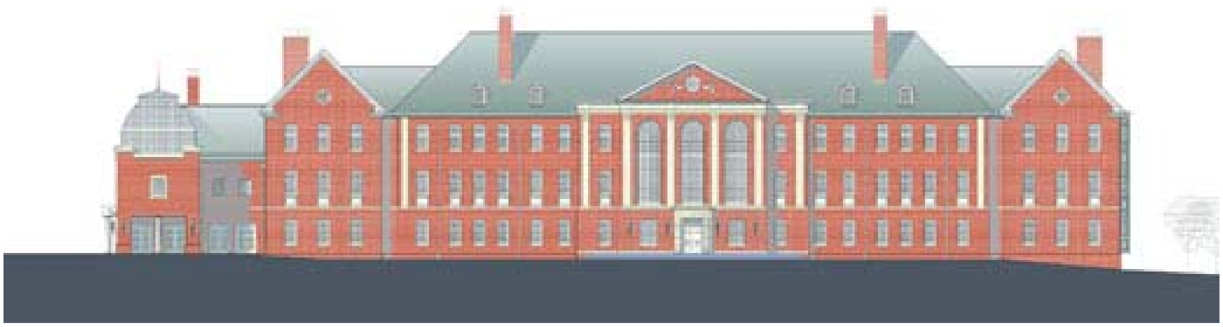
THESIS PROPOSAL



Ann & Richard Barshinger Life Science & Philosophy Building

Franklin & Marshall College
Lancaster, PA

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Mechanical Option

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January 11, 2008

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Executive Summary

The Barshinger Life Science & Philosophy Building (LS&P) at Franklin & Marshall College (F&M) in Lancaster, PA is F&M'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 mechanical system depth redesign proposed in this report will focus on improving the ventilation and energy use of the building. The mechanical system currently utilizes a single network of supply ductwork with VAV system, hydronic reheat coils throughout. The building's airflow is driven by the amount of exhaust in the numerous labs. The building remains positively pressurized, and the exhaust is the primary variable in the system adjusted continuously throughout the day. The proposed solution will create two air distribution systems – a Dedicated Outdoor Air system to provide ventilation, and a Lab Make-Up air system to replace the air removed through the exhaust hoods in those spaces. There will be hydronic loop heat pump units to do the remaining conditioning in each space. This separation of airstreams will allow a better delivery of air for ventilation, and makeup air closer to the room conditions without the use of reheat. Plus, having separate ventilation-only air provides a great deal of control for ASHRAE standard ventilation rates for each space, not just an aggregate for the whole gross building.

Energy recovery is used in the existing VAV system, but it is simple runaround coils with glycol, operated only in heating season. The systems studied throughout the research process will focus on year-round energy recovery, with greater recovery effectiveness than a simple runaround coil, including latent energy recovery.

For the two required breadth studies, the impact on the building's structural system after modifications to the roofing materials will be studied (originally, asphalt shingles were specified; Vermont slate was used), along with the structural support of all the heat pump units, and multiple PV racks and shingles used on the roof. The electrical breadth will cover the distribution system redesign after the additional load with the heat pump units, plus the impact of all the possible Photovoltaic panels on the roof areas. Also included will be the decrease in service size with reduced central equipment.

The Carrier HAP model will be adjusted for accuracy with all actual design values, then used to model all system modifications after the redesign. If the HAP model cannot be made accurate, a new model will be built in eQuest. This could take a great deal of time, but should be done if the HAP model cannot be made accurate. An accurate model will be the only way to guarantee the new systems will consume less energy than the existing VAV system.

Background Information

This new Life Science & Philosophy Building at Franklin and Marshall College is partially funded by a gift from Ann & Richard Barshinger. 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. The college told Einhorn Yaffee Prescott that a Colonial-Revival building was the look they wanted, clad in brick to match the older buildings on campus, one in particular – Fackenthal Science Building. This, and the addition of a $1.1 Million Vermont Slate Roof, allows the building to blend in, at least partly, with the other core campus buildings.

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 was extremely rocky, so excavation was expensive. 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 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 all new towers on the new building’s roof. 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 full of cooling towers within 15 years.

Most students are accustomed to having areas to lounge, study, and relax, usually located in close proximity to their work areas. Because spaces these labs and centers were in before was extremely cramped, no space was given to the students for use at their discretion. The new LS&P Building allows room for the students to relax and study, with close access to resources. Also to be included for the students was a café, now located in the central atrium. Many students need a source of healthy, to-go food in the central area of campus.

The great number of labs in the building need a great deal of airflow. This also requires much equipment that is not known for its aesthetic quality. To hide this, the building gives a large area of the roof to mechanical equipment, hidden behind the sloped slate sections of roof. This allowed all but one main air handler and smaller equipment to be placed on the roof. There is one working gas fireplace in the building located in the Humanities Common Room on the first floor, but there are four other visible chimneys. All are false chimneys, but two of them are used to disguise the discharges from the exhaust air handlers.

Existing System Description / Overview

The vast majority of the building uses an all-air system. Some minimal hydronic heating is provided at large glass areas, but is negligible overall. 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.

The building has three main VAV-type air handlers. AHU-1 and AHU-2 on the main roof serve most of the building. AHU-3 in the basement serves the vivarium areas. AHU-3 is a 100% Outdoor Air unit, while the other two are true-VAV type units with separate return fans. Three exhaust air handling units (EAHU) take air from the building, both general and lab exhaust. EAHU-3 takes air from the vivarium only, and EAHU-1 takes from spaces served by AHU-1, etc. All fans are VFD controlled, and maintain a static pressure 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.

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 psi, 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 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.

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.

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

The chilled water system on the F&M campus is a bit odd. It was originally conceived as one chiller located at the Central Utilities Plant to serve a lab next to the CUP. This was later expanded through the 70's and 80's, and second and third chillers were added as the secondary supply lines were extended to other offices and dorms near the CUP. 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.

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.

Problem Statement

The building requires a great deal of ventilation, mostly because of the exhaust systems throughout the building. These separate hoods have already been centrally exhausted, so energy recovery is easier. The building also requires a great deal of make-up air. This is also handled centrally through the main air handlers, again helping with energy recovery. However, having only one supply air stream and type may not be the best solution for spaces all maintained at roughly the same temperatures, and having very different airflow rates.

Offices, halls, classrooms, and other such "typical" spaces having similar internal heat gains can have one type of air/energy delivery method, and a VAV system with reheat can work quite well for that. However, a laboratory space doesn't fit well with a typical VAV system. The VAV system is intended primarily for ventilation (to standards only) and comfort, not to be used as a make-up air system. If, say, ten people are using a lab with all the lights on, and are also using all the exhaust hoods, a few thousand cfm of air is flowing through the lab because of the exhaust and makeup air. Exhausting air from the room should be kept to a minimum, but is necessary in this case. Introducing makeup air to the room should be done with comfort of the occupants in mind, as well as energy use to condition that air. If all the makeup air to the room is taken from a typical VAV system, the temperature of the room will fall drastically, causing many lab technicians to be cold, and not perform so well. In this building with a single air distribution network, that make-up air must be heated more at each lab or classroom to keep them warm enough for comfort. This can use tons of energy. If a second air distribution (ductwork) network could be used in the building to handle just the makeup air, that would prove quite helpful for ventilation and energy purposes.

There are a few things in this building as it currently is that need to be changed to meet code requirements in a few cases, and to improve overall building quality in one other. Some zones are under ventilated because there is no occupancy sensor in the space, or there is just not quite enough airflow supplied at minimum flow conditions to satisfy the 62.1 calculations methods for required ventilation. Those issues will be addressed in this proposed thesis project.

One other issue is the hollow stud cavities in the exterior walls. The block exterior structural wall is not an easy thing to drill and cut, so making many holes to install fixtures and electrical wall boxes would be difficult, and would not look as nice as they would if installed in a typical drywall section. To help hide this, and not interfere with the structural block wall, and to keep infiltration to a minimum, a 2x4 steel stud wall was framed on the interior of that block wall, adding space for plumbing and wiring, and all outlets and fixtures. However, these cavities were left empty and without insulation. The wall may meet code-required minimums for insulation, and has some pretty good acoustical properties to keep out noise, but this added R-13 or R-15 insulation could nearly double the insulation value of the wall, reducing the heat transfer, and adding some additional absorption for sound that does come through. The additional cost of insulation and installation will not be much, but its added value to the building in an energy-changing world will be very high.

The options and issues presented here are not intended in any way as a criticism of any designer involved; they are merely here for an educational investigation, and will be used to determine if and how some new technologies could be implemented in this project. The existing systems are designed very well, although somewhat traditionally. They keep the spaces comfortable and ventilated during most times of use, but there are some system adjustments that could be made that might make it function a little better. This thesis proposes to investigate these options, and see whether or not the current system is the best option.

Proposed Mechanical Depth

This section covers the two main changes proposed for the Barshinger Life Science & Philosophy Building's mechanical systems. All spaces require ventilation air, and have some additional conditioning needs beyond what that outdoor air can provide. Some areas require additional outside air for replacement of exhausted air in that room. These challenges will be met by these two main design proposals.

Dedicated Outside Air with Hydronic Heat Pump Terminal Units.

The amount of outdoor air required for ventilation is minimal, and does not require a great deal of volume in ductwork or equipment to provide to each space. Above the ceiling in most rooms is a 3 foot plenum, allowing plenty of space for ductwork and local terminal units. The pairing of a dedicated ventilation air system with this local conditioning equipment will be sized to cover all heating and cooling loads within each space. The ventilation end will save energy because of reduced fan size and power at the central air handlers, and it will be much simpler to guarantee enough ventilation air to each room, which is currently a problem with the building as-designed. Since the airflow rates will be drastically reduced with the new DOAS system, some type of terminal unit must be provided for the additional conditioning in the room. One way to do that while taking advantage of a great diversity of spaces is to use hydronic (water loop) heat pumps. These units exchange heat from the room's air and a water loop throughout the building. This loop allows heat to be moved from warm spaces (the terminal units are in cooling mode and warming the water loop) to cooler spaces in the building (their units are in heating mode, taking heat from the water loop) without any boilers or other new energy use in the building. There is some electrical energy used to move the heat, but nowhere near as much energy as is used to make new heat.

This coupled system will be placed in all of the building, offices, student centers, and lounges. The system will provide ventilation and exhaust (with heat reclamation) centrally along with local control of the room temperature. This will cover the background load of the building, and will operate during all conditioning times for the building.

There will be heat reclamation of some type, but it will be determined though the research and testing process in the building model. Three will be researched: a "standard" runaround coil and pumping arrangement, an energy recovery wheel (sensible and latent, with purge section), and a heat pump operating between the two airstreams.

Cooling and heating sources at the DOAS units will likely be DX for cooling, and either a gas burner or steam coil (from campus steam) for heating. Also, humidification must be provided for this centrally-supplied air, and campus steam will be used for that.

Heating and cooling of the hydronic loop will be provided through an open cooling tower with heat exchanger or a closed evaporative cooling tower, and will be determined after research is completed. The loop only must be heated to about 90°F at maximum, so heating will be accomplished by a low-temperature condensing boiler. That will greatly improve fuel use efficiency.

Make-up Air Handlers for Labs

All the labs have general and localized specialty exhaust (hoods, tables, etc.). The air taken from these spaces will be pulled out at a central fan, and make-up air will be distributed to each of these spaces through a secondary system of supply ductwork. Since there is enough room for large ductwork in the building as-is, and the primary air delivery ductwork will be shrinking by quite a bit with the DOAS system, a secondary network of ductwork can be added to make up the air difference in the labs. This air will not be very far below room temperature, and will not require any reheat, saving a great deal of energy there. This makeup air will be provided to the rooms through overhead air diffusers near each exhaust unit to minimize airflow impact on the room, and keep the room much more comfortable. This “lab air” system will also have energy recovery between the two airstreams, and the effectiveness of runaround coils, enthalpy wheels, and heat pumps will be discussed and modeled.

Separating the general ventilation air and conditioning systems for the building and the lab make-up system will help a great deal in reducing energy use, as well as make the labs much simpler to control for airflow and pressurization. General exhaust can be eliminated to make up the difference between conditioning-necessary supply air and process exhaust air. The room can be maintained at a negative pressure with the general ventilation system, and that difference can just be made slightly larger when any of the lab exhaust systems are engaged.

One additional benefit of separating the two systems is the ability to shut down the lab systems at night, when no one is using any of the classroom spaces. The general ventilation system can still operate and maintain adequate airflow through the building, and a great deal of fan energy can be saved.

There is one very obvious drawback to using the DOAS system – there just isn’t enough ductwork volume to carry enough air to operate the building in an economizer mode. This could prove to lose a number of airside “free cooling” days, but hopefully this will be minimized.

Breadth Topics

Structural Breadth

In the initial design, a simple asphalt-shingled roof was specified. After complaints from alumni about the look of asphalt shingles, donations were accepted and a Vermont-slate roof was added to the building. Slate is a great deal heavier than asphalt, and thus increased the structural requirements for the roof. First, this thesis will research how much cost, if any, that additional weight added to the total cost of the structural system. Then, as another form of roofing material, photovoltaic shingles will be researched as a replacement for the VT slate.

An additional aspect of the structure will be researched when investigating the large changes in equipment. The floor slabs may not be designed to hold all the heat pump units, and the roof slab may be reduced because of the smaller equipment there.

Electrical Breadth

Coupled with the structural consideration of PVs on the roof as shingles, is the additional PV potential above all the equipment on the roof. This will provide some shading (everything is currently painted white) and reduce a bit of the solar heat gain on the roof. It will also provide the building with some additional power. It will not be enough to fully power the building, but it will offset some electricity use, and reduce the electric bill somewhat. Plus, it will provide quite a selling point for the college; their first building with green power will be a great recruiting tool.

Also, the lighting power density is far above the maximum for ASHRAE standard 90.1. One option for this is lamp replacement or fixture replacement. Most of the building has simple T8 lamps, which can remain under the power densities required. However, the atrium has nearly 18kW of incandescent lighting, and there are other high-energy lamps throughout the building. These should be replaced with other energy-conserving lights. Also, a daylight-activated dimming system will be investigated for reducing the output power of the lighting during daytime hours when the vast majority of spaces have some natural light.

Tools & Methods

Since the mechanical system will be completely redesigned and replaced, a model of the building showing actual (or acceptably close) loads. Currently, the building is modeled using HAP, and that model will be adjusted to check and see if the model will show maximum loads that match the actual equipment. Hopefully this will match, but if it does not, there will be a much more detailed building model created in eQuest. Further analysis cannot be completed until that model matches the actual building's sized equipment.

Data from equipment manufacturers about the water-loop heat pumps and new diffusers will be input to the energy models, along with the operational data under varying weather and loading conditions for all the chillers and DX units required in the DOAS air handlers. A ventilation schedule will be used, similar to the existing building operation and controls.

For the structural breadth, other structural option students will be consulted, along with the structural faculty, and RAM for analyzing the steel skeleton of the building. The electrical breadth will be analyzed through the re-creation of many of the electrical panels throughout the building. Light fixture replacement will make use of lighting analysis tools, and lighting models for light levels within the spaces. Cooperation with and collaboration with the lighting students, and hopefully faculty, will help to establish accurate models of the spaces. Lighting controls from Lutron will be selected to maintain a minimal use of lighting energy within the building.

List of Articles

Air Balancing Company (http://www.airbalancingco.com)

- Information on problems and possible solutions for currently-used VAV systems in many buildings today. Many tips on how to make a VAV system work, and things many designers forget to include that become shortfalls of many VAV systems

ASHRAE Fundamentals (2005)

- Provides data used in analysis, and basic hand-calculation methods for initial research

ASHRAE HVAC Applications (2003)

- Information on the application of equipment for multiple spaces and building use types

ASHRAE HVAC Systems & Equipment

- System information after many individual pieces of equipment have been included

Construction Documents, Einhorn Yaffee Prescott

- Provided by EYP, includes drawings and specifications, and all final design data

Chilled Beams in Labs – Eliminating Reheat & Saving Energy on a Budget (ASHRAE Journal – January 2007)

- The use of chilled beams is not an option being pursued in this project, but half of the article is aiming to eliminate the reheat in the lab spaces. For this purpose, the article presents quite a bit of information on how to eliminate the reheat in these spaces

Dedicated Outdoor Air Systems (http://doas-radiant.psu.edu)

- Site provides information (from Mumma's research topics) on DOAS systems, their controls, and the secondary heating/cooling systems associated with a central DOAS unit

Dedicated Outdoor Air Systems (ASHRAE Journal – March, 2003)

- The article covers many aspects of the "new" DOAS systems found in some new buildings. It is written as an introductory piece for many curious engineers. Many benefits are presented, along with a few of the drawbacks.

Dedicated Outdoor Air in Parallel with Chilled Beams (Engineered Systems, November 2001)

- This article describes the DOAS systems and one of the secondary parallel cooling systems that is possible with this general system type. While chilled beams will not be used in this particular study, it is only one of many different types of secondary cooling that is typically used with DOAS systems

Schedule / Calendar

January 2008

14 – Spring Semester Begins
14-20 – HAP model adjustments, possible move to eQuest
21 – No Classes – MLK Day
21-23 – DOAS & Make-Up AHU research
24-26 – balance of system (air) equipment research
27-30 – hydronic heat pump unit research
31- – Low-temperature (condensing) boilers research

February 2008

1-6 – Low-temperature (condensing) boilers & Cooling Towers research
7-10 – DX cooling units research (for use in DOAS and Make-Up units)
11-13 – heat recovery system research and selection
14-23 – layout of new ductwork, diffusers, and equipment
24- – Calculations and chiller plant use investigation

March 2008

-3 -
4-7 – Modeling of new mechanical systems
8-16 – Spring Break – lag time for schedule adjustments
18-26 – Structural Breadth (Slab calcs, roof load analysis, steel structural analysis)
27- – Electrical Breadth (PV Research, Balance of Systems)

April 2008

-1 – Electrical Breadth (System layout, energy calculations)
2-9 – Final Report Assembly
10-13 – Presentation Preparation & Practice
14-18 – Faculty Jury Presentation Week

May 2008

2 – Last Day of Classes
2 – Thesis Honors Presentation, Senior Banquet (Nittany Lion Inn)
5-9 – Final Exams Week
16-18 – Commencement Ceremonies