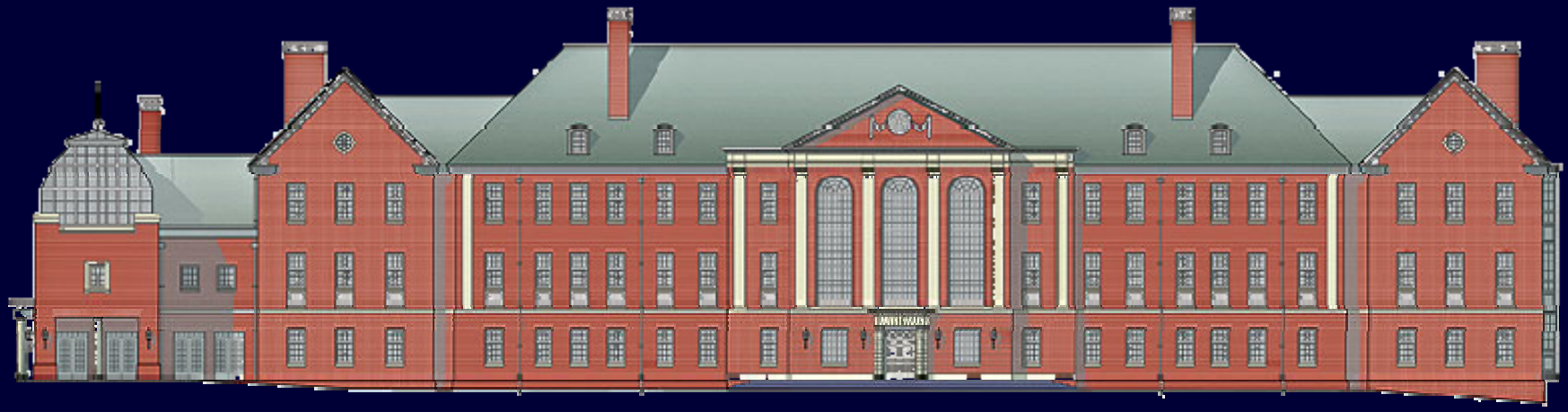
Ann & Richard Barshinger Life Science & Philosophy Building

Franklin & Marshall College

Lancaster, Pennsylvania



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

The Pennsylvania State University – Department of Architectural Engineering

Brian Ault – Mechanical Option

Barshinger Life Science & Philosophy

Spring 2008 Senior Thesis

Building Overview

Building Program:

- 104,000 sq. ft.
- Labs / Research
- General Classrooms
- Faculty/Staff Offices
- Student Study & Recreation

Building Cost:

- $39.9M GMP Contract
- $48.7M Finished

Construction:

- December 2005 – August 2007
- Design – Bid – Build

Building Overview

Electrical System:

- 480/277 3Φ Building Distribution
- 350 kW Emergency Generator (roof)
- 277V T8 primary lighting
  - 120V accents
- 1.945 W/ft^2 lighting power density

Structural System:

- Steel superstructure, braced frame
- Composite 6” concrete slabs
- 8” CMU back-up wall, face brick

Building Overview

Mechanical System:

- (2) 50,000 cfm VAV AHUs on roof
- (1) 15,000 cfm 100% OA VAV AHU in basement
- (3) Exhaust AHUs on roof (matching airflows)
- VAV with hydronic reheat for all zones
- Run-around glycol heat recovery loop (heating only)
- MP Steam from Central Campus Steam System
- 550-ton centrifugal chiller in Central Utilities Plant
- Cooling Tower on building roof, expansion planned
- Exhaust-driven building airflow

	Cooling	Heating	Time
Occupied	72°F	70°F	6a - 6p, M-F
Unoccupied	85°F	65°F	All Other Times

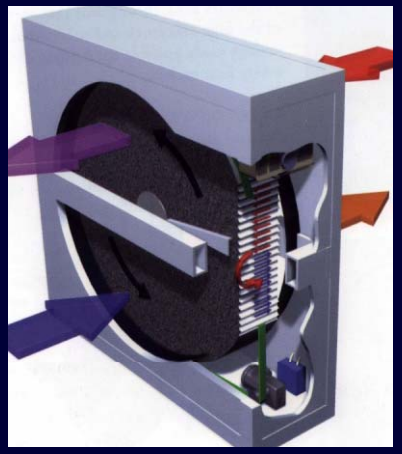
Design Objectives

- Improve Ventilation / Indoor Air Quality
- Reduce CO2 Emissions & Energy Use
- Reduce Operating Costs
- Improve Energy Recovery
- Reduce Equipment size
- Provide on-site “Green Energy” source
- Increase R-value in Envelope
- Education Experience

Mechanical System Redesign

Replace Existing Single VAV Air Distribution System with two separate Air Systems

- DOAS with Parallel Water-Loop Heat Pumps throughout the building
- Make-Up Air Handler for Labs
    - Eliminates need for Reheat
    - Guarantees ASHRAE 62.1 Ventilation Standards are met
    - Greatly reduces airflow requirements



Replace Existing Runaround Loop with Energy Recovery Wheels

- Purge section prevents recirculation of possibly contaminated air
- Provides Sensible & Latent energy recovery year-round

Mechanical System Redesign

DOAS / WLHP System

- (3) DOAS Units (10,000; 13,500; 2,500 cfm)
- 105 WLHP Units (1/2 – 5 tons each), heat pump only
- Provides ventilation & conditioning to entire building

Lab Make-Up Air System

- (1) 19,000 cfm unit on roof
- Existing VAV boxes / lab controls / exhaust hoods
- Replacement air close to room conditions

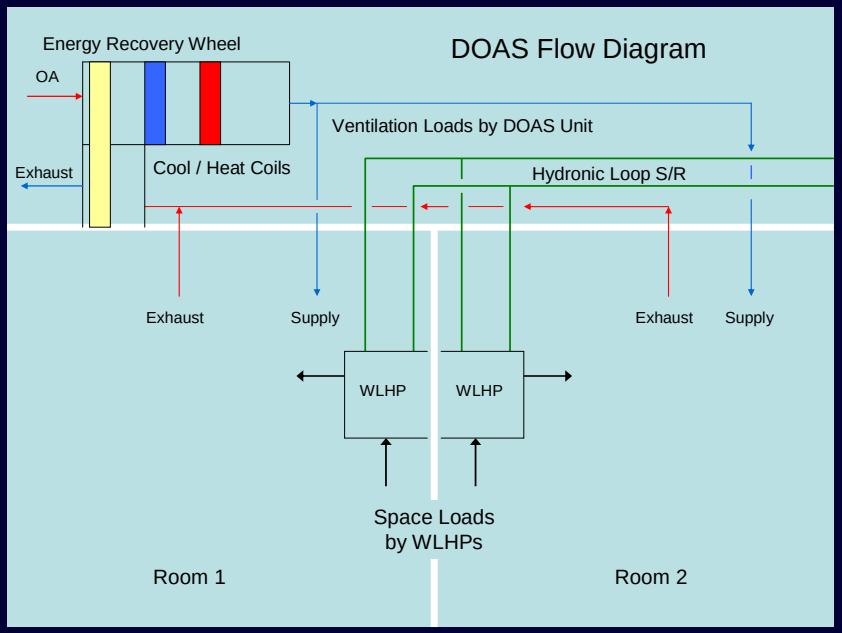
Energy Recovery Wheels

- One Wheel with Purge Section at each of the 4 units

DOAS / Parallel WLHP

DOAS / WLHP System

- Ceiling plenum allows additional equipment
- Lochinvar 97% efficient 1.7 MBH condensing boiler for loop heat
- 300 ton (Chiller) + 200 ton (Loop) Cooling Towers (open, evaporative)
- 300 ton Carrier Screw Chiller
- 40% nominally efficient Recovery Wheels (Sens + Lat)
- Trane Axiom GEH WLHP Terminal Units

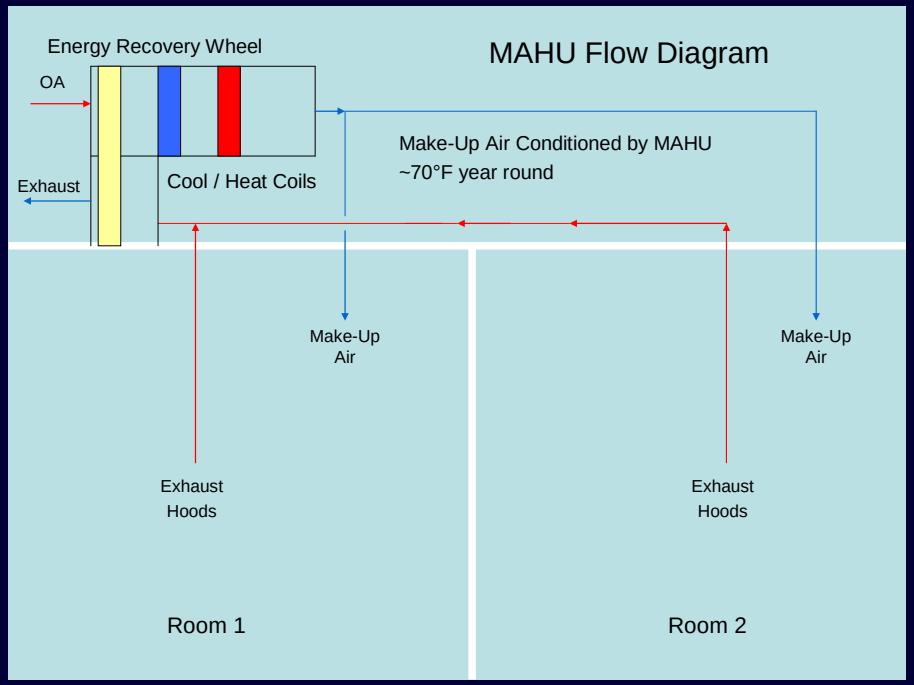


Lab MAHU

Make-Up Air System

- Equipment placed on roof
- Heat provided by central campus steam (September-May)
- Chilled water from building (300 ton) chiller
- 40% nominally efficient Recovery Wheels (Sens + Lat)
- Integrated central lab exhaust

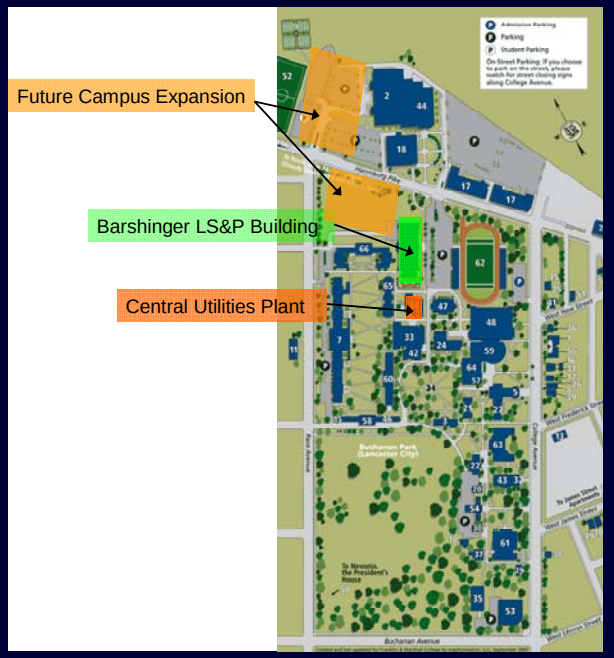
	VAV SA	VAV OA	DOAS Total	Area	DOAS cfm OA	% drop	% drop
	max cfm	min cfm	max cfm	SF	per SF	OA	SA
Unit # 1	50,000	15,000	9,875	39,412	0.251	34.2%	80.3%
Unit # 2	50,000	15,000	13,320	37,390	0.356	11.2%	73.4%
Unit # 3	15,000	7,500	2,460	6,710	0.367	67.2%	83.6%
MAHU	0	0	18,925	20,630	0.92	N/A	
	115,000	37,500	44,580				



New System Components

System Benefits

- 62% reduction in maximum airflow
- Reduced Central Plant Capacity
- 12.5% reduction in Resource Energy Use
- Higher Ventilation Rates



Central Plant Sizing Data		
Item	VAV System	DOAS, w/ insul.
Cooling Equipment Capacity	482 tons	414 tons
Steam Plant Capacity	2683 MBH	1533 MBH
Hydronic Reheat	1210 MBH	0 MBH

	Original System			Re-Designed System		
	Cooling Coil (tons)	Heating Coil (MBH)	Steam Humidifier (# / hr)	Cooling Coil (tons)	Heating Coil (MBH)	Steam Humidifier (# / hr)
Unit # 1	177	675	476	80	101	63
Unit # 2	205	797	548	103	256	83
Unit # 3	28	47	54	20	55	16
MAHU	0	0	0	49	768	165

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

Operating Cost Savings

- Carrier HAP 4.34 Building Model
- Annual energy savings of $34,500
- Actually increased CO_2 emissions by 147 tons/year (VAV System w/ insulation)
- Added insulation reduces peak load, high internal loads increase system run-time

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

First-Cost Savings

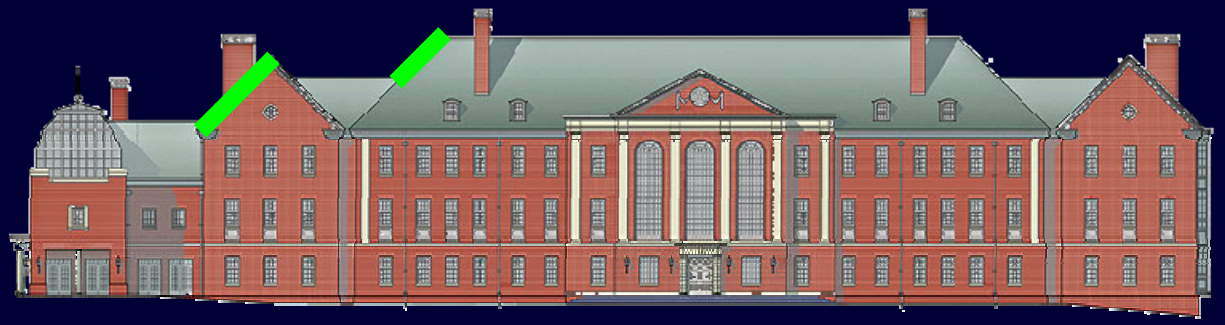
- Turner Construction Bids, RS Means with O&P
- New System greatest savings – ductwork & AHU/EAHUs
- Saves over $580,000 (7.5%) in initial system cost

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

Electrical Breadth

Photovoltaic (PV) System

- North-South Building Orientation provides good opportunity for Solar Energy
- South-facing roof, with Vermont Slate – replace with PVs, fluid-applied membrane
- Favorable Economics
- First Solar Technology on F&M campus
- Grid-tied – provides CO_2 offset, peak reduction, less equipment



Electrical Breadth

System Equipment

- BP Solar Panels (BP SX3195) – 195 W Peak Power
- 178 Panels, 34.71kW Array
- Sunny Boy (SMA America) 6000US Grid-Tie Inverter
    - Integrated AC/DC Disconnect
- 38 tons CO_2 offset per year
- Roughly 55,000 kWh produced per year, on peak
- Weight and Cost offset by VT Slate Roof
- Connects directly to existing 208/120 panels in 3rd floor South Electrical Room

Electrical Breadth

Roof Offsets

- Removed Slate saves weight and installation cost
- Installation of PV System replaces slate with lighter energy-producing surfaces
- Net Savings of 23,000 pounds
- Net Cost Increase of $240,000
- Still a very long payback period, without other incentives / electricity cost increases

	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

Conclusions

- DOAS / WLHP System provides energy & first-cost savings, better ventilation
- Lab Make-Up Air eliminates reheat energy, wasted cooling energy
- Energy Recovery Wheels provide sensible & latent recovery year round
- Insulation reduces peak heating & cooling loads by 6.7%
- PV System provides some CO_2 and energy offset, still has 40 year payback
- Plant Infrastructure (piping) still to exist – future expansion

Recommendations

Include DOAS / WLHP system and Lab Make-Up system

- Energy savings
- First-cost savings
- Flexible System (remodeling through building life)

Include PV System

- Currently, not the best option
- Electricity Prices on the rise
- Building will last >40 years

Add Insulation to reduce peak loads

- Reduce internal loads (electrical power, lighting) to gain further savings

If feasible at a later date, add thermal storage for the campus chilled water system

- Sensible storage tank most likely option

Acknowledgements

- Turner Construction Company
- AE Department, especially the Mechanical Faculty
- Maria Cimilluca & Perry Scheid, Facilities & Operations, F&M
- Jason Weaver; F&M Outreach, Turner Construction (Photo Credits)
- Friends and Family for their support and understanding
- 5th Year AE Class of 2008, for their continued support


Questions?