Georgetown University New Science Center

AE481W/AE897G Senior Thesis

Final Report

PENN STATE UNIVERSITY

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

Prepared By:
Kevin M Edstrom
Mechanical Option
April 7, 2011

Georgetown University New Science Center

Washington, DC

Project Team

Owner:	Georgetown University
Contract Manager:	Whiting-Turner Contracting Co.
Architect:	Payette Associates Inc.
Associate Architect:	Martin Reddy Architects
Structural Engineer:	Simpson Gumpertz & Heger
MEP & Fire Protection:	R.G. Vanderweil Engineers Inc.

Project Information

Size:	153,000 SF
Stories:	5
Delivery Method:	Design-Bid-Build
Construction Dates:	May 2010—July 2012

Structural

- Grade beams foundation on concrete caissons up to 120' below grade
- Wide flange structural steel frame
- 6 1/4" LW concrete slab on deck floor system.

Mechanical

- Campus district Chilled Water and Steam implementation
- Four main 50,000cfm Air Handling Units with enthalpy wheels and preheat coils
- Dedicated Outdoor Air System with active chilled beam system heating and cooling

Architecture

The New Science Center is a state-of-the art research facility that will house the physics, chemistry, and biology departments of Georgetown University. A key goal of the design is to promote interdisciplinary interaction and research. The exterior materials and building features mimic the new Rafik B. Hariri Building across the plaza, creating a strong link between the two buildings. The project is intended to achieve LEED Silver Certification through various sustainable building strategies.

Electrical/Lighting

- 480/277 3-Phase 4-Wye Connection
- Two 4,000A main distribution switchgear
- 800kW Emergency Diesel Generator
- Fluorescent lighting system

Acknowledgements

Penn State University

- William Bahnfleth, PhD, PE *(faculty advisor)*
- Stephen Treado, PhD, PE *(solar instructor)*
- Ute Poerschke, PhD, LEED AP *(Ecotect instruction)*

Project Team

Project Owner: Georgetown University
Construction Management: Whiting-Turner Contracting Company

- Randy Riesner
- Bryan Kelleman
- Gary Murphy

Architecture: Payette Associates, Inc.

- Patrick Jones AIA, LEED AP

HVAC Engineering: R.G. Vanderweil Engineers Inc.

- Benjamin Galuza, PE, LEED AP

Industry Specialists

SOLARHOT

- Clay Compton

Silverback Solar

- Steve Macdonald

Executive Summary

This report includes an overview of the existing design of the New Science Center and a proposed design and evaluation of a solar thermal system on the Georgetown University New Science Center.

The New Science Complex is a five story, 154,000 SF research facility being built on the Georgetown University campus in Washington, DC. The building consists primarily of labs, classrooms, offices, and conference rooms that will support the university's Physics, Biology, and Chemistry departments. Through sustainable design and construction, the building is intended to achieve LEED Silver Certification upon completion.

The existing mechanical design utilizes state-of-the-art, highly efficient technologies. The Dedicated Outdoor Air System is comprised of (4) 50,000 cfm built-up AHU's with enthalpy wheel exhaust heat recovery. Supply and exhaust airflow is adjusted based upon occupancy sensors and schedules using Variable Air Volume control devices. A total of 97 fume hoods support the laboratory spaces throughout the building. Air is supplied to most of the spaces via induction chilled beam diffusers.

Active chilled beams are used in the majority of spaces, providing a large portion of the sensible thermal demand of the building. The heating and cooling equipment is supplied by a Georgetown University's district steam and chilled water plant. A water-side heat pump recovery unit reduces district plant load to the chilled beams and air reheat coils.

The proposed solar thermal system design utilizes the flat roof on the west side of the penthouse floor level for 77 evacuated tube solar collectors. The system will offset the steam consumption of the four hot water heaters of the existing sanitary and lab domestic hot water system. The 2424 sf of collectors will result in a useful solar gain of 496.6 MBtu/year. The system will save approximately 4966 therms of district steam demand annually. The system will pay for itself after only 2 years of operation and provide an10 year revenue of $534,000 in present value.

A structural analysis of typical roof bay found that the existing structure will sufficiently support the additional weight of the solar collectors and the slab and steel members will not require resizing.

A constructability study was performed on the proposed solar thermal system. Using a custom Silverback Solar collector mounting system, the collectors will be capable of tying into the slab-on-deck roofing system, while maintaining a watertight seal and having minimal effect on roof insulation. A trade coordination study found that with efficient planning and coordination, the installation of the system can be achieved by adding an additional solar subcontract with minimal effect on the existing construction schedule.

Table of Contents

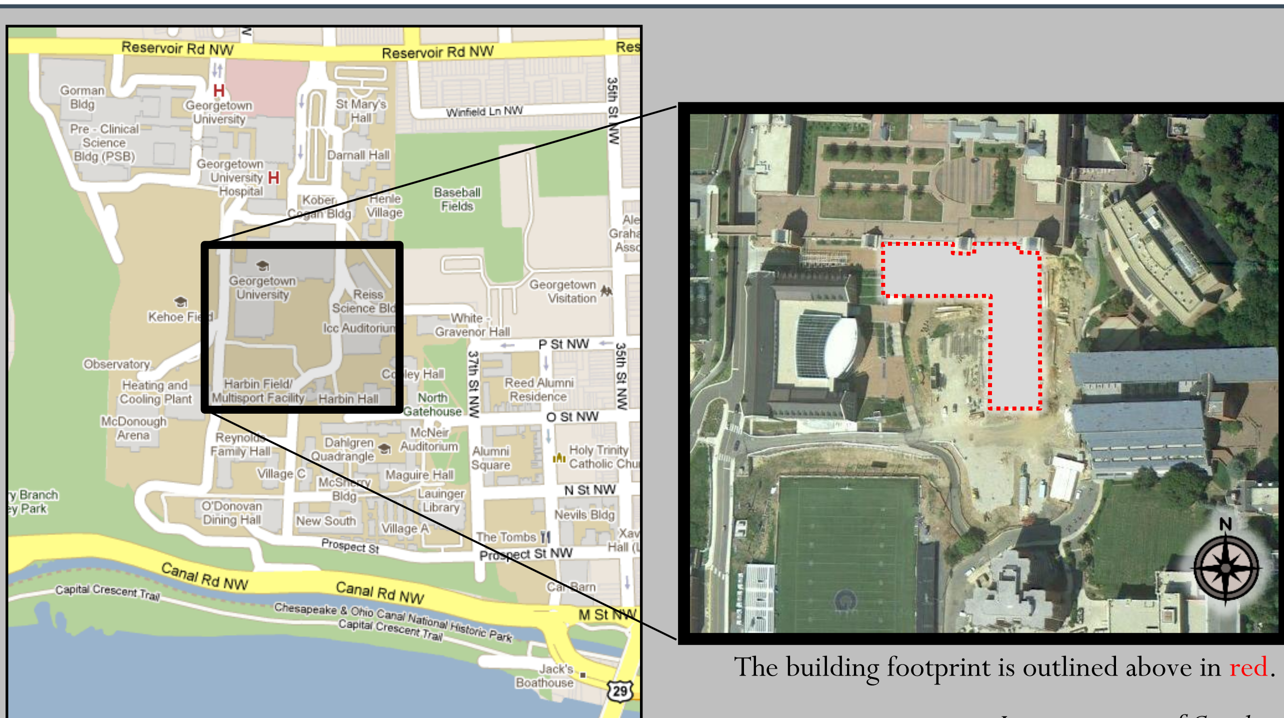
1.0 Building Overview

Introduction

The New Science Center is a 154,000 SF research 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.

Location

The site of the New Science Center is located in the heart of the Georgetown University campus in Washington, DC. The north side of the building will sit along the existing Leavey Center parking garage. To the west of the building is the newly completed Rafik B. Hariri Building of the Georgetown University's business school.



The building footprint is outlined above in red.

Images courtesy of Google

FIGURE 1: SITE LOCATION

Project Team

Owner	Georgetown University
Construction Manager	Whiting-Turner Contracting Co.
Architect	Payette Associates Inc.
Associate Architect	Martin Reddy Architects
Structural Engineer	Simpson Gumpertz & Heger
MEP & Fire Protection Engineers	JVP Engineers R.G. Vanderweil Engineers
Civil Engineer	Dewberry
Geotechnical Engineer	ECS Mid Atlantic

Delivery Method and Construction

The delivery method for the New Science Center is Construction Manager At-Risk with a fixed fee and Guaranteed Maximum Price (GMP). The construction management firm is Whiting-Turner Contracting Company. Construction broke ground in May 2010 and is scheduled to be turned over to Georgetown University by July 2011 for move-in. The combined contract amount is approximately $69.5M excluding owner soft costs for Furniture, Fixtures, and Equipment. Special sustainable construction methods must be maintained for LEED Silver certification. Some of these include a waste management plan to recycle and salvage waste materials, an Erosion & Sediment Control Plan (ESCP) to limit erosion and sedimentation, and recycled content requirements of building materials.

FIGURE 3: RENDERED VIEW FROM SW CORNER OF SITE - *COURTESY OF PAYETTE*

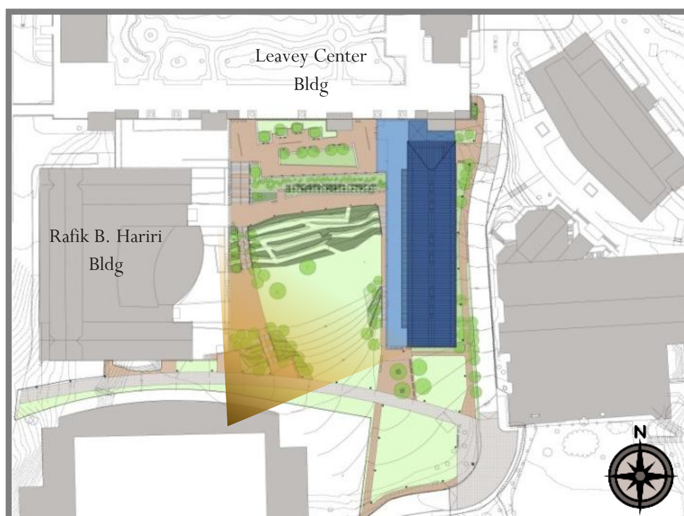


FIGURE 2: SITE PLAN - *COURTESEY OF PAYETTE*

Architecture

The architecture of this New Science Center is intended to fit into the Georgetown campus and compliment adjacent buildings. The building's roof and glass curtainwall mirror the new Rafik B. Harari Building, just across the proposed plaza to the west of the New Science Center. This creates a strong link between the two buildings as shown in Figure 4 and Figure 5.

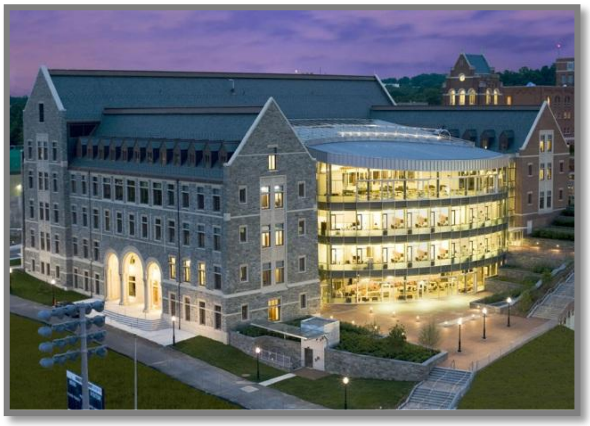


FIGURE 5: RAFIK B. HARIRI BUILDING – *COURTESY OF GOODY*

FIGURE 4: NEW SCIENCE CENTER WEST FAÇADE – *COURTESY OF PAYETTE*

The proposed plaza serves as a natural meeting area in the center of the campus, drawing people into and through the site. The roof of the third floor of the west wing of the building is a green roof that acts as an extension to the plaza as shown in Figure 6. The exterior of the building is mostly terracotta with a high-end curtainwall.

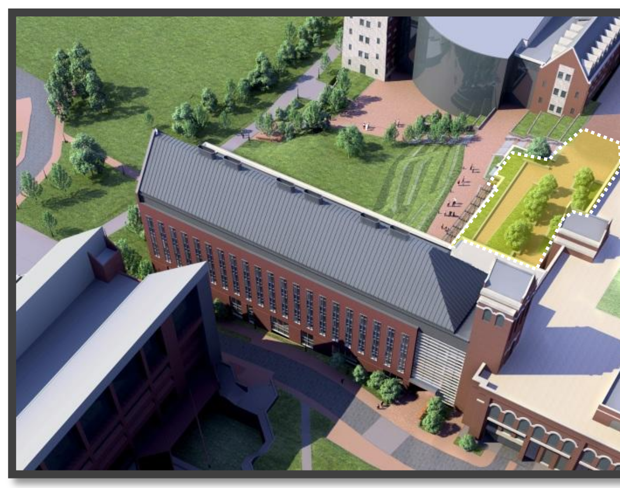


FIGURE 6: SITE ARIAL VIEW - GREEN ROOF HIGHLIGHTED IN YELLOW - *COURTESY OF PAYETTE*

A key goal of the New Science Center's design is to promote interdisciplinary interaction and collaboration between the science departments. Each floor includes research from more than one department, student lounges, and common areas. Some of the labs have glass walls along the hallway allowing people to view the equipment and activities inside.

Sustainability Features

The project is to obtain LEED Silver Certification for New Construction (NC). LEED certification can be challenging for lab buildings due to energy loads of specialty equipment and HVAC loads to maintain the lab spaces. Some of the features that will help achieve this goal in the New Science Center include a sophisticated HVAC system, high efficiency equipment, low-velocity fume hoods, a rainwater reclamation system, daylighting with integrated sensors and shading devices, native plants, and local and renewable materials. The building design also utilizes large open spaces and a small building footprint on the site.

Building Enclosure

FIGURE 7: EAST ELEVATION – *COURTESY PAYETTE*

FIGURE 8: SOUTH ELEVATION - *COURTESY PAYETTE*

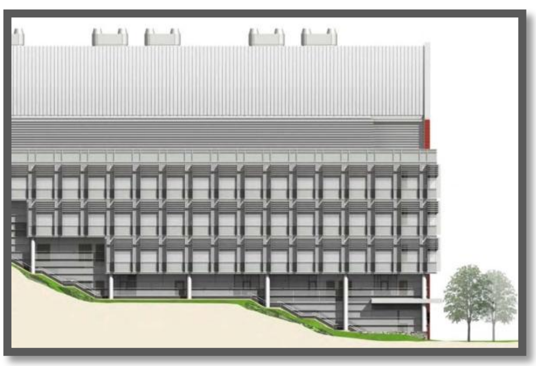


FIGURE 9: WEST ELEVATION - *COURTESY PAYETTE*

Facades

Terra Cotta system:

- Architectural terra cotta wall tile
- 2 ½" rigid insulation
- Air & vapor barrier
- ½" glass fiber reinforced gypsum sheathing

Masonry system:

- 4" face brick
- 2" air space
- 2" rigid insulation
- Air and vapor barrier
- 8" concrete masonry unit

Aluminum wall panel system:

- 4" deep profiled aluminum wall panels
- Rigid insulation
- Air & vapor barrier
- ½" glass fiber reinforced gypsum sheathing

Glazing

Glass curtain wall systems with aluminum sunshade foils and vertical sunscreens are used throughout the building with various types of glass:

Insulated spandrel glass unit
Low "E" insulated glazing
Clear insulated glazing

Roofing

System one (slanted roof):

- Painted aluminum standing seam roofing
- Rosin paper
- High temperature air and vapor barrier
- 5/8" cement board sheathing
- 4" rigid insulation
- Polyethylene vapor retarder
- 5/8" glass-mat gypsum sheething

System two (flat roof)

- TPO membrane roofing
- Tapered rigid insulation
- Vapor retarder

Structural System
The structure of the New Science Center consists of caissons, grade beams, concrete foundation walls and structural steel framing. The grade beams are tied into the concrete caissons that extend down as far as 95 feet below grade. 3 to 5 ½ foot diameter caissons are to be embedded a minimum of 4 feet into weathered rock strata. The structural steel framing consists of a large range of wide-flange beams and columns, and uses brace framing at several locations to support lateral loads. The floor system is a reinforced LW concrete slab on composite deck at 6 ¼" total depth.

Electrical System
The power ties-in to the existing 15 kV utility distribution in the basement of the Leavey Parking Garage adjacent to the New Science Center. The entering utility power is reduced to 480/277V via two 2000kVA transformers in the main Electrical Room of the first floor. Power is then distributed through the building through two 4000A switchgears. Each floor has a separate electrical room containing a 480/277V and a 208/120V distribution panel board. Emergency power is provided by an 800kW diesel powered generator and is supported by two 5 minute UPS's.

Lighting System
A wide variety of lighting fixtures are used throughout the New Science Center. Fluorescent fixtures are used in nearly all spaces. LEDs can be found in lab spaces, high pressure sodium in the loading dock area, and metal halides around exterior stairs in the terrace area. All ballasts are electronic, with dimming capabilities in offices, classrooms, and labs.

Fire Protection
The building's sprinkler system is supplied by a 75hp 1000gmp fire pump and is to be installed in accordance with NFPA 13 and NFPA 14. Manual pull stations, smoke detectors, and heat detectors are used throughout the building.

Transportation
A long, monumental stairway travels from levels one through four, across the glass curtain wall on the west side of the building. There are two adjacent elevators also included in the building's design. The smaller of the two elevators travels from level one through five, and the larger one extends from level one to the penthouse. Two sets of emergency stairs on opposite ends of the building are accessible to all levels.

Lab Support Systems
The laboratories require special systems to support various experiments and activities. These include a compressed air system, liquid nitrogen storage and distribution system, water purification and distribution system, vacuum system, and natural gas distribution system. The lab spaces also consist of a total of 97 fume hoods.

2.0 Existing Mechanical System Overview

Design Influences

Site Conditions

Climate conditions in Washington, DC have a large impact on the design of the mechanical system and equipment. 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 chosen based on availability, cost, and system characteristics. Since the New Science Center is to be a part of the Georgetown University campus, the system is 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. For this building, the system characteristics and equipment 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, comfortable environment for the building occupants.

All new buildings on 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 design, envelope, and building materials.

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 for the Building Automation System and controls to properly integrate with the campus monitoring and operations system.

Another important design 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.

Ventilation Requirements

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, which is easily exceeded in the design by using a DOAS system.

Program

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

Design Loads

Heating and cooling loads of the building were estimated using a block load analysis in Trane Trace 700 energy modeling software. The peak heating and cooling loads were determined to be approximately 1,462 MBh and 230 tons, respectively.

System Design

The New Science Center is conditioned by four Air Handling Units (AHUs), an active chilled beam system, 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 are used in the chemistry labs. Steam and hot water unit heaters are used in emergency stairwells, entrance vestibules, the loading dock, and the mechanical penthouse.

Figure 10 and Figure 11 are schematic flow diagrams of the HVAC hot water and chilled water as designed.

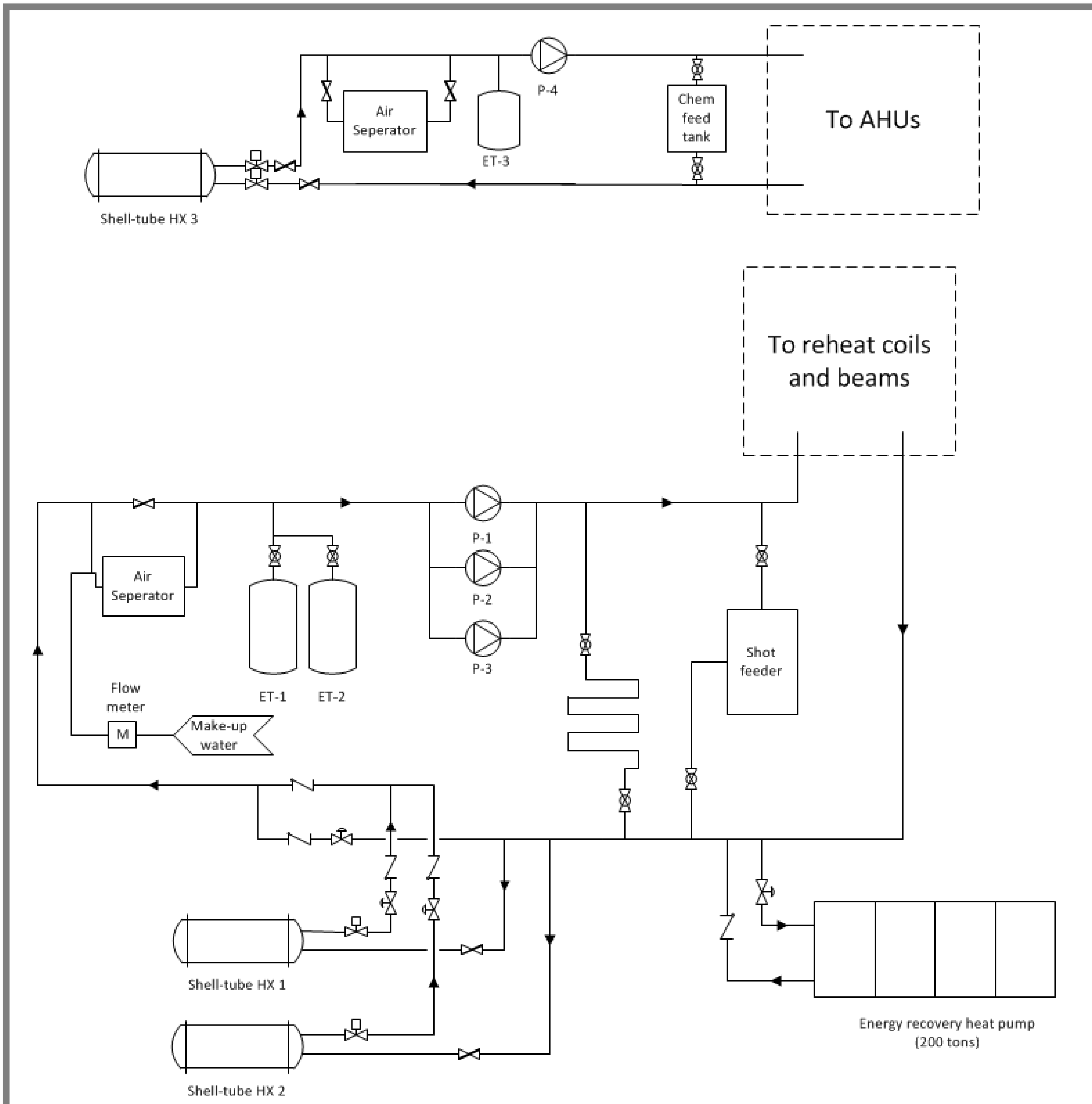


FIGURE 10: EXISTING HOT WATER SCHEMATIC

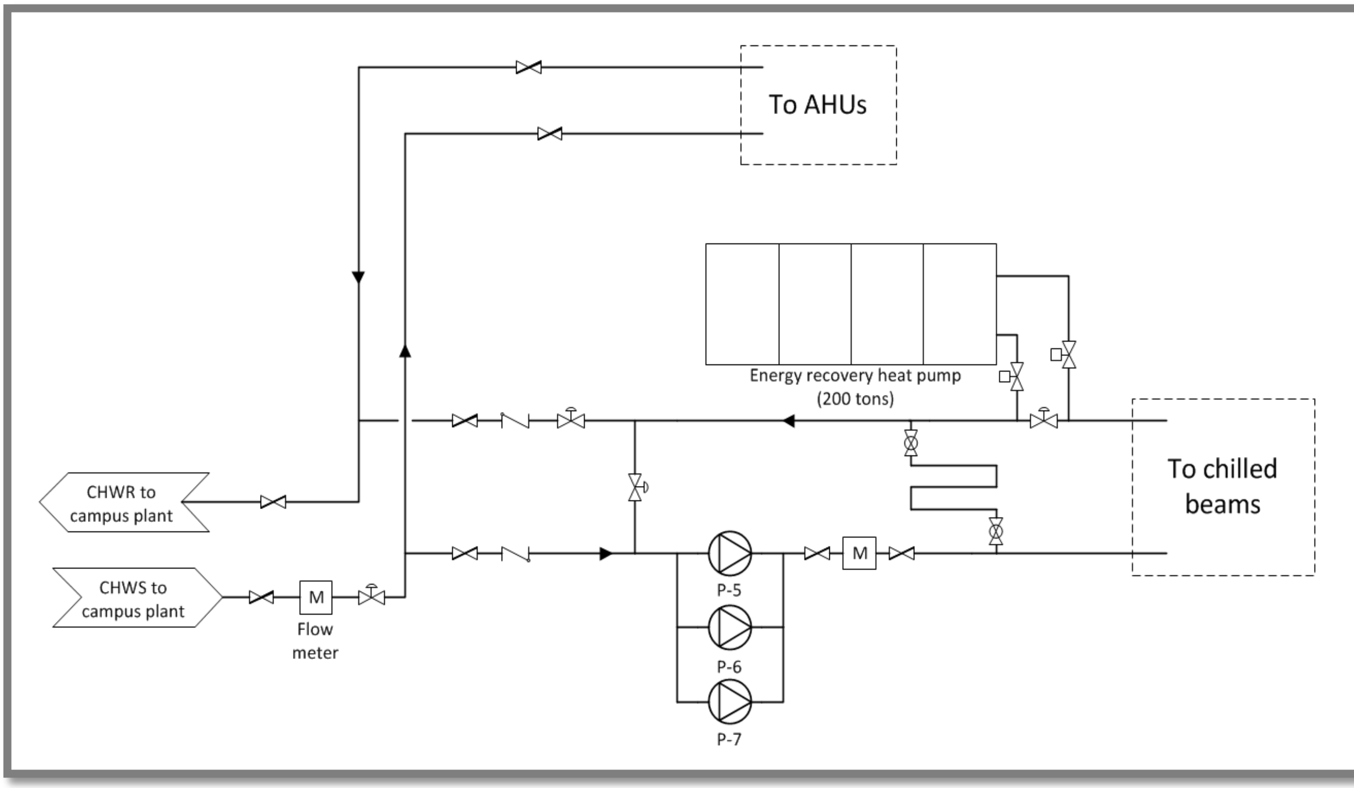


FIGURE 11: EXISTING CHILLED WATER SCHEMATIC

Equipment

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. 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 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 recovery wheel provides sensible and latent energy recovery from the exhaust air to the supply air, reducing the loads on the heating and cooling coils.

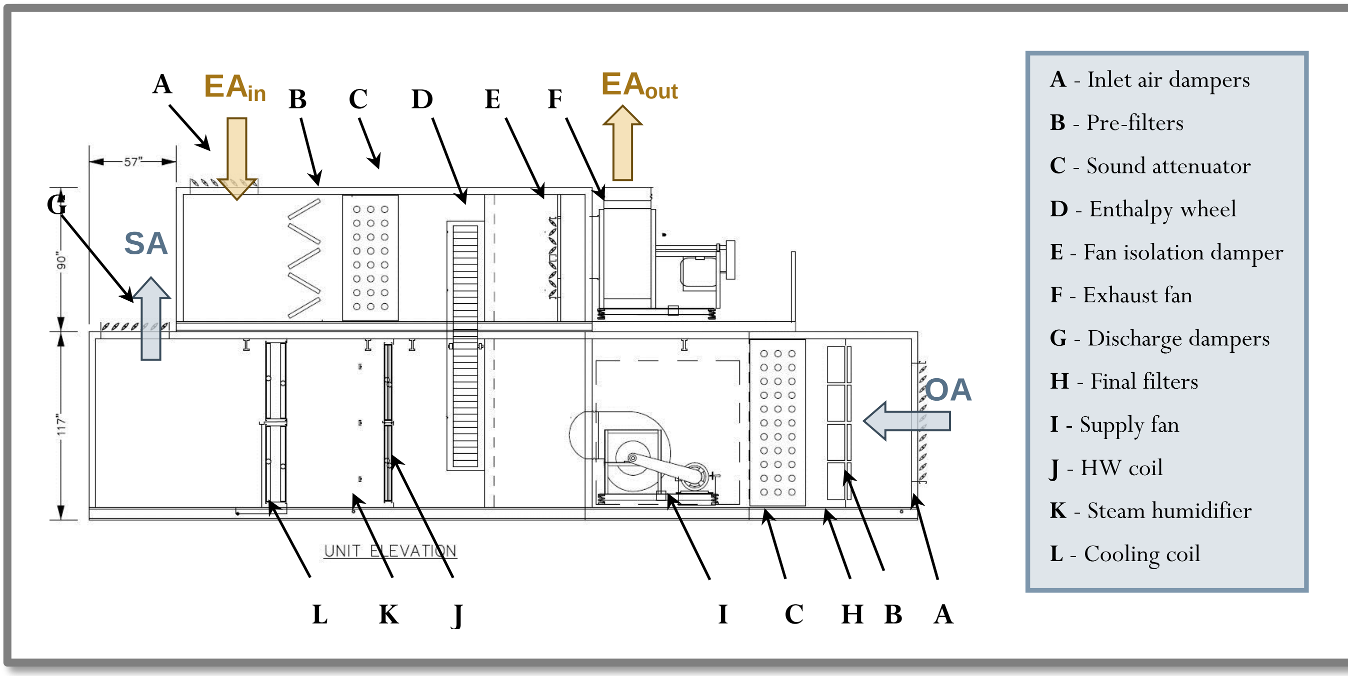


FIGURE 12: TYPICAL AHU DETAIL

TABLE 1: AHU FAN SCHEDULE

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 2: AHU - HEATING AND COOLING

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 occupancy schedules and occupancy sensors. 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 a hot water re-heat coil.

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 3.

TABLE 3: HVAC PUMP SCHEDULE

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

Active chilled beams

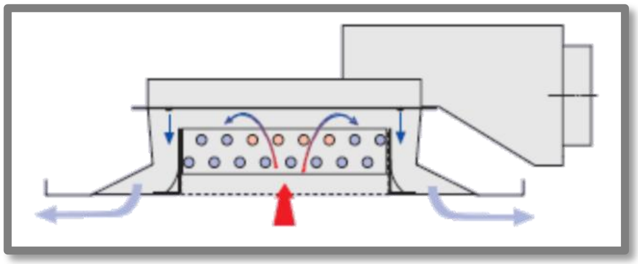


FIGURE 13: CHILLED BEAM DETAIL

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.

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.

Controls

The Building Automation System (BAS) monitors pressures, temperatures, and flow rates, and controls various pieces of equipment including controls valves, VFDs, AHUs, Pumps, etc. The mechanical system controls are direct digital type. Direct Digital Control Field Panels (DDCFPs) perform equipment start-up and shut-down sequences.

The occupancy schedule for typical spaces is defined in the contract documents. Spaces are considered "occupied" from 8AM to 6PM Monday through Friday, and "unoccupied" at all other times. Individual lab scheduling is to be determined by Georgetown University. Offices, conference rooms, and research labs use occupancy sensors for monitoring occupancy during irregular hours. All schedules are adjustable by operators through the BAS.

Airflow from the (4) AHUs is controlled by parallel fans with VFDs. Static pressure setpoints in supply ducts are monitored and adjusted for by the BAS. Within each AHU, the enthalpy recovery wheel is utilized prior to the preheat and cooling coils to maintain supply air temperature. When the enthalpy recovery wheels are insufficient to meet the required load, the pre-heating coils use hot water from a shell-and-tube (steam to water) heat exchanger to maintain supply air temperature at 55°F, or the cooling coils use chilled water from the district chilled water supply to cool entering air to 52.2°F. Lead and lag unit changeover for AHUs is based on run time and is adjusted weekly. The unit with the least run time becomes the lead unit and the units with the next lowest run times are sequenced accordingly.

VAV terminal units control airflow to all spaces. Flow rates are based on minimum ventilation rates that vary according to the space occupancy. A reheat coil is located within each unit to reheat precooled air from the AHUs to 55°F.

Four-pipe chilled beams condition the remaining sensible loads of the spaces. Chilled water and hot water flow control valves modulate to meet each zones heating and cooling requirements. Temperature setpoints adjust according to the occupancy schedule described previously in this section. "Occupied" and "unoccupied" setpoints are described in the *Design Influences - Program and Layout* section of this report. Room temperatures are monitored by wall mounted thermostats within each space.

Energy Use

The mechanical system of the New Science Center consumes energy of three types: district steam, district chilled water, and electricity. Operating history and engineer design values are not available for comparison of the simulation values for energy consumption. To determine the energy consumption of the building a Trane TRACE model was created and an energy simulation was run. The energy consumption and load profile for steam, chilled water, and electricity are shown in Figure 14 through Figure 16.

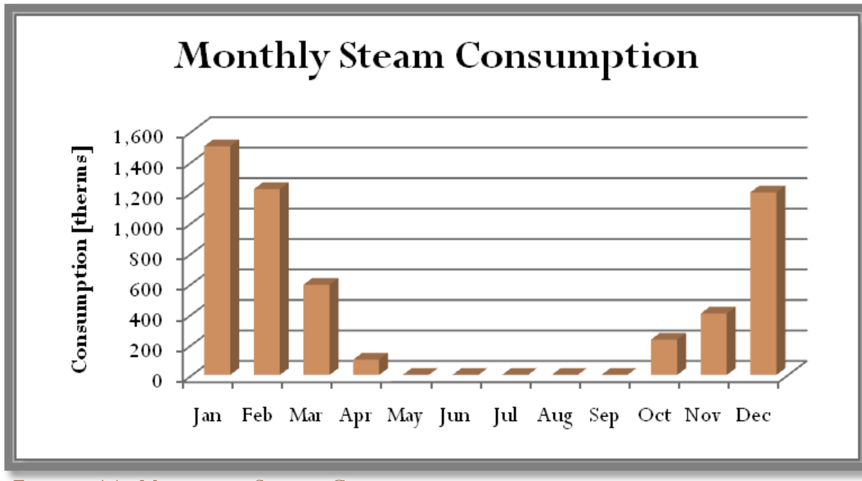


FIGURE 14: MONTHLY STEAM CONSUMPTION

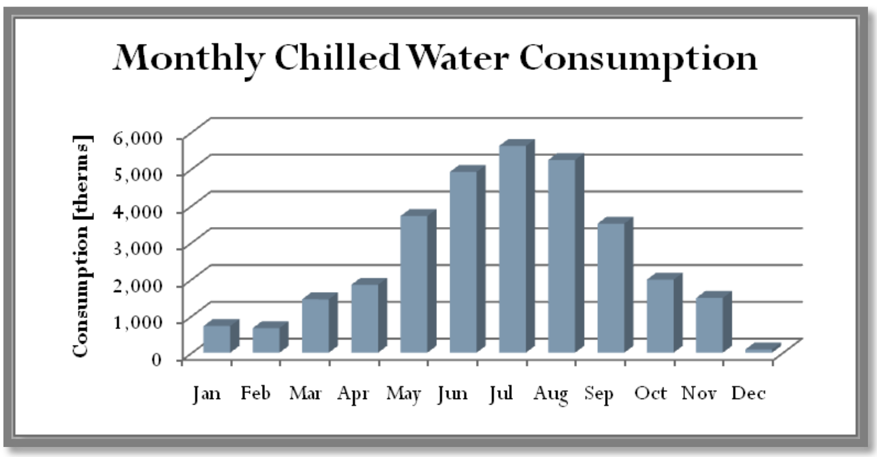


FIGURE 15: MONTHLY CHILLED WATER CONSUMPTION

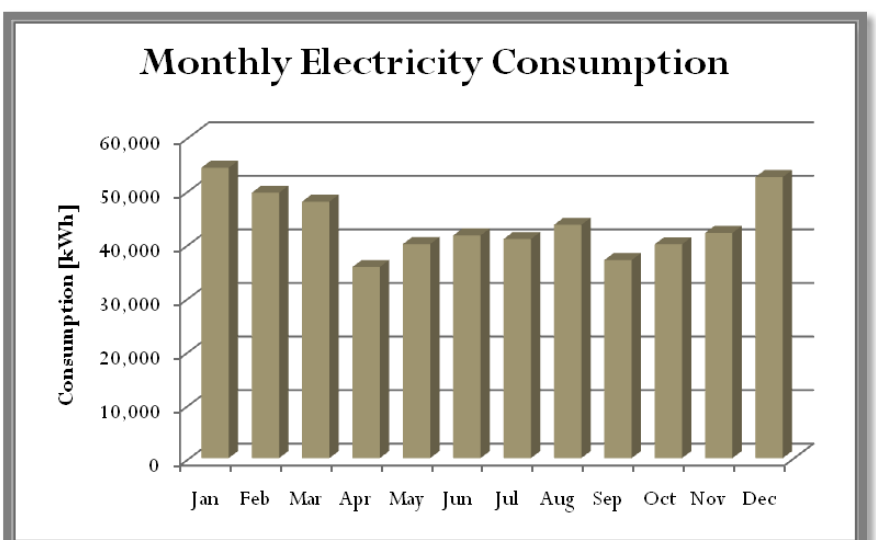


FIGURE 16: MONTHLY ELECTRICITY CONSUMPTION

The energy consumption distribution among the subsystems from the simulation data are shown in Figure 17. It should be noted that the lab equipment used will consume a large amount of energy and is not represented in this diagram.

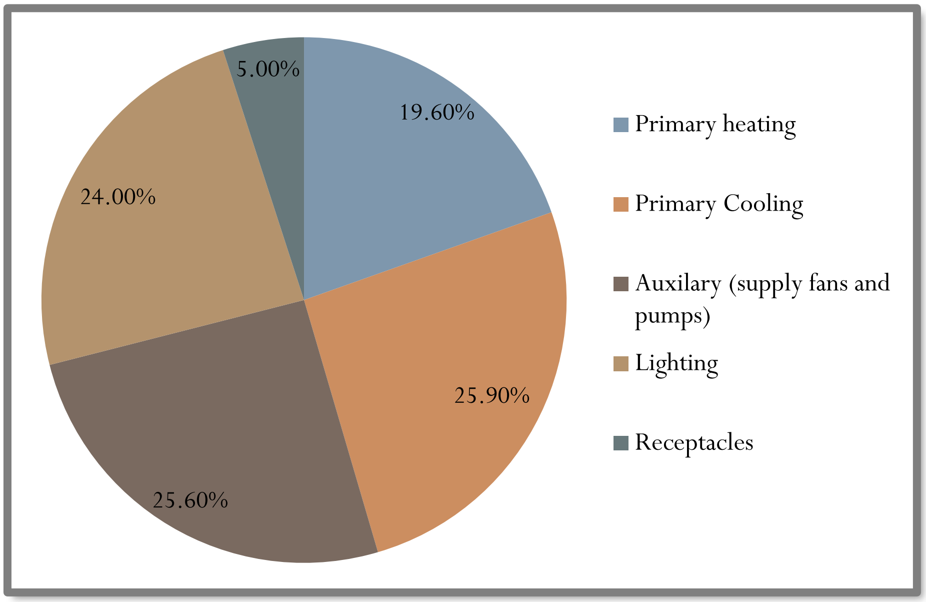


FIGURE 17: ELECTRIC ENERGY SUBSYSTEM DISTRIBUTION

Operating Costs

The first costs of the mechanical system are not available for this report. The steam and electric utility costs are summarized in Table 4 and Table 5. An annual energy cost summary is included in Table 6.

TABLE 4: ANNUAL STEAM COSTS

Annual Steam Costs				
Month	Steam [therm]	Steam [klb]	rate [$/klb]	cost
Jan	1,501	1,792.2	15.30	$27,421
Feb	1,219	1,455.5	15.30	$22,269
Mar	592	706.8	15.30	$10,815
Apr	100	119.4	15.30	$1,827
May	0	0.0	15.30	$0
Jun	0	0.0	15.30	$0
Jul	0	0.0	15.30	$0
Aug	0	0.0	15.30	$0
Sep	0	0.0	15.30	$0
Oct	232	277.0	15.30	$4,238
Nov	403	481.2	15.30	$7,362
Dec	1,198	1,430.4	15.30	$21,885
TOTAL	5,245	6,262.5	15.30	$95,817

TABLE 5: ANNUAL ELECTRIC UTILITY COSTS

Annual Electric Utility Costs							
			Unit Costs		Cost		
Month	Consumption [kWh]	Demand [kW]	[$/kWh]	[$/kW]	Consumption	Demand	Total
Jan	59,370	270	0.10906	0.4531	$6,475	$268	$6,743
Feb	54,263	271	0.10906	0.4531	$5,918	$269	$6,187
Mar	58,576	290	0.10906	0.4531	$6,388	$277	$6,666
Apr	48,819	293	0.10906	0.4531	$5,324	$279	$5,603
May	68,249	371	0.10906	0.4531	$7,443	$314	$7,758
Jun	81,481	443	0.10906	0.4531	$8,886	$347	$9,233
Jul	88,972	462	0.10906	0.4531	$9,703	$356	$10,059
Aug	86,956	441	0.10906	0.4531	$9,483	$346	$9,829
Sep	63,752	404	0.10906	0.4531	$6,953	$329	$7,282
Oct	54,054	303	0.10906	0.4531	$5,895	$283	$6,179
Nov	52,827	276	0.10906	0.4531	$5,761	$271	$6,033
Dec	59,198	244	0.10906	0.4531	$6,456	$257	$6,713
TOTAL	776,517	462					**$88,284**

TABLE 6: TOTAL ENERGY COSTS

Total Energy Costs			
Month	Electric	Steam	Total
Jan	$6,743	$27,421	$34,164
Feb	$6,187	$22,269	$28,456
Mar	$6,666	$10,815	$17,481
Apr	$5,603	$1,827	$7,430
May	$7,758	$0	$7,758
Jun	$9,233	$0	$9,233
Jul	$10,059	$0	$10,059
Aug	$9,829	$0	$9,829
Sep	$7,282	$0	$7,282
Oct	$6,179	$4,238	$10,417
Nov	$6,033	$7,362	$13,395
Dec	$6,713	$21,885	$28,598
TOTAL	$88,284	$95,817	$184,101

The total operating cost per SF per year of the mechanical system is approximately $1.45/SF-yr.

Please note that while many of the design load and operating cost values contained in this report may not be extremely accurate, they will provide a representative baseline system to compare my future design change proposal throughout the remainder of my thesis project.

Lost Usable Space

The lost usable space due to the HVAC equipment is approximately 21,549 SF and is summarized in Table 7. The first level contains two mechanical rooms. One advantage of utilizing district heating and cooling is the space saved by exclusion of a chiller and boiler in the building. Levels two through five contain four mechanical shafts consisting of 540 SF per floor. The mechanical penthouse contains the four AHUs and a supply and return plenum. The total area of the mechanical equipment space is approximately 14% of the building's total floor area.

HVAC Lost Usable Space	
Level	**Area (SF)**
Level 1	4,936
Level 2	540
Level 3	540
Level 4	540
Level 5	540
Penthouse	14,453
Total	**21,549**

TABLE 7: HVAC LOST USABLE SPACE

LEED Assessment

This building is intended to achieve LEED Silver certification. Mechanical designers have a significant role in achieving this goal, especially in the Energy & Atmosphere and Indoor Environmental Quality sections. LEED certification documents are still being prepared for submittal at the time of this report and are not available for reference. This building began construction before the deadline for LEED 3.0 and will be assessed by USGBC based on the LEED 2.2 requirements. This section will assess various points related to the mechanical system based on the newer LEED 3.0 requirements.

Energy & Atmosphere

Credit 1 (Optimize Energy Performance) provides an opportunity for 19 points. This credit involves comparing the building as designed with ASHRAE 90.1 Appendix G. A baseline energy model using Appendix G for the minimum system requirements is compared to an energy model of the system as designed.

Credit 3 (Enhanced Commissioning) will be obtained by designating an independent Commissioning Authority to begin the commissioning from early in the design process and throughout the final design and construction of the project. A systems manual and training must also be provided for operators and building occupants.

Credit 4 (Enhanced Refrigerant Management) is achieved by excluding the use of CFCs and HCFCs as a refrigerant within the building. The water source heat pump is the only piece of equipment using a refrigerant which is R-407C. This is a mixture of R32, R125 and R134a which meet this requirement.

Indoor Environmental Quality

Credit 2 (Increased Ventilation) is easily obtained since this DOAS system provides greater than 30% ventilation rates as required by ASHRAE 62.1.

Credit 5 (Indoor Chemical Pollutant Source Control) is address by allowing for proper storage and disposal of harmful chemicals used in labs, proper pressurization in lab spaces, and exhausting all air with no recirculation

Overall Evaluation Summary

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 maintainability 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, 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. 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.

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 assessed in the following sections of this report.

3.0 Proposed Redesign Overview

Mechanical Depth Topic: Solar-Thermal System

The sun provides a relatively constant and virtually endless supply of clean energy to our planet through irradiation. As world energy demands increase and fossil fuel reserves diminish, solar energy utilization is critical in the building industry to sustain our economy and environment. As solar technologies increase and equipment costs drop, solar energy utilization in buildings is becoming more practical and feasible than ever.

The proposed design will utilize solar-thermal collectors that convert the suns radiation into thermal energy to supplement the steam demand of the building. A variety of collector types, thermal applications, and system layouts are assessed to provide the highest energy and cost savings. The design and sizing of all equipment is explained and specified, and a life-cycle cost analysis is provided to determine the system payback period and annual cost savings of the system.

Breadth Topic 1: Structural Impacts of Solar Thermal Collectors

The addition of the solar collectors and mounting equipment on the roof of the building increases the dead load on the structural system. A typical bay is analyzed to determine if additional structural support is necessary. Increase structural components would result in increased capital costs and would therefore decrease the offset energy savings of the solar-thermal system. The slab-on-deck, beams, and girders that support the typical bay were assessed to determine if resizing is necessary with the addition of the solar thermal components.

Breadth Topic 2: Solar Thermal Installation and Construction Impacts

The installation of the solar thermal system is analyzed for constructability, trade coordination, and construction schedule impacts. A solar collector mounting system is selected that will tie into the existing roof system with minimal impacts on insulation and waterproofing. The installation of the system also requires careful planning and coordination to allow for minimal impact on the existing construction schedule.

4.0 Mechanical Depth Topic: Solar-Thermal System

Objective

- Utilize solar energy to offset fossil fuel consumption ⟹ reducing operating costs and carbon footprint

Site Assessment and System Design

Before designing a solar thermal system, the site and existing conditions must be assessed to determine the best location of solar collectors and the thermal application in the building to supplement.

Collector location

Solar collectors must be installed on an exterior surface of the building that is exposed to the sun. The location chosen for the collectors for this design is the roof on the west side of the penthouse level of the building. This area is highlighted in Figure 18. This location was chosen because of the large area exposed to the sun, minimal aesthetic influence on the building's architecture, and the close proximity to the mechanical penthouse where the piping will enter the building. The sloped roof of the penthouse is oriented East/West which would provide poor solar availability throughout the day, and therefore was not considered for the collector location.

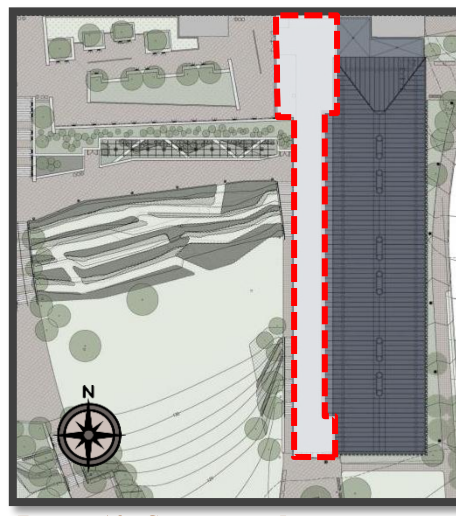


FIGURE 18: COLLECTOR LOCATION

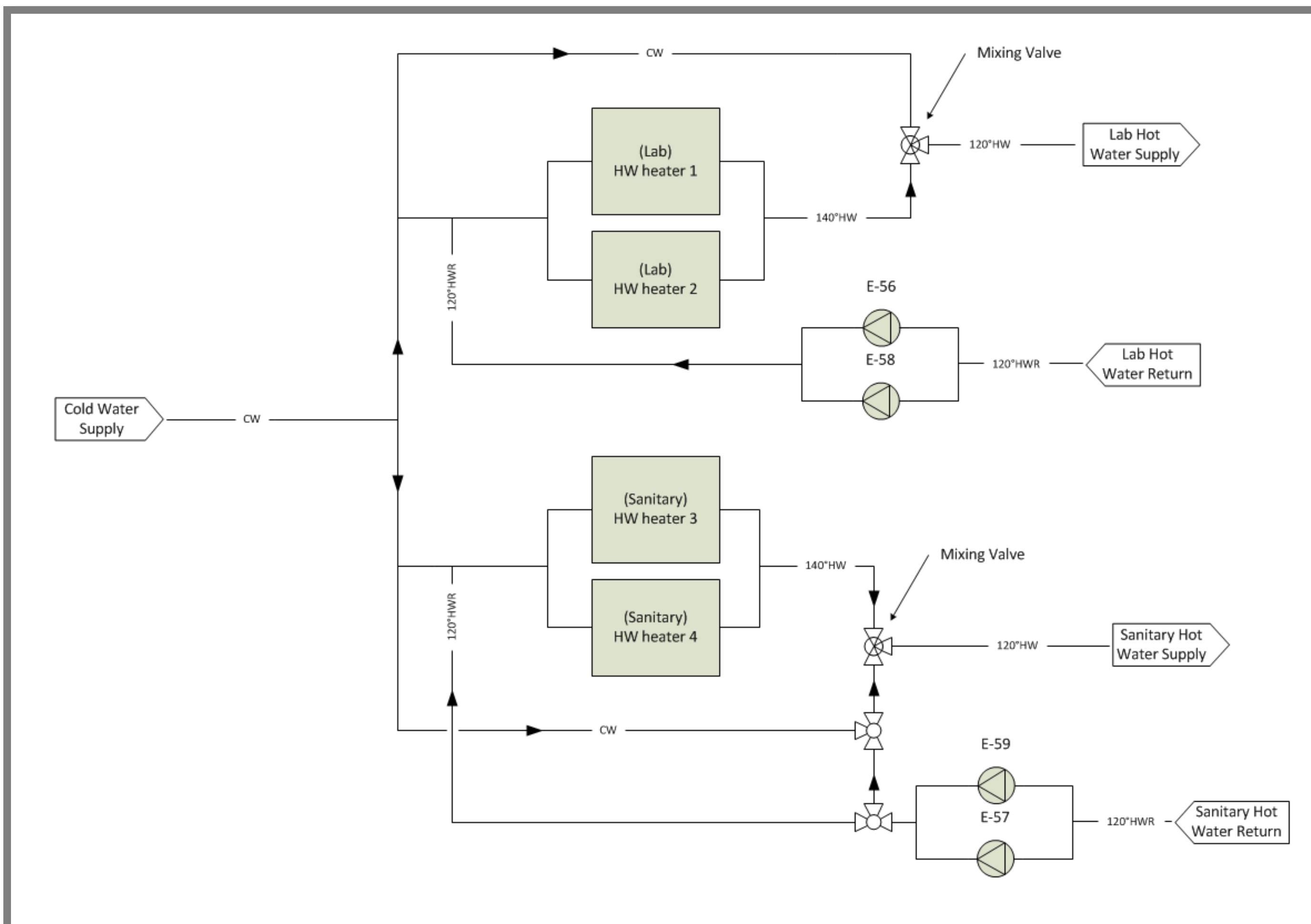
Thermal application

There are a wide variety of thermal applications within this building. The potential services considered for solar thermal integration include: Domestic HW, AHU preheating coils, lab process loads, and chilled beam HW and reheat coils. The AHU preheat coils will only be used when the AHU enthalpy wheels cannot meet the preheating demand. At 76% sensible/74% latent effectiveness, the enthalpy wheels will be capable of supply 55°F supply air throughout most of the year without any demand from the preheat coils, therefore this was not considered for the solar thermal integration. The chilled beams HW and reheat coils were not considered for solar thermal integration because they are already tied into a water-source heat pump recovery unit and will also have an unfavorable load profile to efficiently utilize the sun's nearly constant energy throughout the year. Domestic hot water is the best choice for a solar integration due to the nearly constant demand throughout the year.

The existing domestic hot water system is split into two loops, one for sanitary and one for lab use (See Figure 19). Both loops are recirculated via redundant circulator pumps configured in parallel. Recirculated hot water systems provide instant hot water at the fixtures and reduce water consumption and waste heat that would otherwise be consumed while waiting for water to reach the proper temperature at the fixtures. The sanitary loop supplies a total of 44 lavatory fixtures and 5 mop service basins. The four existing semi-instantaneous hot water heaters use steam that is supplied by the Georgetown University utilities plant. The steam is generated by gas fired boilers at the plant. District steam demand will be minimized by reducing the load on these four domestic water heaters, in turn reducing the carbon footprint of the utilities plant and reducing the operating cost of the building.

A schematic of the existing domestic hot water design is shown in Figure 19. The entering cold water acts as make-up water for the system when hot water is used at the fixtures. The returned hot water from the lab loop will be recirculated through the heaters to reheat as necessary due to pipe losses in the loop. The domestic returned sanitary hot water will also be recirculated through the heaters with an additional water heater bypass if the return water's temperature is above 110°F. The hot water heaters heat the water to 140° which is then mixed with cold water to 120°F through a thermostatic mixing valve. Heating water to 140° limits the Legionella growth within the system. The supply hot water is lowered to 120°F to prevent scalding at the fixtures.

FIGURE 19: EXISTING DOMESTIC HW DISTRIBUTION SCHEMATIC



Domestic Hot Water Demand

The domestic hot water demand is challenging to predict accurately due to the many parameters that it depends upon. Assumptions were made to determine the HW demand as described below. The total occupancy of the building according to the DC Building Code is 1,733 as shown in Table 8. This number is a maximum occupancy load as defined by the building code and is most likely not representative of the number of occupants in the building during typical usage. One obvious example of this is the penthouse's occupancy of 53 persons. The penthouse will be typically unoccupied, except during maintenance which would be performed by only a small number of people.

Level	Occupancy
1	281
2	377
3	453
4	253
5	316
PH	53
TOTAL	**1733**

TABLE 8: BLDG OCCUPANT LOAD PER DCBC

ASHRAE Handbook – HVAC Handbook of Applications (2007) provides hot-water demands for various types of buildings. The closest building type provided is a high school, which requires an average daily hot-water demand of 1.8 gal/student.

To determine the domestic how water load of the New Science Center, the following assumptions were made:

1. Typical daily student occupancy for the building is 60% of the amount occupants specified per code. A large part of the reasoning behind this is the obvious difference in the occupancy load per code compared to actual occupancy under typical conditions. This is also intended to take into account the portion of occupants that will not be students, such as faculty and staff.
2. The daily hot water demand is 2 gal/student, as suggested in ASHRAE Applications. Half of this demand is assumed to be consumed on the sanitary side of the domestic HW system, and the other half is assumed to be used by labs. While it is expected that the labs will consume a greater portion of the load, this proportion will have a minimal effect on the actual energy savings since the thermal storage tanks will be connected in parallel and the tank temperatures will balance naturally.

Daily HW demand calculation:

$$1733\ occupants * 60\% = 1040\ students$$

$$1040\ students * 2\ {}^{gal}/_{student \cdot day} = 2080\ {}^{gal}/_{day}$$

This is the value used for the energy analysis in the Polysun simulation software later in this section to determine the useful solar gain and energy savings.

The following is the estimated heating load required to heat the make-up hot water of this system. This value does not take into account the heat losses through the distribution piping of the recirculated system for simplification.

$$q = \left(2080\, {}^{gal}/_{day}\right)\left(8.4\, {}^{lb_m}/_{gal}\right)\left(1\, {}^{Btu}/_{lb_m \cdot {}^\circ F}\right)(120^\circ F - 50^\circ F) = \mathbf{1223\ MBtu/day}$$

Collector selection

The two most common types of collectors for building applications are flat plate collectors and evacuated tube collectors. Evacuated tube collectors were chosen for this design. While these are more expensive than flat plate collectors, they are far more efficient in colder climates due to the insulation of the vacuum within the glass. Evacuated tube collectors also utilize a greater amount of diffuse radiation than flat plate collectors, which is favorable in this design due to the limited direct radiation during the first half of the day due to the shadows casted by the mechanical penthouse.

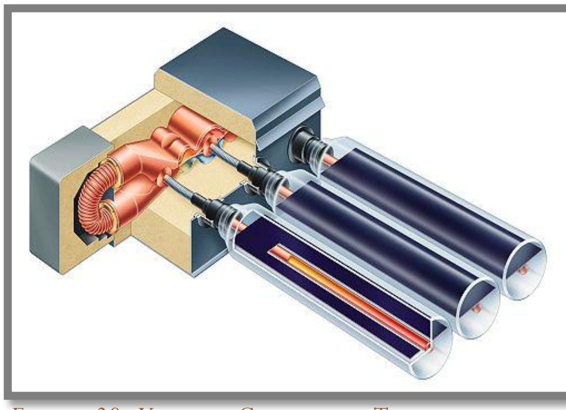


FIGURE 20: VITOSOL COLLECTOR TUBE CONNECTION

The collector selected for this design the Viessman Vitosol 300-T model. This evacuated tube model is a liquid vapor collector. A secondary liquid (methanol) is evaporated within a small copper heat pipe when solar radiation strikes the absorber. The energy is then transferred to the circulated heat transfer medium (glycol-water mixture) in the top of the collector via a dry connection heat exchanger as shown in Figure 20. The dry connection allows for simplified individual tube replacement after the system is already filled. This model also allows for individual tubes to be rotated which allow for improved solar utilization. Due to the shadows casted on the collectors in the first half of the day, it would be beneficial to rotate the tubes slightly to the west to take better advantage of the direct sun in the afternoon. The specifications of this collector model are provided in the manufacturer's data sheets in Appendix B. The collector performance data is summarized in Table 9.

Viessmann Vitosol 300-T Collector Data	
Number of Tubes	20
Gross Area	30.5 sf
Absorber Surface Area	22 sf
Aperture Area	22.7 sf
Optical Efficiency	82.5
Heat Loss Coefficient U_1	1.19 W/(m^2·K)
Heat Loss Coefficient U_2	0.009 W/(m^2·K)
Thermal Capacity	5.4 kJ
Fluid Capacity	0.32 gal
Max Working Pressure	87 psi
Max Stagnation Temp	302 °F
Supply/Return Connections	¾"
Weight	99 lbs
Dimentions (DxWxH)	4-3/4" x 55-3/4" x 78-1/2"
Warranty	10 years

TABLE 9: COLLECTOR SPECIFICATIONS SUMMARY

Collector Orientation and Layout

The latitude of the site is 38.9°N. The sun's altitude (angle between the horizon and the sun) at solar noon ranges from 74.5° at summer solstice (June 21) to 27.7° at winter solstice (December 21). Typically, the latitude of the site is used for the collector tilt angle to provide a balanced solar gain profile throughout the year; however for this design, a tilt angle of 45° was used to favor solar gain in the winter. This was done to account for the lower ambient temperatures in the winter, which increase heat loss through the exterior pipes and collectors, and to take into account the assumption the building hot water demand will be much lower during the summer due to summer break of the academic school year.

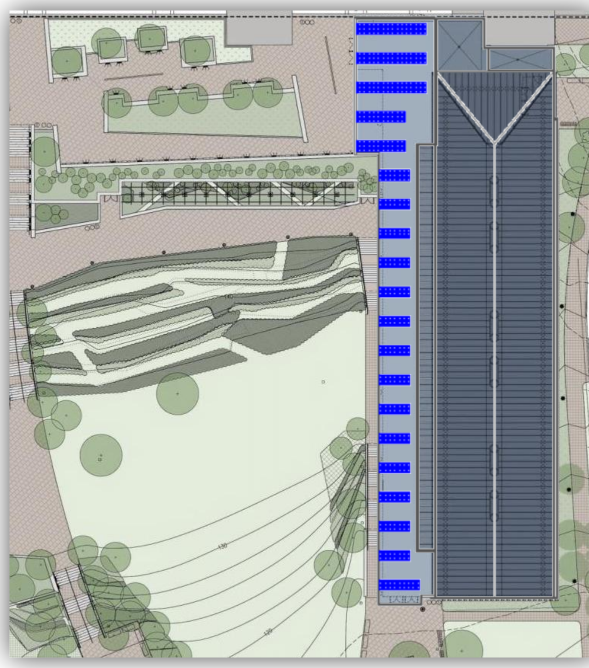


FIGURE 21: SOLAR COLLECTOR LOCATION AND

When laying out collectors on the roof, the row spacing is critical to assure collectors do not cast shadows that would limit the performance of other collectors. Figure 22 demonstrates this principal. The following equation was used to determine spacing of the collector rows.

$$X = \frac{l * \sin(180° - (\alpha + \beta))}{sin\beta}$$

$$X = \frac{80in * \sin(180° - (45° + 27.66°))}{\sin(27.66)} = 164.5in = \mathbf{13.7ft}$$

Note that the value used for solar altitude (β) is at solar noon during winter solstice when shadows are the largest.

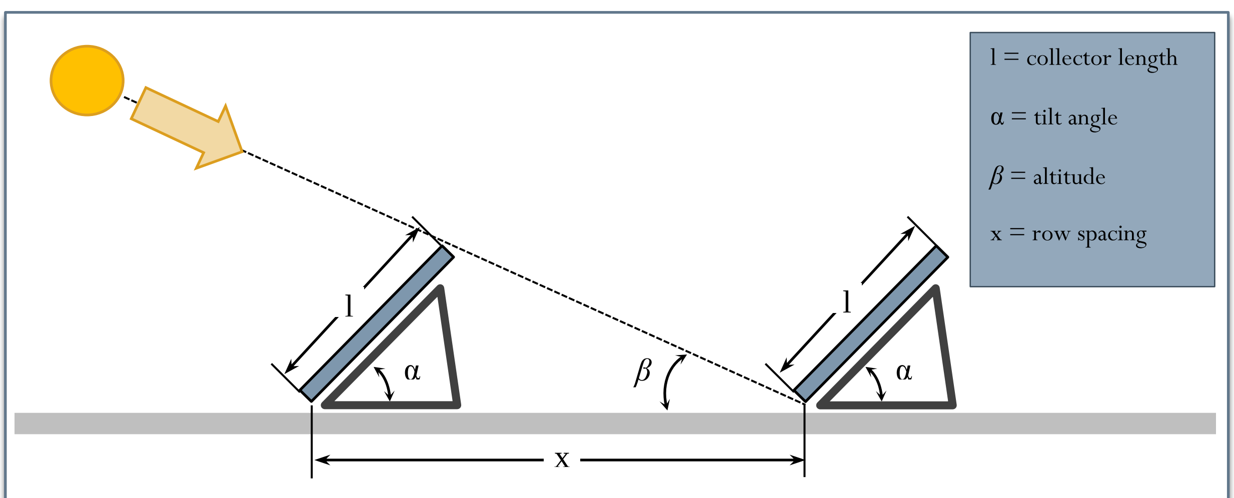


FIGURE 22: SOLAR ANGLES AND COLLECTOR SPACING

Solar Availability

A detailed solar analysis was performed using Autodesk Ecotect simulation software. The solar radiation/weather data used for the simulation is from the Ronald Reagan Washington National Airport in Arlington, VA, located about 5 miles south of the New Science Center site.

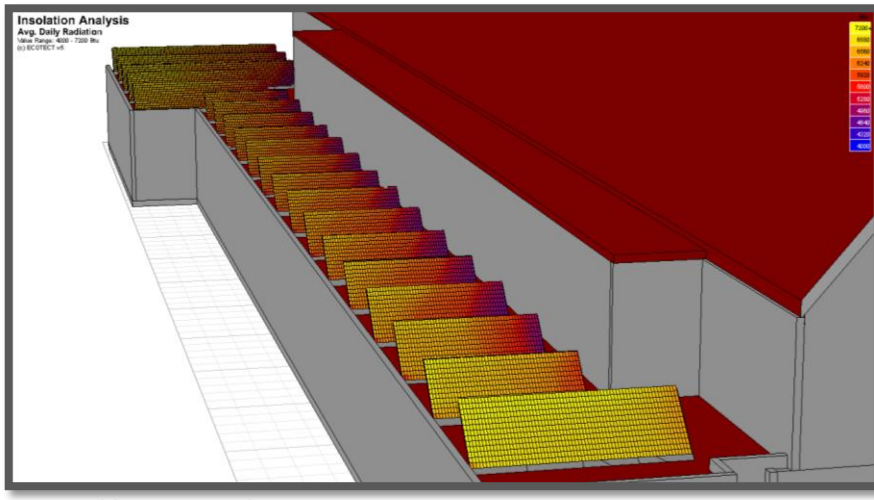


FIGURE 23: ECOTECT SOLAR AVAILABILITY ANALYSIS

A detailed shadow analysis shows that the collectors will not receive full direct sun throughout the morning until 11:05-11:40AM throughout the year as shown in Figure 25 and Figure 24. This means that solar gains at the beginning of the day will be significantly less.

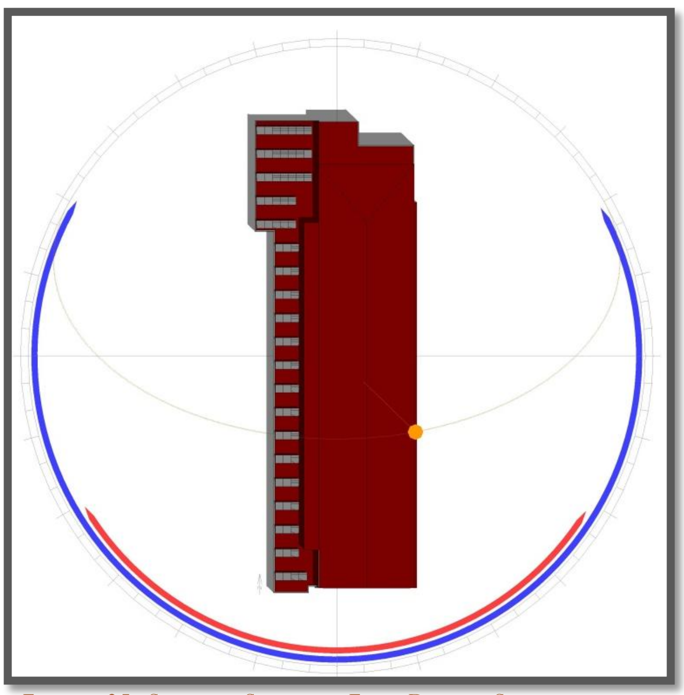


FIGURE 25: SUMMER SOLSTICE FULL DIRECT SUN AT 11:05AM

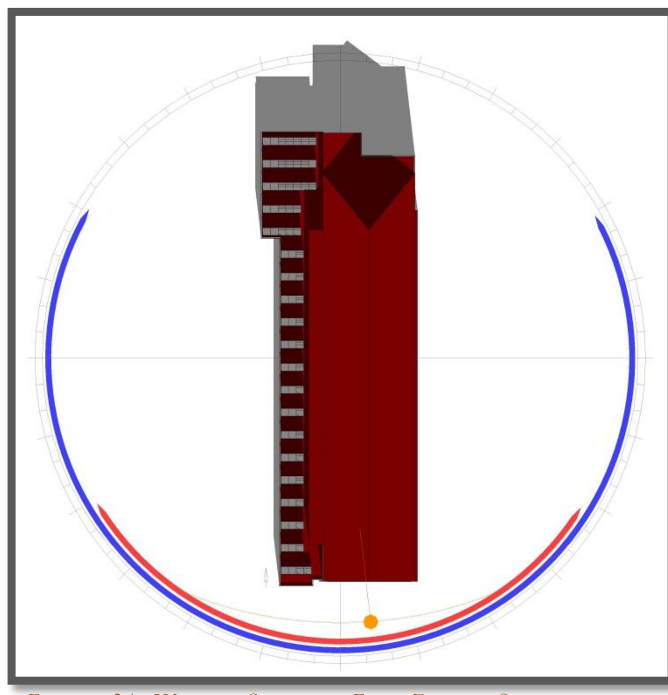


FIGURE 24: WINTER SOLSTICE FULL DIRECT SUN AT 11:40AM

These times will be used to adjust the horizon line within the Polysun energy simulation later in this section.

System Design and Integration

The solar thermal system is designed to act as a preheat to the solar hot water heaters. A schematic of the system is shown in Figure 26. The redesigned system design resembles the existing domestic HW distribution system shown in Figure 19. The additional equipment is shown in red. During periods of high solar radiation, the system will be capable of heating the hot water to 140°F allowing for a bypass of the hot water heaters. When the tanks temperature is lower than the temperature of the entering water, the three-way valves will divert flow to bypass the tank heat exchangers. This will allow for optimal utilization of the solar heat gain.

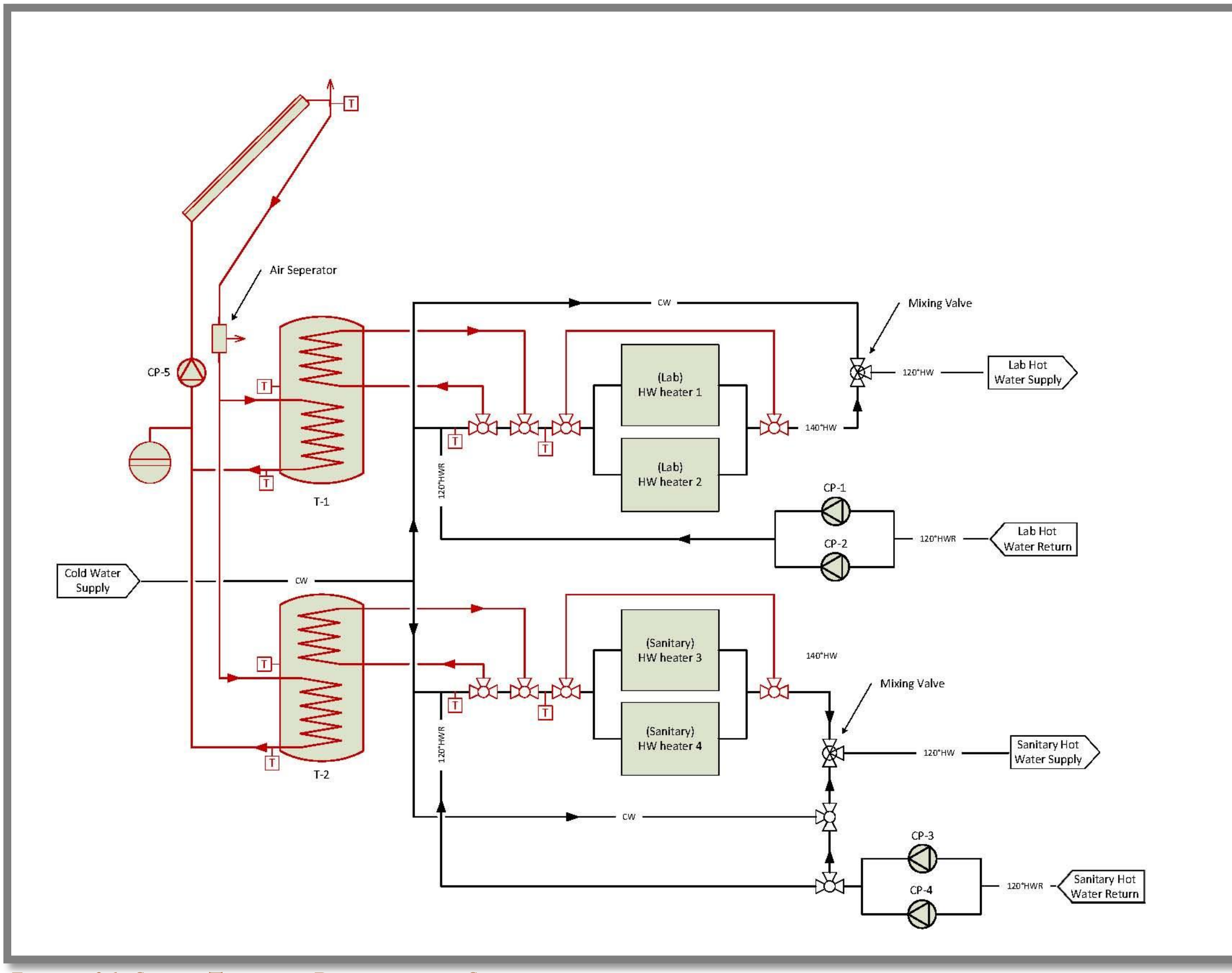


FIGURE 26: SOLAR THERMAL DISTRIBUTION SCHEMATIC

Tank Sizing

Sensible energy storage will be accomplished using a water storage tank. Proper tank sizing is essential for sufficient heat storage, stratification, and system operation. If a thermal storage tank is too large, it will not be possible to reach a high enough temperature to meet the load, and if too small it won't have sufficient capacity. The dimensions of the heat are also important to ensure proper stratification within the tank. Stratification is critical to allow greater utilization of the heat within the tank. With the load heat exchanger at the top of the tank, a proper tank dimensions will allow better utilization of the heat storage since the hot water will rise to the top of the tank. Larger tank height-to-diameter ratios result in greater stratification.

Off-the-shelf tanks are designed by manufacturers to provide optimal stratification based on the size of the tank.

ASHRAE Handbook of Systems & Equipment (2008) suggests unpressurized storage for systems greater than 1000 sf collector area. Since this design includes a total of 1716 sf of collectors, unpressurized storage is used. Unpressurized storage requires an additional heat exchanger on the load side of the tank to isolate the pressurized domestic hot water loop.

ASHRAE Systems & Equipment provides a rule-of-thumb of 1-2.5 gal per sf of collector area for solar thermal storage sizing. Sizing the tank at 1.5 gallons per square foot of collector results in approximately 2500 gallons of storage. The two tanks are used in this design to better accommodate for the two separate loads of the DHW system. The solar thermal energy storage will include two 5000 liter (2,641 gal total) tanks connected in parallel. **Note**: *The parallel connection is not shown on the schematic of Figure 26.*

These tanks will include internal plain tube heat exchangers. The solar loop connection is arranged so the exchanger flow is from top to bottom, and the load loop is bottom to top. This is known as a counter flow configuration which provides maximum heat exchange. These types of collectors would typically be installed at the factory before being shipped to the site.

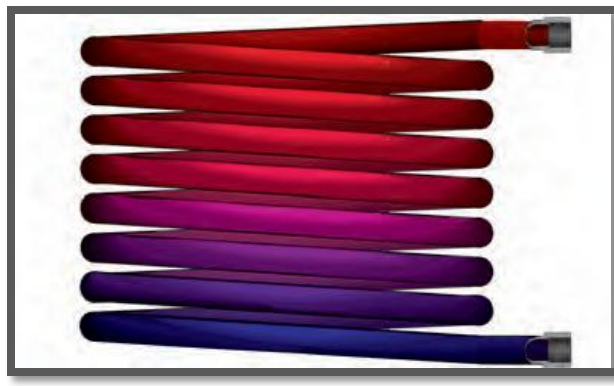


FIGURE 27: PLAIN TUBE INTERNAL HEAT EXCHANGER

Heat Transfer Fluid

A 45% glycol-water solution will be used as the heat transfer medium between the collectors and the external heat exchanger. This provides a greater temperature range, which is essential to prevent freezing during winter months in colder climates. 45% ethylene glycol by volume solution has a freezing point of -23°F and a boiling point of 224°F per ASHRAE Handbook of Fundamentals 2009. The mechanical properties of this fluid are provided in Table 10.

TABLE 10: GLYCOL-WATER SOLUTION PROPERTIES

45% Ethylene Glycol - Water Solution Properties (per ASHRAE Fundamentals 2009)		
	60°F	160°F
Density [lb/ft^3]	66.77	64.92
Specific Heat [Btu/lb·°F]	0.8025	.8505
Viscosity [ft/lb·h]	9.595	2.54

The mechanical properties (specific heat and viscosity) must be considered of heat transfer fluids to properly size piping and heat exchangers.

Piping Layout and Sizing

A schematic of the solar loop piping is shown in Figure 28.

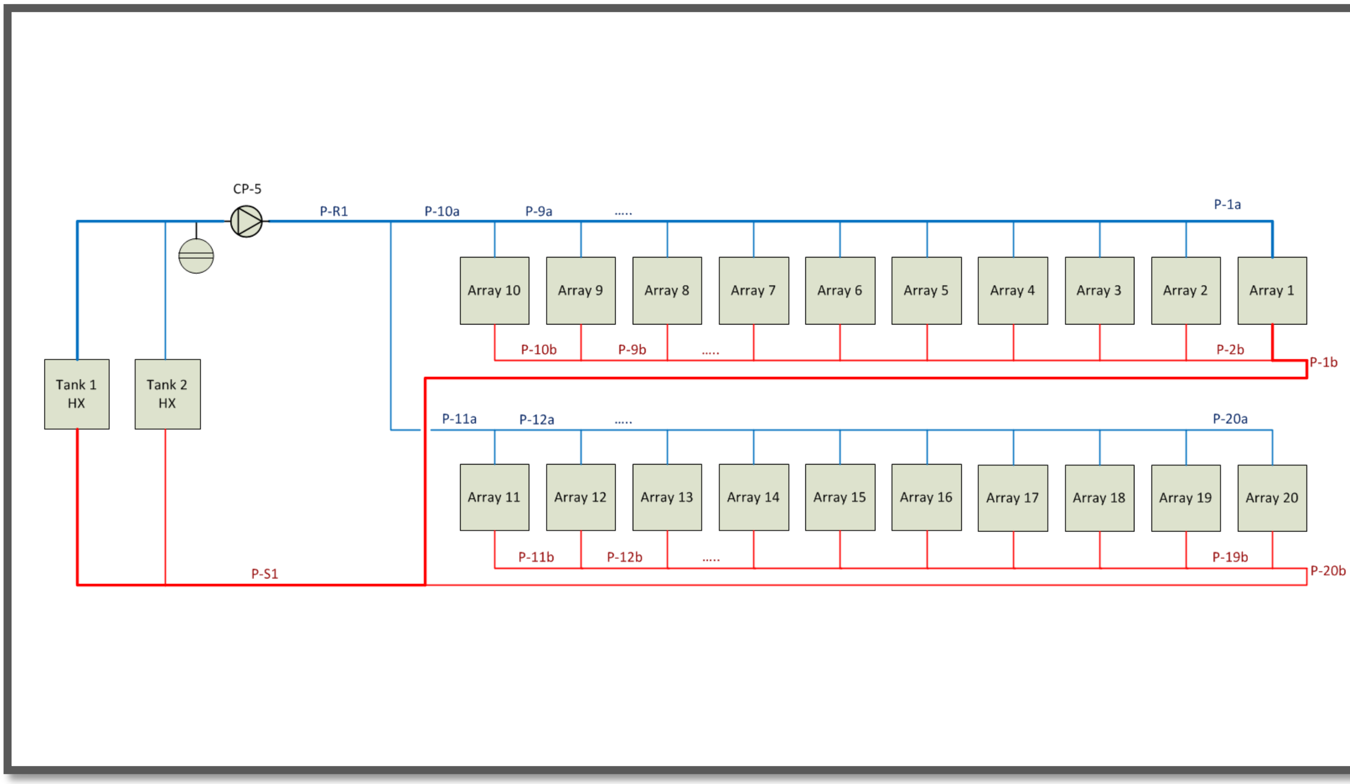


FIGURE 28: COLLECTOR PIPING SCHEMATIC – *PATH OF GREATEST RESISTANCE SHOWN IN BOLD*

This is a closed, reverse return piping loop. The reverse return design is intended to reduce the need for balancing valves after each collector array by creating the same equivalent lengths for each array. The array is split into two separate loops to due to the location of the shaft contain the pipe runs that will extend through the building and connect the collectors to the tanks. There will be a slight difference in equivalent lengths and flow rates in the two loops due to variations in the number of collectors per array. This means that there will be a slight imbalance in the two loops, so balancing valves may be required at pipes "P-1b" and "P-20b".

Piping design criteria:

Proper pipe sizing is necessary to limit noise, erosion, and installation and pumping costs. All piping was sized according to ASHRAE Fundamentals 2009 recommendations. To limit noise, pipes 2 in. and smaller were limited to flow velocities of 4 fps, and pipes greater than 2 inches were limited to flow velocities of 10 fps and pressure drops of 4 ft of water per 100 ft. To entrain air, minimum flow velocities of 2 fps were used for pipes 2 in and smaller, and minimum velocities corresponding to a head loss of 0.75 ft/100ft were used for pipes 2 in and greater. ***Note:*** *All pipes sized for this system are less than 2"*

Type L copper pipe was selected for the solar thermal loop piping. Flow characteristics used for sizing this piping is shown in Figure 29. ***Note:*** *This diagram is intended for pure water piping, even though the system is using*

45% glycol-water solution. This is for simplification purposes and would not be used in ideal design. Detailed head loss and flow velocities for this solution would require use of the Darcy-Weisbach equation with the Moody chart.

The flow rate through each collector array, or row, varies with the number of collectors connected in series. These flow rates are found in the manufacturer's design guidelines as shown in Figure 30. In Figure 28, pipe runs are labeled to correspond to the piping schedules provided in Table 11 and Table 12. The pipe head and velocities were determined using the pipe sizing charts found in ASHRAE Fundamentals (2009), shown in Figure 29. The flow rate of the main glycol-water pipe runs that extend from the roof to the tanks on the first floor is about 17.4 gpm. This was determined by adding all of the required flow rates through each collector array, or row. Using 1-1/2" Type L copper tubing will result in a head loss of 2.8 ft per 100ft of piping and a flow velocity of approximately 3.1 fps, which is within the design range defined by ASHRAE Fundamentals.

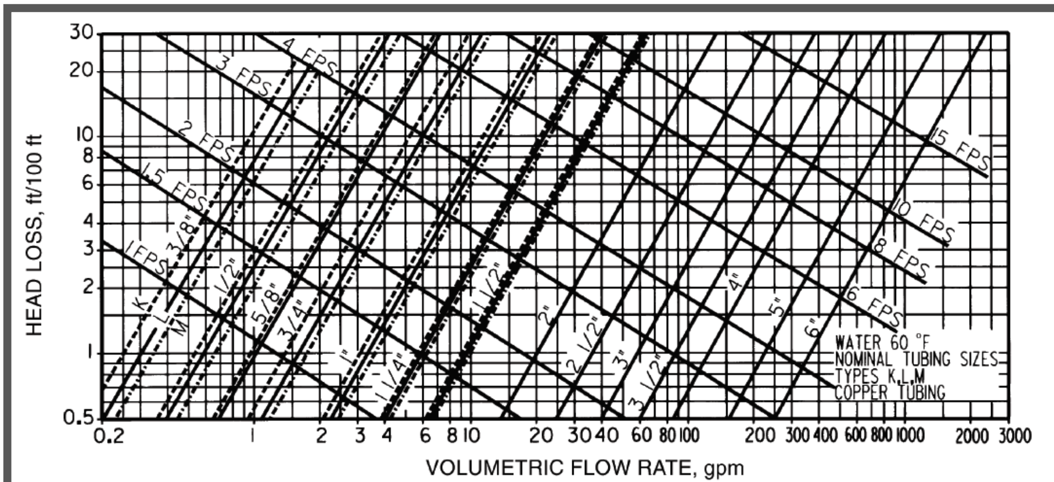


Fig. 5 Friction Loss for Water in Copper Tubing (Types K, L, M)

FIGURE 29: ASHRAE FUNDAMENTALS 2009 COPPER TUBING FLOW

Vitosol 300-T (low-flow operating mode), 25 liters/(h·m^2) or 0.11gpm/m^2

Absorber surface area	**m^2**	**2**	**3**	**4**	**5**	**6**	**8**	**10**	**12**	**15**
Volume flow	gpm liters/min	0.21 0.8	0.3 1.2	0.45 1.7	0.6 2.1	0.7 2.5	0.9 3.3	1.1 4.2	1.3 5.0	1.64 6.2
Flow velocity	ft./s m/s	0.7 to 1.3 0.2 to 0.4								
Pressure drop in the pipework	ft. of head/ft. mbar/m	0.11 to 0.27 1.0 to 2.5								

FIGURE 30: COLLECTOR MANUFACTURER'S RECOMMENDED FLOW RATES

TABLE 12: SOLAR PIPING SIZING 1

Solar Collector In Pipe Schedule (blue)				
Designation (P-#)	Flow [gpm]	Size [in]	Head loss [ft/100ft]	Velocity [fps]
R1	17.4	1 1/2	2.8	3.1
1a	1.6	1/2	5	2
2a	3.2	3/4	3	2
3a	4.7	3/4	6	3
4a	5.9	1	2.7	2.3
5a	7.0	1	3.75	2.75
6a	7.7	1	4.9	3.2
7a	8.4	1 1/4	1.9	2.2
8a	9.0	1 1/4	2.1	2.25
9a	9.7	1 1/4	2.4	2.35
10a	10.4	1 1/4	2.7	2.6
11a	7.0	1	3.75	2.75
12a	6.3	1	3	2.5
13a	5.7	1	2.6	2.2
14a	5.0	3/4	6	3
15a	4.3	3/4	5.1	2.7
16a	3.6	3/4	6	3
17a	2.9	3/4	3	2
18a	2.3	1/2	9	3
19a	1.6	1/2	5	2
20a	0.9	3/8	6.5	2

TABLE 11: SOLAR PIPING SIZING 2

Solar Collector Out Piping (red)				
Designation (P-#)	Flow [gpm]	Size [in]	Head loss [ft/100ft]	Velocity [fps]
S1	17.4	1 1/2	2.8	3.1
1b	10.4	1 1/4	2.7	2.6
2b	8.8	1 1/4	2	2.25
3b	7.2	1	3.9	2.8
4b	5.7	1	2.6	2.2
5b	4.5	3/4	5.5	8.8
6b	3.4	3/4	4.5	2.5
7b	2.7	5/8	5.5	2.5
8b	2.0	1/2	7	2.6
9b	1.4	3/8	9	2.4
10b	0.7	3/8	4.2	1.6
11b	0.7	3/8	4.2	1.6
12b	1.4	3/8	9	2.4
13b	2.0	1/2	7	2.6
14b	2.7	5/8	5.5	2.5
15b	3.4	3/4	4.5	2.5
16b	4.1	3/4	3.5	2.5
17b	4.8	3/4	6	3
18b	5.4	1	2.5	2.2
19b	6.1	1	2.75	2.25
20b	7.0	1	3.75	2.75

Air removal

Air in hydronic systems can cause system performance problems. To eliminate entrained air from the pipe loop, an air separator is included in the main pipe run from the collectors to the tank and an air vent is included on each side of the collector loops array connection as shown in system distribution schematic (Figure 26). The air separator is located at this location because this where the water is at the highest temperature within the system.

Pump Sizing

CP-5 circulates the glycol-water solution from the collectors to the tank heat exchanger. A continuous flow circulator pump is used for this loop. The pump was sized to provide the total flow required by the collectors and the maximum pressure drop of the system. The maximum pressure drop occurs at the pipe loop with the most resistance (greatest head loss). The path of the most resistance is the shown in solar loop schematic in Figure 28. This was calculated by finding the equivalent lengths of all pipes, elbows, valves, and other fittings. The pump head values are summarized in Table 13. A detailed broken out calculation of these values can be found in Appendix C.

Table 13: Pump Head

Pipe	Head [ft]
R1	10.06
1a	2.56
2a	0.94
3a	1.87
4a	0.84
5a	1.10
6a	1.43
7a	0.55
8a	0.61
9a	0.70
10a	0.50
S1	10.06
1b	4.17
static	59.00
TOTAL	**94.4**

Cavitation occurs when the absolute pressure at the suction of the pump approaches the vapor pressure of the fluid. This results in noise and equipment damage and must be avoided by properly designing pumps. To prevent cavitation at the pump inlet, the Net Pump Suction Head Required (NPSHR) of the pump must be met by the Net Pump Suction Head Available (NPSHA) of the system. The NPSHR is determined by the pump manufacturer and provided in the product data.

The pump used must supply a total of 17.4 gpm of flow and provide for a head loss of 59'.

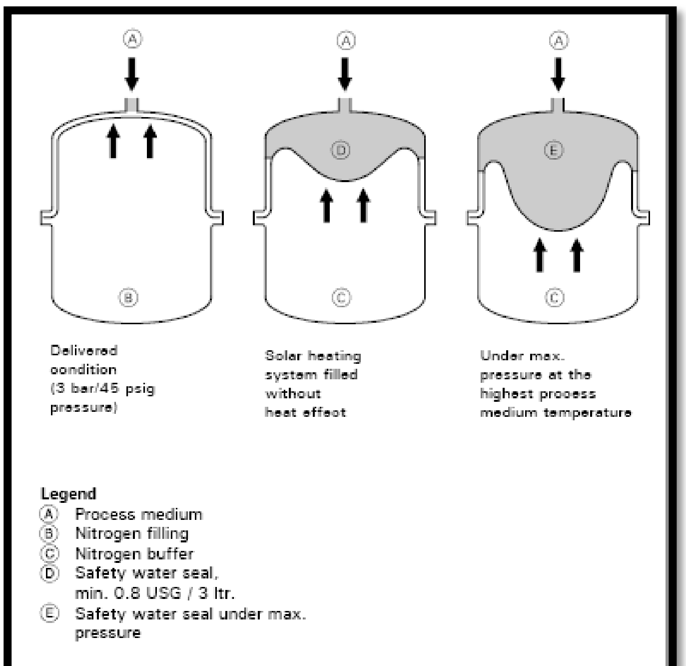


Figure 31: Diaphragm Expansion Tank Loading

Expansion Tank Sizing

Expansion tanks are required in heating systems to accommodate changes in fluid and piping volume due to temperature variations. A close, diaphragm expansion tank is used for this design. The require tank volume was calculated using Engineering Equation Solver (EES) as shown in Appendix D. The EES calculation resulted in a required minimum expansion tank size of 1093 gallons.

Useful Solar Gain and Energy Savings

Polysun simulation software was used to analyze the proposed design's performance. The system location, shading data, and layout were entered into the program, and the equipment performance data for the collectors and tanks were selected from the program catalog to provide representative simulation results for this system design. Shading data from the Ecotect analysis were used to create a horizon line to represent shadows of the penthouse structure, and domestic hot water demand was entered as calculated previously in this section. The simulation estimated that the proposed design will supply a useful solar energy gain of 496.6 MMBtu annually to the system. The monthly load profile of the solar gain is shown in Figure 32.

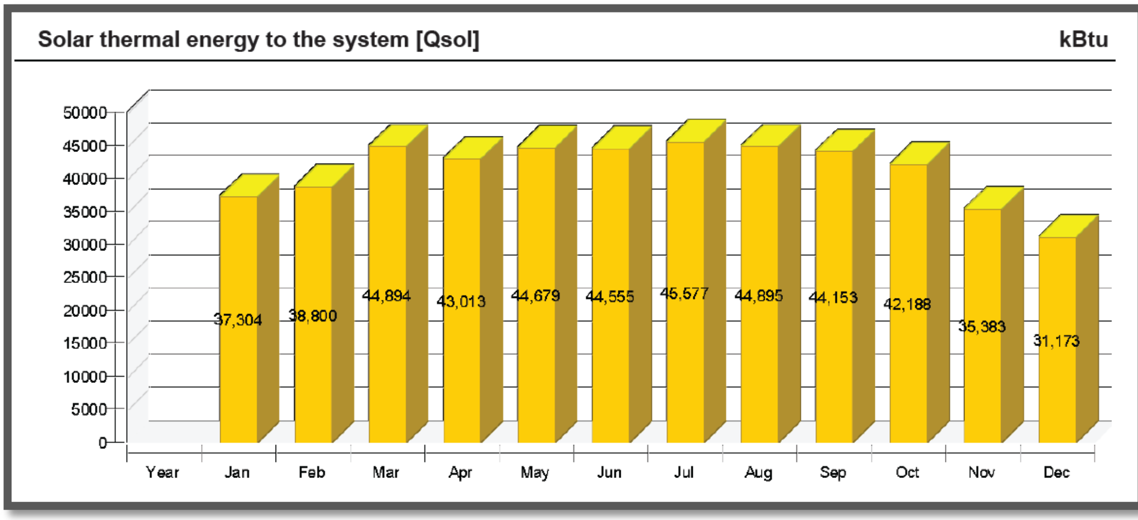


FIGURE 32: MONTHLY USEFUL SOLAR GAIN LOAD PROFILE

To calculate the steam offset cost savings, it will be assumed that the thermal losses in the tank and heat exchangers are equal to the losses due to inefficiency of the hot water heaters. The useful gain added to the system will be assumed to be match up with the load profile of the domestic hot water system and will be assumed to be equal to the steam offset of the system.

Therefore, the annual steam energy savings of the proposed design is 496.6MMBtu or 4966 therms.

Life Cycle Cost Analysis

A client will typically base a large part of their decision of actually implement a design change based on the life cycle-cost of the system. The warranty for most of the major equipment of the design is 10 yrs, however the life of the system is expected to be at least 20 years with proper maintenance and operation. The addition of the solar thermal system will cost roughly $300,000 for equipment and installation. This value is based on a rule-of-thumb for quick estimates of $3,000 per collector. This was suggested by a solar design and contracting specialist from Solarhot. This is slight higher than the value that was suggested for typical flat plate solar thermal system because of the added cost of the evacuated tube collectors and complicated building integration. The US Treasury will provide 30% of the system cost through the Federal Renewable Energy Grants incentive program. This will result in an overall cost to the owner of $210,000 after grants. Additional savings may result from a federal tax exemption called the Residential

Energy Conservation Subsidy Exclusion. However, tax savings are not factored into this life-cycle cost analysis.

A 10 year life cycle cost analysis is shown in Figure 33**Error! Reference source not found.**. The district steam cost savings will be approximately $754,103 over 10 years. Typical maintenance costs are assumed to be $1000. The system will pay for itself after 2 years of operation. The 10 year revenue on the system is $534,103.

10 Year Life Cycle Cost Analysis

Ann energy offset	4966 therms	Base discount rate:	1.9%
Base fuel rate Steam (nat gas)	$14.95 /therm	(based on 7yr OMB estimate as of Apr 2010)	
Ann fuel cost savings (2010)	$74,258		

Date	Analysis year	Capital	PV maint	Nat gas esc.	Base steam savings	PV steam savings		PV revenue per year	PV revenue total
2010		$ (210,000)						$ (210,000)	$ (210,000)
2011									
2012	1		$ (1,000)	1.14	$ 84,655	$ 80,006.93		$ 79,007	$ (130,993)
2013	2		$ (1,000)	1.14	$ 84,655	$ 78,515.14		$ 77,515	$ (53,478)
2014	3		$ (1,000)	1.14	$ 84,655	$ 77,051.17		$ 76,051	$ 22,573
2015	4		$ (1,000)	1.16	$ 86,140	$ 76,941.06		$ 75,941	$ 98,514
2016	5		$ (1,000)	1.17	$ 86,882	$ 76,157.36		$ 75,157	$ 173,672
2017	6		$ (1,000)	1.17	$ 86,882	$ 74,737.35		$ 73,737	$ 247,409
2018	7		$ (1,000)	1.18	$ 87,625	$ 73,970.68		$ 72,971	$ 320,380
2019	8		$ (1,000)	1.18	$ 87,625	$ 72,591.45		$ 71,591	$ 391,971
2020	9		$ (1,000)	1.2	$ 89,110	$ 72,445.35		$ 71,445	$ 463,416
2021	10		$ (1,000)	1.21	$ 89,853	$ 71,687.01		$ 70,687	$ 534,103
Column total		$ (210,000)	$ (10,000)			$ 754,103		**$ 534,103**	

FIGURE 33: 10 YEAR LIFE CYCLE COST ANALYSIS

5.0 Breadth Study: Structural Impacts of Solar Thermal Collectors

Objective:

- To determine whether structural member resizing is required to support the additional solar collectors

A typical structural bay will be analyzed to determine whether additional slab-on-deck, beam, or girder resizing is required with the addition of the solar thermal collectors on the roof.

Structural Design Loads per Contract Documents	
Superimposed Dead Load	29 psf
Live Load	20 psf
Snow Load	30 psf

TABLE 14: STRUCTURAL DESIGN LOADS

Each collector weights 99 lbs. The design loads used by the structural engineers on the project were provided in the contract documents and are summarized in Table 14.

Due to the spacing of the collector arrays, the most collectors that one slab-on-deck span or one beam tributary area will have to support is three. This is the case for the concrete slab-on-deck span and the beam analyzed below.

Additional load of collectors:

The additional loads of the collectors on the roof were calculated as follows:

$$weight\ of\ collector\ array = 99lbs * 3 = 297lbs$$

$$weight\ of\ array\ mounting = 46lbs$$

$$point\ load\ per\ array\ support = \frac{297 + 46}{8} = 42.9lbs$$

$$add'l\ dead\ load = \frac{42.9 * 8}{264} = 1.3psf$$

Slab-on-deck analysis:

The slab-on-deck specified for the penthouse level roof is a 4 ½" reinforced, normal weight concrete slab on 3" deep 18 gage galvanized composite metal deck. The Vulcraft 3 VLI is the model of deck used for this analysis. The manufacturer's structural data sheets can be found in Appendix E.

The superimposed load on the slab-on-deck span analyzed is as follows:

$$Superimposed\ load = 29 + 1.3 + 20 + 30 = 80.3psf$$

$$\mathbf{80.3psf < 210psf} \quad \textbf{Therefore OK}$$

This is less than the maximum allowable load of 210psf according to the Vulcraft data; therefore the existing slab will not have to be resized to accommodate the additional load of the collectors.

Beam analysis

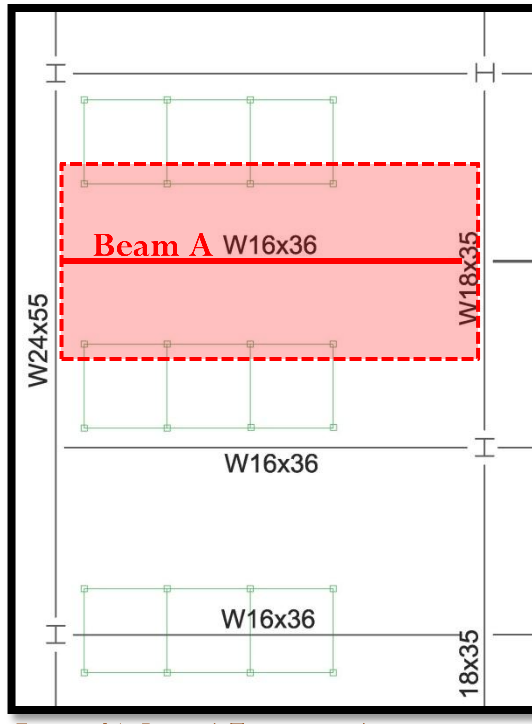


FIGURE 34: BEAM A TRIBUTARY AREA

Structural loads on member A in Figure 34 will be analyzed with the additional weight of the collectors. This is a W16x26 beam that supports the weight of the slab-on-deck in addition to the design loads from the design documents in the contract documents in Table 14 on the previous page.

Factored load:

$$DL = 29 + 1.3 + 75(\text{weight of slab}) = 105.3psf$$

$$W_u = 1.2D + 1.6S + L = 1.2(105.3) + 1.6(30) + (20) = 194.4psf$$

$$V = \frac{w * l}{2} = \frac{(194.4)(24)}{2} = 2.14klf$$

Max Moment:

$$M = \frac{w * l^2}{8} = \frac{(2.14)(24)^2}{8} = 154.1ft \cdot k$$

$$\mathbf{154.1ft \cdot k < 210ft \cdot k} \quad \textbf{Therefore OK}$$

Deflection:

$$105.3 + 30 + 20 = 155.3psf$$

$$W = 155.3 * 11' = 1708.3plf$$

$$W_u = 1.2D + 1.6S = 1.2(29 + 1.3) + 1.6(30) = 84.4psf$$

$$W_u = 83.4 + \#\#\#(\text{W16x26 self wt}) * 11'(\text{tributary width}) = 0.93klf$$

$$\Delta_{TL} = {5wL^2}/{384EI} = \frac{5 * (663.3)(24)^4(1728\frac{in^3}{ft^3})}{384(29{,}000{,}000)(301)} = 0.98"$$

$$\Delta_{max} = {L}/{240} = \frac{24' * 12}{240} = 1.2"$$

$$\mathbf{0.98" < 1.2"} \quad \textbf{Therefore OK}$$

Both the maximum moment and maximum deflection in the beam meet the AISC requirements for this beam, therefore no beam resizing is necessary.

Girder Analysis

Member B is a steel girder supporting the concrete slab-on-deck, two steel beams, and the design loads from Table 14. The beams are assumed to be supporting the maximum possible amount of collector weight as in the previous Beam A analysis.

$$V = P + beam\ self\ wt = 25.7k + 36\left(\frac{24}{2}\right)\left(\frac{1}{1000}\right) = 26.13k$$

Max Moment:

$$M = 26.1 * 11' = 287.1ft \cdot k$$

$$\mathbf{287.1 ft \cdot k < 503 ft \cdot k} \quad \textbf{Therefore OK}$$

Deflection:

$$\Delta_{TL} = {wL^3}/{28EI} = \frac{(26{,}132)(33)^3(1728\frac{in^3}{ft^3})}{28 * 29{,}000{,}000 * 1350} = 1.48"$$

$$\Delta_{max} = {L}/{240} = \frac{33' * 12}{240} = 1.65"$$

$$\mathbf{1.48" < 1.65"} \quad \textbf{Therefore OK}$$

Since the girder's maximum moment and deflection both meet the AISC requirements, this member is adequately sized to support the additional solar collector load and does not require resizing.

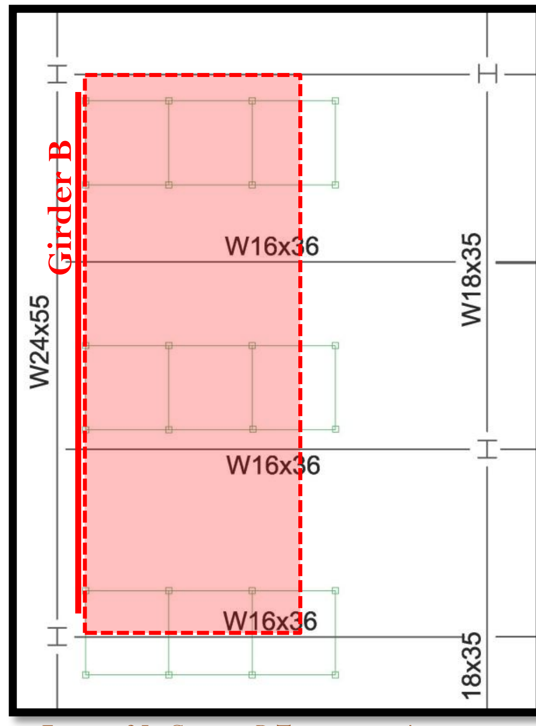


FIGURE 35: GIRDER B TRIBUTARY AREA

6.0 Breadth Study: Solar Thermal Installation and Construction Impacts

Objective

- Assess the constructability of the collectors on the existing roofing system
- Coordinate trades involved with installation
- Address schedule impacts

System mounting method and roof integration

The collector mounting system chosen for this design is the Sloped Frame System, manufactured by Silverback Solar, a sister company of RoofScreen. The frame consists of high strength round steel tubing of 50% post-consumer recycled content that is pre-cut to length. The high strength tubing and custom sizing allow for minimal roof penetrations. A typical detail of this frame is shown in Figure 36.

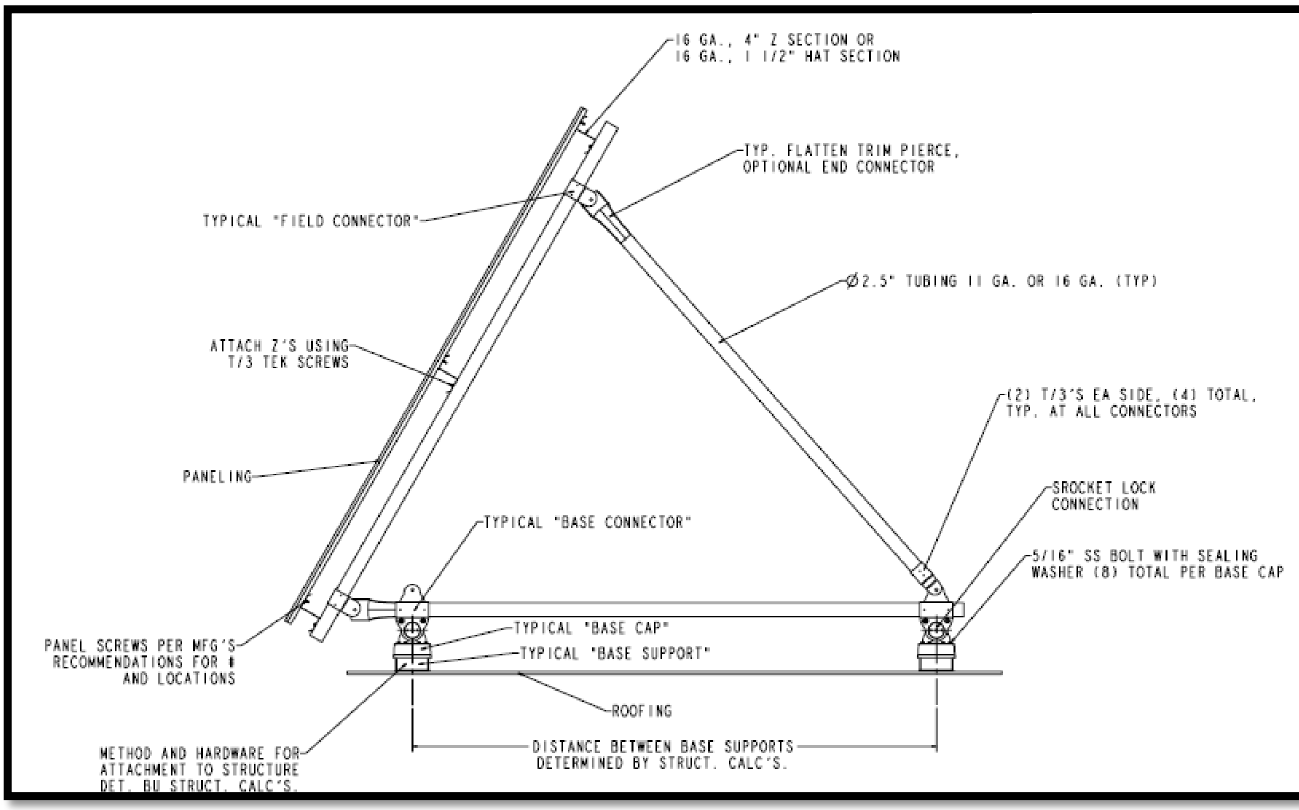


FIGURE 36: SILVERBACK SOLAR SLOPED FRAME SYSTEM

The collectors will be mounted on the 7 ½" concrete slab-on-deck roofing system as shown in Figure 37.

The frames attach to the roof using base supports that are bolted through the slab-on-deck as shown in Figure 39. Base supports are provided in heights ranging from 5"-12" to accommodate variations in insulation thickness. Flashing sleeves cover each base support to ensure watertight penetrations as shown in Figure 38.

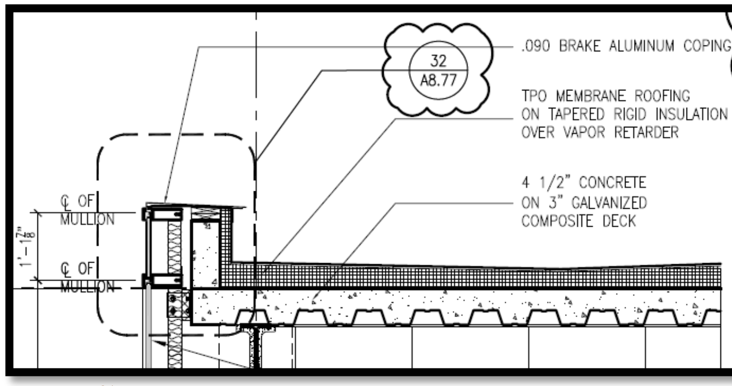


Figure 37: Building Roof Detail

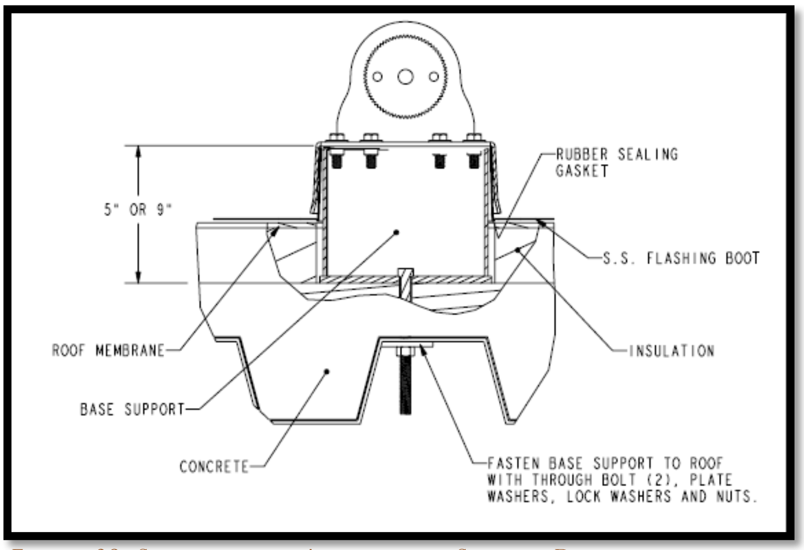


Figure 39: Slab-on-deck Attachment Section Detail

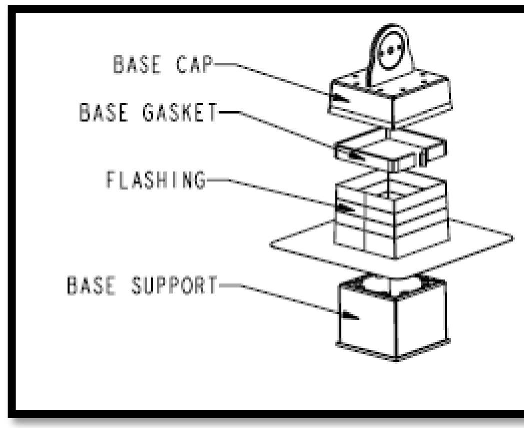


Figure 38: Roof Attachment System

Construction Management - trade coordination and schedule impacts

The installation of the solar thermal system would either require an additional subcontractor on the project or adjustments to the scope-of-work in the contracts of various other subs. Whiting-Turner's construction management (CM) team leading the New Science Center construction has previous experience in projects with large solar thermal installations. After consulting with their project manager, the best method to including the additional work would be organizing a separate solar thermal package to be bid out. This would be done by the CM, Whiting-Turner. The project team's relationships with solar contractors from previous projects will result in a fast, efficient bid process with clear expectations.

Careful planning is necessary to coordinate the additional work on-site. The solar sub selected would be required of the CM to ensure

Assuming the plumbing firm working on the project has experience in this area, it will be assumed that the construction management firm, Whiting-Turner, will choose to adjust the scope of work of various subcontracts. The solar thermal system will have the greatest effect on the scope of work of the plumbing contract, since it ties into the domestic hot water system. The installation of the additional piping and equipment associated with solar thermal system, excluding the collector mounting equipment, will be added to the scope of work of the plumbing contract. The installation of the mounting supports will be added to the scope-of-work of the miscellaneous metals subcontractor. The contract amount of the plumbing and miscellaneous metals contracts will need to be adjusted to account for the additional labor and materials and equipment costs of the equipment.

Careful planning is necessary to coordinate this additional work on-site with the work of all other trades. Trades that will be affected include building envelope, roofing, plumbing, controls, and mechanical commissioning.

Appendix F includes the revised construction schedule of the project to include the solar thermal installation. Additional work is denoted in orange.

After adjusting the project schedule, it has been determined that the solar thermal installation will not delay the original construction schedule. This is important for this project since the client, Georgetown University, is expecting the building to be turned over in July 2012 to prepare for occupancy for the 2012 academic school year.

7.0 Recommendations and Conclusions

The proposed solar thermal system provides an economical solution to reducing the building's carbon footprint and reducing the building operating cost, while having minimal effect on the structure and construction process. The building owner is obviously interested in reducing their carbon footprint because of the sustainable building initiatives at the school. With a two year payback period and large operating cost savings, this system would even generate interest in clients without sustainable interests.

After investigating in several applications, it was determined that a domestic hot water integrated system would be the best option because of the constant load throughout the year. The available roof layout allowed for a total of 77 collectors with 1716sf of total absorber area. Initially this would not appear to be an ideal location for the solar collectors due to the shading of the penthouse structure, but the energy savings turned out to be significant.

The analyses of this report prove that additional investigation of solar thermal integration on this building would be worthwhile for the building owner. Due to the minimal impact on the existing building's design, this system would be feasible to add even after the construction is completed in July 2012. An additional impact of this system that was not previously addressed is the extra LEED points that can be achieved by utilizing solar energy. This further adds to the value of the solar thermal system.

The continuing advancement of solar thermal technology will allow for better, more efficient designs in the future. This advancement will also increase as interest and awareness of these technologies increases. As the future of solar and HVAC industries continue to evolve, these types of systems will become far more common than they currently are.

8.0 MAE Related Study

A significant portion of the mechanical breadth topic of this report included topics covered in AE 558 – Central Heating and AE 596 – Solar Engineering Systems/Independent Study. Many of the topics related to the solar course are obvious due to the nature of the proposed solar thermal system. Specifically solar topics from the course include: the solar orientation, available irradiation, Polysun energy simulation, system integration, and construction issues with solar thermal systems.

The sizing of nearly all of the equipment other than the collectors involved topics covered in Central Heating. The solar thermal pipe loop was essentially treated as a hydronic distribution heating system. Specific topics from this course include: thermal storage, hydronic piping systems, air removal, and life cycle cost analysis.

9.0 References

Georgetown University – New Science Center construction documents.

2009 ASHRAE Handbook – Fundamentals.

2008 ASHAE Handbook – HVAC Systems and Equipment

2007 ASHRAE Handbook - Applications

Sustainable Design of Research Laboratories, Kling-Stubbins

LEED Reference Guide for Green Building Design and Construction, Version 3, 2009 Edition, US Green Building Council.

Planning & Installing Solar Thermal Systems, Second Edition, Earthscan publishing

Solar Engineering of Thermal Processes, John A. Duffie & William A. Beckman

Appendix A: List of Figures and Tables

List of Figures

List of Tables

Appendix B: Collector Product Data - Viessman Vitosol 300-T

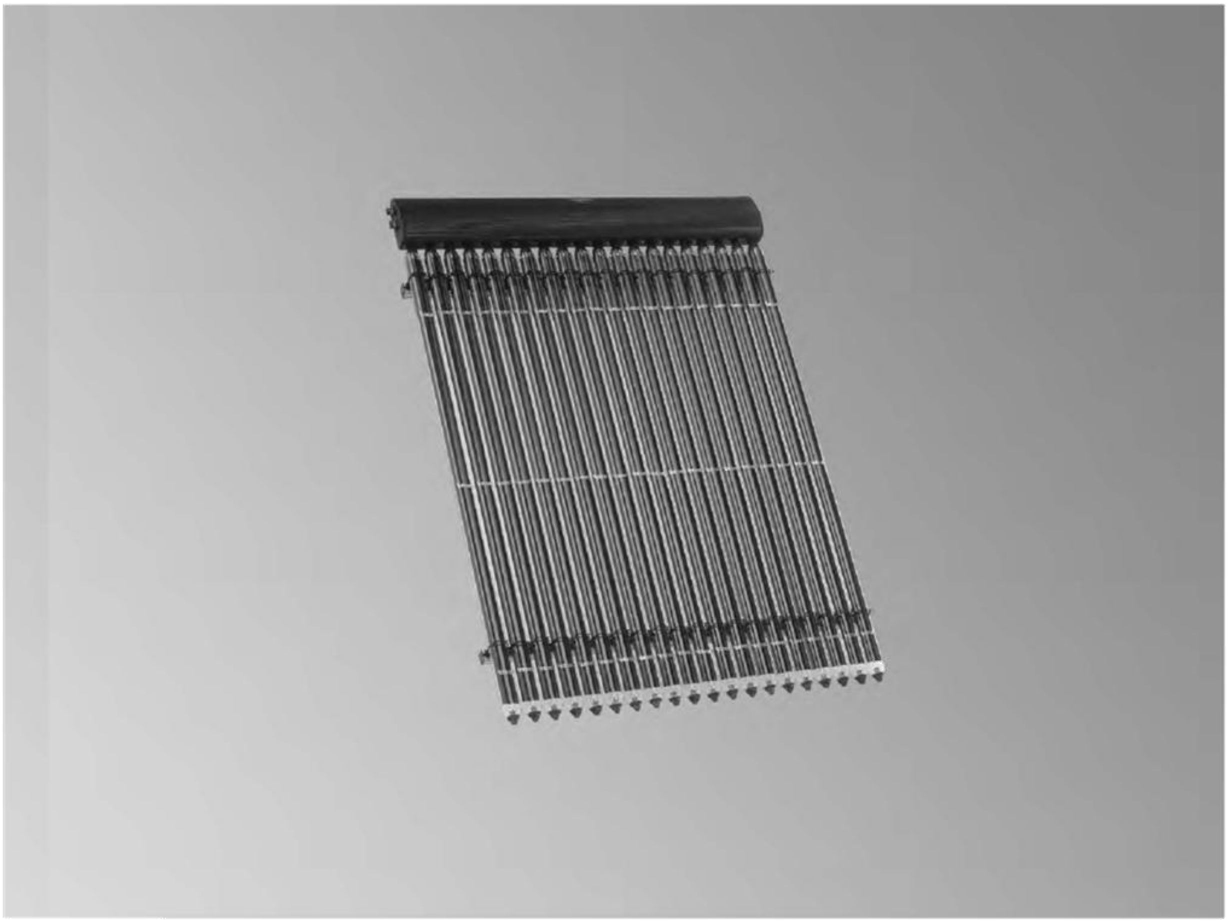
VIESSMANN

VITOSOL 300-T

Vacuum tube solar collector utilizing the heat pipe principle to harness solar energy

Technical Data Manual

Model Nos. and Pricing: see Price List



VITOSOL 300-T Model SP3

Vacuum tube solar collector

for vertical, or angled installation on sloped or flat roofs

To produce domestic hot water, or to supplement low-temperature heating systems or swimming pools via a heat exchanger, as well as the generation of process heat.

Certified in accordance with SRCC OG-100.

Meets the requirements of the German "Blue Angel" certificate of environmental excellence to RAL UZ 73.

Certified in accordance with DIN ISO 9001.

SPF quality seal from the Solar Energy Testing and Research Institute in Rapperswil, Switzerland.

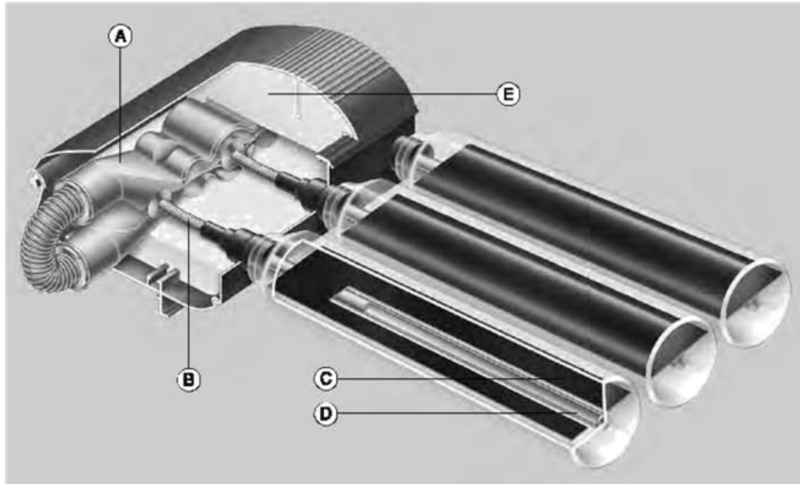
5167 567 v1.6 02/2011

Vitosol 300-T

Model SP3

The benefits at a glance:

- **High level of operational reliability and a long service life** thanks to the use of **high-grade, corrosion-resistant materials** such as borosilicate solar glass, copper and stainless steel. Durable, vacuum-tight glass-to-metal seals.
- **Extremely high efficiency** thanks to the **Sol-titanium coated absorber**; the vacuum collector tubes greatly reduce heat losses.
- **Superior heat utilization** by the patented **"Duotec" double-pipe heat exchanger** which almost completely encloses the condensers for **better heat transfer**.
- Flexible connection between vacuum tube and condenser due to a corrugated pipe. The individual tubes can be rotated for **optimum alignment to the sun**.
- **Straight-forward installation and service** thanks to **dry connection** of collector tubes. Individual tubes can be installed and disassembled without having to drain the solar system.
- **Fast installation times** due to proven plug-in system for the connection of several collectors to form one collector panel (max. 60 tubes).
- Vacuum tube design outperforms conventional flat-plate collectors in cold, cloudy or windy conditions. **Ideally suited for year round energy collection in cold weather climates.**
- **Built-in temperature limiter** inside the condenser controls the heat flow at very high collector temperatures, protecting the heat transfer fluid.



Legend
- (A) Duotec double-pipe heat exchanger
- (B) Bronze flexible coupling
- (C) Sol-titanium coated absorber plate
- (D) Heat pipe
- (E) Insulation

Vitosol 300-T - vacuum tube collector based on the heat pipe principle

Construction and function

Vitosol 300-T vacuum tube solar collectors are available as two models:
- $2 m^2$ with 20 tubes
- $3 m^2$ with 30 tubes

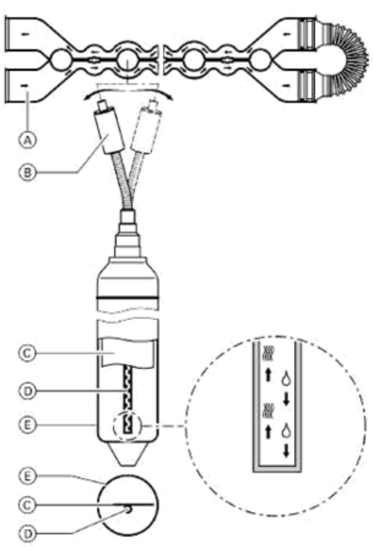
Built into each vacuum tube is a Sol-titanium coated copper absorber, ensuring a high absorption rate of solar radiation and low emission of thermal radiation.

A heat pipe filled with an evaporator liquid is placed on the absorber and connected to the condenser in the Duotec double-pipe heat exchanger via a flexible coupling.
A so-called "dry connection" between the heat pipe and the heat exchanger allows pipes to be rotated or replaced even when the installation is filled and under pressure.
Solar energy is transferred to the heat pipe, causing the liquid to evaporate. The vapor rises into the condenser. Heat is conveyed to the passing heat transfer medium (glycol / water) by the double-pipe heat exchanger containing the condenser; this causes the vapor to condense. The condensate flows back into the heat pipe and the process is repeated.

The angle of inclination of the collector must be at least 25°, in order to guarantee a circulation of the evaporator liquid in the heat exchanger. Corrections for deviations from south can be made by rotating the vacuum tubes.

By means of flexible and insulated connection pipes sealed with O-rings several collectors can be joined to form a total collector surface area of up to 65 $ft.^2$ / 6 m^2 (60 tubes).

A connection kit with clamping ring connections facilitates the attachment of the collector panel to the piping of the solar circuit.
The collector temperature sensor is installed in a sensor mounting clip directly on the Duotec heat exchanger inside the connection housing of the collector.



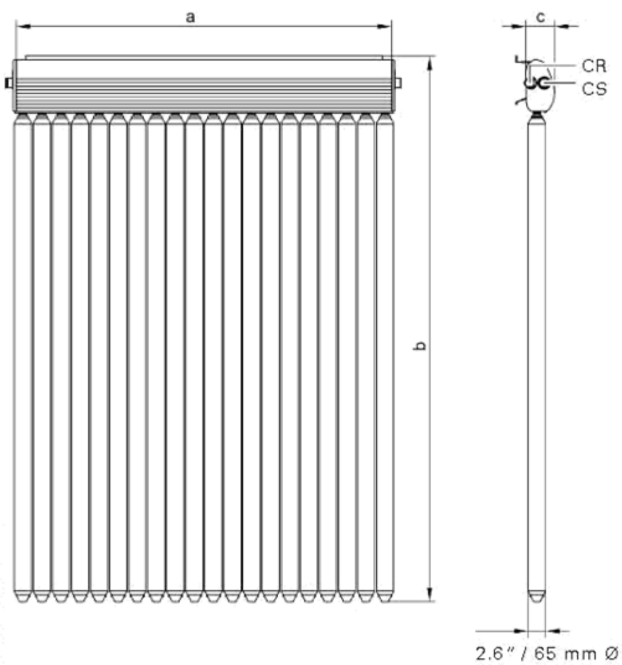
- (A) Duotec double-pipe heat exchanger
- (B) Condenser
- (C) Absorber
- (D) Heat pipe
- (E) Vacuum glass tube

5167 567 v1.6

Technical Data

Model		SP3 2m²	SP3 3m²
Number of tubes		20	30
Gross area	ft.² / m²	31 / 2.88	46.5 / 4.32
Absorber surface area	ft.² / m²	22 / 2.05	33 / 3.07
Aperture area*1	ft.² / m²	22.7 / 2.11	34.1 / 3.17
Dimensions			
Width (a)	inches	55 ¾	83 ¾
	mm	1418	2127
Height (b)	inches	80	80
	mm	2031	2031
Depth (c)	inches	5 ½	5 ½
	mm	143	143
Optical efficiency*2	%	81.5	78.4
Heat loss coefficient K_1*2	$W/(m^2 \cdot K)$	1.43	1.36
K_2*2	$W/(m^2 \cdot K^2)$	0.0076	0.0045
Thermal capacity	$kJ(m^2 \cdot K)$	5.4	5.4
Weight	lbs / kg	112 / 51	167 / 76
Fluid capacity	USG	0.32	0.48
(heat transfer medium)	ltr	1.2	1.8
Maximum working pressure*3	psig	87	87
	bar	6	6
Maximum stagnation temperature*4	°F / °C	302 / 150	302 / 150
Connection ∅	inches	¾	¾
	mm	22	22
Space requirement for flatroof installations	ft.² / m²	approx. 15.6 / 1.45	approx. 20.5 / 1.9
Requirements for installation surface and anchorage		Roof construction with adequate load capacity for prevailing wind forces Minimum angle of inclination: 25°	

*1 *Used when sizing the system.*
*2 *Based on the absorber surface area. (As tested by ISFH in Europe)*
*3 *In sealed systems, operating pressure of at least 15 psig + 0.45 psig x static head (ft.) / 1.0 bar + 0.1 bar x static head (m) must be present in the collectors in cold condition.*
*4 *The stagnation temperature is the temperature which applies to the hottest point of the collector at a global radiation intensity of 3412 Btu/h / 1000 W when no heat is conducted by the heat transfer medium.*



CR Collector return (inlet)
CS Collector supply (outlet)

5167 567 v1.6

Standard equipment

The following are packaged in separate cartons:
– Insulated distribution header with installation rails and Technical Literature
– Vacuum tubes (10 per box)

Accessories (individually packaged, depending on order):
- Mounting accessories
- Connecting pipes with insulation
- General connection set
- Solar-Divicon (pumping station for collector circuit)
- Vitosolic differential control
- Air separator
- Fast air vent valve comes with shut off
- Solar hand pump
- Solar expansion tank
- Heat transfer medium
- Antifreeze tester
- Set of spare parts (assortment of small parts which may be misplaced during installation of collectors)

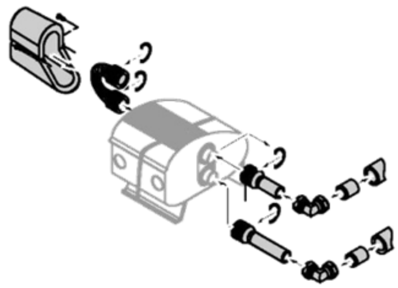
Heat transfer medium

Tyfocor non-toxic liquid for solar heating systems with active anti-corrosion and anti-ageing protection.

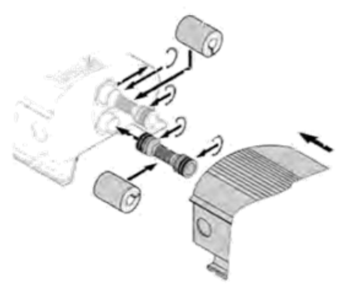
Frost protection:	to -31°F / -35°C
Specific gravity at 68°F / 20°C:	1.032 to 1.035 g/cm^3 to ASTM D 1122
Viscosity at 68°F / 20°C:	6.5 to 8.0 mm^2/s to DIN 51562
pH value:	7.5 to 8.5 to ASTM D 1287
Color:	transparent, blue-green
Container:	5.3 USG / 20 ltr. in a disposable container

Accessories

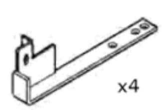
General connection set
Required to connect solar collector to system piping. One set required per collector array - max. 65 ft.^{2} / 6 m^2



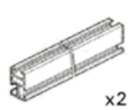
Pipe connection set
Required to connect multiple solar collectors



Sloped roof hardware kit
Required for direct-mounting of collector to shingled roof



x4



x2

Flat roof hardware

Solar Divicon
Preassembled pumping station for solar collector circuit.
Includes: 3-speed pump (2 sizes), pressure gage, 2 thermometers, 2 ball valves, pressure relief valve, flow meter, 2 flowcheck valves, air separator, system fill manifold, and foam insulation cover.

SCU 124/224
Electronic differential temperature control for solar heating.

Printed on environmentally friendly (recycled and recyclable) paper.

Viessmann Manufacturing Company (U.S.) Inc.
45 Access Road
Warwick, Rhode Island • 02886 • USA
Tel. (401) 732-0667 • Fax (401) 732-0590
www.viessmann-us.com • info@viessmann-us.com

Viessmann Manufacturing Company Inc.
750 McMurray Road
Waterloo, Ontario • N2V 2G5 • Canada
Tel. (519) 885-6300 • Fax (519) 885-0887
www.viessmann.ca • info@viessmann.ca

5167 567 v1.6 Technical information subject to change without notice.

Appendix C: Pipe Sizing and Total Head Loss Calculation

Solar Collector In Pipe Schedule (blue)

Designation (P-#)	Flow [gpm]	Length [ft]	elbows	other	Total Eqvt Length [ft]	Size [in]	Head loss [ft/100ft]	Total Head [ft]	Velocity [fps]
R1	17.4	320.0	7	2	359.40	1 1/2	2.8	**10.06**	3.1
1a	1.6	13.7	3	1	51.20	1/2	5	**2.56**	2
2a	3.2	13.7	3	1	31.20	3/4	3	**0.94**	2
3a	4.7	13.7	3	1	31.20	3/4	6	**1.87**	3
4a	5.9	13.7	3	1	31.20	1	2.7	**0.84**	2.3
5a	7.0	13.7	3	1	29.20	1	3.75	**1.10**	2.75
6a	7.7	13.7	3	1	29.20	1	4.9	**1.43**	3.2
7a	8.4	13.7	3	1	29.20	1 1/4	1.9	**0.55**	2.2
8a	9.0	13.7	3	1	29.20	1 1/4	2.1	**0.61**	2.25
9a	9.7	13.7	3	1	29.20	1 1/4	2.4	**0.70**	2.35
10a	10.4	3.7	2	0	18.70	1 1/4	2.7	**0.50**	2.6
11a	7.0	10.0	2	0	25.00	1	3.75	0.94	2.75
12a	6.3	13.7	3	1	31.20	1	3	0.94	2.5
13a	5.7	13.7	3	1	31.20	1	2.6	0.81	2.2
14a	5.0	13.7	3	1	31.20	3/4	6	1.87	3
15a	4.3	13.7	3	1	31.20	3/4	5.1	1.59	2.7
16a	3.6	13.7	3	1	31.20	3/4	6	1.87	3
17a	2.9	13.7	3	1	31.20	3/4	3	0.94	2
18a	2.3	13.7	3	1	31.20	1/2	9	2.81	3
19a	1.6	13.7	3	1	31.20	1/2	5	1.56	2
20a	0.9	13.7	3	1	31.20	3/8	6.5	2.03	2

Solar Collector Out Piping (red)

Designation (P-#)	Flow [gpm]	Length [ft]	elbows	other fitting	Total Eqvt Length [ft]	Size [in]	Head loss [ft/100ft]	Pipe Head [ft]	Velocity [fps]
S1	17.4	320.0	7	0	359.40	1 1/2	2.8	**10.06**	3.1
1b	10.4	127.0	3	1	154.50	1 1/4	2.7	**4.17**	2.6
2b	8.8	13.7	3	1	31.20	1 1/4	2	0.62	2.25
3b	7.2	13.7	3	1	31.20	1	3.9	1.22	2.8
4b	5.7	13.7	3	1	31.20	1	2.6	0.81	2.2
5b	4.5	13.7	3	1	31.20	3/4	5.5	1.72	8.8
6b	3.4	13.7	3	1	31.20	3/4	4.5	1.40	2.5
7b	2.7	13.7	3	1	31.20	5/8	5.5	1.72	2.5
8b	2.0	13.7	3	1	31.20	1/2	7	2.18	2.6
9b	1.4	13.7	3	1	31.20	3/8	9	2.81	2.4
10b	0.7	13.7	3	1	31.20	3/8	4.2	1.31	1.6
11b	0.7	13.7	3	1	31.20	3/8	4.2	1.31	1.6
12b	1.4	13.7	3	1	31.20	3/8	9	2.81	2.4
13b	2.0	13.7	3	1	31.20	1/2	7	2.18	2.6
14b	2.7	13.7	3	1	31.20	5/8	5.5	1.72	2.5
15b	3.4	13.7	3	1	31.20	3/4	4.5	1.40	2.5
16b	4.1	13.7	3	1	31.20	3/4	3.5	1.09	2.5
17b	4.8	13.7	3	1	31.20	3/4	6	1.87	3
18b	5.4	13.7	3	1	31.20	1	2.5	0.78	2.2
19b	6.1	13.7	3	1	31.20	1	2.75	0.86	2.25
20b	7.0	133.3	3	0	140.80	1	3.75	5.28	2.75

Appendix D: Expansion Tank Sizing Calculation using EES Software

EES Ver. 8.651: #1610: For use by students and faculty in Architectural Engineering, Penn State University

$$V_T = V_W \cdot \left[\frac{\frac{v_2}{v_1} - 1 - 3 \cdot \alpha \cdot \Delta T}{1 - \frac{P_1}{P_2}} \right]$$

$\alpha = 9.5 \cdot 10^{-6}$

Initial conditions

$V_W = 10000$

$T_1 = 60$

$P_{1,g} = 60$

$P_1 = P_{1,g} + 14.7$ [psia]

$v_1 = \frac{1}{66.77}$ *(1/density of 45% ethylene glycol at 60F) per ASHRAE Fundamentals 2009 pg 31.7*

Final conditions

$T_2 = 250$

$P_{2,g} = 80$

$P_2 = P_{2,g} + 14.7$ [psia]

$v_2 = \frac{1}{64.92}$ *(1/density of 45% ethylene glycol at 250F) per ASHRAE Fundamentals 2009 pg 31.7*

$\Delta T = T_2 - T_1$

SOLUTION

Unit Settings: Eng F psia mass deg

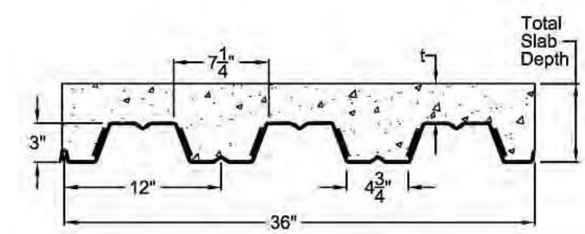
α = 0.0000095	ΔT = 190	P_1 = 74.7 [psia]
$P_{1,g}$ = 60 [psig]	P_2 = 94.7 [psia]	$P_{2,g}$ = 80 [psig]
T_1 = 60 [F]	T_2 = 250 [F]	v_1 = 0.01498 [ft^3/lbm]
v_2 = 0.0154 [ft^3/lbm]	V_T = 1093 [gal]	V_W = 10000 [gal]

1 potential unit problem was detected.

VULCRAFT

3 VLI

Maximum Sheet Length 42'-0
Extra Charge for Lengths Under 6'-0
ICBO Approved (No. 3415)



Interlocking side lap is not drawn to show actual detail.

COMPOSITE

STEEL SECTION PROPERTIES

Deck Type	Design Thickness in	Deck Weight psf	I_p in⁴/ft	S_p in³/ft	I_n in⁴/ft	S_n in³/ft	V_a lbs/ft	F_y ksi
			Section Properties					
3VLI22	0.0295	1.77	0.730	0.414	0.729	0.426	1528	50
3VLI20	0.0358	2.14	0.920	0.534	0.919	0.551	2698	50
3VLI19	0.0418	2.50	1.104	0.654	1.102	0.676	3678	50
3VLI18	0.0474	2.84	1.254	0.770	1.252	0.797	4729	50
3VLI16	0.0598	3.58	1.580	1.013	1.580	1.013	5309	40

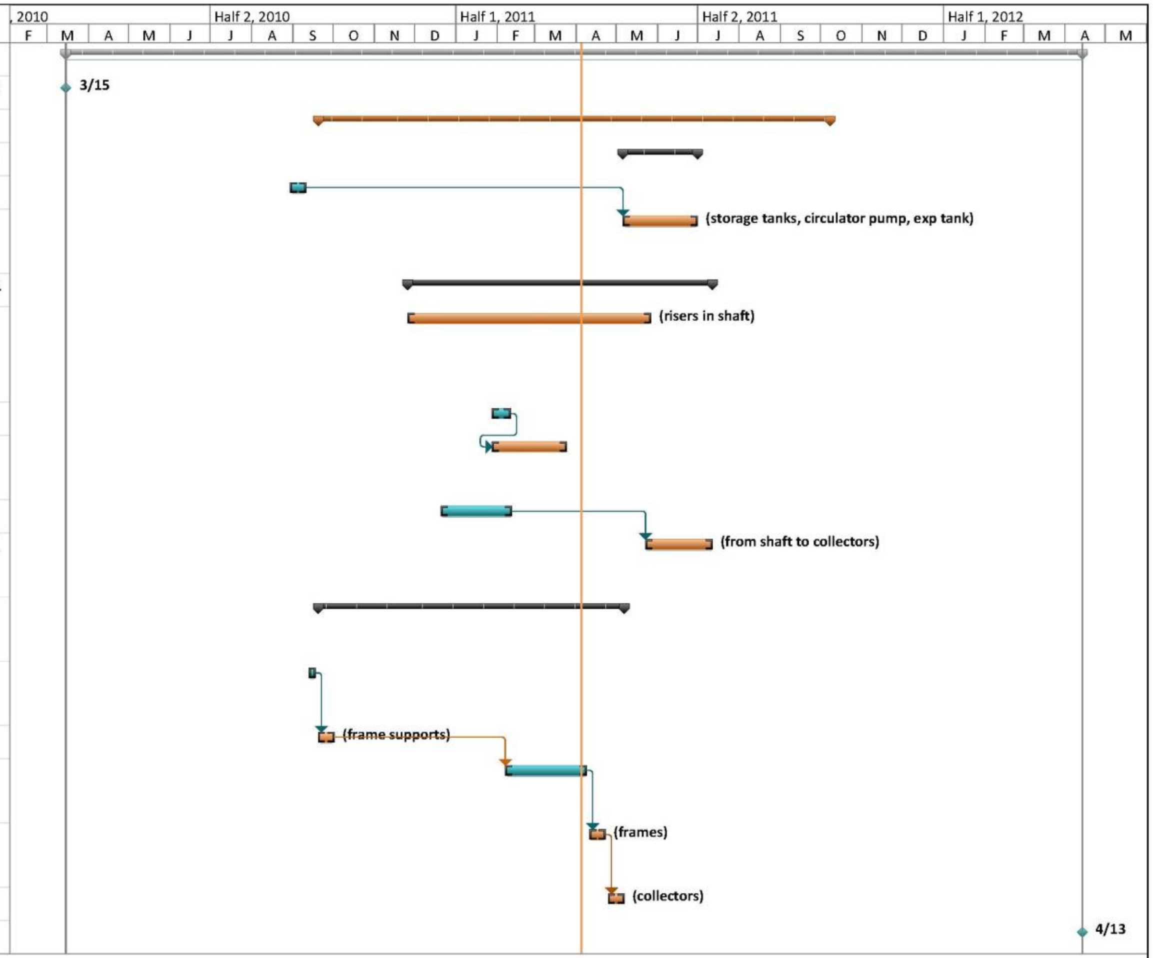
(N=9.35) NORMAL WEIGHT CONCRETE (145 PCF)

TOTAL SLAB DEPTH	DECK TYPE	SDI Max. Unshored Clear Span 1 SPAN	2 SPAN	3 SPAN	Superimposed Live Load, PSF Clear Span (ft.-in.) 7'-0	7'-6	8'-0	8'-6	9'-0	9'-6	10'-0	10'-6	11'-0	11'-6	12'-0	12'-6	13'-0	13'-6	14'-0
	3VLI22	9'-2	10'-7	11'-8	216	195	176	161	148	109	99	90	83	76	70	64	59	54	50
5.00	3VLI20	10'-8	12'-11	13'-4	241	216	196	178	163	150	139	129	93	85	78	72	66	61	57
(t=2.00)	3VLI19	12'-0	14'-4	14'-7	266	237	214	194	178	163	151	140	131	122	115	79	73	67	62
45 PSF	3VLI18	12'-10	15'-1	15'-1	289	261	238	218	201	186	173	161	151	142	134	127	92	86	80
	3VLI16	13'-5	15'-7	15'-11	327	294	267	243	223	208	191	178	167	156	147	139	132	96	89
	3VLI22	8'-9	9'-8	10'-11	247	222	201	184	137	124	113	103	94	87	80	73	67	62	57
5.50	3VLI20	10'-1	12'-4	12'-9	275	247	223	203	186	171	159	116	106	97	89	82	76	70	65
(t=2.50)	3VLI19	11'-4	13'-8	14'-2	302	270	244	222	203	188	172	160	149	107	98	90	83	77	71
51 PSF	3VLI18	12'-5	14'-7	14'-7	330	298	271	248	229	212	197	184	173	162	153	112	105	98	92
	3VLI16	12'-9	14'-11	15'-5	373	335	304	277	255	235	218	203	190	178	168	159	117	109	102
	3VLI22	8'-4	8'-10	10'-1	277	249	226	171	154	140	127	116	106	97	89	82	76	70	65
6.00	3VLI20	9'-8	11'-10	12'-3	309	277	250	228	209	193	143	130	119	109	100	92	85	79	73
(t=3.00)	3VLI19	10'-10	13'-2	13'-7	339	304	274	249	227	209	193	179	131	120	110	102	94	87	80
57 PSF	3VLI18	11'-10	14'-2	14'-2	370	334	304	279	257	238	221	207	194	182	136	126	118	110	103
	3VLI16	12'-2	14'-4	14'-10	400	378	341	311	286	264	245	228	213	200	189	141	132	123	115
	3VLI22	8'-0	8'-3	9'-4	307	277	251	190	171	155	141	129	118	108	99	91	84	78	72
6.50	3VLI20	9'-3	11'-5	11'-9	343	307	278	253	232	174	158	144	132	121	111	103	95	87	81
(t=3.50)	3VLI19	10'-4	12'-8	13'-1	377	337	304	276	252	232	214	169	146	134	123	113	104	96	89
63 PSF	3VLI18	11'-4	13'-9	13'-10	400	371	338	309	285	264	246	229	215	162	151	140	131	122	115
	3VLI16	11'-7	13'-10	14'-3	400	400	376	345	317	293	272	253	237	222	189	157	148	136	128
	3VLI22	7'-9	7'-8	8'-8	338	304	233	209	188	171	155	142	130	119	109	101	93	86	79
7.00	3VLI20	9'-0	10'-11	11'-4	377	338	305	278	255	192	174	159	145	133	122	113	104	96	89
(t=4.00)	3VLI19	10'-1	12'-3	12'-7	400	370	334	303	277	256	236	176	160	147	135	124	116	106	98
69 PSF	3VLI18	11'-0	13'-3	13'-6	400	400	371	340	313	290	270	252	236	178	166	154	144	135	126
	3VLI16	11'-4	13'-4	13'-9	400	400	400	379	348	322	298	278	260	200	185	172	161	150	140
	3VLI22	7'-7	7'-2	8'-2	368	331	254	228	205	186	169	154	141	130	119	110	101	93	86
7.50	3VLI20	8'-9	10'-2	11'-0	400	368	333	303	231	209	190	173	158	145	134	123	113	105	97
(t=4.50)	3VLI19	9'-10	11'-10	12'-2	400	400	364	331	302	278	209	191	175	160	147	136	126	116	107
75 PSF	3VLI18	10'-9	12'-10	13'-3	400	400	400	370	341	316	294	275	210	195	181	168	157	147	138
	3VLI16	11'-0	12'-11	13'-4	400	400	400	400	380	351	325	303	283	216	202	188	175	164	153

Notes:
1. Minimum exterior bearing length required is 2.50 inches. Minimum interior bearing length required is 5.00 inches. If these minimum lengths are not provided, web crippling must be checked.
2. Always contact Vulcraft when using loads in excess of 200 psf. Such loads often result from concentrated, dynamic, or long term load cases for which reductions due to bond breakage, concrete creep, etc. should be evaluated.
3. All fire rated assemblies are subject to an upper live load limit of 250 psf.

Appendix F: Revised Construction Coordination Schedule

ID	Task Name	Duration	Start	Finish
1	**Building Construction**	**545 days**	**Mon 3/15/10**	**Fri 4/13/12**
2	Start Construction	0 days	Mon 3/15/10	Mon 3/15/10
3	**Solar Thermal Installation**	**275 days**	Mon 9/20/10	**Fri 10/7/11**
4	**Distribution Equipment**	**40 days**	**Fri 5/6/11**	**Thu 6/30/11**
5	Foundation Slab-on-grade	10 days	Mon 8/30/10	Fri 9/10/10
6	Start-up Mechanical / Electrical Equipment	40 days	Fri 5/6/11	Thu 6/30/11
7	**Piping**	**162 days**	**Fri 11/26/10**	**Mon 7/11/11**
8	Core HVAC/Plumbing/Fire Protect. Rough-in/Risers All Levels	130 days	Fri 11/26/10	Thu 5/26/11
9	Frame Partitions Level 1	10 days	Fri 1/28/11	Thu 2/10/11
10	Mechanical Branch Rough-in / Distribution Level 1	40 days	Fri 1/28/11	Thu 3/24/11
11	Building Envelope Exterior Wall	39 days	Tue 12/21/10	Fri 2/11/11
12	Mechanical Branch Rough-in / Distribution PH level	36 days	Mon 5/23/11	Mon 7/11/11
13	**Collectors and Mounting Equipment**	**165 days**	**Mon 9/20/10**	**Fri 5/6/11**
14	Concrete Slab-on-deck - Penthouse Level	5 days	Mon 9/13/10	Fri 9/17/10
15	Install Frame Base Supports	10 days	Mon 9/20/10	Fri 10/1/10
16	Main Roofing & Plaza Deck Waterproofing	45 days	Mon 2/7/11	Fri 4/8/11
17	Install Collector Mounting Equipment	10 days	Mon 4/11/11	Fri 4/22/11
18	Install Solar Collectors	10 days	Mon 4/25/11	Fri 5/6/11
19	Construction Complete	0 days	Fri 4/13/12	Fri 4/13/12



Project: Project coordination sche
Date: Tue 4/5/11

Task | Split | Milestone | Summary | Project Summary | External Tasks | External Milestone | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | Deadline | Progress