Georgetown University New Science Center

Final Thesis Proposal

PENN STATE UNIVERSITY

Prepared For:
Dr. William P. Bahnfleth
Department of Architectural Engineering

Prepared By:
Kevin M Edstrom
Mechanical Option
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GEORGETOWN UNIVERSITY NEW SCIENCE CENTER

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Executive Summary

This report outlines the proposed thesis topics pertaining to the design and construction of the New Science Center of Georgetown University. The proposed topics include a modified a make-up air configuration for lab spaces, integration of a Ground Source Heat Pump (GSHP), an improved natural daylighting strategy, and construction impacts relating to these design changes.

The existing mechanical system of the New Science Center implements various energy saving methods and technologies. It was found to be highly energy efficient, as expected from a LEED Silver project. The design changes proposed address aspects of the existing design that have potential for improvement in operating cost savings, energy savings, and reduced environmental impacts.

The modified makeup air system will use transfer air from non-hazardous spaces (primarily offices) to be used as make-up air for labs. This addresses the large amount of energy consumed in the labs due to the strict air-change rates and fume-hood exhaust rates.

A GSHP will utilize geothermal energy to reduce the thermal loads within the building. This will reduce the demand on the district chilled water and steam plant, which as a result will save energy, reduce pollution, and save in operating costs.

Implementing double height windows in offices and labs will allow additional light to enter the building, greatly reducing the building's lighting power density. Several technologies will be considered for proper lighting design, including shading devices and sensors with automatic dimming ballasts.

The final topic addressed is construction impacts relating to the previous three topics. Schedule and coordination challenges of each design change will be addressed. Particular attention will be put on the construction of the geothermal wells and rerouting parts of the mechanical distribution systems to accommodate for the double height windows.

Various tools and methods will be used to analyze each of these topics, including energy modeling and simulation software, life-cycle cost analysis, equipment sizing software, lighting modeling software, and additional research from design guides, handbooks, and publications.

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Introduction

The New Science Complex is a 154,000 SF research and teaching facility being built on the Georgetown University campus in Washington, DC. The building is to house the Physics, Biology, and Chemistry departments. It will consist primarily of labs, classrooms, offices, and conference rooms. The building stands five stories above grade and is designed to achieve LEED Silver Certification.

This report will provide a brief description and evaluation of the existing mechanical system design, followed proposal for design alternatives for future thesis research.

Mechanical System Summary

Design Criteria and Objectives

Site Conditions

Climate conditions of the building's location have a large impact on the design of the mechanical system and equipment. The New Science Center is located in Washington, DC. Outdoor design conditions for this location vary drastically throughout summer and winter seasons. The heating and cooling systems must accommodate a wide range of outdoor air conditions. The values listed in Table 1 are outdoor design conditions from ASHRAE Handbook of Fundamentals 2009 for the Washington, DC area.

TABLE 1

ASHRAE Weather Data for Washington, DC*		
	DB Temp [°F]	WB Temp [°F]
Summer Design (0.4%)	93.5	75.1
Winter Design (99.6%)	10.7	-

* Washington DC Dulles International Airport

Energy sources for mechanical systems are typically dependent on availability, cost, and system characteristics. Since the New Science Center is to be a part of the Georgetown University campus, the system is to be integrated into the district steam and chilled water plant of the university. The Georgetown University district plant consists of three gas/oil fired high pressure boilers, eight electric motor driven chillers, and a thermal storage tank. In this building's case, the system characteristics and equipment within the building were chosen based on the energy source (district steam and chilled water).

Client Goals and Requirements

Georgetown University is building the New Science Center to expand and upgrade their existing Physics, Biology, and Chemistry departments. As required by the client and code, these spaces are to provide a safe, healthy, and comfortable environment for the students and teachers occupying them.

All new buildings at Georgetown University are required to achieve a minimum of LEED Silver certification to comply with the campus planning and sustainability initiatives. This affected many aspects New Science Center's mechanical system, envelope, building materials, and construction.

The Georgetown University utilities department requires the system to tie into the existing district steam and chilled supply. This has a large influence on the system and equipment chosen for the mechanical design. GU utilities also requires a specific subcontractor and manufacturer to be used to integrate the Building Automation System and controls with the campus monitoring and operations system.

Another important concern of the client is the costs involved in the mechanical design. This includes both capital cost and operating costs. Money is often the limiting factor when it comes to efficiency and sophistication of mechanical systems. Generally, a higher initial investment in the system and equipment will lead to decreased operating costs and long term savings. Investing in sustainable technologies improves the client's public image for being environmentally conscious.

Program and Layout

The building will consist of primarily of lab, classroom, and office spaces. Each space has unique loads, however particular attention must be put towards the lab spaces within the building. Proper ventilation and exhaust are essential in proper design of lab spaces.

Table 2 contains indoor air temperature setpoints based on space usage as defined in the contract documents.

TABLE 2

Indoor Design Setpoints [°F]	
Office, Circulation Spaces & Toilet Rooms	
Occupied cooling	75
Occupied heating	70
Unoccupied cooling	78
Unoccupied heating	65
Laboratory and Lab Equipment Spaces	
Occupied cooling	74
Occupied heating	72
Unoccupied cooling	78
Unoccupied heating	68

In Technical Report 1: *ASHRAE Standard 62.1 and 90.1 Compliance Report* minimum ventilation rates were determined based on the ventilation rate procedure of ASHRAE 62.1. The minimum total ventilation requirement for this building according to ASHRAE Standard 62.1 is 32,465 cfm. The designer ventilation rates are not available; however the airflow rate for the building is known to be "exhaust driven," meaning ventilation rates as designed will easily exceed ASHRAE requirements.

Heating and cooling loads of the building were estimated in Technical Report 2: *Building and Plant Energy Analysis Report*. The peak heating and cooling loads were determined to be 1,462 MBh and 230 tons, respectfully. These values were calculated using Trane TRACE 700 energy modeling software. Many assumptions were taken into account to determine these values. See Technical Report 2: *Building and Plant Energy Analysis Report* for an in-depth description and justification of these assumptions.

Existing Systems and Equipment

The building is conditioned by (4) Air Handling Units, active chilled beams, fan coil units, and steam and hot water unit heaters. The AHUs supply 100% outdoor air to all occupied spaces within the building. The chilled beams are used in offices, physics and biology labs, conference rooms, computer labs, and some of the lounges. Fan coil units provide for supplemental thermal load requirements of chemistry labs. Steam and hot water unit heaters are used in emergency stairwells, entrance vestibules, the loading dock, and the mechanical penthouse.

Air Handling Units

Four identical built-up AHUs supply 100% outdoor air throughout the building. These are custom designed and engineered by Haakon Industries. Each contains four mixed-flow fans powered by electric motors with Variable Frequency Drives. Two fans are configured in parallel for supply air and two in parallel for exhaust for each AHU. Fan staging and VFDs adjust the airflow capacity to the meet the amount required by the building. This saves electrical energy consumption by reducing the power used by the motors at part load. Each AHU has a capacity range of 50,000 cfm to 15,000 cfm. Supply air from all four AHUs enters a common plenum from which it is distributed throughout the building through a ducted system. All AHUs were sized for 15% additional capacity for future growth.

Each AHU also contains a heating and cooling coil, a steam humidifier, and an enthalpy recovery wheel. The enthalpy wheel provides sensible and latent energy recovery from the exhaust air to the supply air, reducing the loads on the heating and cooling coils.

TABLE 3

Air Handling Units – Fan Schedule						
	Supply fans			Exhaust fans		
	capacity [cfm]	motor HP	control	capacity [cfm]	motor HP	control
AHU-1	54,402	2@50	VFD	54,402	2@40	VFD
AHU-2	54,402	2@50	VFD	54,402	2@40	VFD
AHU-3	54,402	2@50	VFD	54,402	2@40	VFD
AHU-4	54,402	2@50	VFD	54,402	2@40	VFD

TABLE 4

Air Handling Units – Preheating/Cooling						
	Preheat HW Coil		Cooling Coil		Enthalpy Wheel	
	EWT [°F]	GPM	EWT	GPM	Effectiveness Sens.	Effectiveness Latent
AHU-1	80	80	45	398.8	76%	74%
AHU-2	80	80	45	398.8	76%	74%
AHU-3	80	80	45	398.8	76%	74%
AHU-4	80	80	45	398.8	76%	74%

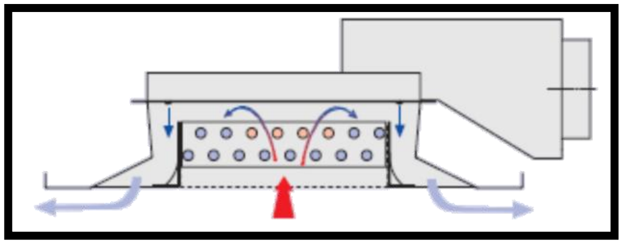
Variable Air Volume terminal units

VAV terminal units are used throughout the building to adjust airflow based on load and ventilation requirements of each zone. This improves efficiency and control of the air handling system and saves energy by reducing fan power during part load. These are also essential in maintaining proper pressurization of critical spaces within the building to prevent infiltration of hazardous contaminants into adjacent spaces. VAV supply and exhaust boxes are used throughout the offices, recitation spaces, and conference rooms. Special VAV valves are used in lab spaces for more precise control of ventilation and exhaust rates. The VAV terminal units specified vary based on the airflow range to each space. Most supply VAV terminal units used throughout the building include hot water re-heat coils.

Active chilled beams

Four-pipe, active chilled beams are used in all office, lounge, recitation, conference, and biology and physics lab spaces. These serve the remainder of the sensible heating or cooling loads that are not met by the AHU coils. The models used vary in length and nozzle size depending on the design load and ventilation requirements of each space.

FIGURE 1 - CHILLED BEAM DETAIL



Pumps

All pumps used in the mechanical system design utilize Variable Frequency Drives. This saves motor energy when operating at part load. Some pumps are configured in parallel to increase efficiency at part loads and for redundancy. The pump schedule can be found in Table 5.

TABLE 5

Pump Schedule					
Pump	**Service**	**Capacity [gpm]**	**Head [ft]**	**Motor HP**	**RPM**
P-1	Reheat HW	300	85	15	1750
P-2	Reheat HW	300	85	15	1750
P-3	Reheat HW	300	85	15	1750
P-4	Preheat HW	270	50	7.5	1750
P-5	CW Supply	500	85	20	1750
P-6	CW Supply	500	85	20	1750
P-7	CW Supply	500	85	20	1750
P-8	Process CW	240	75	10	1750
P-9	Process CW	240	75	10	1750
CP-1 (2)	Condensate Return	90	-	2@7.5	1750
CP-2 (2)	Condensate Return	90	-	2@7.5	3500

Heat pump recovery unit

Large buildings often have simultaneous heating and cooling loads due to internal heat gains and supply air reheat needs. The designers utilize a water source heat pump system to recover waste heat from the chilled beams' chilled water return. Heat from the chilled water return is transferred to the hot water supply serving reheat coils and chilled beams. Four Multistack modules connected in series make up this system.

Mechanical System Evaluation

The mechanical system selection of the New Science Center provides an energy efficient solution to meet the design requirements of the building. The system contains a comprehensive monitoring and controls system that will allow for minimal maintenance after the initial balancing of the system. Alarms are set to monitor for any variations from normal operation. This will allow campus operators to easily be able to determine when maintenance or cleaning needs to be performed on specific parts of the system.

Various energy savings strategies were utilized in the mechanical system. Some of the technologies used include air-side enthalpy recovery wheels, a water-side energy recovery heat pump, variable frequency drives in pumps and fans, chilled beams to reduce airflow requirements, low-emittance (low-E) glass, high efficiency fume hoods, and vertical and horizontal shading devices. A LEED Silver certification will be the outcome of the integration of these strategies into the system design.

An occupancy schedule and occupancy sensors allow for additional energy savings by lowering temperature setpoints and ventilation/exhaust rates when spaces are not in use. All setpoints and schedules can be adjusted by an operator through the Building Operating System allowing for further control.

One advantage of this project is access to district chilled water and district steam from the campus plant. District plants have many benefits both environmentally and economically. Emissions are easier to control and monitoring from one large plant compared to individual plants. District plants also reduce the number of operators necessary for monitoring and maintaining equipment, increase the usable space within the building by reducing the need of boilers and chillers, and can achieve higher efficiencies than separate plants due to cycling equipment based on load requirements of multiple buildings.

Indoor Air Quality is maintained by providing 100% outdoor air, which passes through MERV 14 filters, to all occupied spaces within the building. Most of the labs are "exhaust-driven" meaning ventilation air requirements easily exceeded by the make-up air requirements of the fume-hoods and air-change rates. Proper pressurization of spaces within the building prevents infiltration from hazardous zones within the building. Pressurization is monitored by the BAS and controlled by VFD supply and exhaust fans and VAV supply and exhaust boxes.

The building has a total of 86 fume hoods. Many of these are "low-flow," VAV fume hoods requiring only 60 fpm face velocities and adjusted based on time-of-day schedules.

Due to the energy intensive equipment and systems that come with any lab building, various opportunities for improved energy savings are available and will be evaluated for this building in future research.

Proposal

The following is a proposal for design change topics for various systems of the New Science Center. The topics described will be researched and analyzed based on the following criteria:

- feasibility
- energy efficiency
- initial costs, operating costs, and life-cycle costs
- practicality

Tools and methods for analysis of proposed topics are described in the next section of this proposal.

Lab Make-up Air

This topic involves transferring return air from offices and non-hazardous spaces into labs as makeup air to save energy in heating, cooling, and humidifying outdoor air.

The current mechanical system utilizes a Dedicated Outdoor Air System. Four AHUs supply and exhaust all air to and from all spaces of the building. This system was chosen by designers to meet the high air change demands of lab spaces, while minimizing the risk of hazardous lab contaminants from reentering the building.

Due to the strict exhaust requirements and fume-hoods, most of the labs in the building are "exhaust driven." Only about half of this total floor area is made up of non-lab spaces allowing for a significant amount of return air to be used for recirculation. This presents an opportunity to save energy by transferring return air from offices and non-hazardous spaces to lab spaces as make-up air for exhaust.

Research for this topic would include an energy analysis comparing the energy savings of both systems, studies on control strategies to maximize energy savings while maintaining safe ventilation requirements, and associated cost analysis and layout of ductwork and fans to operate this system.

Ground Source Heat Pump

A Ground Source Heat Pump (GSHP) utilizes the geothermal energy of the earth as the thermal energy source for heating and cooling equipment. Geothermal energy is a renewable resource that exists naturally within the earth. Soil temperatures vary widely by geographical location, but remain fairly constant throughout the year.

By utilizing a GSHP in the New Science Center, steam and chilled water loads will be greatly reduced. This will save energy and reduce pollution at the district plant. It may also qualify for LEED 3.0 "Green Energy" credits.

For this building, the building loads consist of mostly cooling throughout the year. This means that there will be an imbalance of heat being added to the ground through the wells on a yearly basis, which would ultimately lead to the gradual deterioration of well performance and efficiency. Strategies will be researched and analyzed to balance the annual heat exchange within the wells. Some of these strategies may include a "hybrid" GSHP, and implementing a "peak shaving" strategy in the summer.

A feasibility study of this system will be performed based on the soil and climate conditions of the site, as well as energy and cost analysis to compare savings.

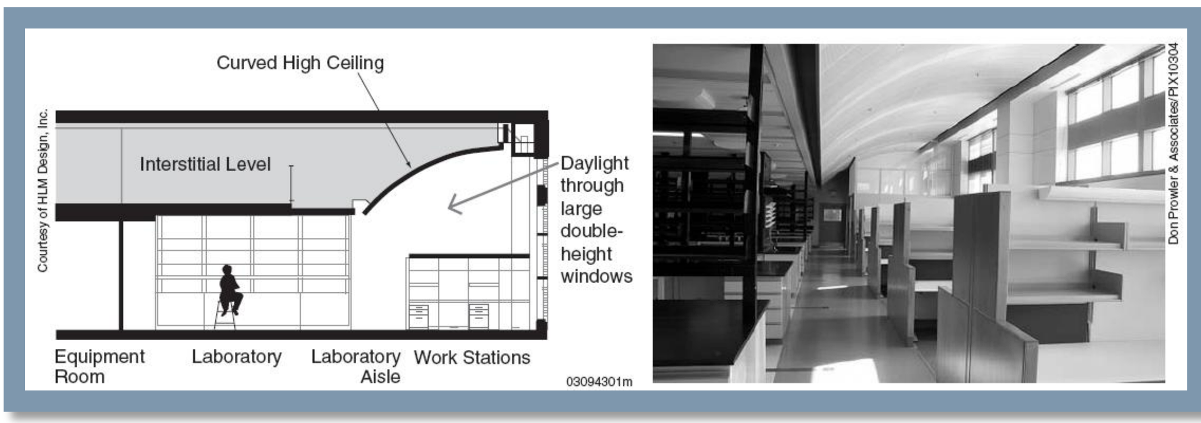
Breadth Topics

Natural Daylighting

This design change will replace the existing windows and glazing system with "double height" windows and a curved high-ceiling to reflect and distribute light throughout perimeter spaces. Most of the windows currently used in the building's design already extend floor to floor, so this design change will mainly affect the reduction of plenum spaces due to the curved-high ceilings. Additional sensors and continuous dimming ballasts may need to be integrated into the building controls system.

Research for this topic will include the feasibility of reducing the plenum space. This may require rerouting mechanical systems which may not be feasible in some spaces. The majority of the perimeter rooms on the east side of the building are labs; while the majority on the left side are offices. Lighting studies will be required to assess any glare and other problems that may lead to discomfort or insufficient lighting in these spaces. Fixed shading devices, automatic shades, revised room layouts, and alternate glazing types may be investigated to address these problems. Electrical energy and cost analysis of this design change will be performed.

FIGURE 2 - DOUBLE-HEIGHT WINDOW DETAIL



Construction Impacts

Construction impacts of the design changes mentioned above will be assessed. Excavation of the geothermal heat pump wells will need to be coordinated early in the project. Depending on the location of these wells, additional coordination may be needed between the wells and the concrete structural caissons. The natural daylighting strategy will lead to less plenum space, which will require rerouting of some of the mechanical system and careful coordination. Schedule impacts due to these design changes will also be evaluated.

Tools and Methods

Energy modeling and simulation data will be used to determine existing loads within the building. Various methods will be considered in comparing the energy consumption and new thermal load requirements of the "transfer air to lab makeup air" and GSHP alterations. Some of these methods include energy modeling simulation software, manual/spreadsheet calculations, and BIN calculations.

Resizing of the mechanical equipment to account for the lab makeup air modification will be performed using Greenheck's Computer Aided Product Selection Program (CAPS). Resizing of heating and cooling equipment will be based on the new thermal load requirements.

Analyzing the proposed natural lighting strategy will involve solar path studies. These may be performed by a computer program such as Autodesk Ecotect Analysis. Lighting simulation software such as Radiance may be used to compare various aspects of the curved high-roof design, alternate room layouts, and shading options. Lighting power density savings will be calculated based on the energy simulation results for different times of year.

Life-cycle cost analysis of both mechanical design alternatives will be performed using National Institute of Standards and Technology (NIST) methodology. Initial costs will be determined by contacting equipment vendors and mechanical contractors, as well as by utilizing RSMeans cost data.

References

- Georgetown University – New Science Center construction documents.
- 2009 ASHRAE Handbook—Fundamentals.
- ASHRAE Standard 62.1-2010.
- ASHRAE Standard 90.1-2010.
- LEED Reference Guide for Green Building Design and Construction, Version 3, 2009 Edition, US Green Building Council.
- Http://www.labs21century.gov/.

Appendix A – List of Figures and Tables

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Appendix B – Preliminary Research

Handbooks:

- 2007 ASHRAE Handbook – HVAC Applications.
  Chapter 8 – Applied Heat Pump and Heat Recovery Systems
  Chapter 32 – Geothermal Energy
- 2008 ASHRAE Handbook – HVAC Systems and Equipment.
  Chapter 6 – Educational Facilities
- NIST Handbook 135 – Life-Cycle Costing Manual for FEMP
- NIST Supplement – Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – 2010

Articles:

- "An Introduction to Low-Energy Design." *Laboratories for the 21st Century*. U.S. Environmental Protection Agency. <http://www.labs21century.gov/>.
- "Daylighting in Laboratories." *Laboratories for the 21st Century*. U.S. Environmental Protection Agency. <http://www.labs21century.gov/>.
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- "Labs21 Environmental Performance Criteria 3.0." *Laboratories for the 21st Century*. U.S. Environmental Protection Agency. <http://www.labs21century.gov/>.
- Mathew, Paul. "Metrics for Energy Efficiency." *ASHRAE Journal* (2008).
- Mescher, Kirk. "Simplified GCHP System." *ASHRAE Journal* (2009).

Appendix C – Proposed Spring Semester Work Schedule