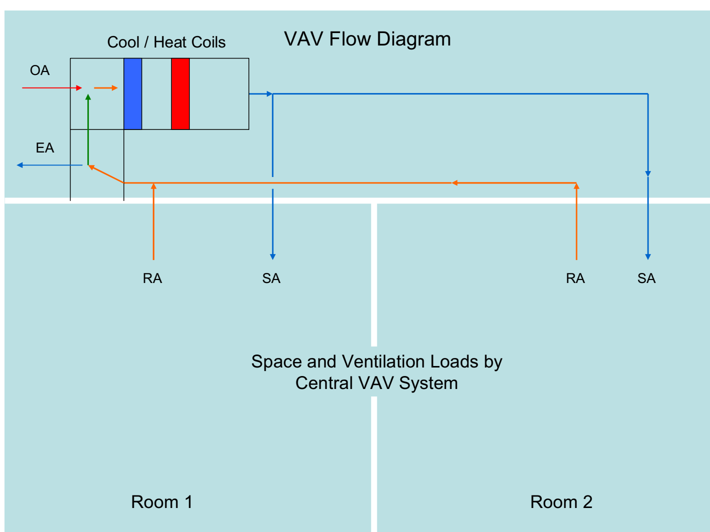
6.0 – Mechanical Redesign – Depth Study

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

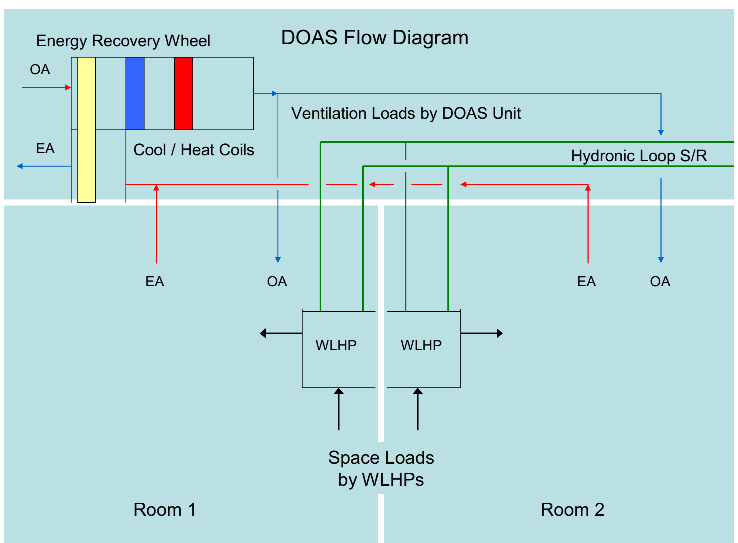
The building as-designed is served entirely by a standard VAV with hydronic reheat system operating from three VAV Air Handling Units, two on the roof, and one in the basement. All the supply ductwork is interconnected to provide backup air supply to an area if one of the AHUs would fail for any reason. 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.

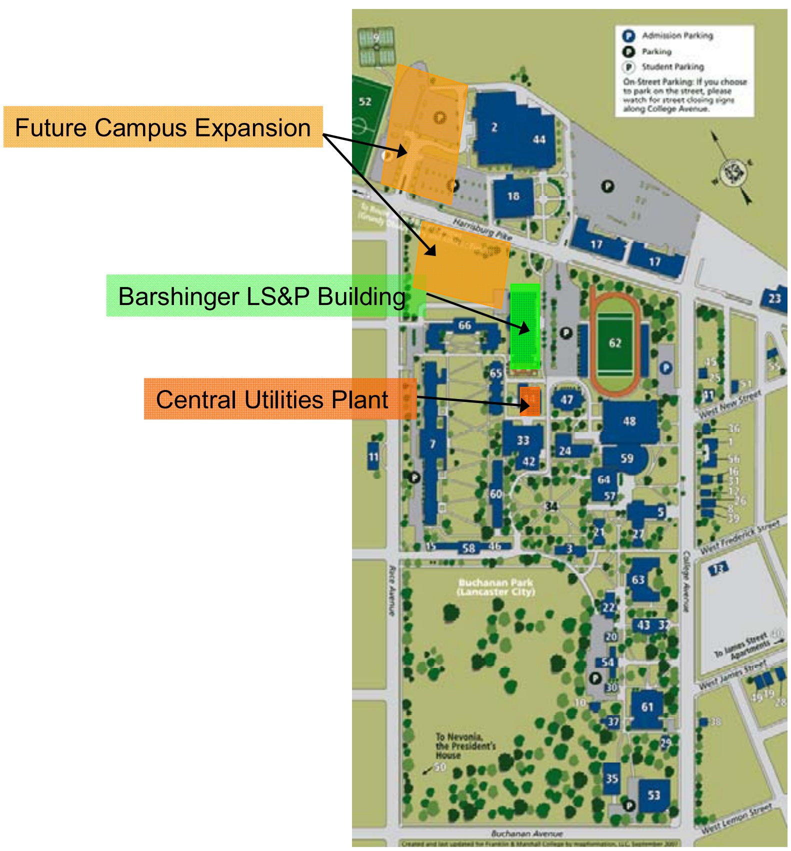
The heating steam directly serves the humidifiers and steam coils in all the building's air handlers, as well as a few duct-mounted humidifiers. This is not usually a recommended setup because of the chemicals added to the boiler feedwater to minimize scaling and fouling, but F&M does not treat the feedwater 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

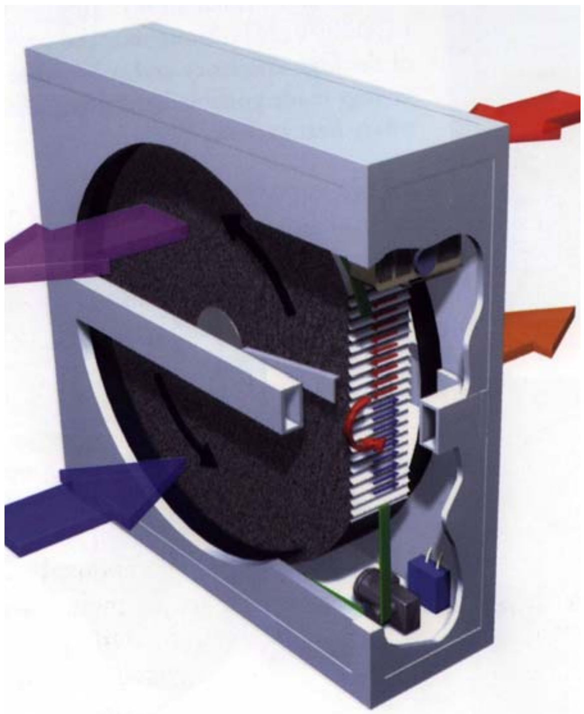
One of the original intents of this project was to investigate the use of thermal storage (specifically ice) to help shift the peak load on the DOAS units out of the midday times, and help evenly use power through the entire day. The screw chiller is capable of making cold enough fluid for this; however, 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.