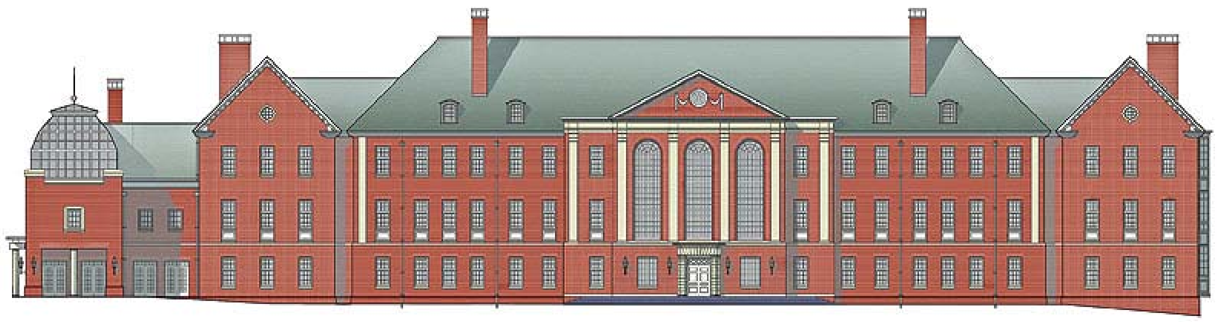
# Integration of DOAS and Make-Up Air Systems in a Multiple-Use Facility



## Ann & Richard Barshinger Life Science & Philosophy Building

Franklin & Marshall College
Lancaster, PA


Brian Ault
The Pennsylvania State University
Architectural Engineering
Mechanical Option

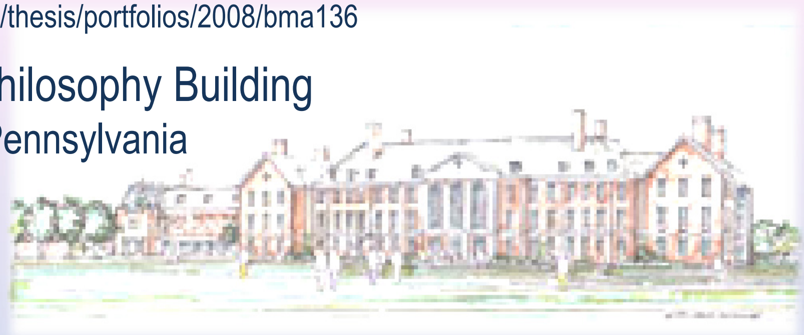
Faculty Advisor:
Dr. William Bahnfleth


April 9, 2008

# Ann & Richard Barshinger Life Science & Philosophy Building

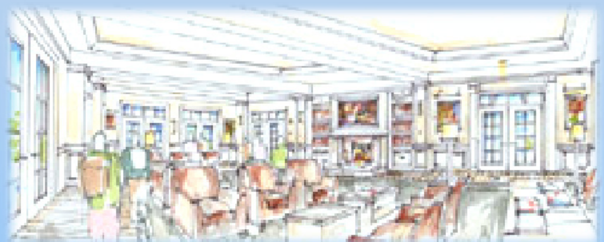
## Franklin & Marshall College, Lancaster, Pennsylvania

Architect: Einhorn Yaffee Prescott
GC / CM: Turner Construction



### ARCHITECTURE / GENERAL

-104,000 SF LABORATORY / INSTRUCTION FACILITY
- CONSTRUCTION: DECEMBER 2005 – AUGUST 2007
- OCCUPIED BY THREE COLLEGE DEPARTMENTS, TWO PREMIER PROGRAM AREAS
- BRICK FACADE TO MATCH OLDER STYLES ON CAMPUS
-120-SEAT LECTURE HALL AND ATRIUM USED FOR COLLEGE & COMMUNITY EVENTS
- SOUTH ROOF GREENHOUSE, BASEMENT OBSERVATION VIVARIUM
- VERMONT SLATE ROOF
- NUMEROUS STUDENT LOUNGE SPACES



### CONSTRUCTION

- DESIGN – BID – BUILD PROJECT
- $39M GMP CONTRACT
- EXTENSIVE ROCK EXCAVATION
-ONGOING CAMPUS SERVICES RENOVATIONS

### MECHANICAL

- (2) 50,000 CFM AHUS ON ROOF, (1) 15,000 CFM AHU IN BASEMENT
- (2) 25,000 CFM AND (1) 15,000 CFM EXHAUST FANS ON ROOF
- GLYCOL ENERGY RECOVERY LOOP BETWEEN EXHAUST AND MAKE-UP AIR
-550 TON CENTRIFUGAL CHILLER IN CENTRAL UTILITIES BUILDING
- COOLING TOWER ON ROOF, ROOM FOR EXPANSION
-MP STEAM FED FROM CENTRAL CAMPUS SERVICES (4880MBH HTX)
- LP STEAM SUMMER BOILER ON ROOF (3392 MBH)

### STRUCTURAL

-STEEL BRACED FRAME STRUCTURE
- CONCRETE SLABS ON COMPOSITE METAL DECK
- 8” CMU EXTERIOR BACKUP WALLS
- BRICK EXTERIOR FACADE
- PRE-CAST CONCRETE PANELS (DECORATIVE)
- LIMESTONE LINTELS & CAPSTONE

### ELECTRICAL / LIGHTING

- 15KV, 3 PHASE DELTA BUILDING POWER FEED
- 1300 KVA TRANSFORMER (15KV – 480/277Y)
- 350KW 480/277Y STANDBY DIESEL GENERATOR
- 277V T-8 LINEAR FLUORESCENT LIGHTING
- 120V INCANDESCENT ACCENT LIGHTING

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## Acknowledgements

I would like to thank the Penn State AE Department for their collective advice and guidance over this past year, and their great understanding and flexibility throughout this entire Senior Thesis process. I would especially like to thank Dr. Bahnfleth for his continued support and review of my ideas, keeping the research focused much more than I would have otherwise.

Also, thanks to Franklin & Marshall College, specifically Maria Cimilluca and Perry Scheid, two of F&M's Facilities and Operations managers, who have helped me a great deal with data acquisition and familiarity with the building. Turner Construction Company's assistance with drawings and specs has been greatly appreciated. Dee Shellenberger and Bill Swanson were instrumental in tours for the building during construction and handling almost everything that came up during the early portions of the project.

I would like to extend my deep gratitude to Jason Weaver as well; since the two of us were assigned this building by the department, our collaborative efforts were extremely helpful to speed through most of the process.

My thanks go out to the mentors on the discussion board and to all the other AE students. Without all of us doing this at once, we never would have done this as well as we have.

Thank you to my family and friends both here and at home who have all seen very little of me this past year because of all my activities associated with Thesis and Penn State. I owe them all many hours of time, and will always remember what they have done for me.

## 1.0 – Executive Summary

This building is Franklin & Marshall's new laboratory, office, and classroom facility for the Biology, Psychology, and Philosophy departments and their associated education spaces. It is a 3-story building plus basement. This steel braced-frame structure encompasses 104,000 square feet.

The air distribution system for the main section of the building (floors 1-3) is a VAV system with hydronic reheat coils, fed by two air handlers on the roof (AHU-1 and AHU-2). These two units provide a great deal of outdoor air to the building to compensate for large amounts of exhaust air removed from the lab exhaust hoods. They serve a multitude of occupancy spaces, from faculty offices to anatomy/biology labs. These units are both sized at 50,000 cfm nominal.

The basement is home to the vivarium for animal housing and observation. This area is served by AHU-3, a 100% Outdoor Air unit located in the basement mechanical room. This unit provides 7,500-15,000 cfm of fresh conditioned air to the spaces 24/7 to keep the animals healthy.

The goal of this thesis study is to design a new mechanical system that costs less and takes less energy to operate, and finally cost less up front as well. Also included is a grid-tied Photovoltaic system to provide some energy generation on site throughout the year. The structural system was essentially checked, but no size reductions were found.

The new mechanical system consists of Dedicated Outdoor Air Units for ventilation air, and a Make-Up air handler for the lab spaces in the building. The remaining space loads will be handled by Water Loop Heat Pumps throughout the building. This new system will better ventilate the building, while consuming less energy through the year.

In total, the new mechanical system will cost 7% less up front (roughly $540k), and $35k less to operate each year. The 34.7kW PV system will generate almost 55,000 kWh per year, saving 80,000 pounds of Carbon Dioxide and roughly $5100 per year in electricity costs.

The 34.71kW PV system on the roof will generate roughly 55,000 kWh per year on average, having a payback with materials offset (net) of 42 years. This will offset 80,000 pounds of Carbon Dioxide yearly. If both systems (new mechanical and PVs) are adopted together, the total cost of the building will still be reduced; the new mechanical system saves over $500,000, and the PV system costs net $240,000.

## 2.0 – Background

This new Life Science & Philosophy Building at Franklin and Marshall College in Lancaster, Pennsylvania is partially funded by a gift from Ann & Richard Barshinger. This is the second building with their namesake at the F&M campus. The building provides a common space for the Biology, Psychology, and Philosophy Departments, as well as the Biological Foundations of Behavior and Scientific and Philosophical Studies of the Mind Programs. These labs, support offices/student spaces, faculty offices, and common study areas partly replace older facilities spread throughout the campus, and provide 40% more area for these departments and programs to spread and continue their growth, as well as provide the most cutting-edge resources to the students and faculty studying at F&M.

F&M has not been building many new facilities in recent years, mostly due to a dislike of the look and feel of most "new, sleek" buildings. Much care was taken to have this new facility blend with the rest of campus. The planned location was in place of 11 turf tennis courts to the west of the faculty/staff parking lot, and to the north of the Central Utilities Plant. This put the new building right at the heart of old campus. The college told Einhorn Yaffee Prescott that a Colonial-Revival building was the style they wanted, clad in brick to match the older buildings on campus, one in particular – Fackenthal Science Building. This, and the addition of a $1.1Million Vermont Slate Roof, allows the building to blend in, at least partly, with the other core campus buildings.

The Barshinger LS&P Building encompasses 104,000 square feet of floor space in three above-grade floors, and a slightly smaller basement. The basement houses an observation vivarium and the upper floors house all the labs, classrooms, and faculty / student support spaces. Construction began in December of 2005, and the building was turned over in August of 2007, having just completed its first full academic year this spring. Turner Construction gave a GMP contract for the building at $39.9Million, and the fully finished building cost F&M $48.7Million at turnover.

This is to be the first of a few buildings slated for construction in the northwest quadrant of campus. Most of the infrastructure of "old campus" has been pushed to its limits, including the central chilled water plant. Originally, 4,000 square feet of floor space in the basement was planned for a new chiller plant, with all cooling towers placed on the flat hidden section of the new building's roof. However, after the soils reports came back, this plan was scrapped, and the building's chiller was relocated. The soil under the tennis courts was extremely rocky, so excavation was expensive. Because of this, the excavation for the chiller plant was eliminated, and kept to only the minimum needed for the vivarium, and vital mechanical systems. The building's chiller was moved to the central plant, and crammed into a very tight spot next to an existing chiller, but the tower was kept on the new roof. The new growth/master plan is to place the chiller plant (if possible) in one of the new buildings, or to place one chiller in each of those buildings, and locate the towers on the new building. Also planned is a reduction of the Central Utilities Plant, back to the original 1932 building. That requires shifting the existing chillers in the building to towers located on the roof of the new building. There is a great deal of space available up there, and it will be packed full of cooling towers within 10-15 years.

# 3.0 – Existing Conditions

## *3.1 – Architecture*

The Life Sciences and Philosophy Building at Franklin and Marshall College is a brand new steel structure at the heart of the campus in Lancaster, Pennsylvania. The building is wrapped in a brick and limestone facade, and done in a Colonial-Revival style. The north and south wings of the building are laid out nearly symmetrically, but not entirely to provide some interesting aesthetic aspects. At the east center of the building lies its central three-story interior lobby and atrium space. The first floor holds a study lounge and café area, all of which is open to the second and third floor balconies above. A grand open staircase ties all three floors together, and makes the space simple to navigate. The majority of the mechanical equipment is housed on the roof, but some is still housed in the basement, next to the electrical equipment. The roof is clad in Vermont slate, possible only by a donation from F&M alumni. The south end of the building roof holds a greenhouse used for plant study, growth, and research. Just to the west of the main lobby floor is a 120-seat state of the art lecture hall. This hall and atrium are planned for use during classes and speeches, as well as many community events. The building is also the mechanical hub of campus. Many future planned buildings will have their cooling and heating provided through the Life Sciences and Philosophy Building.

## *3.2 – Historical Requirements*

Many buildings on the F&M campus are Colonial Revival style, and the desire for this building was to have it blend in with the rest of campus. Great care was given to the brickwork. All masons were required to mimic the work on the Fackenthal Science Building. Built in the late 1920's, masons were not well-trained, so the mortar beds and lines were not straight or plumb. The Life Sciences & Philosophy Building had one site Superintendent that did nothing but walk the scaffolds and inspect the brickwork. On many occasions, the work had to be re-done because the work looked too well-done and clean. One other recent addition to campus used an asphalt roof. Due to unfavorable reactions from alumni, this new building has a $1.1Million Vermont Slate roof, similar to other long-standing buildings on campus.

## *3.3 – Building Envelope*

Exterior walls are brick exterior facade, limestone panels, or pre-cast concrete panels, 1" airspace, 8" CMU back-up wall, with interior 2x4 insulated steel stud wall, gwb interior finish surface. All windows are double-hung, double pane, low-e coated, argon filled; only select windows are operable for fire escape purposes. The architecturally visible roof is a sloped slate rain diverter. The actual waterproofing surface is a flat roof with membrane and insulation. The greenhouse is aluminum framed double-pane glass with automated operable sections to provide ventilation.

### *3.4 - Construction*

The building project was bid to Skanska in December 2005. Initial testing was completed, and overall design / preservation concerns were addressed. The sidewalk and parking area to the east of the site needed to be preserved throughout construction, as they were the main access routes from campus to Harrisburg Pike, and much off-campus housing. Also, many of the trees in the same area were to be preserved to keep the aesthetics of an “old” longstanding campus. Not only was this convenient to have all preserved features in the same area, but it was also a necessity. The main electrical feeders for all of F&M’s campus run underground just to the east of the site. After some months passed, the project was turned over to Turner who completed the project on time in August 2007. The re-negotiated contract between F&M and Turner was a Guaranteed Maximum Price of $39.9Million. Construction site offices and staging were located to the north at first, but were moved to the new asphalt access path (for building loading docks later on) for the majority of construction. After substantial completion, Turner offices were set up in the basement of the central services building, south of the project.

### *3.5 – Electrical*

Electrical service is provided to the building at 12.5kV from the campus distribution network. Power is provided to the unitary substation in the electrical room located at the north-west corner of the building. One main 1333kVA transformer steps this down to the 480/277 building distribution system. Most loads (lighting and power) in the building are served by two bus ducts, one North, one South. Equipment on the roof, and most basement vivarium loads (lighting and power) are served by separate feeders from the main switchgear. Each floor’s power and lighting loads are fed through 2 electrical rooms on each floor, having both high and low voltage panels, plus a step-down transformer for service. Emergency power is provided to the building by a 350 kW, 480/277V standby diesel generator on the roof. This feeds to automatic transfer switches that feed two main distribution panels on the roof. These serve pumps, major equipment, emergency lighting throughout the building and some outside, life safety equipment, and most of the vivarium, including the air handler (AHU-3) in the basement.

### *3.6 – Lighting*

The vast majority of lighting in the building is 277V-fed T-8 lamps. There is some 120V incandescent lighting for accents, but not for general lighting purposes. Most classrooms, offices, and study spaces have recessed louvered parabolic troffers. Recessed wall-washer compact florescent light fixtures are used to wash chalkboards and display areas. Special function areas (Humanities Reading Room, study lounges, atrium) use a great deal of incandescent fixtures. The Humanities Reading Room has fixtures fit for a very formal space – chandeliers, recessed accents, and wall sconces. Hallways are lit primarily by recessed linear fixtures, with some can-type CFL downlights to highlight trophy cases and other areas of interest. Exterior lighting is fairly simple – lights at building entrances and walkway lighting are HID lamps and CFLs, and landscape lights are used outside the Humanities Reading Room at the south of the building shining up into trees planted in the patio. More detailed plans for additional exterior lighting have been made, but the campus is still in the very early stages of this developmental plan, so installation will wait until more of the new buildings are finished.

### *3.7 – Structural*

The building is a braced steel frame building, with composite concrete slabs flown for each floor above grade. Typical bays are 20' x 32' with W18x90 girders, and W16x26 beams. Most columns (interior) are W12x65. Flown floors are 6-1/2" composite slabs, with 2" 18-ga galvanized deck and 4-1/2" of Normal Weight Concrete. Slab on Grade areas of the first floor are 5" NWC with reinforcement. All footings are spread footings with perimeter footers and concrete walls. The rain-screening roof sections (Vermont Slate) is supported by galvanized metal deck on a structural steel skeleton, with the actual rain-proof surface as a flat roof with membrane.

### *3.8 – Supporting Systems*

3.8.1 – Fire Protection – The Fire Annunciation Panel is located in the main Atrium at the first floor level, connected to local fire alarm panels on each floor, except for the basement. The main dialing panel is attached to the fire panel serving the basement, located just off the atrium in the lighting control room under the main stairs. Floors 1-3 have their fire panels located in the north electrical rooms, and all fire alarm wiring terminates there. Door hold-opens, smoke detectors, flow sensors, alarm strobes and chimes are all wired to these cabinets. Each floor is fully sprinkled, including the penthouse areas containing all mechanical equipment. The fire system sensors for the penthouse are wired to the third floor fire panel, oversized to accommodate the additional sensors and alarms.

3.8.2 – Transportation – The elevator for the building is located in the south "core" area. It is a hydraulic-powered lift from below. This lift serves all four interior floors, along with the penthouse for easy maintenance access. There are two main stair towers passing from Basement to Penthouse/Roof. These are located at the North and South ends of the building. There is a main public open stairwell located at the west side of the central atrium. This stair serves floors 1-3, and is open to the corridors on each floor, and open to the atrium space. Handrails are provided to partly separate the spaces, but open area is left to a maximum.

3.8.3 – Telecommunications – Each floor has, in addition to the electrical rooms, two telecom rooms, one north and one south, to serve every floor. These handle all telephone and data lines for the building. Service entrance to the building is located in the basement in room M058. This room is fed by panels located in the CUP and Thomas Hall for both cable and voice lines. These cable lines and fiber optic lines serve to provide network services to the building, as well as surveillance for security purposes. Servers, HUBs, and switches are located in many equipment racks in each of the telecom closets and the main service entrance room in the basement.

# 4.0 – Existing Conditions – Mechanical Systems

The Barshinger Life Science & Philosophy Building has three air handling units, two located on the roof and one in the basement. The two roof-mounted VAV units serve the north (AHU-1) end of the building, and the south (AHU-2) end. The main lecture hall, statistics instruction lab, and atrium are served by both units. These main two AHUs also serve some general spaces in the basement. The majority of the basement of the building holds the vivarium, served by AHU-3. This 100% Outdoor Air unit serves only the vivarium to keep any airborne pathogens separate from the rest of the building. All zone terminals have pressure-independent VAV boxes, each with a hydronic reheat coil controlled by zone thermostats. Three exhaust air handling units (EAHU) located on the roof take air from the building, both general and lab exhaust, through still more PI-VAV boxes. EAHU-3 takes air from the vivarium only, and EAHU-1 takes from spaces served by AHU-1, etc.

## *4.1 – System Location and Space Allocation*

The building has a very tight layout of all mechanical system components. Most of the big equipment is housed on the roof or in the central utilities plant, with the minimum equipment located in the building's basement.

| Space Type | Area (SF) | % of Total |
|---|---|---|
| Gross Building (interior) | 96,500 | 100.0% |
| Mech./Elec./Telecom Rooms | 5,058 | 5.2% |
| Shaft Spaces (all) | 1,065 | 1.1% |
| Total Lost Space | 6,123 | 6.3% |

Most of the lost space is from the mechanical and electrical rooms, not all the shaft penetrations. The vast majority of this area (3650 / 5058 – 72%) comes from just three main mechanical/electrical rooms located in the basement. Placing all this equipment outside the actively-used areas prevents any inconveniences to occupants during times of system maintenance.

## *4.2 - Controls*

All of the systems within the new Life Science & Philosophy Building are controlled by a DDC controls system, and will be tied into the new centralized controls system that will be used throughout the planned expansion of campus facilities, once the other updated facilities are built. All fans are VFD controlled, and maintain a static pressure differential setpoint in the ductwork. The supply and exhaust air is volume-controlled by pressure-independent VAV boxes, but the return ductwork has only static setpoints.

Most pumps in the building are controlled by Variable Frequency Drives. They all have differential pressure sensors placed throughout the building, and are set to maintain varying and adjustable pressure differences between the supply and return lines. This eliminates the need for balancing valves, but they are provided at *every* load coil none the less. All load coils (hydronic) are controlled by 2-way valves; no 3-way bypass valves are provided. To keep the hot water in the hydronic loop hot all the time, the fin-tube radiation in the north-end study alcoves is left on year-round. This provides some flow at the ends of branches at all times, and continuously heats that space, even if it is 95°F outside.

*<u>4.3 – Central Plant</u>*

The building's heating and cooling power is provided through central campus steam and chilled water from the campus north loop. This centralized system provides a more cost-effective and slightly more efficient energy delivery for all of campus. There is a pressure reduction station to keep building steam pressures down to 10-12 psig, and the building has two chilled water pumps to pull water from the north loop, supplied by the central chiller plant. Steam drives all the main AHU heating coils, domestic water heaters, the main hydronic heating loop heat exchanger, and provides steam for all the building's humidifiers. Chilled water is provided through a Primary/Secondary central chilled water plant. More expansion is planned in the future for the north loop, but for now this building is the only one utilizing that chilled water. The new 550 ton chiller is slightly oversized to account for growth and load sharing and for use during low total loading of the central plant. This can save the campus from operating any of the other three older, less efficient chillers to satisfy the load on a swing-season day.

When the designers combined the separated chilled water systems (each had been a P/S system before, each serving dedicated loads) into one, they kept all the secondary CHWS lines connected, and shared a common line with the primary return, secondary return (as usual), but also connected that line to the primary supply, but not through a decoupler line. This reduces central plant flexibility, especially in areas far from the CUP where pressure differentials are not high enough without full secondary pumping power engaged. Also, because primary chilled water can't be sent to both sets of secondary pumps without being warmed by return water from the North Loop (the LS&P building), if there isn't enough pressure to induce flow at the far chilled water coils, not only must the other set of secondary pumps be turned on, but also one of the older chillers in the other section of the main plant. While all 4 chillers are located in the same building, not 70 feet apart, they are plumbed into opposite ends of the hydraulic system, so they act like two separated plants. Outlying buildings still maintain their own cooling power independent of the central system. The new LS&P project was originally supposed to house the new central chilled water plant in the basement, but that idea was scrapped because of extensive excavation expenses. The roof of the LS&P Building still has cooling towers planned for installation for all the chillers, but the chillers themselves will need to be located somewhere else.

*<u>4.4 – Air Systems</u>*

The building has an all-air system. Three air handlers serve a network of ducts, conditioning and ventilating the building. Two of these AHUs are located on the roof, each 50,000 cfm units, primarily serving the North and South wings of the building, 1$^{st}$-3$^{rd}$ floors. The third AHU is located in the basement mechanical room, and primarily serves the vivarium areas. In the event of a partial system failure, all ductwork is connected to allow even building pressurization and airflow. Three exhaust air handlers take a majority of the building's air for discharge, mainly from lab exhaust hoods, and other non-ideal air locations. Because of the great amount of fresh air supplied to the building, a simple set of glycol runaround coils is provided between AHU-1 and EAU-1, typical for all three sets. This provides some means of energy recovery. The building is served by boilers and chillers located in the Central Utilities Plant (CUP) to the south of the building. Services are provided via underground tunnels for the campus distribution system. A 550 ton electric centrifugal chiller in the CUP serves the Life Science Building (LSB). The cooling tower is on the roof of the LSB. Many additional towers are planned for the LSB roof, and large tower water supply and return lines have been run through the basement to accommodate this. Also, a central campus chilled-water system is planned for eventual use, and this building is the first to include plans to hook up to that loop; it is the hub of that loop, actually. During the summer, when Medium Pressure steam from the CUP is shut off, a Low Pressure summer boiler on the roof provides all heating needs for the building. Domestic water and fire protection water (with pumps) service enters in the basement, and passes up through the building's core.

All zones (except electrical/telecom rooms, and the main electrical room) have hydronic reheat coils, fed from a central heat exchanger using the campus' steam distribution system. This loop also provides heat to the fin-tube radiators, but they are controlled by two-position valves using outdoor temperature reset. Each zone has its own thermostat, which throttles the airflow through each VAV box down to the minimum cooling required, then opening the reheat valves. If that does not provide enough heat (such as during morning warmup), the box is allowed to open proportionally to increase heat delivery. Most spaces have both general and contaminant exhaust, since most of the building is labs. Some offices, corridors, and common gathering areas have return air that will be directed back to the main air handling units. This air is drawn back to the main AHUs (1 and 2 only have return fans) and can then be sent back into the building, or out through a relief damper.

The building's airflow is driven primarily by exhaust systems. The inputs to the whole building are provided by the operation of hoods and sashes. As the pressure in the exhaust ductwork increases, the exhaust air handlers ramp up because of the differential pressure sensors' (shown on the controls diagrams, not found plans) signals provided to the VFD controllers. This causes the building overall to become less positively pressurized, and the amount of outdoor (and supply, if necessary) is increased to maintain the building at a positive pressure differential to the outside. Building differential pressure sensors are indicated on the controls diagrams, but never located on the mechanical floor plans. If there is a call for supply air while no air is being exhausted, a great deal of return air is drawn from the building and directed through the air handler, conditioned, then delivered back to the spaces. Return air is drawn back to the air handler, but can either be re-sent to the building, or sent outside through the relief dampers. The air handlers can function in an economizer mode, but only one set of outdoor air dampers is provided, so controlling ventilation can be an issue. During economizer operation, all air returned from the building is directed out as relief air. If more outdoor air is needed for conditioning than is needed for building pressurization, the exhaust systems draw more air from the general exhaust grilles to keep positive pressurization limited. This control feedback override isn't provided for ventilation reasons; the designers assume that there will always be some exhausting going on while the building is occupied, enough to meet minimum ventilation requirements for the gross building.

# 5.0 – ASHRAE Standards Analysis

## *5.1 – ASHRAE 62.1-2007*

ASHRAE Standard 62.1-2007, Chapter 6, specifies the calculation methods for providing adequate ventilation to indoor spaces, as well as the required minimum ventilation rates. The Ventilation Rate Procedure was used to calculate the required outdoor air amounts for the entire building. The VRP is a fairly straightforward procedure, but requires some time and knowledge of system operation characteristics. The table below summarizes the results of these calculations; for a more detailed analysis, see Technical Report 1.

| | Calculated OA | Minimum OA | Supply Minimum | Supply Maximum | 62.1-2007 compliance |
|---|---|---|---|---|---|
| AHU-1 | 326,590 | 15,000 | 20,000 | 50,000 | NO |
| AHU-2 | 77,880 | 15,000 | 20,000 | 50,000 | NO |
| AHU-3 | 2,448 | 7,500 | 7,500 | 15,000 | YES |

AHU-3 easily meets the ventilation requirements of the standard because it is a 100% OA unit, and conditioning the spaces requires far more air than for ventilation only. AHU-1 and AHU-2 do not meet the ventilation requirements outright. This is due to a low minimum airflow for a select few zones through the building. During normal building operation, when these spaces are not occupied there will be adequate ventilation air provided. As soon as people occupy the spaces, the load imposed on the system because of their presence will require more conditioned air for delivery to the space to maintain the setpoint. This is the reason the room seems under-ventilated by just applying the standards. If further calculations are done, we can see that the least-ventilated room (the Lecture Hall) will actually have maximum ventilation provided the lights are on and more than 50 people are in the room. Since the room will be adequately ventilated when there are no people there and the lights are off, the room can accommodate up to 24 people without any supply air beyond the minimum set at the VAV boxes. The other rooms that prevent the systems from fulfilling the requirements outright are aquatic lab suites, which must be kept to minimum airflows to keep the delicate environments needed for these aquatic experiments. Since these rooms will not be occupied at all times, as noted on the lab access sheets for the 2007-2008 school year, some additional calculations show that they are in fact adequately ventilated.

The vivarium is greatly over-ventilated by AHU-3, and the energy associated with conditioning that much outdoor air will be reduced by the DOAS system proposed in the mechanical system redesign.

Chapter 5 of 62.1-2007 sets minimum standards for building's mechanical systems based on their location and climate, as well as standard good engineering practice. The building has met all of these requirements since the building is a very typically-built system, with standard details.

### *5.2 – ASHRAE Standard 90.1-2004*

Standard 90.1 sets maximum "energy use" for a building. These values (such as minimum R-values for insulating walls) are minimum values, and may be exceeded at any time, provided the owner has the resources for this additional infrastructure. All the requirements are based on the building type and location, taking local climate conditions into account.

The building meets the vast majority of these requirements; however there are a few which are not met. The ones not met are the efficiency of the summer boiler on the roof and the ventilation of the building. Ventilation is taken care of by what was stated above, so a more detailed analysis than the minimum is required to fully understand the building's system operation, and the assumptions of the VRP in 62.1. The boiler is outright short of the efficiency minimum. Since it is only used during the summer, a detailed analysis could be performed to show that the building is consuming an equivalent amount of resources of a building using a code-compliant boiler year round, but due to rising energy costs, environmental impacts, and the opinion of the author, minimum efficiency should be met unconditionally.

The lighting densities were calculated using the space-by-space method, and were above the recommended maximum values listed in 90.1. The building is a School/University building, limited to 1.2W/SF overall. The building is 62% over the maximum allowed power for lighting, which amounts to 63.1kW above the maximum allowed. The table below summarizes the results of the detailed analysis contained in Technical Report 2.

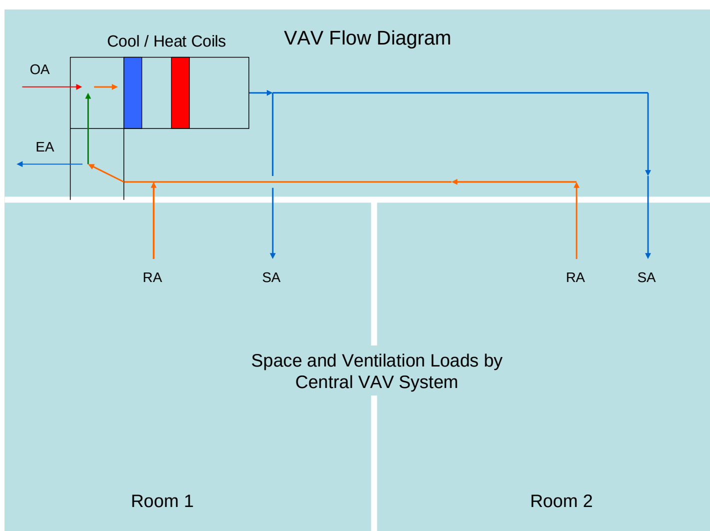
| Building Lighting | | |
|---|---|---|
| SF | Watts lights | Watts / SF |
| 84,762 | 164,887 | 1.945 |

# 6.0 – Mechanical Redesign – Depth Study

The redesigned mechanical systems for the Barshinger LS&P Building are presented here for educational exercise only, and are not intended to influence any design decisions made by the original design team. There are two main portions to this redesign depth, with small ancillary additions providing many benefits to the system overall. Energy use and ventilation are the two primary concerns of building mechanical systems, and this building is no exception. One possible solution for the high exhaust rates in the laboratory spaces will be investigated, and the reheat energy use will be eliminated.

## *6.1 – Air-Side System and Operation*

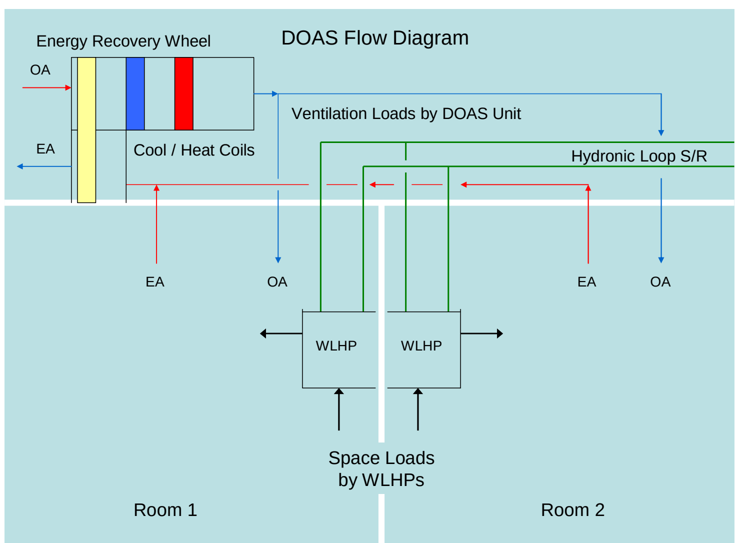
The building as-designed is served entirely by a standard VAV with hydronic reheat system operating from three VAV Air Handling Units, two on the roof, and one in the basement. All the supply ductwork is interconnected to provide backup air supply to an area if one of the AHUs would fail for any reason. This single network of air distribution handles all ventilation and space-conditioning air, as well as the make-up air for all the labs. This well-tested and reliable system leaves a bit to be desired in the labs; all the supply air is very close to 56°F, standard but quite cool. This causes a great need for reheat during high airflow periods without a coincident load in the space, which occurs during experimentation times in all the labs.




VAV System Generic Schematic

Variable Air Volume systems are commonly used in buildings with similar spaces and space uses, such as offices, classrooms, or hotels. They perform fairly well when used in these big effectively single-occupancy buildings, or areas within buildings. However, when there are many types of spaces, a mix of offices, classrooms, study areas, labs, and hazardous chemical use areas, each having its own necessary ventilation, conditioning, and exhaust rates and loads, this single VAV system does not perform as well as other alternatives. To handle loads properly, a VAV/reheat system cools all the supply air to a fairly cool temperature at nearly saturated conditions. This keeps the humidity in a comfortable range, and the amount of heat and airflow provided to a zone are varied to maintain the temperature and humidity levels. When this cool moist supply air is introduced into a lab, or any other room with high exhaust rates for that matter, a great deal of cool air drives the space temperature down, causing the reheat coil to operate, using a good bit of energy in the process.

Separation is the key with this mix of spaces and uses. All of the spaces in the building must be ventilated to meet the ASHRAE 62.1 codes, and all the spaces must be conditioned to maintain occupant comfort. This is where the similarities stop. Each space has widely varying ventilation rates, and a respectable difference in loads from internal sources as well as envelope gains and losses. The laboratory areas must exhaust a great deal of air to prevent the buildup of contaminants such as airborne pathogens, spores, allergens, and plant bacteria. This requires a nearly equal amount of make-up air be delivered to these lab areas (a slightly negative net airflow is desirable to prevent contamination of neighboring spaces). This make-up air should be close to the room's conditions, since the air will be just passing through the room to keep all the contaminants diluted.




Dedicated Outdoor Air System Schematic, with Water Loop Heat Pumps in Parallel

Combining a Dedicated Outdoor Air System to provide general ventilation air to the entire building and Water-Loop Heat Pumps throughout the building that will handle the remaining loads can easily keep the spaces very well-ventilated and most occupants comfortable. The separately controlled ventilation and conditioning systems also allow for better setback at unoccupied times. Each zone can be individually controlled for both ventilation and temperature/humidity based entirely on the occupants of that particular space. Zones not used overnight or on the weekends can be locked out and turned off, saving a great deal of energy over the life of the building. Also, having separate thermostats for each zone allows a greater range of operating temperatures throughout the building, with occupants in control of their own environment. This ability to control the temperature has been proven to make occupants feel more comfortable, even if the space is maintained at the exact same conditions as before. The WLHP units could be any equivalent unit, but calculations are based on Trane Axiom GEH units, ranging from 0.5 – 5.0 tons, nominally.

Trane GEH Water Source (Loop) Heat Pump Unit

The ventilation air supplied through the central DOAS air handling units will be delivered to each space at a lower temperature and humidity than with the VAV system. There will also be a great reduction in the volume of air delivered, making the ductwork smaller and lighter. While in most DOAS designs, these central air handlers are the single source for dehumidification, with this system each space also has a Direct Expansion Evaporator coil to handle both sensible and latent loads, even if these terminal units are slightly undersized, or the loads change on the building as it is remodeled throughout the years. This provides a much more flexible and adaptable system for the foreseeable life of the building, and still allows for new walls, offices, and classrooms to be made where other rooms were before.

Due to the layout of spaces and assignments for rooms and research areas, as well as the cross-contamination concerns with all the biological material in the building, as well as the live animals in the basement vivarium, all zones were maintained in their original condition with only a few exceptions. The alterations were made to study spaces and corridors; these areas were combined on one WLHP unit since there is no concern for contamination of the hallways with the study and write-up spaces attached to the halls. The main DOAS units will remain close to their current VAV AHU location because the proximity to vertical mechanical chase spaces is extremely beneficial.

The make-up air supplied to the lab spaces varies widely, depending on the position of all the exhaust hood sashes, adjusted manually at each hood. The designer's intent is to close these hoods when there is not an active experiment occurring. Since this is a somewhat haphazard and randomized "control" sequence, the system must be designed and able to react to all exhausting conditions. People will forget to close the hoods when they leave for the evening or weekend. This poses a problem and an area for F&M to raise awareness about energy use associated with their research.

The existing air handlers and separate exhaust air handlers will be eliminated, and new combined units will be used as part of the Dedicated Outdoor Air System. The existing exhaust ductwork will continue to function as the laboratory exhaust system, and will be reduced in weight by almost 50%. All the VAV boxes for exhaust will still exist, but about half the number will actually stay in the building. The existing return ductwork will be used as general exhaust ductwork for the main DOAS conditioning and ventilation system. The existing supply ductwork will be modified to accept the ventilation air from the DOAS units on the roof and in the basement, and the size will be cut to slightly less than one third. However, the make-up air to the labs still must be delivered through the building. This may add "new" ductwork, but it still only amounts to slightly over one third of the original supply ductwork. Below is a summary table for airflows provided by each of the main air handling units.

| | VAV SA max cfm | VAV OA min cfm | DOAS Total max cfm | Area SF | DOAS cfm OA per SF | % drop in OA | % drop in SA |
|---|---|---|---|---|---|---|---|
| Unit # 1 | 52,490 | 15,000 | 9,875 | 39,412 | 0.251 | 34.2% | 81.2% |
| Unit # 2 | 53,370 | 15,000 | 13,320 | 37,390 | 0.356 | 11.2% | 75.0% |
| Unit # 3 | 13,200 | 7,500 | 2,460 | 6,710 | 0.367 | 67.2% | 81.4% |
| MAHU | 0 | 0 | 18,925 | 20,630 | 0.92 | N/A | |
| | 119,060 | 37,500 | 44,580 | | | | |

Airflow Summary Table, all units

*6.2 – Envelope Alterations*

The building envelope is extremely influential on sizing most mechanical systems in buildings. The Barshinger LS&P Building has exterior walls that meet the prescriptive insulation standards for climate zone 5A, so legally there is nothing more required. However, to allow for piping and wiring to be run in the exterior walls without drilling holes in the CMU block back-up wall, a 2x4 steel stud wall exists on the interior side of that CMU back-up wall, allowing plenty of space to run all the conduit and piping necessary. This space was left empty, without insulation. Since the only cost increase would be the actual fiberglass batt insulation and its installation, the building models assembled in Carrier's Hourly Analysis Program assume that an R-13 batt blanket has been added to this assembly, nearly doubling the R-Value of the assembly. For the roughly 35,000 square feet of solid exterior wall, this $1.10 per square foot of installed R-13 batt costs only $40,000 for the entire building. Since the walls will be open, and the space is already there, this simple additional insulation should be included in the design.

After analyzing the model results, the additional insulation reduces both the heating and cooling load peak, but the annual energy consumption rises by roughly 0.5%.

The benefit of a reduced peak load is great, but the duality of the problem presents itself on further investigation. The internal loads must also be reduced to realize significant savings. This is possibly another area for F&M's facilities energy-saving programs to show their strength. If the insulation can be combined with a reduced internal load, the building's energy use will be drastically reduced.

### *6.3 – Internal Loads*

The second part of this high energy use is the high loads generated in the building. This is dominated by lighting loads. ASHRAE 90.1 recommends a maximum of 1.2 Watts / square foot for a University or educational building use, and this building has, on average for the entire building, 1.945 Watts / square foot, which causes an overage of 67kW in lighting power. Most rooms have standard single-pole switches to control the lighting, without motion detectors or light level sensors, so it is entirely up to the occupants to decide how much lighting energy to consume. Keeping the switches just as they are, but running the power through a motion detector / timer before the switches (similar to the general purpose classrooms here at Penn State) would eliminate any possibility of lights left on when no one is in the room. As stated earlier, an education program to reduce energy use on campus already exists, and this would be a very visible and beneficial place to implement more initiatives for energy conservation.

The building has a great deal of thermal mass, so it will be able to stay fairly stable during the daily temperature cycles. All the electrical loads in the building warm up that thermal mass fairly consistently through the day. Before the insulation was added, this heat was able to move out through the envelope slowly during the night. Now all that accumulated energy must be moved by the mechanical system, which requires energy to do this cooling.

### *6.4 – Central Plant*

The current central plant paired with the VAV/reheat system uses central campus steam during the winter and building-provided steam (through a boiler on the roof) in the summer months for all heating needs at the AHUs, as well as the hydronic reheat loop, and the domestic hot water. Chilled water is provided through a new 550-ton chiller located in the Central Utilities Plant just south of the LS&P Building. A large utility trench runs from the CUP to the new building that will act as the new distribution center for many of the campus services as more buildings are constructed in the northwest quadrant of campus. Part of Turner's work was also to upgrade the central plant heating and cooling equipment, performing some maintenance, and the replacement of the two main steam boilers for the campus. The existing boilers are almost 60 years old, and are showing their age. F&M will be purchasing new boilers within 5 years for central steam production.

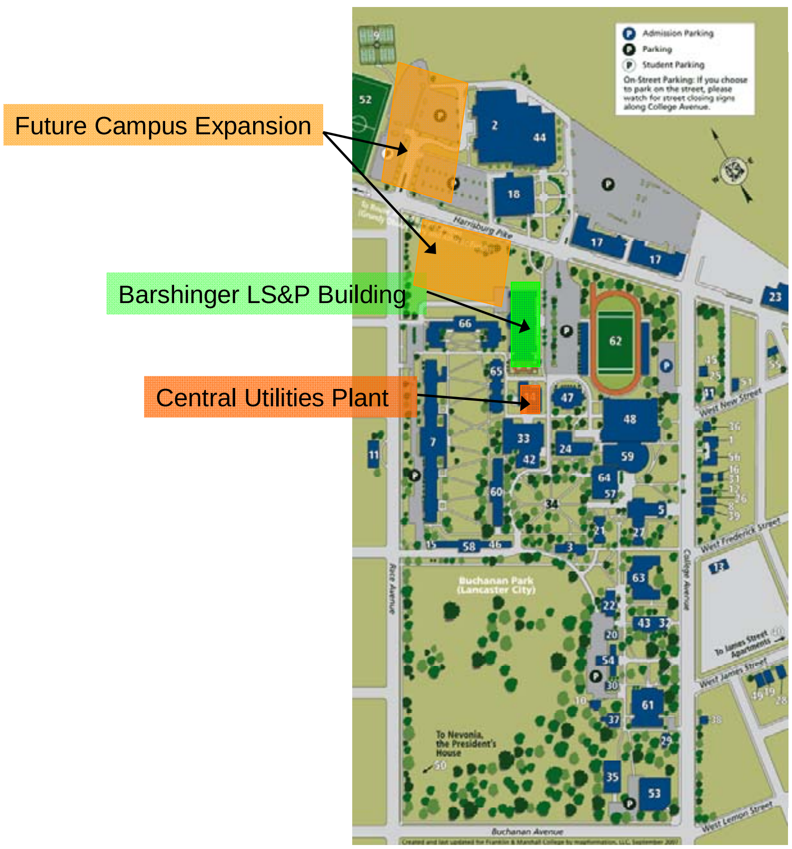
The heating steam directly serves the humidifiers and steam coils in all the building's air handlers, as well as a few duct-mounted humidifiers. This is not usually a recommended setup because of the chemicals added to the boiler feedwater to minimize scaling and fouling, but F&M does not treat the feedwater into the boilers, so no chemicals can be released into the building air. The boilers will need to be replaced more often though.

The existing chiller plant serving campus is a somewhat variable flow Primary/Secondary system that has been connected from what were two separate chiller plants serving different areas of campus.  This connection is a bit odd, but it does allow all of campus to be served by any of the chillers.  The operators and programmers must watch a few places for reversed flow conditions though, because it is possible to supply returned chilled water to some loads on campus if the pump controls are not maintained properly.  This chilled water is only supplied to three coils in the new building, one at each air handler.


Carrier 300-ton Screw Chiller

The changes recommended for the central plant for the building are to eliminate the 550-ton centrifugal chiller in the CUP and replace it with a 300-ton screw chiller in the basement mechanical room of the Life Science & Philosophy Building (Rm # M001) .  Any screw-driven chiller is acceptable, but a Carrier 23XRV Evergreen ® chiller is recommended.  This will allow the building to be independent of the rest of campus' chilled water, and have the lower chilled water temperatures necessary for DOAS operation.  There is plenty of room in that space for this equipment; the AHU will be smaller in that room, and the slab-on-grade will minimize the vibration effects on the entire building.  The 300-ton chiller is slightly oversized, allowing for some tie back into the campus system, since all the chilled water piping will still be running through the basement.  A valve set would be needed to ensure proper mixing and flow direction, but the LS&P building chiller could provide some backup to the North Loop of the chilled water system.  The steam from the main boilers in the CUP will still be used at all four of the AHUs in the main heating coils (with integrated face/bypass dampers to prevent freezing) and in the humidifiers throughout the building.  Also recommended is that the campus steam be used to boil filtered water that will actually be injected into the airstream, not inject the heating steam directly.  However, this is an added expense that would have to be implemented across campus; all of the buildings' humidifiers use this working steam for humidification, so the justification to treat the boiler feedwater is still not possible because multiple buildings are involved.  There is currently one cooling tower on the roof of the new building to serve the 550-ton chiller in the CUP.

The condenser water piping is oversized to allow all the cooling towers for most of the chillers on campus to eventually be placed on the roof. While eliminating the piping (2x 20" Supply and Return lines) would save a great deal on up-front costs, the lines would still be needed later as the campus continues to grow. Two towers would be placed on the roof, one for the 300-ton chiller, and one for the Water Loop Heat Pumps. Piping for this loop will use the old reheat piping and pumps, but the pumps would need to be moved to the roof from their current location in the basement. Heating for the WLHPs will be provided through a 1700MBtu condensing boiler on the roof, also eliminating the reheat steam-to-water heat exchanger. Removing the steam boiler on the roof leaves domestic hot water unavailable during the summer; the main campus steam boilers do not operate in non-heating seasons. This leaves the steam-to-hot-water domestic water heaters without an energy source. Two small condensing boilers have been selected for this purpose. The existing storage tanks will remain in line after the heating units to help buffer the system during periods of high water use.




Franklin & Marshall Campus Map

## *6.5 – Energy Storage*

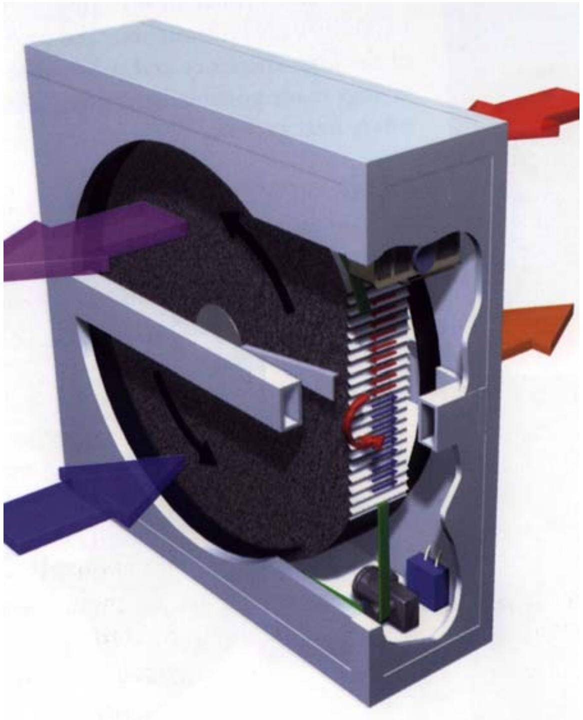
One of the original intents of this project was to investigate the use of thermal storage (specifically ice) to help shift the peak load on the DOAS units out of the midday times, and help evenly use power through the entire day. The screw chiller is capable of making cold enough fluid for this; however, switching from chilled water to an alcohol-water mix poses some more serious problems. First, the system can no longer be tied into the existing campus chilled water system. The multiple temperatures can be tackled with valving, but two different fluids forces an additional heat exchanger into use.

Cryogel Ice Ball system, exterior TES-Ice installation

There is also the issue of where to store this energy for use later. Originally this building was to house the new campus central chilled water plant, down in the basement. The soils reports came back and showed a great deal of rock under the old tennis courts. This made the extensive excavation prohibitively expensive, and moved much of the mechanical equipment to the roof. The only location for this ice storage would be on the roof of the building, which is completely exposed to the elements, including a whole lot of sunshine. Due to the weight of ice and water plus all the additional equipment, the losses to the outdoors or the added expense of a semi-conditioned enclosure, and the added maintenance cost for a fairly small system, the best solution is to not attempt to store all the energy needed, but to reduce the use of energy overall.

*6.6 – Energy Recovery*

The existing VAV air handlers do incorporate a simple form of energy recovery. Each AHU/EAHU pair is fitted with a runaround glycol loop to offset some of the sensible heating during the winter months. The system is not used in the summer since most of the building's use is not during that time, and because there is no latent energy recovery associated with a runaround loop. Many methods exist to recover some latent energy from a stream of air, and they are becoming widely acceptable methods for minimizing energy use. One place where these enthalpy wheels can fall short is when they are used with an air system that has some contaminants in it that you do not want to recirculate back into the building. The chances of this are extremely low, but the possibility exists none the less. This is why the manufacturers make wheels that have a purge section, effectively clearing the stagnant air in the thickness of the wheel before the wheel rotates into the ventilation air stream. The only major requirement of this system is that the exhaust fan be placed after the enthalpy wheel to draw outside air through the purge section and "clean" the wheel. Since this is a DOAS unit, and the exhaust fans are usually the very last component the air will pass through on the way out of the building, this is not an issue.



Energy Recovery Wheel, shown with Purge Section

*6.7 – Economic Impact*

The economic impact of this new system will be noticed in the first costs as well as in the operating costs for the building. Hand-in-hand with that is the energy use of the building over its foreseeable life. Currently the building is slated to be "useful" to F&M for 50-60 years. Most educational institutions keep their buildings until they are well past the designed age. We do not need to look very far to see evidence of such practices. The investment in this building is a large one, and should not be made without the complete picture of our future with this structure. A fully complete picture is not possible, so we will fill in the places we know, and make a strong and flexible enough design to work through the rest.

Many components are being removed from the building, and others are added to replace or modify the old system pieces. The reasoning for each component's removal has been explained previously, and the following chart summarizes the financial first costs for this new system.

| Component | VAV System Cost | DOAS Cost | DOAS Savings |
|---|---|---|---|
| HVAC Piping | $2,465,900 | $2,465,900 | $0 |
| Plumbing/Specialty Piping | $1,780,000 | $1,765,000 | $15,000 |
| Sheet Metal | $1,900,000 | $1,620,000 | $280,000 |
| BAS | $538,000 | $538,000 | $0 |
| Test/Balance | $93,300 | $93,300 | $0 |
| AHUs/EAHUs (& VAV/Rs) | $672,000 | $294,950 | $377,050 |
| Chiller | $175,000 | $91,500 | $83,500 |
| Cooling Tower(s) | $80,000 | $82,400 | ($2,400) |
| Steam-Hydronic RH HTX | $24,860 | $0 | $24,860 |
| Summer Boiler | $23,100 | $0 | $23,100 |
| WLHP Boiler | $0 | $19,540 | ($19,540) |
| Dom. Hot Water Boilers | $0 | $32,600 | ($32,600) |
| WLHP Units | $0 | $163,275 | ($163,275) |
| | $7,752,160 | $7,166,465 | $585,695 |

Summary of System Construction Costs

The redesigned system does cost less at first, which should make most good designers a bit skeptical of the system's energy use, or of the cost estimate. Fortunately, all costs associated with the original VAV system from Turner Construction matched all the data found in the 2006 RS Means Mechanical Cost Data handbook for the same equipment. The data from Turner was a bit lower, but by only 1%-6%, which is a perfectly acceptable error bound in engineering. The operating expenses were modeled in Carrier's Hourly Analysis Program (HAP 4.3), and did not seem to be extremely unreasonable. An early and very rough estimate I thought should be close for energy reduction (between 8-11%) was actually fairly close. The overall energy savings from just installing this new mechanical system would use approximately 26% less energy at the site, 12.5% less energy at the source, and cost would decrease by about 12.7%. The model is not completely accurate between the two systems; the assumptions hold that the VAV system in total brings in all the building's ventilation air, the makeup air, and recirculates the rest to maintain space temperatures. This is an accurate assumption for the two main AHUs on the roof; AHU-3 serving the vivarium is a 100% Outdoor Air unit, so the energy use there is rather high. Maximum laboratory ventilation is assumed for both cases, as is maximum occupancy, internal heat sources, and the weather was kept dead-on the same. Whether or not either of these models accurately depicts the real dollar costs of operating the building is an extremely interesting issue, since there is no way to check how much this new building is actually costing F&M in utility bills. The building is not metered independently from the rest of campus; the college pays one lump sum for all electricity, gas, and water/sewer services for the entire campus. While this makes the paperwork easier on their end, it does make it very difficult to see the low-hanging fruit for saving energy and reducing the overall utility costs. The importance of model consistency between the two comparisons has been maintained using these assumptions, and the results are summarized below.

| Annual Site Energy Use (MMBTU) | VAV System | DOAS w/ WLHPs | DOAS Savings |
|---|---|---|---|
| Air System Fans | 3,292 | 1,494 | 1798 |
| Cooling | 1,615 | 2,188 | (573) |
| Heating | 5,584 | 1,572 | 4012 |
| Pumps | 158 | 939 | (781) |
| CT Fans | 266 | 380 | (114) |
| HVAC Sub-Total | 10,915 | 6,573 | 4342 |
| Lights | 5,031 | 5,031 | 0 |
| Electric Equipment | 535 | 535 | 0 |
| Non-HVAC Sub-Total | 5,566 | 5,566 | 0 |
| Grand Total | 16,481 | 12,139 | 4342 |

Annual Site Energy Use, Million BTUs

| Annual Source Energy Use (MMBTU) | VAV System | DOAS w/ WLHPs | DOAS Savings |
|---|---|---|---|
| Air System Fans | 9,684 | 4,393 | 5291 |
| Cooling | 4,752 | 6,434 | (1682) |
| Heating | 5,598 | 1,841 | 3757 |
| Pumps | 465 | 2,763 | (2298) |
| CT Fans | 783 | 1,117 | (334) |
| HVAC Sub-Total | 21,282 | 16,548 | 4734 |
| Lights | 14,796 | 14,796 | 0 |
| Electric Equipment | 1,574 | 1,574 | 0 |
| Non-HVAC Sub-Total | 16,370 | 16,370 | 0 |
| Grand Total | 37,652 | 32,918 | 4734 |

Annual Source Energy Use, Million BTUs

| Annual Costs ($) | VAV System | DOAS w/ WLHPs | DOAS Savings |
|---|---|---|---|
| Air System Fans | $68,334 | $30,995 | $37,339 |
| Cooling | $33,521 | $45,397 | ($11,876) |
| Heating | $45,344 | $17,642 | $27,702 |
| Pumps | $3,278 | $19,492 | ($16,214) |
| CT Fans | $5,523 | $7,883 | ($2,360) |
| HVAC Sub-Total | $156,000 | $121,409 | $34,591 |
| Lights | $104,418 | $104,418 | $0 |
| Electric Equipment | $11,105 | $11,105 | $0 |
| Non-HVAC Sub-Total | $115,523 | $115,523 | $0 |
| Grand Total | $271,523 | $236,932 | $34,591 |

Annual Operating Costs, US Dollars

## *6.8 – Mechanical Breadth Conclusions*

The redesigned system will not cost as much up front as the existing VAV system, and it will cost less to operate, so there is an immediate dollar savings all around. When this is coupled with the reduced energy use, and the fact that energy prices are rising dramatically every day, the new system begins to look very appealing. The entire redesigned system with new DOAS air handlers, Water Loop Heat Pumps, new screw chiller, and two cooling towers, is recommended for incorporation in the building. While energy storage is a possibility with this system, it is not recommended at this time. If this system were considered earlier in the design process, energy storage may have been possible with slight modifications to the roof/penthouse design.

Further efforts to reduce energy use can be made, but not through any foreseeable changes in the plant, systems, or operating standards for the building. The remaining energy savings will be realized with slightly modified lighting controls, possibly different fixtures, and an educated and energy-conscious occupant population within the building.

## 7.0 – Electrical System – Breadth 1

One very interesting method to reduce the impact of a building on the environment is to include photovoltaic panels somewhere in the project. These panels make electricity from light, and are usually faced south on a wall or roof surface for most buildings in the US. The Life Science & Philosophy Building has a fairly steep roof rain screen covered with Vermont Slate. While this roof is very aesthetically pleasing, it is also very heavy and expensive. A simple way to reduce the overall effective cost of the building is to put PV panels on the roof instead of the slate, offsetting some costs up front, and providing a return on the initial investment, even if it is an extended period of time. The PVs are also a great deal lighter than the slate, and could provide some structural savings as well.

There are two main types of panels; standard "outside-the-building" panels, and Building Integrated PVs. These BIPV options are very enticing because they can directly replace a building material such as a brick facade or roof tile/shingles with an energy-producing element. However, these types of systems, as do most combined systems, tend to not work as well technically because some sacrifices must be made to fully integrate the panels into the building elements/envelope. This makes standard rack-mounted PV panels the simplest, most cost-effective efficient means of generating solar-power without damaging any of the infrastructure and initial investment. The rack system and panels will directly replace the slate tiles placed on the metal deck and plywood rain screen in selected areas of the building, offsetting a bit of the cost and weight of both systems. Since their lifetimes are similar (many PVs are still in use today from the 1970's), the short-term view of this material surface is called into question.

Since cost and reliability are very big concerns with this type of system, panels from BP Solar will be a likely selection. The BP SX3195 panels are 195 watt panels at peak power, and using these panels, the array can be sized up to a 34.71kW array. This layout is not concerned with shadow paths since the array will be mounted on directly south-facing roof (at 45° pitch), and will have no objects that could cast shadows on those surfaces. Some information for the SX3195 is below.

| Electrical Characteristics2 | SX 3195 | SX3190 |
|---|---|---|
| Maximum power (Pmax)3 | 195W | 190W |
| Voltage at Pmax (Vmp) | 24.4V | 24.3V |
| Current at Pmax (Imp) | 7.96A | 7.82A |
| Warranted minimum Pmax | 177.5W | 172.9W |
| Short-circuit current (Isc) | 8.6A | 8.5A |
| Open-circuit voltage (Voc) | 30.7V | 30.6V |

Temperature coefficient of Isc (0.065±0.015)%/ °C
Temperature coefficient of Voc -(111±10)mV/°C
Temperature coefficient of power -(0.5±0.05)%/°C
NOCT (Air 20°C; Sun 0.8kW/m2; wind 1m/s) 47±2°C
Maximum series fuse rating 15A
Maximum system voltage 600V (U.S. NEC rating)

To tie the DC-power into the building and the electric grid, grid-tie inverters must be used. Selected for this project is SMA-America's Sunny Boy line of inverters, specifically the SB6000US. This 95% or greater efficient inverter is designed with a single integrated AC/DC disconnect switch for servicing the system, and is compact in design to allow maximum mounting flexibility. The five (5) units that will be used can be mounted outdoors, provided precipitation doesn't fall directly on them. Mounting the inverters on the underside of the rain screen roof will provide them with sufficient weather protection and take up no space in the already tight electrical rooms on the 3rd floor. The inverters will be single-phase 208V, and will tie into both normal and emergency power systems in the building. This will help to offset some fuel consumption during generator use, and will provide utility offset year round.

SB6000US, with integrated AC/DC Disconnect

With the array placed on these south-facing sections of the roof, sized at the maximum 34.71 kW, energy production should be around 55,000 kWh per year, on average. This provides a sizeable reduction in annual electricity bills (~$5,100/yr), and reduces the Carbon Footprint of this particular building by roughly 40 tons of Carbon Dioxide per year. This array will not come anywhere near close to making the building net-zero energy, but it will help to reduce the impact of this building on the environment. This will also be F&M's first inclusion of solar energy on campus, and could be used as a great PR selling point to attract new students to campus and show their awareness of energy in our future.

Usually these PVs are mounted over an existing roof. They do not mount well over slate because attaching the racks can be very difficult through the slate. The slate tiles will not be installed in this area of the roof, but a fluid-applied roofing membrane will be applied instead. This will provide a waterproof surface behind the panels at a lower cost than the slate. Around this section of the roof the slate will remain to maintain the aesthetic appearance of the building.

The entire array will use 3,250 sq. ft. of roof space, and removing the slate at $52.13 per SF while adding the new roof membrane at $3.20 per SF and the installed cost of the PV array at $122.82 per SF comes out to an overall cost increase of $73.89 per SF, or $240,000 overall. The actual cost of the installed PV array will be much closer to $400,000 installed, but since the slate costs will be offset, this helps the finances quite a bit. Assuming average solar radiation and fairly constant electricity costs for the payback life of the system, an 82 year payback will make up the cost of the entire $400,000 PV system. However, when the cost of the slate is removed from the initial financing, the payback period is reduced to around a 48 year span. This combination shows the costs as they will be for the building, and give a payback time well within the foreseeable life of the building, without any electric energy cost increases through the years. The electric prices that will rise very quickly and very soon will continue to reduce the payback periods of such systems in conjunction with multiple governmental grants and tax incentives provided for installers and owners of these PV systems.

See Appendix A for cut sheets for the panels, as well as panelboard layouts for connection to the building's electrical grid.

## 8.0 – Structural Loads – Breadth 2

The building is supported by a steel structural system with concrete slabs on metal deck. Nothing jumps out immediately, but because a large lecture hall is located on the first floor of the building, a Vierendeel Truss was used to carry all the loads to the sides of this large clear-span room at the perimeter of the building, along the west wall.

The intent of this structural study was to adjust the concrete slab thickness and to check if any of the steel members could be reduced in size because of new mechanical equipment on the roof, and because of the lack of weight of slate shingles from the electrical breadth. The original design live loads are 70 psf for all non-public spaces (classrooms, offices, labs, etc.), and are 100psf for all other areas. Floor slabs are 4-1/2" Normal Weight Concrete on 2" composite deck, for a total slab thickness of 6-1/2". The roof slab is identical to all floor slabs except for thermal insulation board applied on top of the concrete slab.

The roof is designed for a 30psf snow load on flat sections, and a 28 psf snow load on the sloped sections of screen roof. The Vermont Slate shingles weigh 9.5 pounds per square foot, in the plane-of-roof dimensions. Replacing these shingles with PV panels saved a net of 7.1 psf on these surfaces, but the load is still dominated by snow loads, so no member sizes could be reduced. The 3" Type N metal roof deck could be reduced to 2-1/2" in this 3250 square foot area, and that would result in approximately a $1000 savings. However, the additional labor hours it would take to match the 2-1/2" and 3" roof deck sections together, in hips and valleys of a slate roof more than make up for the cost savings in materials, so for overall simplicity and costs it would be best to leave the roof a bit oversized in this area.

The chiller replacement will not save any structural costs in the Central Utilities Plant. The room for the chiller was originally built to have a chiller sit in that location. Placing the new chiller in the 800 square foot north mechanical room (M001) requires a slightly thicker slab-on-grade, 6-1/2" instead of the existing 5" SOG. This increases costs by roughly $250. A housekeeping slab will be necessary under the chiller, and will cost another additional (net, with removal of the full AHU-3) $540.

All the Water Loop Heat Pump units added to the building weigh a total dead load of 22.5k. When this load is distributed over the floor area, the increase is under 0.25 psf increase. The system can accommodate this increase in load due to the reduced weight of lighter ductwork. The net results of removed ductwork (0.11 psf) and the additional WLHP units is a net increase of 0.14 psf. The only stipulation with these unit is that they be hung from anchors embedded in the concrete slab, not just attached to the metal deck. If possible, they could be attached to the steel above, but since the average beams are 7' apart, and most of these units "long" dimension is less than half that distance, it would be best to hang them from the embedded anchors. Since each floor system is designed to hold up to 8psf of mechanical equipment, plus all other plumbing, electrical, etc., and the mechanical equipment (ductwork, WLHPs, piping) still only comes in at 6.3 psf, the system is slightly over designed, but again could not be reduced in size. See Appendix B for WLHP Data and weights.

The roof has seen more significant weight reductions. Removing the old summer boiler (6.2k) and all the AHUs and EAHUs (total of 50k), as well as the reduction in ductwork has reduced the penthouse dead load by just over 3psf. The entire penthouse/roof is designed to accommodate all the mechanical equipment as distributed loads, with the only concentrated loads being the four chimneys and the dunnage steel for cooling towers.

The additional cooling tower only adds 12k net during operation, and since the towers sit directly on steel connected to the column matrix at the building core, and this steel is designed for 5 more 700 ton (70k) cooling towers, this small increase does not require any steel increases.

Adding the WLHP Condensing Boiler in the penthouse mechanical room, even with the pumps, still only increases the area loading by 2k. The roof finally nets a 2.1 psf decrease in dead load from mechanical equipment. None of the roof or penthouse elements can be reduced in size because the load reductions are not as significant as was expected, and because these slabs are still dominated by a 70 psf design live load and 30 psf snow load. This requires the 6-1/2" slab in 2" composite deck, with insulation for the roof.

The intent was to reduce structural loads on the roof/penthouse enough to remove ½" or 1" of concrete from the slab, which would have reduced the slab weight by ~9 psf, 175k total dead load. Unfortunately this was not able to occur due to other loading constraints that were overlooked at the beginning of the process.

The structural system is completely sound, and well-designed to maximize the structural dollars. I am not able to offer a better suggestion than what they have already done.

## 9.0 – Conclusions & Recommendations

The final recommendation for the Barshinger Life Science & Philosophy Building is that a new mechanical system be included in the design. This new system will have a Dedicated Outdoor Air System to provide ventilation air to each space, and all zones will have a heat pump in parallel with the DOAS to maintain comfort. These heat pumps will be tied together in a water/hydronic loop to help move energy throughout the building, preventing some energy consumption in the process. The benefit of this tied-together system is that during shoulder seasons there is a good chance neither the boilers nor cooling towers will operate for this loop. Insulation should be added to the exterior walls in the 3-1/2" cavity behind the drywall. This will minimize the peak loads placed on the building during design conditions. The high internal loads (mostly lighting) can be reduced through motion detectors and timers, as well as an occupant education program about energy conservation, which the college is already implementing in the dorms.

The redesigned system will cost roughly $500k less up front (~7%), and will have annual savings of nearly $35k over the existing VAV system.

A grid-tied Photovoltaic system is recommended on energy-awareness alone, but would be entirely affordable given the half-million dollar savings on the new mechanical system. This is an investment that will yield energy over the life of the building, as well as offset nearly 80,000 pounds of Carbon Dioxide each year, saving about $425 a month in electricity bills as well.

The structural system in the building is designed to be very robust, and there are no over- or under-designed areas in the building. Structurally this is a very sturdy and stable building that will be here for years to come.

## 10.0 – References

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R.S. Means. Mechanical Cost Data 2006. Means, Inc. Kingston, MA 2005.

Trane. Product Data – Axiom Hydronic Heat Pumps. American Standard Companies, Inc., from http://www.trane.com/Commercial/DNA/View.aspx?i=1013

## 11.0 – Appendix A – Electrical Breadth

| Description | GP3S | | | | Description |
|---|---|---|---|---|---|
| | 208 120 | Ckt # | | 100A | |
| REC RM 364, AREA 303 | | 1 | 2 | | REC RM 354A,B,C |
| REC RM 364 | | 3 | 4 | | REC RM 354A,B,C |
| REC RM 373 | | 5 | 6 | | REC RM 354A,B,C |
| REC RM 373 | | 7 | 8 | | REC RM 354, 354D |
| REC CORR 300F,H | | 9 | 10 | | REC RM 354, 354D |
| SPARE | | 11 | 12 | | REC RM 354, 354D |
| SPARE | | 13 | 14 | | REC RM 354 |
| SPARE | | 15 | 16 | | REC RM 401V & ROOF |
| UH-1A/1B, RM 402 | | 17 | 18 | | REC RM 373 |
| CUH-6, RM 401V | | 19 | 20 | | REC ROOF |
| SPARE | | 21 | 22 | | LTG & REC EF-2A/2B ROOF |
| ROOF REC | | 23 | 24 | | SPARE |
| SPARE | | 25 | 26 | | SPARE |
| SPARE | | 27 | 28 | | SPARE |
| SPARE | | 29 | 30 | | SPARE |
| SPARE | | 31 | 32 | | SPARE |
| SPARE | | 33 | 34 | | SPARE |
| SPARE | | 35 | 36 | | SPARE |
| SPARE | | 37 | 38 | | SPARE |
| PV ARRAY # 2 | | 39 | 40 | | PV ARRAY # 3 |
| | | 41 | 42 | | |

| Description | EQ3S-1 | | | | Description |
|---|---|---|---|---|---|
| | 208 120 | Ckt # | | 225A | |
| ATC RM 382 | | 1 | 2 | | REC RM 363A |
| SPARE | | 3 | 4 | | REC RM 363 |
| ATC RM 308 | | 5 | 6 | | REC RM 363 |
| ATC RM 308 | | 7 | 8 | | REC RM 363 |
| FAN F-9 | | 9 | 10 | | REC RM 363 |
| REC RM 347A | | 11 | 12 | | REC RM 374 |
| REC RM 347A | | 13 | 14 | | REC RM 374 |
| REC RM 347, 347A | | 15 | 16 | | REC RM 374, 374A |
| REC RM 347, 345 | | 17 | 18 | | REC RM 374 |
| REC RM 344, 345A | | 19 | 20 | | SPARE |
| REC RM 344 | | 21 | 22 | | REC RM 376 |
| REC RM 344 | | 23 | 24 | | REC RM 376 |
| REC RM 341A | | 25 | 26 | | REC RM 310, 310A |
| REC RM 341A | | 27 | 28 | | REC RM 312 |
| PV ARRAY # 5 | | 29 | 30 | | REC RM 312A |
| | | 31 | 32 | | REC RM 315 |
| COLD UNIT RM 342A | | 33 | 34 | | REC RM 315 |
| COLD UNIT RM 342A | | 35 | 36 | | REC RM 315A |
| COLD UNIT RM 342A | | 37 | 38 | | REC RM 315A |
| REC RM 342 | | 39 | 40 | | REC RM 315A |
| REC RM 342 | | 41 | 42 | | REC RM 315A |

| Description | EQ3S-2 | | | | Description |
|---|---|---|---|---|---|
| | 208 120 | Ckt # | | 225A | |
| REC RM 342 | | 43 | 44 | | REC RM 315A |
| REC RM 341 | | 45 | 46 | | REC RM 315A |
| REC RM 340A | | 47 | 48 | | REC RM 317 |
| REC RM 340 | | 49 | 50 | | REC RM 309 |
| REC RM 338 | | 51 | 52 | | REC RM 309 |
| REC RM 338A | | 53 | 54 | | REC RM 309 |
| REC RM 338A | | 55 | 56 | | REC RM 308,309 |
| REC RM 383 | | 57 | 58 | | ATC RM 308 |
| REC RM 383 | | 59 | 60 | | SPARE |
| REC RM 383 | | 61 | 62 | | REC RM 402,403 |
| REC RM 382,383 | | 63 | 64 | | REC RM 355 |
| PV ARRAY # 1 | | 65 | 66 | | REC RM 355 |
| | | 67 | 68 | | REC RM 362A |
| PV ARRAY # 4 | | 69 | 70 | | SPARE |
| | | 71 | 72 | | SPARE |
| GROW CHAMBER RM 355 | | 73 | 74 | | GROW CHAMBER RM 355 |
| GROW CHAMBER RM 355 | | 75 | 76 | | GROW CHAMBER RM 355 |
| GROW CHAMBER RM 355 | | 77 | 78 | | GROW CHAMBER RM 355 |
| GROW CHAMBER RM 355 | | 79 | 80 | | GROW CHAMBER RM 355 |
| GROW CHAMBER RM 355 | | 81 | 82 | | GROW CHAMBER RM 355 |
| GROW CHAMBER RM 355 | | 83 | 84 | | GROW CHAMBER RM 355 |

| Array Size (kW) | | 34.71 | | Inverter Eff. | | 0.955 | | $ / kWh | $0.092 | | lbm CO2/kWh | | 1.445 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| kWh / period | | | | | | | | | | | | | | |
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
| | | 31 | 28 | 31 | 30 | 31 | 30 | 31 | 31 | 30 | 31 | 30 | 31 | Year Sum |
| Avg | 45 | 3546.1 | 3918.5 | 4915.4 | 5177.9 | 5497.1 | 5494.9 | 5678.0 | 5531.4 | 5036.0 | 4661.1 | 3365.3 | 2973.8 | 55795.6 |
| Min | 45 | 2866.2 | 2624.1 | 4235.5 | 4169.8 | 4455.4 | 4799.1 | 4959.1 | 4920.1 | 4169.8 | 3766.0 | 2290.9 | 2186.3 | 45442.3 |
| Max | 45 | 4406.9 | 5018.5 | 5883.8 | 6290.1 | 6431.2 | 5982.3 | 6289.4 | 6499.8 | 5973.2 | 6059.9 | 4335.7 | 3619.4 | 66790.3 |
| $ / period | | | | | | | | | | | | | | |
| Avg | 45 | $311.56 | $344.28 | $431.86 | $454.93 | $482.98 | $482.78 | $498.87 | $485.99 | $442.46 | $409.53 | $295.68 | $261.28 | $4,902.20 |
| Min | 45 | $251.82 | $230.55 | $372.13 | $366.36 | $391.45 | $421.65 | $435.71 | $432.28 | $366.36 | $330.88 | $201.27 | $192.09 | $3,992.56 |
| Max | 45 | $387.19 | $440.93 | $516.95 | $552.65 | $565.05 | $525.61 | $552.58 | $571.07 | $524.80 | $532.43 | $380.93 | $318.00 | $5,868.20 |
| tons CO2 offset / period | | | | | | | | | | | | | | |
| Avg | 45 | 2.4 | 2.7 | 3.4 | 3.6 | 3.8 | 3.8 | 3.9 | 3.8 | 3.5 | 3.2 | 2.3 | 2.1 | 38.5 |
| Min | 45 | 2.0 | 1.8 | 2.9 | 2.9 | 3.1 | 3.3 | 3.4 | 3.4 | 2.9 | 2.6 | 1.6 | 1.5 | 31.4 |
| Max | 45 | 3.0 | 3.5 | 4.1 | 4.3 | 4.4 | 4.1 | 4.3 | 4.5 | 4.1 | 4.2 | 3.0 | 2.5 | 46.1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| VT Slate Roof | | $1,100,000 | | Total SF Area | | 21100 | $ / SF | $52.13 |
| lbs / square | | 950 | | # squares | | 211 | lbs slate | 200450 |
| | | | | | | | lbs / SF | 9.5 |
| SF PV Array | | 3250 | | | | | | |
| | | | | | | | | |
| # PVs | 178 | PV kW | 0.195 | Array kW | | 34.71 | | |
| lbs/PV | 40 | | | Total Array lbs | | 7120 | | |
| | | | | Total Array psf | | 2.2 | | |
| PV $ / kW | | $11,500 | | Gross Array Cost | | $399,165 | | |
| | | | | Gross Array $/SF | | $122.82 | | |
| Fluid-Applied Roof Membrane $/SF | | | | $3.20 | | | | |
| Fluid-Applied Roof Membrane Cost | | | | $10,400.00 | | | | |
| Fluid-Applied Roof Membrane PSF | | | | 0.25 | | | | |

| | per SF | Total |
|---|---|---|
| Saved $ | $52.13 | $169,431.28 |
| Saved weight | 9.5 | 30,875 |
| Additional $ | $126.02 | $409,565.00 |
| Additional weight | 2.4 | 7,933 |
| NET $ | $73.89 | $240,133.72 |
| NET weight | -7.1 | -22,943 |

| Simple Payback Period (years) | | | |
|---|---|---|---|
| | Average | Minimum | Maximum |
| Full System | 83.5 | 102.6 | 69.8 |
| Marginal Cost | 49.0 | 60.1 | 40.9 |

bp solar

# SX 3195

195 watt photovoltaic module

**High-efficiency photovoltaic module using silicon nitride multicrystalline silicon cells**

## Performance

| | |
|---|---|
| Rated power ($P_{max}$) | 195W |
| Power tolerance | ±9% |
| Nominal voltage | 16V |
| Limited Warranty[1] | 25 years |

## Configuration

S Silver frame with output cables and polarized Multicontact (MC) connectors

B Bronze frame with output cables and polarized Multicontact (MC) connectors

## Electrical Characteristics[2]

| Electrical Characteristics[2] | SX 3195 | SX3190 |
|---|---|---|
| Maximum power ($P_{max}$)[3] | 195W | 190W |
| Voltage at $P_{max}$ ($V_{mp}$) | 24.4 | 24.3V |
| Current at $P_{max}$ ($I_{mp}$) | 7.96A | 7.82A |
| Warranted minimum $P_{max}$ | 177.5W | 172.9W |
| Short-circuit current ($I_{sc}$) | 8.6A | 8.5A |
| Open-circuit voltage ($V_{oc}$) | 30.7V | 30.6V |
| Temperature coefficient of $I_{sc}$ | (0.065±0.015)%/°C | |
| Temperature coefficient of $V_{oc}$ | -(111±10)mV/°C | |
| Temperature coefficient of power | -(0.5±0.05)%/°C | |
| NOCT (Air 20°C; Sun 0.8kW/m²; wind 1m/s) | 47±2°C | |
| Maximum series fuse rating | 15A | |
| Maximum system voltage | 600V (U.S. NEC rating) | |

## Mechanical Characteristics

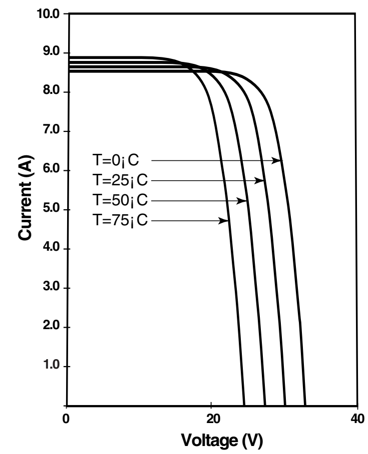
| | |
|---|---|
| Dimensions | Length: 1680mm (66.14”) Width: 837mm (32.95”) Depth: 50mm (1.97”) |
| Weight | 15.4 kg (33.95 pounds) |
| Solar Cells | 50 cells (156mm x 156mm) in a 5x10 matrix connected in series |
| Output Cables | RHW-2 AWG# 12 (4mm²), cable with polarized weatherproof DC rated Multicontact connectors; asymmetrical lengths - 1250mm (-) and 800mm (+) |
| Diodes | ***IntegraBus™*** technology includes Schottky by-pass diodes integrated into the printed circuit board bus |
| Construction | Front: High-transmission 3mm (1/8th in) tempered glass; Back: Tedlar; Encapsulant: EVA |
| Frame | **S** Anodized aluminium alloy type 6063T6 Universal frame; Color: silver<br>**B** Anodized aluminium alloy type 6063T6 Universal frame; Color: bronze |

1. Module warranty: 25-year limited warranty of 80% power output; 12-year limited warranty of 90% power output; 5-year limited warranty of materials and workmanship. See your local representative for full terms of these warranties.
2. This data represents the performance of typical SX 3195 products, and is based on measurements made in accordance with ASTM E1036 corrected to SRC (STC.)
3. During the stabilization process that occurs during the first few months of deployment, module power may decrease by up to 1% from typical $P_{max}$.

## Quality and Safety

| | |
|---|---|
| **ESTI** | Module power measurements calibrated to World Radiometric Reference through ESTI (European Solar Test Installation at Ispra, Italy) |
| UL | Listed by Underwriter's Laboratories for electrical and fire safety (Class C fire rating) |

## SX 3195 I-V Curves

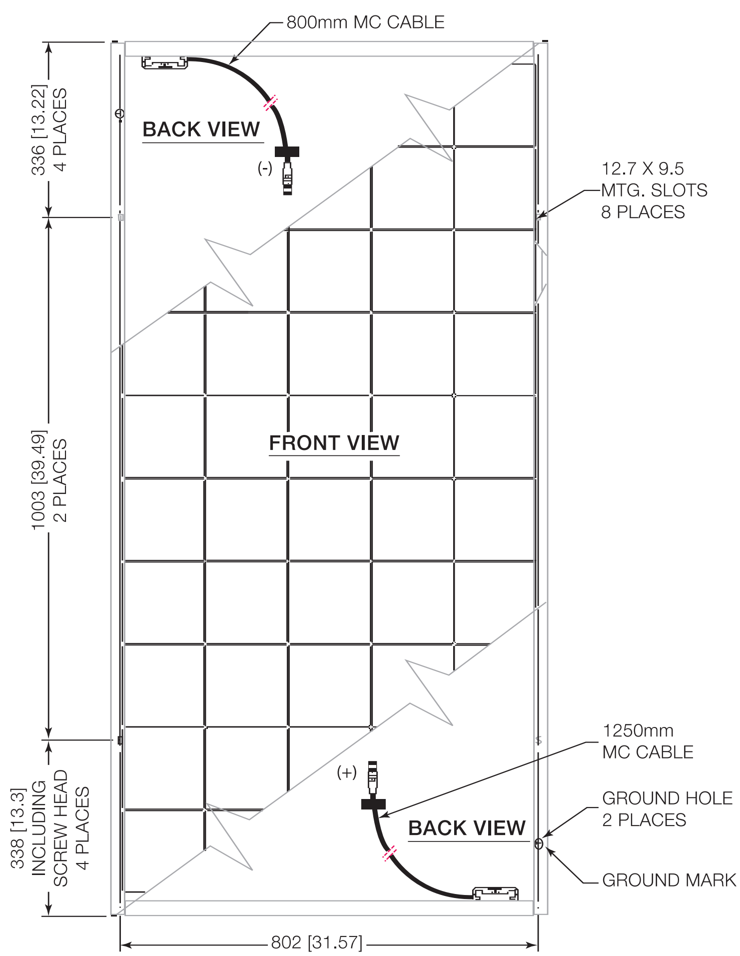


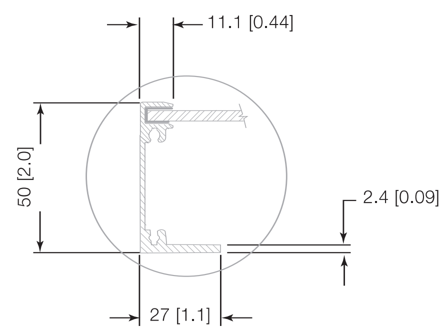

## Qualification Test Parameters

| | |
|---|---|
| Temperature cycling range | -40°C to +85°C (-40°F to 185°F) |
| Humidity freeze, damp heat | 85% RH |
| Static load front and back (e.g. wind) | 2,400 pa (50psf) |
| Front loading (e.g. snow) | 5,400 pa (113psf) |
| Hailstone impact | 25mm Ø (1 inch) at 23 m/s (52mph) |

## Module Diagram

Dimensions in brackets are in inches. Un-bracketed dimensions are in millimeters. Overall tolerances ±3mm (1/8").




SECTION A-A

Included with each module: self-tapping grounding screw, instruction sheet and warranty documents.

**Note:** This publication summarizes product warranty and specifications, which are subject to change without notice. Additional information may be found on our web site: **www.bpsolar.us**

bp solar

# 12.0 – Appendix B – WLHP Data

| | | | | Cooling | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Quantity | $ installed | Unit | cfm SA | gpm | Total Btu/hr | Sens Btu/hr | Power kW | EER | Reject Btu/hr | Ft Head |
| 25 | $1,265 | GEH006 | 190 | 1.5 | 7000 | 5300 | 0.59 | 11.9 | 9000 | 2.5 |
| 21 | $1,335 | GEH009 | 285 | 2.1 | 8600 | 6500 | 0.72 | 11.9 | 11100 | 4.2 |
| 11 | $1,435 | GEH012 | 380 | 2.8 | 12200 | 9200 | 1.03 | 11.8 | 15700 | 7.6 |
| 17 | $1,595 | GEH018 | 570 | 4.2 | 19820 | 14790 | 1.54 | 12.7 | 25080 | 5.7 |
| 6 | $1,665 | GEH024 | 760 | 5.5 | 25200 | 19000 | 2.18 | 11.6 | 32600 | 7.1 |
| 7 | $1,765 | GEH030 | 900 | 6.9 | 28100 | 21600 | 2.33 | 12.1 | 36100 | 12.8 |
| 7 | $1,920 | GEH036 | 1140 | 8.3 | 34900 | 27900 | 2.9 | 12 | 44800 | 8.8 |
| 4 | $2,000 | GEH042 | 1330 | 9.7 | 39500 | 31700 | 3.46 | 11.4 | 51300 | 12.5 |
| 4 | $2,215 | GEH048 | 1520 | 11 | 47300 | 36400 | 4.27 | 11.1 | 61900 | 9.1 |
| 3 | $2,690 | GEH060 | 1900 | 14.5 | 57900 | 46100 | 4.91 | 11.8 | 74700 | 12.5 |
| 105.0 | | units | | | | | | | | |
| 160.3 | $163,275 | tons | | | 1939840.00 | 1492830.00 | | | 2495960.00 | |
| | | | | | 161.65 | 124.40 | | | 208.00 | |

| Heating | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Btu/hr | Power kW | COP | Absorb Btu/hr | Ft. Head | Volts | FLA | Fan HP | Min Ckt Amp | Max Prot Dev | Running Weight (lbs) |
| 7800 | 0.6 | 3.8 | 5700 | 2.9 | 208/60/1 | 3.4 | 1/12 | 4.1 | 15 | 158 |
| 9600 | 0.69 | 4.1 | 7300 | 5 | 208/60/1 | 4 | 1/12 | 4.9 | 15 | 158 |
| 12400 | 0.94 | 3.9 | 9200 | 8.9 | 208/60/1 | 5.7 | 1/8 | 7 | 15 | 158 |
| 19860 | 1.5 | 3.8 | 14750 | 7 | 208/60/1 | 9.5 | 1/8 | 11.65 | 20 | 248 |
| 27200 | 2.02 | 3.9 | 20300 | 8.6 | 208/60/1 | 12.7 | 1/3 | 15.7 | 25 | 248 |
| 29400 | 2.19 | 3.9 | 21900 | 15.2 | 208/60/1 | 14.2 | 1/3 | 17.6 | 30 | 248 |
| 37100 | 2.72 | 4 | 27800 | 10.4 | 208/60/1 | 19.3 | 1/2 | 23.6 | 35 | 288 |
| 41700 | 3.29 | 3.7 | 30500 | 14.8 | 208/60/1 | 21.3 | 1/2 | 26.1 | 40 | 288 |
| 49600 | 3.94 | 3.7 | 36200 | 10.2 | 208/60/1 | 23.2 | 1/2 | 28.3 | 50 | 398 |
| 64600 | 4.84 | 3.9 | 48100 | 14.4 | 208/60/1 | 33.4 | 1 | 40.4 | 60 | 398 |
| | | | | | | | | | | |
| | | | 1,528,550 | | | | | | | 22400 |