and lead to cost savings in the future. An analysis of the existing lighting system versus a high-efficiency alternative is provided below. Other alternatives include installing lighting control systems or motion sensors. These two options will be evaluated and discussed later in my electrical breadth section. This analysis focuses on the significant energy and operation cost savings in just one retrofit element.

34WF34T12 fluorescent lamps are the most common lamps used in the existing Rogers Hall. This analysis proposes replacing the current F34T12 lamps with 32WF32T8 lamps because they are significantly more efficient in light output and energy consumption. The T8 lamp and high-frequency electronic ballast combination provides a rich source of lighting that delivers a high lumen package, a high color rendering index rating and exceptional energy efficiency.

Existing T12 lamps and T8 Lamp Retrofits

For years, commercial lighting has been dominated by the common T12 (1.5-inch diameter) cool-white fluorescent lamps and transformer-type magnetic ballasts. Unfortunately, time and experience revealed that technical problems between this lamp-ballast combination resulted in reduced lamp life, poor color rendering, and low light output. High efficiency T8 (1 inch) lamps teamed up with electronic ballasts are now setting new standards for low power consumption, low life-cycle cost and illumination that more closely resembles natural light.

The combination of the 32WT8 lamp with the high-frequency eletronic ballast produces a fluorescent lamp that is energy efficient, offers a high lumen and color rendering index package, and has very attractive economics. The following T8 features and operating characteristics show the reasons for the lamp’s superior performance.

- **Energy savings** (up to 40% less energy)

The 32-watt T8 lamps produce similar levels of light as the older 40-watt T12 bulbs. The slim profile of the T8 lamps enables its gases and rare-earth phosphors to function more efficiently. The energy efficiency also improves because the eye can see easily with these “tri-phosphors,” so less light is required to accomplish a given task than is needed with other types of lamps. The smaller diameter provides the opportunity for more light to be delivered from the fixture than is possible from a T12 lamp.

Figure 9.8.1 – T5, T8, T12 Diameter Image

- **Better color rendering**

The light from T8 lamps has a higher color rendering index (CRI) than standard T12s. The higher CRI makes objects and surfaces in a room appear more like they would under natural light.

- **More output and longer length of life**

Fluorescent T8 electronic fixtures give 40% more light output then T12 magnetic. After 10,000 hours, T8 lamps are still running at 95% light output, unlike T12s, which are at only 85%. T8s also last up to 24,000 hours versus 20,000 hours for T12s.

- **Cooler operation**

Electronic ballasts consume fewer watts than magnetic ballasts. Lighting systems generate less heat, which reduces cooling loads.

- **Quieter operation**

T8 electric ballasts are 13% quieter than traditional fluorescents.

- **Lightweight design**

Electronic ballasts are less than half the weight of magnetic ballasts. A retrofit of electronic ballasts could eliminate nearly six pounds from a typical four-lamp fixture[5].

- **No flicker during start-up or operation**

Fluorescent T8 fixtures do not flicker for less eyestrain, better relaxation and concentration.

Straight T8 lamps have the same medium bi-pin bases as T12 lamps, so they can fit the same sockets. However, T8 lamps require an electronic ballast specifically designed to operate lamps at a lower current than T12 lamps. Whenever T12 lamps are replaced with T8 lamps, the ballast must also be replaced.

Magnetic Ballasts versus Electric Ballasts

Rogers Hall's lighting design currently uses standard magnetic ballasts with a 0.88 ballast factor. Newer, more energy-efficient electronic ballasts should be considered. Electronic ballasts use high frequency, solid-state circuitry instead of heavy copper windings to provide the right voltage and current. As a result, electronic ballasts produce more light for each watt, run cooler, and last longer. The ballast is flicker free and produces virtually no sound.

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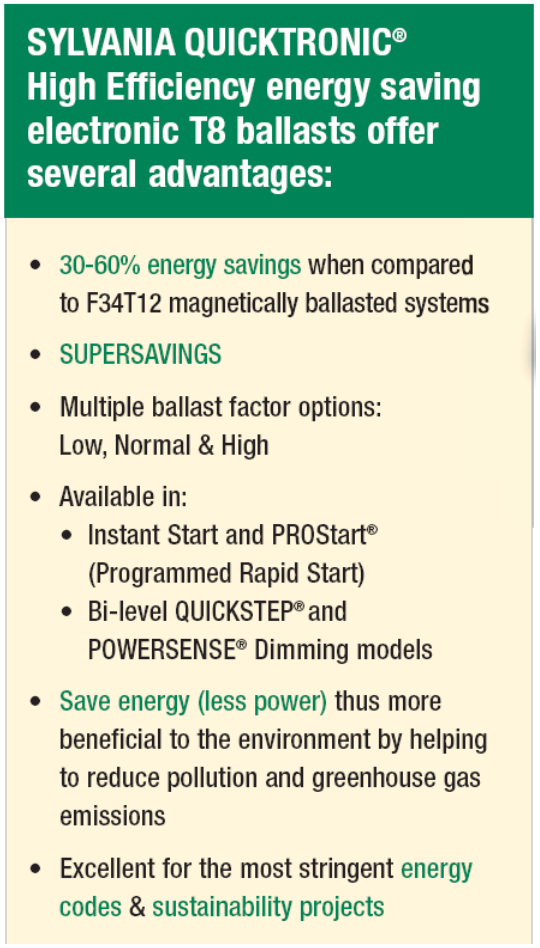
[5] Lightweight Design - http://www.mge.com/business/saving/detail/t8.htm

After electronic ballasts were chosen, the next choice is between rapid and instant start. Instant start ballasts were selected in this analysis because they are more economical. Instant start ballasts can be 5 to 10 percent less expensive than the rapid start ballasts which can become a significant difference with the number of ballasts required to operate an entire laboratory facility. The instant start ballasts do not require constant current to maintain lamp operation as is with rapid start ballasts. This provides greater energy savings of about two watts per lamp. Two watts per lamp multiplied by thousands of lamps can have a significant impact on energy use.

Figure 9.8.2[6] – Ballast Image



SYLVANIA QUICKTRONIC® High Efficiency energy saving electronic T8 ballasts offer several advantages:

- 30-60% energy savings when compared to F34T12 magnetically ballasted systems
- SUPERSAVINGS
- Multiple ballast factor options: Low, Normal & High
- Available in:
  - Instant Start and PROStart® (Programmed Rapid Start)
  - Bi-level QUICKSTEP® and POWERSENSE® Dimming models
- Save energy (less power) thus more beneficial to the environment by helping to reduce pollution and greenhouse gas emissions
- Excellent for the most stringent energy codes & sustainability projects

Figure 9.8.3[6] – QUICKTRONIC Advantages

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[6] Figures 9.8.2 and 9.8.3 taken from Sylvania's Ballast Technology Applications & Specification Guide http://content.sylvania.com/app/display.aspx?docid=003699308

9.9 Energy Comparison

A comparison of energy usage for the existing F34T12 and F32T8 is shown in the chart below. By replacing the T12 lamp-magnetic ballast combination with T8s and electronic ballasts, not only does the amount of energy being used decrease but the number of effective lumens actually increases. The 94.3 lumens per watt ratio for the T8 lamps is significantly greater than the T12 lamp's 63.0 lumens per watt. As we will see later, the decrease in energy usage will result in considerable electrical savings. Information regarding the lamps and ballasts of each were taken from the Sylvania product catalog. Please refer to **Appendix E** for the product data sheets used.

	Existing **34WF34T12** W/ Magnetic Ballast (0.88 Ballast Factor)	Proposed **32WF32T8** W/ Electronic Ballast (0.88 Ballast Factor)
Rated Lamp Wattage	34 W	**32 W**
Actual Energy Use	37 W	**28 W**
Effective Lumens*	2,332	**2,640**
Lumens per Watt	63.0 L/W	**94.3 L/W**
Rated Life	20,000 hrs.	**24,000 hrs.**

Table 9.9.1 – T8 and T12 Energy Comparison

*Effective lumens are determined by multiplying the rated lumens of a lamp by the ballast factor.

The 34WF34T12 lamp has an initial rating of about 2,650 lumens. The magnetic core and coil energy-efficient ballast operating this lamp has a ballast factor of 0.88:

0.88 * 2,650 lumens = 2,332 lumens.

This equation tells the designer that the lamp-ballast combination will produce about 2,332 lumens. Rule of thumb indicates that only about 50 percent of this light will reach the work surface.

The 32WF32T8 lamp has an initial rating of about 3,000 lumens. The electronic ballast has a ballast factor of 88 percent:

0.88 * 3,000 lumens = 2,640 lumens.

9.10 Energy Cost Comparison

Fixture Type	Number of Fixtures	Watts/Fixture	Operation Hours/Day	Electric Rate (cents/kWh)	Energy Cost ($/year)
4' 2 Lamp 34WF34T12 w/magnetic ballast (0.88 ballast factor)	284	82	12	7.31	$7,456.31
4' 2 Lamp F32T8 w/electric ballast (0.88 ballast factor)	284	55	12	7.31	$5,001.18
					$2,455.13
4' 4 Lamp 34WF34T12 w/magnetic ballast (0.88 ballast factor)	361	164	12	7.31	$18,955.82
4' 4 Lamp F32T8 w/electric ballast (0.88 ballast factor)	361	107	12	7.31	$12,367.52
					$6,588.30
				Savings Per Year	**$9,043.43**

Table 9.10.1 – T8 and T12 Energy Cost Comparison

Rogers Hall contains 284 4' 2 lamp fixtures and 361 4' 4 lamp fixtures. Converting from F32T12 lamps to F32T8s would conserve **28,245 watts** of electricity a year, assuming these lights are used 12 hours a day and 365 days a year. Using Virginia's 2008 average retail price of electricity of 7.31 cents per kilowatt-hour, the College of William and Mary would save over **$9,000** a year. This results in a **34.2%** annual savings. A breakdown of the data used is shown above.

9.11 Construction Cost and Schedule Considerations

Cost

There is no doubt that retrofitting would save energy and therefore reduce the electrical operating costs for the owner. However, the savings would initially be offset by the first cost for purchasing and installing the new devices. The question is how long will it take before the system pays for itself in energy savings.

Lamps	Quantity	Case Size	Cases Needed	Cost/Case	Cost
F032T8/800XP	2012	30	74*	$240.60	$17,804.00
Ballasts					
QHE 2X32T8/UNV ISN-SC	284	10	29	$191.70	$5,559.30
QHE 4X32T8/UNV ISN-SC	361	10	37	$302.80	$11,203.60
				Total Cost	**$34,567.30**

Table 9.11.1 – Construction Cost Comparison

*Specifications call for an additional 10% of lamps for storage.

The chart on the previous page shows the initial cost breakdown for the new lamps and ballasts. Sylvania's 32 watt 4' T8 800 Series Extended Performance fluorescent light bulbs come in cases of 30 at $240.60 per case. 74 cases would be needed to supply Rogers Hall with all new lamps and have an additional 10% left for storage. The 2 and 4 lamp QHE Instant Start ballasts come in packs of 10 and cost $191.70 and $302.80 per pack respectively. This would come to a total initial cost of **$34,567.30** for the new materials.

Unlike lamp replacement, which may be done by a custodian, ballast replacement usually requires use of a licensed electrician to avoid problems and liabilities. RS Means 2009 was referenced to determine the labor cost of replacing the ballasts. Using the unit labor cost of $32.63 (location factor included), the cost of installing 645 ballasts would be **$21,044.13.**

Based on the figures above, the new lighting devices and installation would cost a total of **$55,612**. With energy savings of $9,043 a year, it would take **6.15** years to pay itself off. Not only would the new lamps produce annual operation savings, they cost less to maintain and are replaced less frequently.

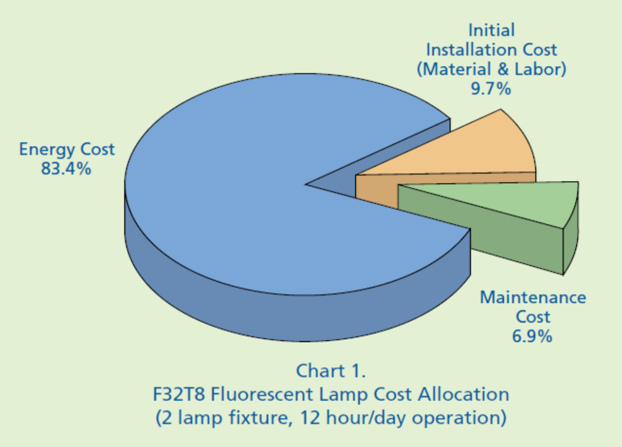

Chart 9.11.1 [7] – T8 Lamp Cost Allocation

The figure to the left shows the F32T8 fluorescent lamp cost distribution based on a 2 lamp fixture operating at 12 hours per day. Even though the percent allocation between initial installation cost, maintenance cost, and energy cost may vary depending on operating conditions, the initial cost of the system is small compared to its lifetime operating cost.

<u>Schedule</u>

Although the installation of the new lamps and ballasts would take some time, it would have very little, if any, impact on the construction schedule. RS Means 2009 was used to determine the labor hours required to replace the ballasts. One electrician can change 10 indoor fluorescent ballasts in one, eight hour work day. It would take **13 work days** for a **crew of five** labors to replace the 645 ballasts in Rogers Hall. The reference page from RS Means can be found in **Appendix C**. Most, if not all, this work could be done simultaneously while other construction processes and building finishes are taking place.

[7] Chart 9.11.1 found at http://www.heco.com/vcmcontent/Energy%20Services/Powerlines/pl_2006_summer.pdf

9.12 Conclusions and Recommendations

While conducting research for this analysis, every source concurred that proper retrofitting results in significant savings overtime. When the lighting system upgrade was applied to Rogers Hall, the resulting cost studies verified just that. Even only one retrofit would result in considerable energy and operation cost savings. Based on this analysis, I would strongly recommend replacing the F34T12 lamps with F32T8s saving money for the owner.

Initially, the College of William and Mary would have to invest **$34,567.30** for the new bulbs and ballasts plus an additional **$21,044.13** for their installation. However, changing the bulbs to T8s would conserve **28,245 watts** of electricity a year and result in the college saving over **$9,000** a year, an annual savings of **34.2%** compared to the existing lamps. The new system would pay for itself after **6.15 years**.

Not only would these new lamps result in future savings for the owner, they would be more consistent with the lamps used in the new ISC addition. These lamps also provide better quality characteristics, such as improved color, which would benefit the facility occupants.

	Existing **34WF34T12** W/ Magnetic Ballast (0.88 Ballast Factor)	Proposed **32WF32T8** W/ Electronic Ballast (0.88 Ballast Factor)
Initial Material Cost and Installation	**$0**	$55,612
Actual Energy Use	37 W	**28 W**
Annual Energy Costs	$26,412.13	**$17,368.70**
Effective Lumens	2,332	**2,640**
Rated Life	20,000 hrs.	**24,000 hrs.**

Table 9.12.1 – Lamp Cost and Energy Comparison

The owner representative at the College of William may be hesitant to pay the extra amount upfront because of additional funding that would be needed. In order to help persuade the owner, the following is a list of benefits that the lighting retrofit would offer the Rogers Hall building owner and occupants:

- **Energy savings**

As seen previously, by upgrading lighting components to more efficient and advanced technologies energy consumption is reduced and result in lower energy bills.

- **Improved quality**

New technologies provide better quality characteristics, such as improved color, and add increased reliability to the systems so fewer short term quality issues arise.

- **Reduced maintenance and labor costs**

Improvements in lighting technologies have led to increased lifetimes for components that will result in fewer failures and lengthen the time between maintenance activities.

- **Building Consistency**

Rogers Hall's addition, the Integrated Science Center, is currently designed to install T8 lamps. Changing the bulbs in Rogers Hall to T8s would provide more consistent lighting characteristics and better flow between buildings.

- **Pollution reduction**

By consuming less electricity, the facility will help reduce the demand and associated harmful emissions, such as CO_2 and other greenhouse gases, from off-site power generation.

- **Green Power systems**

Using more efficient lighting will require less power to be generated, stored, and used to accomplish the same tasks, making alternative power systems more economically and technically feasible.

10| Implementation of Daylighting

AE Lighting & Electrical Breadth

10.1 Introduction

Through the addition of the Integrated Science Center and the renovation of Rogers Hall, the trustees of the College of William and Mary hope the university becomes a national leader in research and teaching facilities in the departments of Chemistry, Biology, and Psychology. Therefore, these buildings should include features that promote a better learning environment such as introducing natural light inside. Studies conducted in schools show that daylighting helps to increase productivity and enhance performance. According to the Laboratories for the 21st Century (Labs 21), “Daylighting helps to provide an interior work environment that stimulates creativity and discovery.” And discovery is what research laboratories are all about.

The Integrated Science Center is designed with three large windows in every laboratory of the building that will provide a sufficient amount of natural light to satisfy daylighting practices. However, this natural light will not result in any energy savings as long as the lights are still turned on. By adding daylighting photosensors that trigger some of the lights to shut off in the labs, the penetrating natural light could provide increased benefits to the occupants as well as reduced energy consumption.

10.2 Problem Statement

The current lighting system assumes that lights are on continuously throughout the school day. This is costly and reduces the benefits that natural light is capable of providing. The electric lighting also decreases the quality and benefits of penetrating natural light. Because students’ performance improves in areas of higher levels of natural light, daylighting practices should be implemented in the laboratories.

10.3 Goal

The purpose of this study is to coordinate the daylighting design with the electric lighting design so they work together as one system. This requires an analysis of the current laboratory layout, lighting configuration, and amount of daylight present. If the current design does not utilize daylighting efficiently, alternative techniques and designs will be implemented and reassessed. This analysis complements the previous retrofit study and will include the possible energy and cost savings as well as the construction impacts.

10.4 Methodology

1. Explore possible daylighting designs and techniques for laboratories.
2. Research the benefits of natural light to building occupants
3. Inquire industry members or meet with AE faculty to obtain advice and guidance.
4. Use computer programs to run daylighting calculations on current room design.
5. Redesign the room configuration and lighting layout based on the program analysis.
6. Run daylight calculations for new room layout.
7. Compare results from lighting tests and determine if the amount of daylighting is sufficient to be beneficial to building occupants.
8. Determine any energy savings provided by using daylighting features.
9. Determine the cost and schedule impacts of implementing new techniques.
10. Come to a conclusion and make recommendation whether the installation of daylighting features is a worthwhile investment.

10.5 Tools and Resources

1. Integrated Science Center construction documents
2. Penn State AE faculty and 5th year lighting students
3. Internet articles and online sources on daylighting practices and benefits
4. AutoCAD 2008
5. AGi32 Lighting and Electrical computer software
6. USGBC's LEED for New Construction v2.2

10.6 Expectations

Current laboratory configurations are assumed to provide an inadequate amount of daylighting features which means that in the benefits of natural light are not being enjoyed. By incorporating natural light enhancing techniques, such as occupancy or light level sensors, energy consumption will be greatly reduced and it will produce a better environment for the success of the building occupants. After improved coordination between the daylighting design and the electric lighting design is achieved, it will be a worthwhile investment for the owner.

10.7 Research on Daylighting

Daylighting is the controlled entry of natural light into a building. The use of daylighting allows photosensors to dim or turn off a building's electric lights to save energy. Daylighting not only saves energy, it increases productivity and generally improves occupant satisfaction and comfort. Science can improve our lives dramatically; therefore, it important to provide scientists and researchers with laboratories that foster innovation and enhance performance.

Providing a pleasant work environment, such as access to natural light and exterior views in labs is a good way to recruit and retain top scientists, technicians, and other key research personnel. Since the goal of the College of William and Mary is to attract the best professors and students in the departments of chemistry, biology, and psychology, incorporating daylighting techniques into the Integrated Science Center addition could be of interest to the owner. In addition, the owner will reap the energy cost savings each month from the reduced electrical load. Daylighting saves energy only when the lights are dimmed or shut off; therefore, photosenor controls are needed to ensure this.

10.8 Light Level and Occupancy Sensors

Energy demands and heating loads are reduced when lights are turned off or dimmed. Therefore, it would be best to have controls that trigger the lights to dim or turn off based on a predetermined illuminance. There are two major control systems that can be used to complement daylighting: light level and occupancy sensors.

Light Level Sensors

Light level sensors are installed to trigger certain lamps to dim or turn off when a programmed illuminance level is met within a space. These sensors are equipped photoelectric “eye” that measures the illumination. To prevent the lights from turning off when there is a momentary cloud cover, the sensors contain preset delay timers. Fluorescent lamps, such as the ones found in the Integrated Science Center, are the most common lamps used for daylighting practices. In order to approximate the operational cost savings of implementing light level sensors, sensors that switch lights off, rather than dimmed, are used. Switching lights off is also more economical because dimming requires special dimming ballasts which cost more than the on-off ballasts already installed in the labs.

Occupancy Sensors

Occupancy sensors use infrared technology to detect when a space is occupied. The lights are signaled to stay on by an individual’s heat or movement. Lights will automatically be turned off once a preset amount time passes without detection of any motion. These sensor controls are practical for college campuses. Even during the day, not all the classrooms in a building are being used and typically the lights are left on. This has the potential to build up electrical costs especially with the number of buildings on a college campus. An analysis of the amount of energy occupancy sensors would save would be difficult for the Integrated Science Center because the room usage is unknown.

10.9 Choosing a Light Level Sensor

Wattstopper.com was used to select the daylight controlling device for the Integrated Science Center. The following decisions were necessary to determine the proper controlling mechanism:

- *Standalone or system control*

The standalone system was chosen because it controls a single group of lights. For the ISC facility, the lights closest to the windows are the one single group to be controlled. The standalone system is also easy to install and low in cost.

- *Single or multiple control zones*

A single control zone was selected because only one zone is being controlled per sensor. This is also the most common for standalone systems.

- *Open or closed loop technology*

The closed loop technology was selected because it provides on-off switching and measures both daylight and electric levels in the room. The closed loop allows for manual override incase extra lighting is needed.

- *Room location*

Sensors would be placed on the ceiling near the window and pointed toward workspace areas.

Based on the above process, the Light Saver LS-101 Daylighting Controller was selected for the ISC laboratories. Please refer to **Appendix F** for data information on the Light Saver LS-101.

→ Daylighting Sensors & Controls → Stand-alone/Single Channel

LightSaver® LS-101 Daylighting Controller

Watt Stopper/Legrand's LS-101 Daylighting Controller is a single zone, ON/OFF device that turns lighting off automatically when sufficient natural daylight is present.

Figure 10.9.1[8] – LightSaver LS-101 Daylighting Controller

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[8] Figure 10.9.1 taken from Wattstopper.com's product brochure at http://wattstopper.com/products/details.html?id=180&category=29&type=Commercial

10.10 Daylighting Technical Write-up and Calculations

In order to perform a daylighting study on the designed and proposed lighting layouts, AutoCAD 2009 was used to create a basic three dimensional model of a typical laboratory space found in the Integrated Science Center. The model was then imported into AGi32, a lighting design software, to determine the illuminance levels from the natural light.

Below is a description of room and lighting details found in each laboratory space according to the construction documents and specifications.

- **Room Size:**

  Each laboratory space is 31’-0” x 29’-0”
- **Ceiling Height:**

  The first 8’-6” closest to the windows has a ceiling height of 11’-0”. The rest of the room has a ceiling height of 10’-0”. The difference in height is due to the fact that space near the windows was not needed for electrical and mechanical equipment so the added floor-to-ceiling height provides an opportunity for taller windows. The higher daylight can enter a space, the farther back it can reach.
- **Windows:**

  Three (3) 7’-0” x 4’-0” double-pane windows are located in each room. A transparency of 0.8 is used in AGi32.
- **Light Fixtures:**

  A laboratory contains 15 cable-mounted light fixtures each requiring two (2) T8 lamps. There are two switches per room. One switch turns on one lamp in the 12 fixtures furthest from the windows. The other turns on all the lamps for the 3 fixtures closest to the window plus the remaining 12 lamps in the 12 fixtures furthest from the windows. See Figure 10.10.1 for the typical lighting plan.

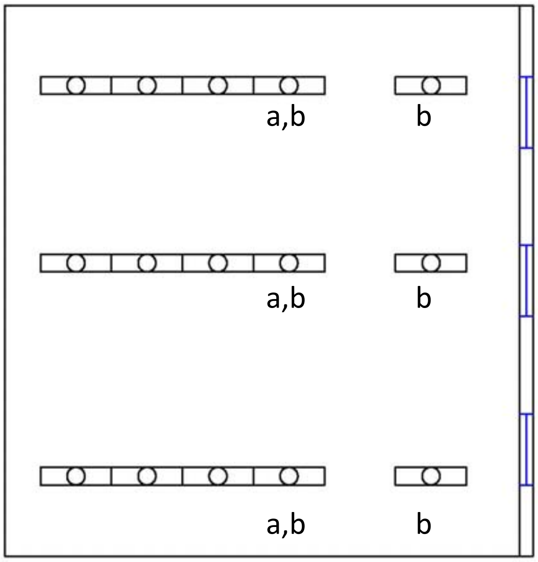


Figure 10.10.1 – Typical Lab Lighting Plan

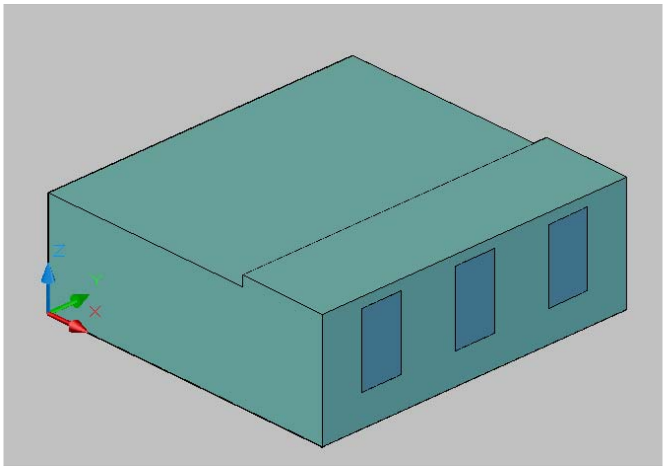
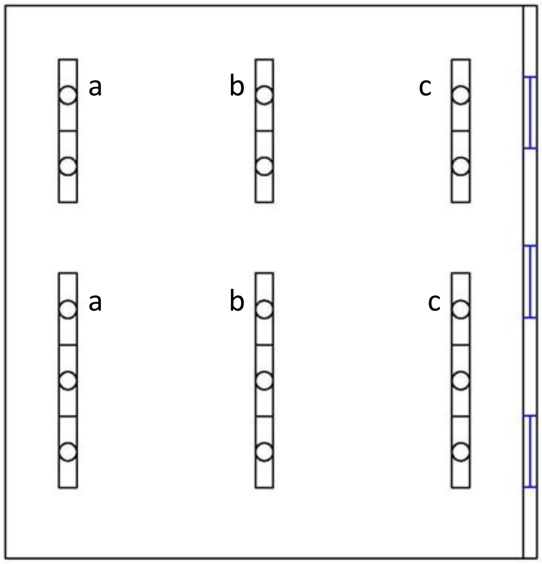


Figure 10.10.2 – 3D Model of Typ. Lab Space

The way the space's lighting fixtures are laid out and wired, using a light level sensor would provide no benefit to the owner. The lights closest to the windows cannot be shut off without turning off lamps in the further fixtures. This design does not take advantage of natural lighting which would result in energy and cost savings. To incorporate energy savings through daylighting, the following lighting arrangement is proposed.



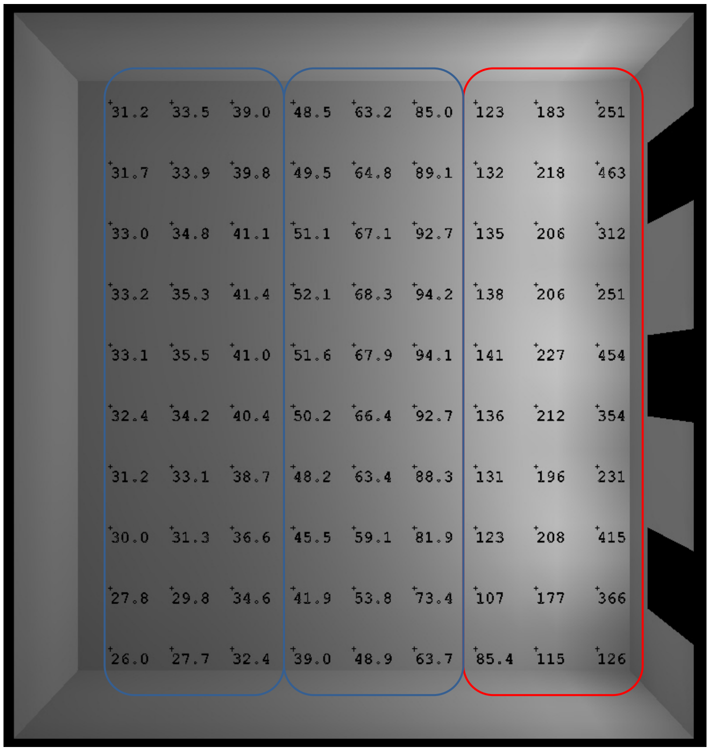
10.10.3 – Proposed Lab Lighting Plan

As seen in the figure to the left, the number of fixtures and lamps used remains the same as the designed plan. The proposed layout uses three switches instead of the original two. The row of lights closest to the window would automatically turn off when sufficient levels of illuminance are met. As light penetrates further into the space, the second row of fixtures would turn off and so on. For a room this size, two lighting sensors would be needed per lab.

To estimate the electrical cost savings provided by the implementation of light level sensors, AGi32 was used to determine the illuminance levels on a 3'-0" work plane. Analyses were run on the east façade windows every hour from 7 AM to 6 PM (when daylight is present). No lights were on so natural was the only consideration.

The following assumptions were made for the AGi32 calculations.

- Reflectance:
  - Ceilings: 0.8
  - Walls: 0.5
  - Floor: 0.2
- Lab station height (work plane): 3'-0"
- Goal illuminance: 80 footcandles for a laboratory (specifications)
- Sky type: cloudy (conservative model)
- Date: September 22, 2009 – The autumnal equinox was used as an average amount of daylight per day over the course of a year.



31.2	33.5	39.0	48.5	63.2	85.0	123	183	251
31.7	33.9	39.8	49.5	64.8	89.1	132	218	463
33.0	34.8	41.1	51.1	67.1	92.7	135	206	312
33.2	35.3	41.4	52.1	68.3	94.2	138	206	251
33.1	35.5	41.0	51.6	67.9	94.1	141	227	454
32.4	34.2	40.4	50.2	66.4	92.7	136	212	354
31.2	33.1	38.7	48.2	63.4	88.3	131	196	231
30.0	31.3	36.6	45.5	59.1	81.9	123	208	415
27.8	29.8	34.6	41.9	53.8	73.4	107	177	366
26.0	27.7	32.4	39.0	48.9	63.7	85.4	115	126

Figure 10.10.4 – AGi32 Illuminance Levels at 1 PM on September 22, 2009

Figure 10.10.4 to the left is an example of the AGi32 results for September 22,2009 at 1 PM. The area circled in red meets the 80 footcandle illuminance requirements for a laboratory space. The light level sensors would detect this and automatically turn off the first row of fixtures closest to the window. The areas in blue do not meet the illuminance requirements so the lights will remain on. Please refer to **Appendix G** for all other times on September 22, 2009. The results from AGi32 are in the table below.

	Number of Fixtures On Proposed - Sensors	**Number of Fixtures On** Designed – No Sensors	**Difference**
7 AM	15	15	0
8 AM	10	15	**-5**
9 AM	5	15	**-10**
10 AM	5	15	**-10**
11 AM	10	15	**-5**
12 PM	10	15	**-5**
1PM	10	15	**-5**
2 PM	10	15	**-5**
3 PM	15	15	0
4 PM	15	15	0
5 PM	15	15	0
6 PM	15	15	0

Table 10.10.1 – Number of Fixtures On by Hour for September 22, 2009 for Designed and Proposed Layouts

Each fixture contains two 32WF32T8 lamps and one instant-start, electronic ballast. The actual energy use per fixture is 55W. Please refer to **Appendix E** for the product data sheets of these items.

10.11 Construction Cost and Schedule Considerations

Cost

The proposed lighting layout did not change the number or type of lighting fixtures. Therefore, the only additional cost to the owner would be the light level sensors. A sensor could cost between $100 and $200. The rooms are also rather long so two sensors would be needed per room. A total of 66 light level sensors would be needed to effectively equip the Integrated Science Center. This would be at least an additional $6,600 plus installation costs. The sensors would pay back themselves in 5.3 years.

Schedule

The photosensors would not cause any delay or extra time in the schedule. They are readily available through a manufacturer and therefore not a long lead item. The design phase would be heavily impacted by daylighting techniques. If incorporating daylighting is of interest to the owner, it should be addressed in the initial schematic phase of the facility. Architects and lighting designers need to work together to create a system that works both aesthetically and electrically.

10.12 Conclusion and Recommendations

Assuming each fixture remains on the full hour and that the light level sensors are not manually overdriven, the electricity savings provided by use of daylighting can be estimated. The following table compares the energy consumption and operation costs between a laboratory with light level sensors and a lab without sensors.

	Proposed: sensors	**Designed:** no sensors	**Difference**
Number of Fixtures On/day	135	180	**-45**
Actual Energy Use/Fixture	55 W	55 W	-
Total Wattage/Room	7,425 W	9,900 W	**-2,475 W**
Cents /Kw	7.31 [9]	7.31 [9]	-
Energy Cost/Room	$0.54	$0.72	**-$0.18**
Number of Rooms	33	33	**-**
Electric Cost/day	$17.91	$23.88	**-$5.97**
Average Number of Partly Cloudy or Nicer Days/year	209 [10]	209 [10]	**-**
Estimated Annual Electricity Costs	**$3,743.47**	**$4,991.29**	**-$1,247.82**

Table 10.10.2 – Designed and Proposed Layout Energy and Cost Comparison

[9] Electricity costs for Virginia -http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_a.html

[10] Williamsburg's weather (annual average) - http://www.weather.com/weather/wxclimatology/monthly/graph/23185

Using the illumination data from AGi32, the amount of fixtures that would automatically turn off due to daylighting can be found for each hour natural light is present. This was multiplied by the actual energy use per fixture and the number of laboratory spaces in the ISC to get the daily energy savings. When lights are remained on during daylight hours (no sensors) 326,700 W of energy are consumed in the laboratories. If daylight sensors are used, only 245,025 W of electricity is used, a **savings of 81,675 W**. This is a **25**% **energy reduction** for the lab spaces.

When running the AGi32 analysis, cloudy skies were assumed to provide a conservative model. According to weather.com, the average number of partly cloudy days (or nicer) in Williamsburg, Virginia is 209 days per year. This was used to make an approximate estimate of annual electrical savings. The incorporation of daylighting to the lighting system through the use of light level sensors would reduce the annual electricity costs by approximately **$1,247.82**.

Based on the above analysis, I would advise the owner to consider the installation of light level sensors to encourage “green” construction on the College of William and Mary campus. The designed windows are large enough to implement this daylight technique and would result in significant electrical cost savings. The estimated annual savings calculated above was based off a few assumptions so I would not be surprised if actual savings would be greater than $1,250 a year. For additional savings, dimming ballasts or occupancy sensors could also be considered.

11| Solar Heat Gain and Cooling Load Reduction

AE Mechanical Breadth

11.1 Introduction

The previous analysis described the many benefits of using natural lighting in indoor spaces. In addition to energy savings, daylit spaces have been associated with positive worker benefits such as increased productivity, reduced levels of stress, and better worker attitude. The large windows used in the Integrated Science Center facility provide improved daylighting to the spacious laboratories. In Rogers Hall however, these windows are not lighting large laboratory areas but small office spaces. During the daytime, solar radiation through the windows causes significant heat gains in these smaller spaces resulting in increased cooling loads. By installing window shading devices, solar heat gains are mitigated while enough daylight is transmitted to reduce the need for artificial lighting and its resulting cooling loads.

Exterior overhangs serve as shading devices, preventing solar gain from entering the building which results in reduced cooling loads. A properly sized window overhang on the south-facing windows can reduce energy use by 6% [11]. They also block the majority of direct sunlight, providing shade underneath the window and provide a better view.

11.2 Problem Statement

The small offices facing the south each contain one large window which results in significant heat gain and glare caused by sunlight streaming into the building. Solar energy passes through the glass, is absorbed by materials within the room, and then transformed into heat that must be removed by the air conditioner. Keeping unwanted heat out is not only a comfort issue but also an economic one. When heat from the sun is effectively eliminated or controlled through the use of shading strategies, the cooling load on the mechanical system is reduced.

11.3 Goal

The purpose of this study is to provide a shading strategy on the south facing windows to reduce the direct solar radiation into the offices and thus decreasing the cooling loads for the building. This requires an analysis of the current solar penetration through the windows as well as the solar penetration after a shading device is applied. Cooling loads for both options will be calculated using the CLTD/SCL/CLF method as described in the 1997 ASHRAE Handbook of Fundamentals. All other cooling factors, other than solar load, will remain constant. This analysis complements the previous studies and will include the possible energy and cost savings as well as the construction impacts.

[11] Overhangs - http://greenbuildings.santa-monica.org/Content/envelope/envshading.html

11.4 Methodology

1. Explore possible techniques to reduce cooling loads
2. Research the benefits of reducing the amount of direct sunlight and its effect on cooling loads
3. Talk to faculty and industry members for advice and guidance on the subject
4. Calculate solar angles for Williamsburg, Virginia
5. Use computer programs to calculate the amount of daylight into the room with and without a shading device
6. Compare the effects of shading devices on the amount of solar penetration through the windows
7. Calculate the differences in cooling loads
8. Determine any energy savings provided by using shading features
9. Determine cost and schedule impacts of implementing the new design.
10. Come to a conclusion and make recommendation about whether the shading device would be a reasonable investment

11.5 Tools and Resources

1. Rogers Hall existing construction documents
2. Penn State AE faculty and 5th year mechanical students
3. Internet articles and online sources on exterior window overhangs, solar reflectance, space heat gain and cooling loads
4. AutoCAD 2008
5. AGi32 Lighting and Electrical computer software
6. 1997 and 2001 ASHRAE Handbook of Fundamentals

11.6 Expectations

The designed window configuration results in large amounts of direct sunlight to enter small rooms resulting in considerable heat gain, especially during the summer months. By incorporating shading techniques to the south facade, solar gain and glare will be greatly reduced, substantially lowering the building’s energy needs. This would result in operational cost savings as well as possibly reducing equipment costs (due to smaller size equipment being needed). Shading would also provide an improved environment for the building occupants by reducing glare and increasing comfort. Although the cooling loads would be reduced, I do not believe they will be significant enough to be considered by the owner. The new shading devices would not fit in with the standard W&M architecture of the adjacent buildings, a factor in design.

11.7 Research on Solar Heat Gain and Cooling Loads

Heat Gain

Heat gain is the rate at which energy is transferred to or is generated within a space. It usually occurs in the following forms:

1. Solar radiation through openings
2. Heat conduction through exterior walls, roofs, internal partitions, ceilings, and floors
3. Heat generated within the space by occupants, lights, appliances, and equipment
4. Ventilation (outside air) and infiltration air

This analysis will focus on the transmission of solar radiation through fenestration. The total heat admission through glass is

Total heat gain = Solar heat gain + Conduction heat gain[12]

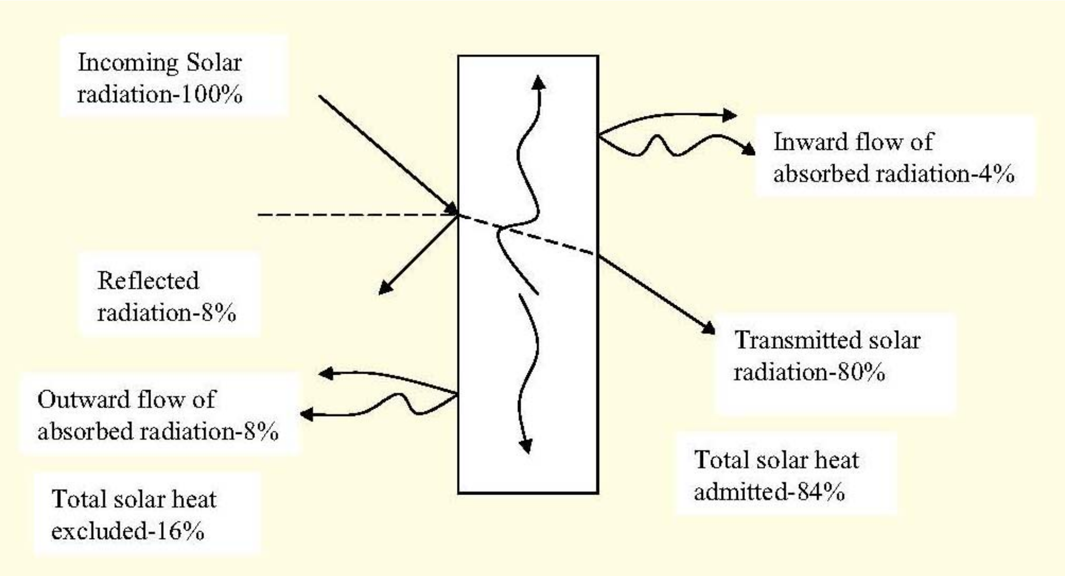


Figure 11.7.1[10] – Solar Radiation through Fenestration

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[12] Solar radiation through fenestration - http://www.ninfee.net/UserFiles/File/ZHENQIAN_Space%20Heat%20Load%20and%20Cooling%20Load.pdf

Cooling Loads

Cooling load is a rate at which energy must be removed from a space to maintain the temperature and humidity at the design values. The total building cooling load consists of heat transferred through the building envelope (windows, walls, roof, doors etc.) and heat generated by occupants, equipment, and lights.

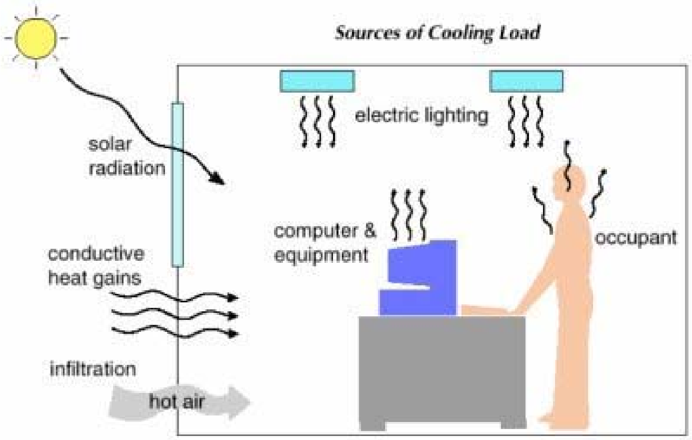

Figure 11.7.1[13] - Sources of Cooling Loads

The cooling load will generally differ from the heat gain because most of the radiation heat is first absorbed by internal surfaces. Due to the thermal capacity of the roof, floor, walls, etc. their temperature increases slowly due to the absorption of radiant heat. This produces a time lag and the effect of radiation will be felt even when the source of radiation (the sun) is removed.

The CLTD/SCL/CLF Method

(Cooling Load Temperature Difference/Solar Cooling Load/Cooling Load Factor Method)

As mentioned before, the heat gain to the building is not converted to cooling load instantaneously. The CLTD/SCL/CLF method is a simplified way to calculate cooling loads manually. The CLTD accounts for the lag in heat transfer through the wall or roof. SCL accounts for the variation of the solar heat gain with time, the massiveness of the structure, and the geographical location. The CLF accounts for the thermal response of the space to various internal gains.

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[13] Sources of Cooling Loads - http://me.lsu.edu/~meniki/me4643/downloads/COOLING%20LOAD%20%20%20LECTURE%20OUTLINE.pdf

[14] Solar heat gain factors - http://books.google.com/books?id=OpD226SXKisC&pg=PT1373&lpg=PT1373&dq=solar+heat+gain+factor+for+shaded+window&source=bl&ots=IavdV37qYq&sig=e0GO8hu_D0UVReFmfFjWKenJl-A&hl=en&ei=OIDYSZDeMKDUlQfi7NzVDA&sa=X&oi=book_result&ct=result&resnum=2#PPT1373,M1

Focusing on the solar heat gain portion, the window cooling load has two components: conductive and solar.

Conductive: $\mathbf{q_{win\,(con)} = U \cdot A \cdot CLTD_{win\,c}}$ [15]

Solar: $\mathbf{q_{win\,(sol)} = A \cdot (SC) \cdot (SCL)}$ [15]

Conductive:

Step 1) Determine U value

2) Select $CLTD_{win}$ from ASHRAE Table 34

3) Corrections

$$CLTD_{win\,c} = [CLTD_{win} + (78 - T_R) + (T_M - 85)]$$

$(78 - T_R)$ = indoor design temperature correction

$(T_M - 85)$ = outdoor design temperature correction

Mean Outdoor Temp $(T_m) = T_{MAX} - (\text{Daily range}) / 2$

T_{MAX} = Maximum outdoor temperature

4) Determine area from architectural plans

5) $q_{win\,(con)} = U \cdot A \cdot CLTD_{win\,c}$

Solar:

Step 1) Determine shading coefficient (SC) from ASHRAE Tables 15-21 Chapter 29

2) Determine zone type from ASHRAE Tables 35B

3) Determine solar cooling load (SCL) from ASHRAE Table 36

4) Determine area from architectural plans

5) $q_{win\,(sol)} = A \cdot (SC) \cdot (SCL)$

Non-uniform exterior shading, caused by roof overhangs or side fins, must be handled differently. Separate calculations for the externally shaded and unshaded areas are required. The SCL for the north orientation is a close approximation for the shaded glass area at latitudes greater than 24°. Williamsburg falls into this category; therefore, the northern SCL will be used for the shaded areas. The cooling load equations for a window with an overhang are as follows.

$$\mathbf{q = q_{unsh} + q_{sh}}$$

$$\mathbf{q = (A_s \times SHGF \times SC) + (A_{sh} \times SHGF_{sh} \times SC)}$$ [14]

A_s, A_{sh} = sunlit and shaded areas of glass (ft^2)

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[15] Conductive and solar cooling load equations - http://me.lsu.edu/~meniki/me4643/downloads/COOLING%20LOAD%20%20%20LECTURE%20OUTLINE.pdf

11.8 Shading Devices

There are two types of shading strategies: indoor shading devices and outdoor shading devices. Commonly used internal shading techniques include blinds, roller shades, and drapes. External shading devices incorporate the installing overhangs, side fins, louvers, and patter grilles to the roof or façade. All strategies reduce the sunlit area of the window glass effectively and therefore decrease the solar heat gain. By preventing excess solar heat gain, cooling loads are reduced cutting air conditioning bills. For this study, overhangs were selected as the means of window shading.

A well designed overhang can shade south facing windows from the high summer sun while still allowing the low winter sun to shine in and provide welcome solar heating. Overhangs are not effective on east or west facing windows because the sun is too low in the morning and afternoon for an overhang to provide any effective shade. They usually only affect the amount of direct solar radiation that strikes a surface; reflected radiation gains are not directly affected.

There are various overhang options available. They may be solid, louvered, or vegetation-supporting. Overhangs may also be fixed, operable, or removable. This study assumes a solid, fixed overhang located directly above the window. The solstices and equinoxes for Williamsburg, Virginia were calculated and the shadow lines were applied to window/wall section of a typical office space. Please see figures below. The summer solstice shadow line was located at the bottom of the sill to determine a minimum overhang length of 1’ 5-1/2”.

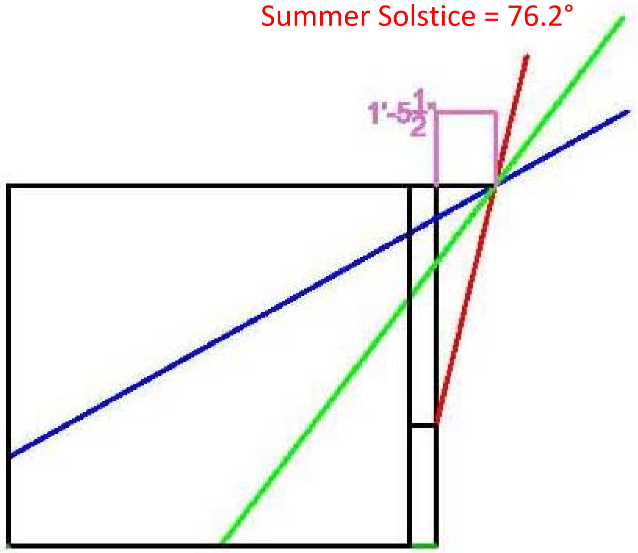

Figure 11.8.1 – Sun Angles through Typical Office Space in Rogers Hall

<u>Typical Office Layout</u>

- Size: 12’-6” x 10’-0”
- Ceiling Height: 9’-0”
- Window: (1) 5’-0” x 6’-0”

Sun Angle Equations

Angle of sun away from vertical = 90⁰ - sun angle (above horizon) [16]

Solar noon zenith angle = latitude – solar declination [16]

- Latitude (Williamsburg, Virginia) = 37.3
- Solar declinations
  - Summer solstice = 23.5
  - Winter solstice = -23.5
  - Equinoxes = 0

11.9 Cooling Load Technical Write-up and Calculations

The following are the steps and sample calculations used to determine the cooling loads for a sunlit window throughout a 24 hour day. The cooling loads for the same window but with an external shade will also be calculated. The maximum cooling loads for each situation will then be compared to determine an approximate amount of energy saved through the reduction of solar radiation through the window. This study focuses exclusively on the heat gain through fenestration. All other factors that go into the total cooling load (such as heat generated by equipment occupants, etc.) will be assumed to constant because they are not affected by the installation of an overhang and will be the same in both scenarios.

****NOTE:** The solar cooling load (SCL) is required to calculate the solar cooling load. The SCL for a particular zone is dependent on latitude, direction and internal zone parameters, which affect the absorption and release of radiant heat. *The Cooling and Heating Load Calculation Manual Second Edition* (1992) by Faye McQuiston and Jeffery Spitler contained SCL tables for three latitudes; 24, 36, and 48° north; and one month, July. According to this source, supplementary tabular data would have to be generated for other months. I was unable to find any information regarding a means to produce these tables other than using a computer software called SHADE. This affected my original goal of calculating the annual cooling load and cost savings provided by shading the south facing windows. A footnote below the SCL table says that the "data will suffice for about 2 weeks from the 21st day of the given month."[17] To get a general idea of the savings provided by external shading, I will calculate the savings over this two week period.

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[16] Sun Angle Calculations - http://scienceworld.wolfram.com/astronomy/topics/Sun.html

[17] Faye McQuiston and Jeffery Spitler's *Heating Load Calculation Manual Second Edition* (1992)

The following are weather and design conditions for Williamsburg, Virginia necessary for cooling calculations. Please refer to **Appendix H** for tables from *Heating Load Calculation Manual Second Edition* (1992) used in the CLTD/SCL/CLF Method.

Weather Data and Design Conditions[17]	
City:	Williamsburg
State:	Virginia
Latitude:	37.3° N[18]
Longitude:	76.7° W[18]
Maximum Temperature:	99° F
Mean Daily Range:	20

Table 11.9.1 – Weather Data and Existing Design Conditions for Williamsburg, Virginia

Cooling Load for Sunlit Window (existing)

Conductive: $q_{\text{win (con)}} = U \cdot A \cdot CLTD_{\text{win c}}$

$U = 0.4$ for existing double pane window
$A = 30\ ft^2$ exposed glass area

$CLTD_{\text{win c}} = [CLTD_{\text{win}} + (78 - T_R) + (T_M - 85)]$

$CLTD_{\text{win}} = 9°F$ at 12 PM (noon)
$T_R = 70\ °F$ *Assume room temperature of 70°F
$T_M = 99°\ F$
$CLTD_{\text{win c}} = [9 + (78 - 70) + (99 - 85)]$
$CLTD_{\text{win c}} = 31°F$

$q_{\text{win (con)}} = (0.4)\ (30)\ (31)$
$\mathbf{q_{\text{win (con)}} = 372\ Btu/h}$

Solar: $q_{\text{win (sol)}} = A \cdot (SC) \cdot (SCL)$

$A = 30\ ft^2$ exposed glass area
SC = 0.88 (Table 8.10[17])
SCL = 71 (Table 8.9B[17])

$q_{\text{win (sol)}} = (30)\ (0.88)\ (71)$
$\mathbf{q_{\text{win (sol)}} = 1874.4\ Btu/h}$

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[18] Latitude and longitude of Williamsburg - http://www.terraserver.com/view.asp?cx=347811.315165605&cy=4126237.26883864&proj=32618&mpp=0.75&pic=-1&prov=-1&stac=-1&styp=AD

SC = 0.88 (Table 8.10[17])

- Double insulating glass
- Nominal thickness of each light = 1/8
- Transmittance = 0.71

Solar Glass Zone Type = B (Table 8.8C[17])

- 4 walls
- Carpet flooring
- 2.5 in. concrete floors
- With ceiling
- Gypsum partitions
- No inside shade

SCL = 71 (Table 8.9B[17])

- Zone Type B
- Glass facing south
- 36 ° North Latitude
- July 21st
- 12 PM (noon)

Total heat gain = Solar heat gain + Conduction heat gain

$q_{total} = 1874.4 + 372$

$\mathbf{q_{total} = 2246.4}$ **Btu/h** * at 12 PM (noon)

Cooling Load for Sunlit Window with External Shade (existing)

Conductive: $q_{\text{win (con)}} = U \cdot A \cdot CLTD_{\text{win c}}$

U = 0.4 for existing double pane window
$A = 30\ ft^2$ exposed glass area

$CLTD_{\text{win c}} = [CLTD_{\text{win}} + (78 - T_R) + (T_M - 85)]$

$CLTD_{\text{win}} = 9°F$ at 12 PM (noon)
$T_R = 70\ °F$ *Assume room temperature of 70°F
$T_M = 99°\ F$

$CLTD_{\text{win c}} = [9 + (78 - 70) + (99 - 85)]$
$CLTD_{\text{win c}} = 31°F$

$q_{\text{win (con)}} = (0.4)\ (30)\ (31)$
$\mathbf{q_{\text{win (con)}} = 372}$ **Btu/h**

Solar: $q_{\text{sol total}} = q_{\text{sh}} + q_{\text{unsh}}$

12 PM July 21 = 66.76°[19]

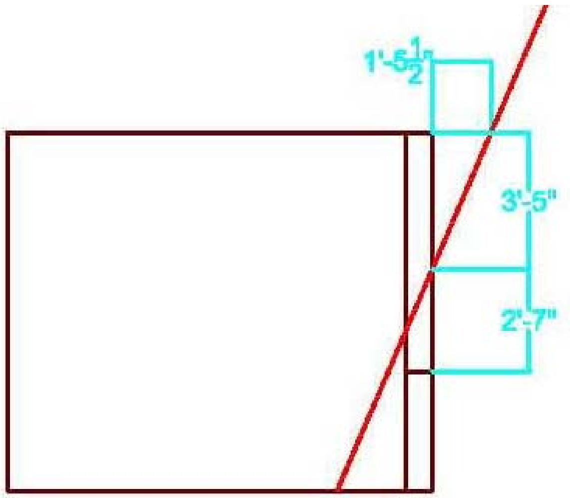

Figure 9.11.1 - Sun Angle on July 21

$q_{\text{unsh}} = A_{\text{unsh}} \cdot (SC) \cdot (SCL)_{\text{unsh}}$

$A_{\text{unsh}} = 12.92\ \text{ft}^2$ exposed glass area
SC = 0.88 (Table 8.10[17])
SCL = 71 (Table 8.9B[17]) *south SCL

$q_{\text{unsh}} = (12.92)\ (0.88)\ (71)$
$\mathbf{q_{\text{unsh}} = 807.2\ Btu/h}$

$q_{\text{sh}} = A_{\text{sh}} \cdot (SC) \cdot (SCL)_{\text{sh}}$

$A_{\text{sh}} = 17.08\ \text{ft}^2$ exposed glass area
SC = 0.88 (Table 8.10[17])
SCL = 38 (Table 8.9B[17]) *north SCL

$q_{\text{sh}} = (17.08)\ (0.88)\ (38)$
$\mathbf{q_{\text{sh}} = 571.2\ Btu/h}$

$q_{\text{sol total}} = q_{\text{unsh}} + q_{\text{sh}}$
$q_{\text{sol total}} = 807.2 + 571.2$
$\mathbf{q_{\text{sol total}} = 1378.4\ Btu/h}$ * at 12 PM (noon)

$q_{\text{total}} = q_{\text{sol}} + q_{\text{con}}$
$q_{\text{total}} = 1378.4 + 372$
$\mathbf{q_{\text{total}} = 1750.4\ Btu/h}$ * at 12 PM (noon)

	$q_{\text{conductive}}$ (Btu/h)	q_{unshaded} (Btu/h)	q_{shaded} (Btu/h)	q_{total} (Btu/h)
Proposed – Window with Shade Device	372.0	807.2	571.2	1750.4
Designed – Window without Shade Device	372.0	1874.4	0	2246.4
Difference	**0**	**-1067.2**	**571.2**	**-496.0**

Table 9.11.2 – Cooling Loads for July 21st at 12 PM

Table 9.11.2 compares the conductive, solar, and total cooling loads for a room with a window shading device and a room without on July 21st at 12 PM. Even though the data applies only one hour of one day, energy savings can be seen. As seen above, only the solar cooling load is affected by shading.

[19] Sun angle determination - http://www.geocities.com/senol_gulgonul/sun/

[20] National Propane Gas Association's energy costs - http://www.npga.org/i4a/pages/index.cfm?pageid=914

11.10 Cooling Load Comparison

Using the same calculations as the previous section, the total cooling load for the designed and proposed systems were calculated for each hour on July 21, 2009.

	q_{total} (Btu/hr) Proposed – Window with Shade Device	**q_{total} (Btu/hr) Designed –** Window without Shade Device	**Difference (Btu/hr)**
1 AM	328.80	328.80	0
2 AM	316.80	316.80	0
3 AM	278.40	278.40	0
4 AM	266.40	266.40	0
5 AM	266.40	266.40	0
6 AM	424.80	424.80	0
7 AM	621.70	609.60	12.10
8 AM	828.67	818.40	10.27
9 AM	1097.97	1106.40	-8.43
10 AM	1462.97	1552.80	-89.83
11 AM	1715.48	1958.40	-242.92
12 PM	**1750.40**	2246.40	-496.10
1 PM	1598.20	**2308.80**	-710.60
2 PM	1645.95	2136.00	-490.05
3 PM	1602.22	1804.80	-202.59
4 PM	1443.45	1514.40	-70.95
5 PM	1147.20	1147.20	0
6 PM	1077.90	1041.60	36.3
7 PM	730.50	727.20	3.30
8 PM	597.97	597.60	0
9 PM	520.80	520.80	0
10 PM	444.00	444.00	0
11 PM	405.60	405.60	0
12 AM	367.20	367.20	0
Daily Total	**21083.67 Btu**	**23332.80 Btu**	**-2249.13 Btu**

Table 11.10.1 – Cooling Load Comparison for July 21, 2009

Table 11.10.1 shows the total cooling load due to fenestrations for two similar office spaces, one containing a window with a shading device and one without. As seen above, the peak cooling load for the room originally designed window without an overhang is **2308.8 Btu/hr**. For the same room but containing a window with an overhang, the peak cooling load is only **1750.4 Btu/hr**. This is a difference of **558.4 Btu/hr**. The overhang reduced the daily total cooling load by **2249.13 Btu**. This is a **9.6%** reduction.

There are 22 rooms located on the south façade. By installing an overhang, the cooling load would be reduced **49,480.86 Btu** on July 21st and **692,732.04 Btu**'s of energy would be saved over two weeks. Natural gas costs approximately $1.218/therm (100,000 Btu)[20]. Just looking at the 2 week period studied in this analysis, operation cost savings would be **$8.44**.

11.11 Construction Cost and Schedule Considerations

Cost

The material and labor costs are directly related to the size and type of overhang desired. The south façade faces a commonly driven road through Williamsburg so it would be of interest to the college to have the design be aesthetically pleasing. Due to the variety of overhang options, the cost is difficult to estimate. According to the Santa Monica Green Building Program, a single overhang could run approximately $100[9].

Schedule

The installation of overhangs on the south façade of Rogers Hall would not have any impact on the overall construction schedule. There are only 22 windows and overhang construction would be occurring on the building exterior at the same time as the interior renovation. New window installation is the only activity to be coordinated with.

11.12 Conclusion and Recommendations

The original objective for this analysis was to calculate the annual cooling loads for the two window designs, with and without an overhang, and then determine the energy cost savings per year. Due to limited information, I was only able to determine the hourly cooling loads for July 21st. A footnote below the SCL table says that the "data will suffice for about 2 weeks from the 21st day of the given month."[15] So the figures calculated in this analysis are the daily cooling loads for July 21st through August 4th. The months of July and August are usually brutally hot and humid, so the cooling loads calculated will peak at this time. Using this information, I can still draw some conclusions and make recommendations about whether installing overhangs above the south facing windows would be economically feasible.

The overhangs would, without a doubt, reduce the daily cooling loads and result in energy consumption and operational cost savings. July 21st alone results in an energy reduction of **2249.13 Btu** when a shading device is in place. Because this data is adequate through August 4, this results in a saving of **31,487.82 Btus** over a 2 weeks period. Multiplied by 12 for the total number of offices on the south façade, **377,853.84 Btu**'s of energy is saved. The overhang also results in lowering the peak cooling load. On July 21st, the largest cooling load required is **2308.8 Btu/hr** for an office containing a window without a shading device. For the same room but with a window overhang, the peak cooling load is only **1750.4 Btu/hr**, a difference of **558.4 Btu/hr**.

Based on the July 21st data, the shading device produces **9.5%** reduction in energy during the summer. This percentage may be a little high for the annual energy savings but it would be close. July 21st falls in the middle of the warmest months. Because

Williamsburg will experience warmer and cooler days than typically on July 21st, the energy reduction will balance out around this 9.5%.

Even though the overhangs would reduce the required cooling loads and decrease the cost for energy, I would not recommend them to be placed on the Rogers Hall façade. Savings are insignificant when the entire building is considered and would not be realized for many years. Just looking at the 2 week period studied in this analysis, operation cost savings for the 22 rooms on the south façade would be **$8.44**. It would take years to pay off the initial costs of material and installation. From an architecture standpoint, the new overhangs would not fit in with the typical W&M style of the adjacent buildings. College of William and Mary campus is protecting its colonial architectural consistency. Window overhangs would not be aesthetically pleasing nor do they blend in with the other buildings on campus.