ANALYSIS OF DESICCANT DEHUMIDIFICATION FOR USE IN THE WAVERLY ON LAKE EOLA

AN ARCHITECTURAL ENGINEERING SENIOR THESIS REPORT

BY BLAKE HERRSCHAFT
THE PENNSYLVANIA STATE UNIVERSITY
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EXECUTIVE SUMMARY

This report studies possible improvements in HVAC performance for The Waverly on Lake Eola. The Waverly is a 22 story luxury apartment high-rise in downtown Orlando, Florida. The water source heat pump system already applied to the building is extremely efficient for a system that takes up very little space in the building and that gives each apartment individual control.

Possible envelope improvements on the floor-to-ceiling window system were first analyzed. Florida Building Code does not make efficient window technology mandatory. Since no window data was found on The Waverly, Florida code minimum for double glazing was assumed. Carrier's Hourly Analysis Program was used to calculate the load decrease associated with tinted, reflective, and triple pane glass.

A construction management study was done on the window system for a breadth topic. Triple pane glass was found to be too heavy and expensive for the gains associated. Reflective glass creates an annual savings of $10,102 for the mechanical system. Tinted glass produces a savings of $5,809 per year. The payback of 32 years for reflective glass may be too long for the owner; however, with rising energy prices this window change may prove more beneficial than this payback shows.

Solar air conditioning using desiccant technology was examined as a way to eliminate rooftop heat pumps. The total solar panel area needed for desiccant reactivation proved more than available on the roof of The Waverly. Passive desiccant systems were examined to see if a lesser load on the rooftop heat pumps would produce positive results. EcoFresh, Rotor Source, and SEMCO desiccant wheels were analyzed for load decrease. SEMCO wheels proved to be the most effective with an annual savings of 5,765 MBtus and a payback of less than 4 years.

An acoustical analysis of the parking garage's effect on the building spaces was performed as a breadth topic. The effectiveness of a storage room used as a noise damper between the garage and the lobby was first analyzed. This space was found to be more than effective as a damper. Next, the infiltration of garage noise into a typical 5th floor bedroom was examined. The noise heard in the bedroom from the garage was found to exceed standard maximum levels. This would be remedied with noise dampening panels on the roof of the parking garage's 4th story.

PROJECT BACKGROUND

Completed on April 1, 2002, The Waverly on Lake Eola rises 22-stories creating a distinctive addition to the downtown Orlando skyline. ZOM development saw a need for high-rise luxury condominiums in the downtown area and began the design phase of The Waverly in 1999. After purchasing property on scenic Lake Eola, directly in downtown Orlando, ZOM requested a unique, artistic design to improve upon the beauty of the site.

Architect Graham Gund quickly jumped on the opportunity. The building's distinctive "Wave" is a response to the L-shaped site and a desire to maximize the number of units with lake and city views. The Waverly contains over 230 luxury condominiums and a 450-car parking garage. The design responds to a complicated context of large and small scale buildings surrounding the exquisite lakeside Orlando site. The punched super grid of the tower and the horizontal waves and banding of the lower section, combined with the buildings abstract forms, create a contemporary feel to rival Orlando's better known resort architecture.

The Waverly's concrete framed structure supports 400 parking spaces contained on four levels of covered parking. A 15-story "Wave" apartment structure rests atop this. Also, along the project's Central Boulevard elevation, a 22-story "Tube" structure, integral with the "wave" portion of the complex, terminates with a roof feature called the "Zombrero," in recognition of project developer Zom Development Inc.

The apartment complex features 174 luxury apartments in its "Wave" portion, while the "Tube" section houses 56 luxury apartments, including four penthouse suites and one over 3000 square foot grand penthouse, all offering views of Lake Eola. All amenities are provided to residents of the complex. The aforementioned downtown parking garage available is just one. The Waverly also boasts an executive business center with butler kitchen, a sundries shop, concierge services, a modern welcoming lobby with 24-hour door attendant, and cardiovascular and weight-training studios. The 5th floor, located directly above the parking garage contains a pool, sundeck and spa area; along with wellness and massage facilities to help with relaxation for a busy lifestyle.

Primary Project Team:

Owner: ZOM Development
Architect: Graham Gund Architects
MEP Engineers: GRG Inc.
Plumbing Contractor: Progressive Plumbing
General Contractor: Hardin Construction
Electrical: Encompass Electrical Technologies
Structural: HWA Structural Engineers

Basic System Information:

Electrical:

This building has two main distribution panels, each of which provides energy for different voltage levels. 48,358 Amps feed the 120/208 Volt panel that provides electricity to tenant areas. 35,798 Amps feed teh 277/480 Volt panel that gives power to common areas and building systems.

Lighting:

The crown's metal panels are illuminated at night, giving the Waverly a distinctive presence in Orlando's skyline. compact fluorescent downlights and wallwashes provide exquisite lighting arrangements to common areas while also helping with energy savings.

Mechanical:

The residences are served by a water source heat pump system consisting of heat pump units in each individual apartment. Each heat pump acts as a separate air handling unit for that apartment. Three rooftop air handling units pressurize corridors feeding the smaller heat pumps and handle excess cooling loads during peak load conditions. 100% Outdoor air is supplied to these rooftop heat pumps to satisfy the OA needs for the building. A two cell closed circuit fluid cooler, on atmospheric boiler, distribution pumps and associated piping are located on the roof and on the penthouse level.

Structural:

Haynes Whaley Associates incorporated systems of two-way, flat-plate, post-tensioned slabs with 27-foot bay spacings to provide large, column-free areas for flexibility in room layouts. Cast-in-place concrete columns provide the main support structure for the building. A unique design feature of the Waverly is the12-foot-high structural steel “crown” that sits atop the building. Cantilevering 12 feet from its supports, this fan-shaped element was designed by Haynes Whaley Associates with in-plane bracing to integrate the crown into a single three dimensional shape as opposed to individual pieces. The crown’s metal panels will be illuminated at night, giving the Waverly a distinctive presence in Orlando’s skyline.

Fire Protection:

The sprinkler system serving the entire building features a single fire pump on the ground floor. A dry-pump system serves the parking garage.

Plumbing:

The sanitary system utilizes a “Sovent” system which eliminates the need for separate vent stacks. Utilized FlowGaurd Gold CPVC piping for all plumbing pipes and fittings saving 30%-40% over copper on domestic piping costs.

Transportation:

The Wave section of the building houses two stairwells and two elevators. The Tower has two stairwells to allow for proper egress in the case of a fire or emergency and also contains two elevators.

Special Systems:

The Waverly contains security alarms for each unit as well as protected access at entrances. The parking garage is also restricted to residents and their guests to maintain the feel of a more safe “gated” community while protecting the residents and their possessions.

SYSTEM BACKGROUND

DESIGN OBJECTIVES AND REQUIREMENTS

Floor to ceiling windows throughout the building, while providing gorgeous views of the surrounding area, created a load issue for the mechanical designer of the project, GRG. Since the condominiums are sold off to tenants by the developer, first cost of the mechanical system was a primary concern. A good mechanical designer would prefer the opportunity to design based on life cycle cost, energy efficiency, and environmental impact. This, however, is not the case with The Waverly and had to be taken into account.

GRG utilized a system consisting of different water source heat pumps for each condominium to condition the spaces. Spaces are to be maintained at approximately 72 ºF and less than 50% RH. With the hot and humid climate of Orlando, this creates a large cooling load for the building. All these factors must be taken into account when designing the mechanical systems for the Waverly.

BUILDING ENVELOPE

Standards for the design of building envelopes reside in chapter 5 of ASHRAE standard 90.1. All parts that separate the conditioned interior of the building from the outside air make up the building envelope. This includes the exterior doors, walls, windows, and the roof of the building.

Vertical Glazing:
ASHRAE standard 90.1 requires that the total area of vertical glass on building be less than 50% of the total building envelope. Since floor to ceiling windows dominate the envelope, The Waverly on Lake Eola is on the border of passing this requirement. After calculations of the total wall area and glazing were performed, The Waverly was found to have glass on 46% of the total envelope.
Percentage Glazing: 46% < 50%, therefore building passes requirement.

Total glazing: 75,648.5 ft^2
Total building envelope: 163,200 ft^2

Floors	Glass(sf)	Total (sf)	%
3,4,6-18	4699.5	8496	55.31427
Penthouse	1214	2574	47.16395
20,21	1158	2574	44.98834
5	3769.5	8496	44.36794
2	1305	3096	42.15116
1	1251	3096	40.40698
Roof	0	21846	0
Total	75648.5	163200	46.35325

BASIC SYSTEM OPERATION

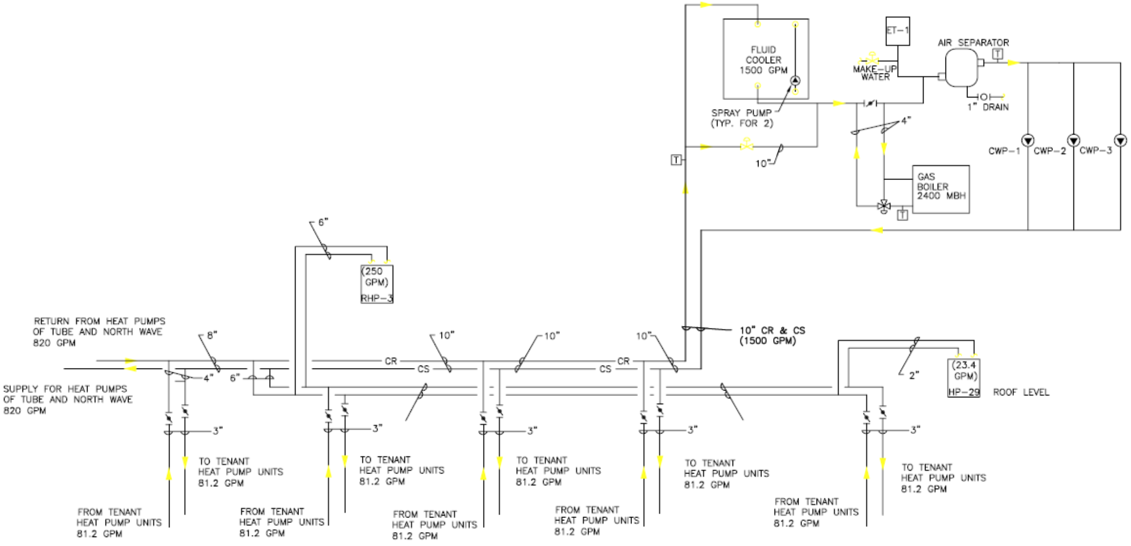
AIR-SIDE:

Water source heat pumps provide the primary heating and cooling of conditioned spaces throughout The Waverly on Lake Eola. Each condominium is serviced by at least one private heat pump servicing only that unit. Separate heat pumps also serve to handle air to the public and shared spaces of the building. This includes the gym facilities, lobbies, conference rooms, public restrooms, and other lifestyle amenities areas available for use by the tenants. All heat pumps are supplied outdoor air from one of three corridors. Three rooftop heat pumps, two serving the wave section and one serving the tube section, supply air to the corridors. These rooftop heat pumps are primarily used to provide positive pressure through the building at all times. However, when the separate heat pumps cannot handle the full cooling load of the building, the rooftop heat pumps are able to handle extra cooling load during peak load conditions. At high humidity ratios the rooftop heat pumps aid mainly in dehumidification.

Tenant spaces account for the majority of the building layout, and basic operation of tenant heat pumps will be discussed first. Each water source heat pump is located in a small mechanical closet next to the unit. 100% outdoor air is supplied to the heat pump from a duct extending vertically to the roof. This duct is pressurized by one of three separate rooftop heat pump units. These units are primarily used as fans, but are used to handle excess cooling loads during extreme peak load conditions. Cold water supplied from the rooftop closed circuit fluid cooler works with the heat pump to cool and dehumidify the outdoor air. The air is then heated by the heat pump and supplied to the space at conditioned temperatures. Cold return water is pumped back to the rooftop fluid cooler. A negative pressurization in the main part of the condominium creates an airflow taking the air towards exhaust ducts located in the hallway, kitchens, and bathrooms. Air exhausted from the space is brought to a vertical exhaust shaft and exhausted out the roof.

WATER-SIDE:

The cold water supply for the water source heat pumps both on the roof and throughout the building is crucial to the design. All pumps are supplied with water from one closed circuit fluid cooler located on the roof. This EVAPCO fluid cooler is capable of cooling 1500 GPM of return water. The water is supplied to the cooler from the return line coming from heat pump units. After cooling and condensing the water is temperature tested and can be mixed with water from the atmospheric boiler to heat if necessary. An AMTROL expansion tank is located at this point to maintain safe pressures so that equipment is not damaged. Next, a Bell & Gossett air separator is utilized to remove air bubbles from the supply water to ensure maximum efficiency. Cold water pumps then pump the water to heat pump units throughout the building. Cold water returns after it is used by the heat pumps to cool and dehumidify the outdoor air. A portion of the cdws system is shown in the flow chart below.



Cost and Load Data:

Carrier's Hourly Analysis Program (HAP) was used to analyze HVAC cost and load data. The Waverly's building and systems were analyzed so that an annual cost analysis based on average hourly weather data could be run. The results of this study are summarized in the following tables. Full HAP simulation estimations can be found in APPENDIX??????

Table 1. Annual Costs

Component	WSHP ($)
Air System Fans	25,347
Cooling	1,041
Heating	169
Pumps	27,335
Cooling Tower Fans	3,470
HVAC Sub-Total	**57,363**

1. Annual Coil Loads

Component	Load (kBTU)	(kBTU/ft²)
Cooling Coil Loads	24,589,650	85.504
Heating Coil Loads	1,267,536	4.408
Grand Total	**25,857,182**	**89.912**

2. Energy Consumption by System Component

Component	Site Energy (kBTU)	Site Energy (kBTU/ft²)	Source Energy (kBTU)	Source Energy (kBTU/ft²)
Air System Fans	1,015,470	3.531	3,626,679	12.611
Cooling	41,719	0.145	148,997	0.518
Heating	6,777	0.024	24,203	0.084
Pumps	1,095,080	3.808	3,911,000	13.600
Cooling Towers	139,026	0.483	496,522	1.727
HVAC Sub-Total	**2,298,072**	**7.991**	**8,207,401**	**28.539**

DESIGN VENTILATION REQUIREMENTS

All building HVAC systems in the United States must comply with local zoning standards. Most zoning authorities throughout the US base their regulations on ASHRAE standard 62.1. This report examines the compliance of The Waverly on Lake Eola with ASHRAE standard 62.1 by a comparison with ASHRAE's ventilation rate calculation procedure. ASHRAE standard 62.1 is used to assure that systems are designed with proper ventilation levels to avoid health problems, and maximize zone comfort. The Waverly on Lake Eola is a 23 story luxury condominium facility. There are five stories of parking and other amenities for residents of the building. The 3rd through 5th floor include some apartments in addition to parking. The 22nd floor is a 3,000 square foot luxury penthouse. The 23rd floor is reserved for building systems.

The Waverly is split into a 23 story tower section, and a "wave" section of 19 floors. Since all apartments are designed to similar specifications based on their occupancy, calculations were focused to a specific part of the building. All zones with heat pumps attached to a specific relief hood were studied. The Southwestern most section of the tower was chosen for evaluation. This relief hood is connected to heat pumps supplying apartments from the 3rd to the 22nd floors. This required studying the supply air, occupancy, space use, and floor area of each space supplied by this corridor. Since The Waverly operates on 100% OA, the required OA must simply be compared with the amount of air being pumped into the space.

After running calculations based on ASHRAE standard 62.1, it is apparent that these spaces not only meet outdoor air requirements, but far exceed the necessary specifications. This provides for a healthy and comfortable environment for residents of the building. The use of 100% outdoor air provides consistently high levels of outdoor air entering each space. The reason all buildings are not designed to 100% outdoor air specifications is to decrease energy use. The design of The Waverly on Lake Eola focuses more on clean air than energy savings, providing a comfortable environment for residents.

OUTDOOR AND INDOOR DESIGN CONDITIONS

Outdoor design conditions for Orlando, Florida were taken from the ASHRAE Fundamentals Handbook, 2001 edition. The data can be found on pages 27.8 and 27.9.Summer figures represent conditions that are exceeded 0.4% of the year. Winter figures represent figures that are exceeded except for 0.4% of the year. The system is not designed for any extreme conditions outside of this range, and may not meet indoor air requirements in those situations.

Latitude: 28.43

Longitude: 81.42

Elevation: 105 feet

Summer conditions:

Design dry bulb: 94 ºF
Mean coincident wet bulb: 76 ºF

Winter conditions:

Design dry bulb: 37 ºF

Indoor Air requirements:

Dry bulb temperature: 72 degrees F
Relative Humidity: 50%

Dry bulb Temperature: 68 degrees F
Relative Humidity: 40%

DEPTH STUDY

Fifth year thesis gives the graduating Architectural Engineering student an opportunity to examine an existing design, and look into ways to improve that design. Engineering is a design process, requiring an imaginative mind to choose the right design for the right application. There is never only one solution to a problem.

The existing mechanical design of The Waverly on Lake Eola was created by Professional Engineers with years of experience under their belts, and serves the building well. While this system works well, there are many other ways to address occupant comfort in the building.

My primary objective for this thesis is to improve the energy efficiency of The Waverly's mechanical system. I plan to use the original duct localized water source heat pump design, while looking into the possibility of implementing more advanced technologies on the air entering the building. I will use energy use data to analyze the effectiveness of this design. Another objective of this report is to use innovative technologies, proving that forward-thinking engineering can be successfully implemented throughout the building industry today and in the future. The world's fossil fuel supplies will not last forever, and buildings use 40% of the energy in the US. Energy efficient design and eventual worldwide use of renewable technologies are imperative to the future welfare of society as a whole. Use of these technologies will also help keep the environment from deteriorating to uninhabitable conditions.

Cost is an issue in any aspect of the building industry, and if first cost can be brought down by downsizing equipment this would show that the system is both efficient and affordable. However, if first cost is not lowered, this does not mean that the design will not save money. Lowering annual building costs will provide a payback if excess funding would be needed for innovative technologies. While cost is obviously an important issue to owners, I must once again emphasize the focus on energy efficiency in this design. As fuel prices continue to rise, this efficiency will benefit more than can be estimated by typical economic applications

CONSIDERED ALTERNATIVES

This semester I am taking a Co-generation class with the distinguished Dr. James Freihaut. As this class will be taking place during my senior design, I first considered the possibility of using combined heat and power on the building. When power is created by the local utility companies it is sent into the grid and distributed via high voltage cables to buildings and localized demand sites. As the electricity flows through miles of wire, approximately 50% of the energy will be lost due to wire resistance.

A building utilizing cogeneration makes electricity on-site, which means much less energy is lost due to transmission. The heat generated during the process of burning fuel to make electricity can then be used to help with heating the building. Recent applications of combined heat and power have proven both efficient and innovative. The Waverly is located in Orlando, FL meaning the system is primarily used for cooling. This makes the idea of heat recovery less than ideal for this specific application. Also, the extra cost and maintenance required in generating on-site electricity is not ideal in the case of residential development.

The location of The Waverly directly on Lake Eola creates interesting cooling situations. A surface water heat pump system using the cooler temperatures of Lake Eola has the potential to produce high energy savings with low first cost using relatively simple technologies. This entails pumping water from the lake and using a heat exchanger to cool the cold water supply. This could create the possibility of purchasing a smaller closed circuit fluid cooler, and saving on water cooling throughout the life of the building. With a lake surface area of 28 acres, Eola seems to have enormous potential for a surface water heat pump system. However, Iola has a mean depth of 11.5 ft. and a maximum depth of 23.67 ft. This means that temperatures during summer conditions will rise to temperatures in the high 80s, making the idea of a water source heat pump system impractical. Also, the system could potentially alter the local ecosystem by raising the temperature of the lake.

ENVELOPE IMPROVEMENTS

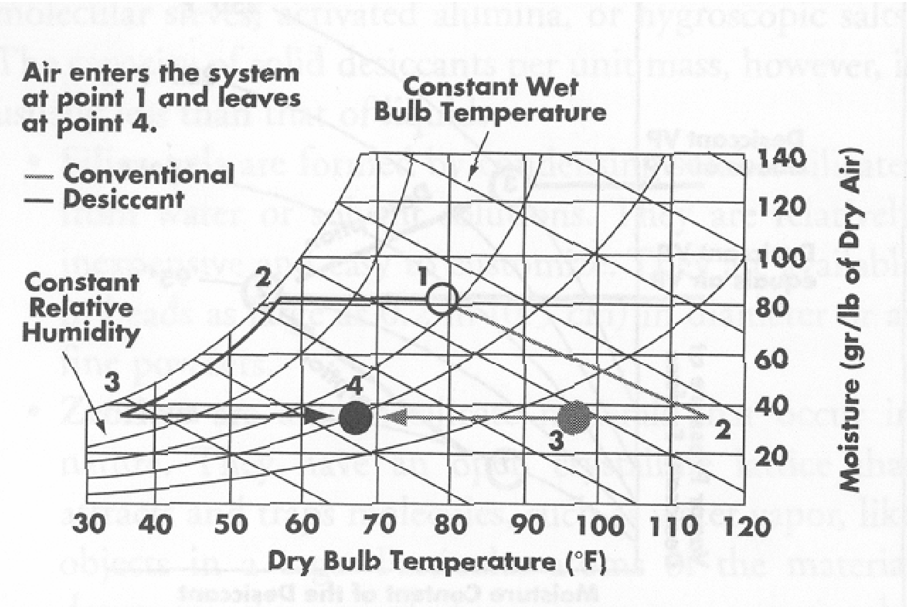
Time has shown that buildings are best engineered through a collaborative effort between all designers involved in the project. Each system of the building has an effect on the other systems. If, as the architect designs a building, he allows suggestions from all engineers involved from the start, the chances increase for an all-around well-designed facility. One critical issue that affects the mechanical system is the choice of building envelope.

Since The Waverly incorporates floor to ceiling windows on the majority of its external walls, the potential for a high mechanical load is inherent. The building does comply with ASHRAE std. 90.1’s section regarding glazing percentage; however, all spaces in the building are subjected to a substantial increase in load based on the amount of window area. Windows almost always have a higher U-value than walls, creating higher heat gain to the space during the summer, and higher heat loss during the winter.

An analysis of envelope redesign energy and cost savings will be analyzed in the construction management depth section of the report.

DESICCANT DEHUMIDIFICATION

During both heating and cooling conditions mechanical systems must satisfy both sensible and latent loads. During cooling typical refrigeration-based systems focus first on sensible cooling by lowering the temperature to saturation temperatures. Desiccant systems provide latent cooling or dehumidification in order to start the cooling process. The air is dehumidified adiabatically producing hot, dry air. This air can then be cooled while maintaining a constant relative humidity to supply air temperatures. This process is extremely effective for systems that experience high humidity during the cooling season or buildings that need specific humidity control.



Desiccants are solid of liquid substances that have a high affinity for water and are often used in drying applications. This affinity for water allows the desiccant material to attract water vapor directly from airstreams. The desiccant material will then become saturated with moisture. When the heat is added to the material, the water is driven back into the air through evaporation and the desiccant returns to its original state. The process of renewing the ability to collect moisture is known as regeneration.

<u>Types of desiccants</u>:

<u>Solid Adsorbents</u> are media with tremendous internal surface area per unit mass. These materials collect moisture and hold it on the surface of the material like a sponge. Typical examples are silica gels, molecular sieves, activated alumina, and carbons.

<u>Liquid Absorbents</u> have a lower vapor pressure than water at the same temperature. Typically liquids, these desiccants undergo a physical change upon

collecting moisture. Liquid desiccants generally have more capacity per unit mass than adsorbents, however tend to be more corrosive on equipment. Hygroscopic salt solutions such as lithium chloride, calcium chloride, and glycols are some examples of absorbents.

Types of systems:

Liquid Spray tower: Air to be conditioned enters a conditioner chamber. Cooling coils cool the air in the conditioner. Liquid absorbent solution is then sprayed into the conditioner and continuously circulated to absorb water vapor in the air. This desiccant is then continuously re-circulated through a heat exchanger that uses scavenger airflow to regenerate the media. These systems can have large capacities, but are more expensive than other options.

Solid Desiccant Tower: Solid Adsorbent material is loaded into a vertical tower. The dry desiccant picks up moisture from entering air as it is dehumidified. As the material becomes saturated, process air is diverted to a second desiccant loaded vertical tower. While this tower processed the air, the other desiccant is being regenerated by hot air. These systems are extremely good for high-pressure gas dehumidification, but are less than ideal for air at ambient temperatures. Towers cannot handle a load of more than 5,000 cfm; too small for The Waverly application.

Rotating Beds: This system utilizes a horizontal rotating desiccant filled bed that is exposed to process air and regeneration air simultaneously. Seals separate the two airstreams as the bed casing slowly rotates. As the wheel rotates the saturated desiccant spins into the regeneration airstream where hot air desorps the desiccant material. This technology has a much lower cost than the previously discussed methods.

Rotating Wheel: At about the same cost as the rotating bed application, rotating wheels are becoming increasingly more common in the building industry. The wheel functions essentially the same way, however, the rotating wheel has a corrugated heat exchanger type surface packed with solid desiccant. These systems have both an inexpensive first cost and a low operating cost. Rotating wheel systems typically have the least required maintenance of all types of desiccant systems. This is the most applicable for The Waverly on Lake Eola and will be studied further as a solution throughout the report.

Active vs. Passive Desiccant Systems: During the desiccant regeneration process heat is added to the desiccant to remove moisture. In the previously discussed rotating wheel, building exhaust air is used to regenerate desiccant material. A passive system uses the exhaust air directly as a source of regeneration air. Active systems utilize a heater, typically gas-fired, to heat the exhaust stream. This active system has the capability of increasing the amount of moisture removed from the desiccant, making the desiccant dryer as it enters the ventilation air stream. This means that while active systems require a heater, they can reduce the humidity ratio of outdoor air by greater levels.

HEAT RECOVERY WHEELS

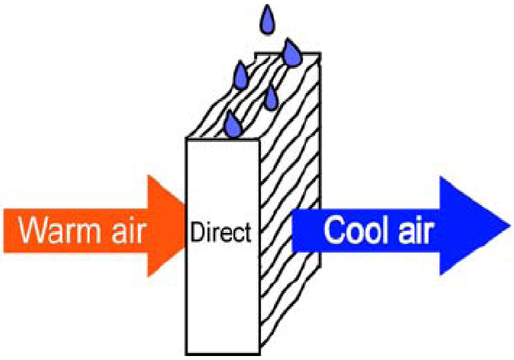
Desiccant dehumidification leaves cooled with a significantly lower humidity ratio and a slightly higher temperature. That is to say, while latent heat is rejected from the entering air, the air also experiences a sensible heat gain. Heat recovery wheels work with the same idea as a rotating desiccant wheel, and can be used in series with a desiccant wheel to further condition the entering air. As the warm dry air enters the recovery wheel, a heat exchange occurs with exhaust air from the building. This both reduces the temperature of the process air and increases the temperature of the exhaust air so that it can more easily be used for regeneration. Heat recovery wheels are almost always used in conjunction with desiccant dehumidification and will be a good addition to The Waverly's mechanical system.

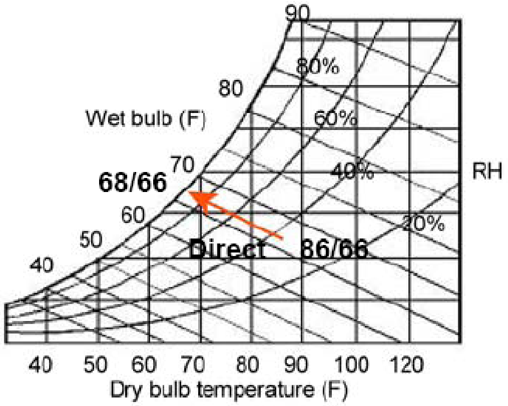
SOLAR REACTIVATION

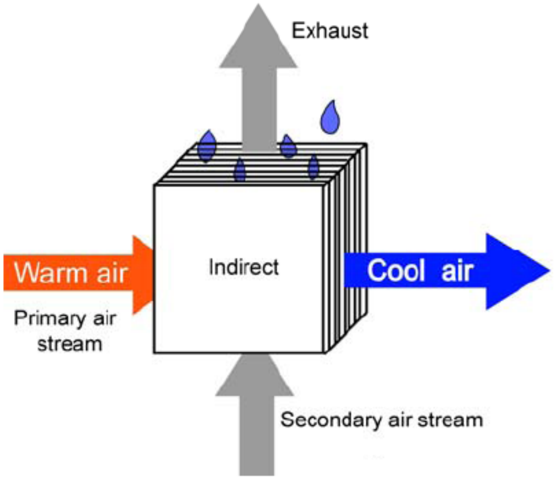
After the dehumidification cycle, desiccant is left saturated with moisture from the conditioned air. In an active system, exhaust air needs excess heat after going through the heat exchanger. Though this is typically done using a gas-fired heater, other technologies can be used as well. Waste heat from building systems or solar air heating has been used in the past to heat this air with “free” energy. High reactivation temperatures are needed for reactivation, making flat-plate collectors obsolete. Evacuated-tube solar collectors are able to create water with temperatures up to and exceeding 300 °F. An active desiccant system utilizing solar reactivation will be examined for effectiveness in conjunction with The Waverly on Lake Eola.

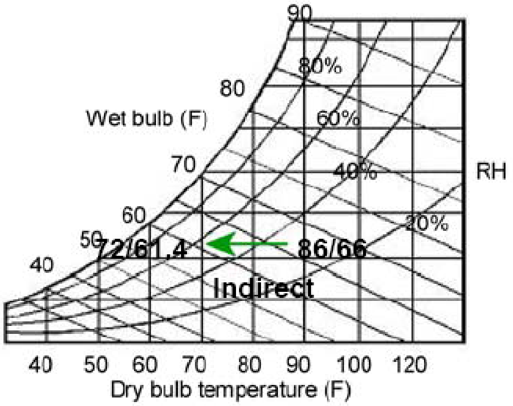
EVAPORATIVE COOLING

Direct evaporative cooling, commonly referred to as swamp cooling, uses a blower to force air through a permeable, water-soaked pad. As the air passes through the pad it is cooled and humidified. Air typically leaves the cooling pad close to saturation. This can be used to further decrease the dry bulb temperature of the air. However, this process produces an opposite adiabatic effect of the desiccant wheel on the psychometric chart, following a line of constant enthalpy, and will not be useful unless the design supply wet bulb temperature is met before entering system.



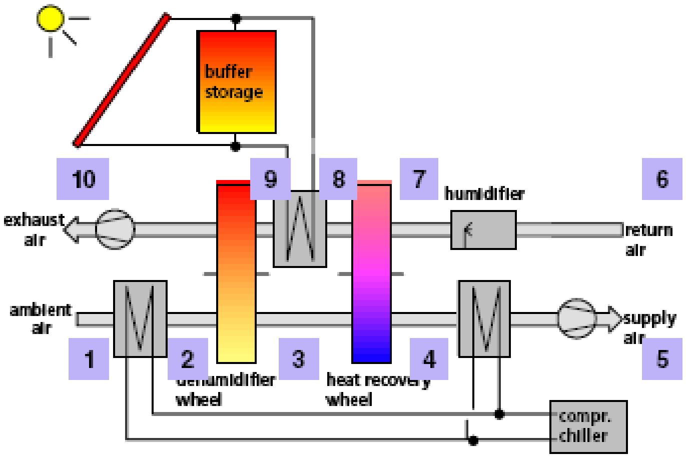






Indirect evaporative cooling uses a secondary “scavenger” stream that is cooled by water. The cooled secondary stream enters a heat exchanger, where it cools the primary air stream. This primary air stream is circulated to the indoor air by a blower. Indirect evaporative cooling does not add moisture to the air, however it requires more airflow to generate a secondary airstream.

A diagram depicting the typical setup of a solar air-conditioning system being studied is shown on the following page:



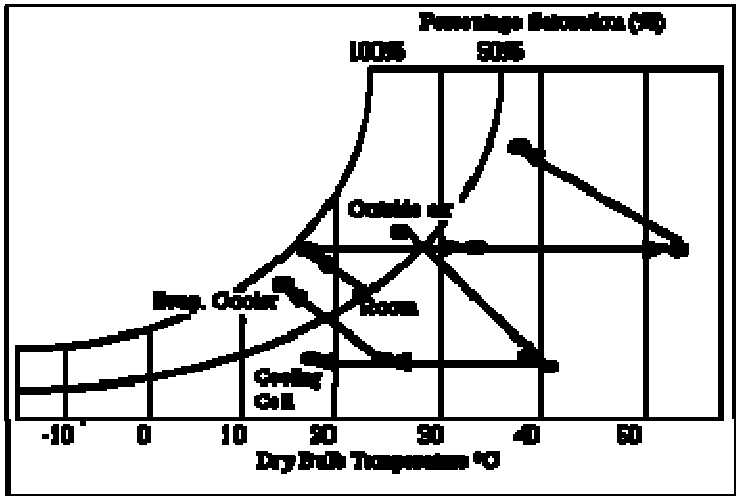
Supply Side:

1) Ambient air enters and is pre-cooled by an evaporative cooler
2) Air enters desiccant wheel at high temperature, high humidity
3) Air leaves desiccant wheel at higher temp. lower humidity
4) Air leaves total energy wheel at low humidity, near supply temp.
5) Air is indirectly evaporative cooled (sensible only) to supply conditions.

Exhaust Side:

6) Air is exhausted at Return air conditions (skip humidifier step)
7) Air enters heat recovery wheel to exchange energy with supply air
8) Air is heated via water-to-air heat exchanger from solar buffer storage to reach temperatures over 180°F
9) Air enters desiccant wheel for reactivation.
10) Air is exhausted at high temperature, high humidity into atmosphere.

Psychometrics:



Desiccant System in Cooling/Dehumidification Mode

DESICCANT DEHUMIDIFICATION ANALYSIS

The existing water source heat pump system with vertical corridors leading to rooftop heat pump units will be modified to include desiccant dehumidification. The rooftop heat pumps will be altered with or replaced by desiccant wheel systems which will feed pre-conditioned air to corridors servicing the heat pump units. The exhaust air needed for heat recovery will be fed from full load exhaust vents 8-10 feet from each RHP. The rooftop heat pumps account for 9.7 million kBtus of annual HVAC load.

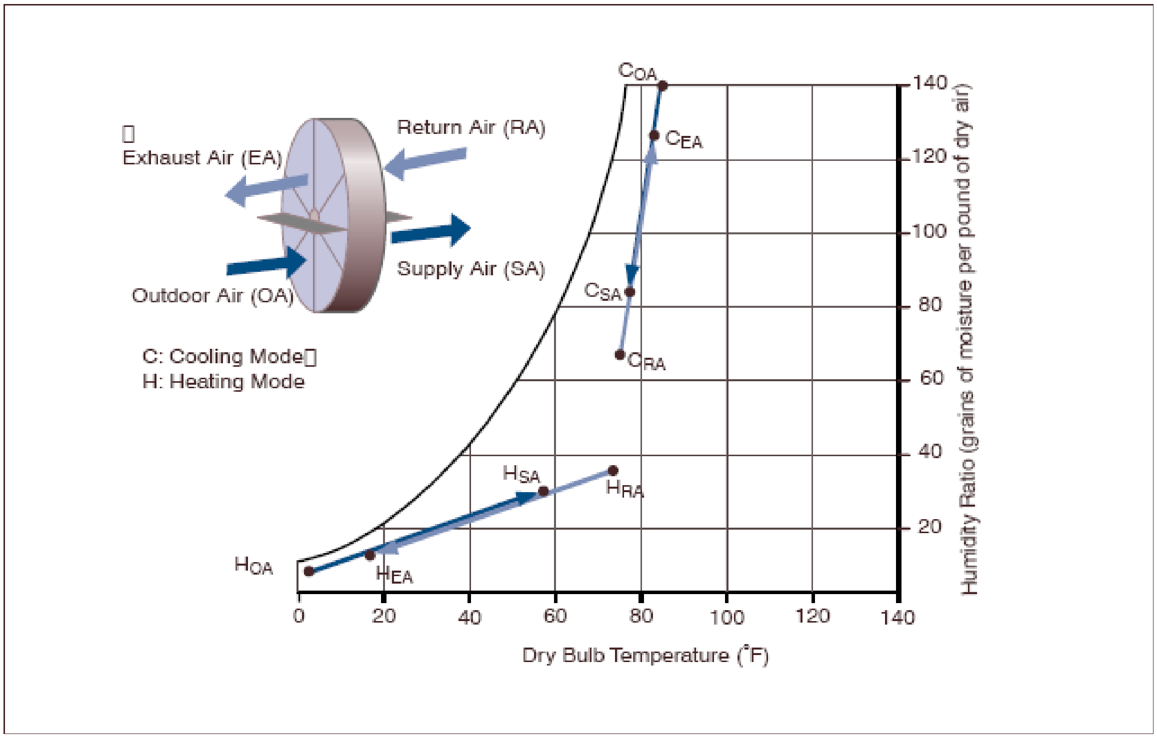
Total load on Waverly's rooftop heat pumps:

	CFM	Ql (kBtu)	Qs (kBtu)	Total
RHP 1	5610	1529350	1216026	2745376
RHP 2	4830	1316713	1046953	2363666
RHP 3	9520	2595260	2063560	4658820
			Total	9,767,862

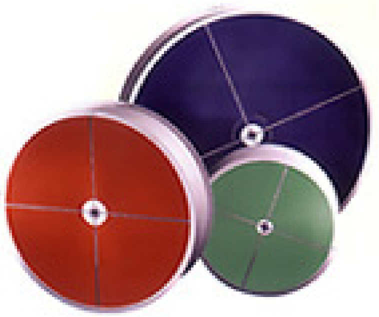
Since the total building load is 25.9 million kBtus, these units account for about 40% of the total building load. 100% outdoor air enters these rooftop heat pump units. Florida's humid climate make this a high both sensible and latent load during the cooling season. Using desiccant dehumidification should decrease the total cooling load on the heat pump units, and provide potential to decrease the size and cost of the cooling towers.

PASSIVE SYSTEMS:

Passive dehumidification can be done with an enthalpy wheel. Enthalpy wheels are based on heat recovery wheel design. Exhaust air enters one side of the wheel, while supply air runs through the other side. A spoked-wheel configuration is used to transfer energy from the exhaust air to the supply air. The heat recovery properties create provide sensible cooling. The wheel is then coated with a solid desiccant, usually silica gel or molecular sieve based, on an aluminum honeycomb platform, to provide latent cooling. The effects of total energy recovery wheels are displayed on the psychometric chart.



Three companies' enthalpy wheel technologies were analyzed for cooling gains:



Rotor Source:

Rotor Source is a supplier of energy recovery wheels, desiccant wheels, and evaporative cooling pads. Enventus Amerivent enthalpy wheel uses 4Å non-migrating molecular sieve desiccant, on an extra thick heavy duty aluminum substrate. With a two week lead time, rotor source has the industry's quickest delivery. I contacted Rotor Source engineering representative Spencer Goland for design and price information. Mr. Goland provided Rotor Source's Eselect energy recovery wheel software program to assist with design. TMY-2 provides average hourly weather data for 239 cities for 8760 hours throughout the year. A BIN data conversion provides fairly accurate data for quicker energy load calculations. Analysis of Amerivent enthalpy wheels utilized the Eselect program as applied to BIN data. The results of these analyses are summarized in the following table:

				Saved kBtu				
SEMCO	CFM	Model	fpm	Ql	Qs	Total	%	Cost
RHP 1	5610	TA-60	700	932018.2	123183.2	1055201	0.384356	5,850
RHP 2	4830	TA-60	600	1082530	143076.1	1225607	0.518519	5,850
RHP 3	9520	TA-84	600	1785178	242795.9	2027974	0.435298	10,300
					Total	4308782	0.441118	22,000

Exact costs for each model were provided by Spencer Goland of Rotor Source.

Eco-Dry:

Eco-dry is a manufacturer of desiccant, and heat recovery rotors and cassettes. Eco-Fresh is Eco-Dry's heat recovery wheel technology. These wheels are available for sale as rotors or cassettes, and can be bought as both sensible and total enthalpy wheel systems. They use either molecular sieve 3Ū (Ecosorb 300) or molecular sieve 4Š (Ecosorb 400) coated on aluminum substrate. The supplier provided an Eco-Fresh software design program. Inputting TMY-2 data into the Eco-Fresh software program for total enthalpy design provided the following results:

				Saved kBtu				
EcoFresh	CFM	Model	fpm	Ql	Qs	Total	%	Cost
RHP 1	5610	HRW1600-200	600	805147.6	96261	901408.6	0.328337	?
RHP 2	4830	HRW1400-200	700	693387.2	82990.32	776377.5	0.328463	?
RHP 3	9520	HRW1900-200	700	1375508	185113	1560621	0.334982	?
					Total	3238407	0.331537	?

No costs were available for the Eco-Fresh rotors, but the relatively low load decrease makes these rotors less than ideal.

SEMCO:

SEMCO is an industry leader in enthalpy wheel technology. This total energy wheel uses a patented EXCLU-SIEVE technology coating. EXCLU-SIEVE utilizes a 3Å molecular sieve desiccant coating to limit the risk of desiccant cross-contamination. This technology is developed specifically for "selective adsorption." The non-wearing extruded four-pass labyrinth seal is never in contact with the rotating wheel, and thus does not experience significant corrosive effects. Beth Wilson, a representative for SEMCO incorporated provided an excel-based program to design and analyze the effectiveness of their energy recovery wheels. Ritchie Hall, a representative for Air Tectonics Incorporated, helped with technical questions related to SEMCO products, which they distribute n Pennsylvania. The results found using the SEMCO analysis spreadsheet were checked against BIN data. These analyses are summarized below:

				Saved kBtu				
SEMCO	CFM	Model	fpm	Ql	Qs	Total	%	Cost
RHP 1	5610	TE-9	700	928078.9	62927.91	991006.8	0.360973	13,015
RHP 2	4830	TE-9	600	798996.8	798996.8	1597994	0.676066	13,015
RHP 3	9520	TE18	600	1588068	1588068	3176136	0.681747	22,086
					Total	5765137	0.590215	48,116

A total cost of 48,116$ for all three rotors is not overly expensive. The decrease in load to the heat pump may be a worthwhile investment.

Conclusion:

The Eco-Fresh heat pumps show the least amount of saved energy out of the three models. Rotor Source and SEMCO products display substantial savings on the rooftop heat pump loads. While the rotor source heat pumps are half the price of SEMCO products, the SEMCO pumps are more efficient. This leaves the mechanical designer with the typical choices: cost or efficiency. The difference between systems is summarized in the following chart:

	Annual				
	Load Saved (kBtu)	%saved	$ saved	Cost	Payback
RotorSource	4308781.543	0.441118	9543.036	22,000	2.305346
SEMCO	5765136.881	0.590215	12768.55	48116	3.76832

While the SEMCO products are more expensive, the payback will be less than four years. The increase in energy savings is worthwhile in the long run. SEMCO total energy wheels are suggested for implementation with the rooftop heat pump units in this design.

Active Systems: Solar Air Conditioning

Active Desiccant systems are used for humidity control. They decrease the humidity of incoming air, while increasing the dry bulb temperature. Active systems are capable of produces substantial drops on humidity ratio, but require high temperatures to reactivate the desiccant. Some active rotors require temperatures as high as 280°F for reactivation. Typically exhaust air is brought to reactivation temperatures by use of a gas-fired air heater, however other technologies are available. Use of a gas-fired heater would make active desiccant cooling too inefficient for use on The Waverly. These systems are best implemented when extremely low humidity ratios are required for industrial process or storage applications. Solar heating has been used as a renewable source of reactivation for desiccant dehumidification. Since energy efficiency is the primary purpose of this report, solar regeneration will be analyzed for use with active desiccant wheels in this report.

Rotor Source:

Spencer Goland of Rotor Source provided an active desiccant rotor analysis program for their rotors. PPS desiccant dehumidification rotors utilize a PPS silica gel with 98% inorganic content. This is important because the less organic material, the less desiccant media loss experienced throughout the life of the rotor. These rotors are set to a 75/25 supply/regeneration flow area. While this allows for maximum conditioned airflow, this ratio requires exhaust air temperatures of approximately 280°F for full desiccant media regeneration. While it is possible to obtain these temperatures from solar power, it would take an enormous plate surface area. Supplementary gas-fired heating would be required. Calculations as to gains experienced with a combination of Rotor Source Desiccant rotors in series with total energy wheels were done, however the high energy cost of the gas-fired heater makes these rotors inefficient for use on The Waverly.

Eco-Dry:

Eco-Dry is another manufacturer of desiccant cassettes and rotors. Their Eco-Dry rotors are available with 3 different desiccant choices:

G3-LH: Employs a pure synthetic zeolite which approximates the ideal 1M desiccant, anchored with a small quantity of metal silicates. These rotors are ideal for extremely low humidity applications.

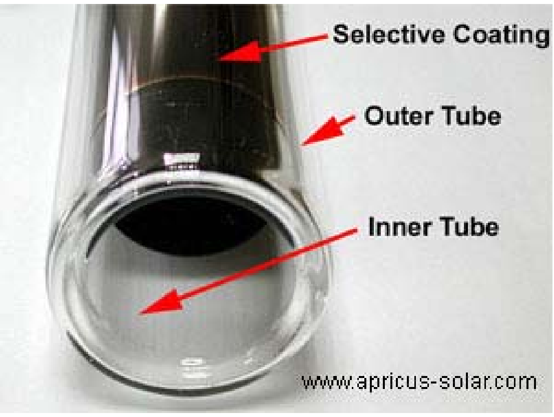
G3-MH: Employ highly active metal silicates. These rotors are suitable for a wide range of low humidity level industrial applications

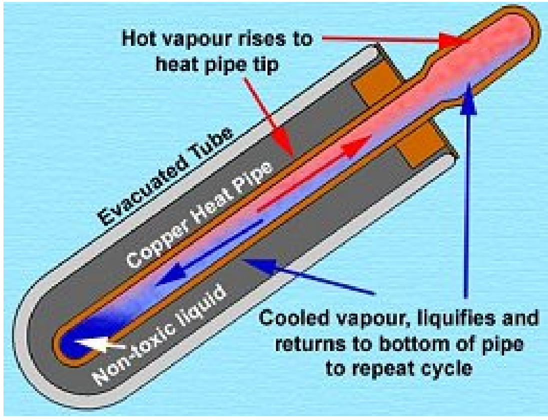
G3-HH: These rotors contain metal silicates specifically tailored with high pore volume, to suite high humidity level inlet condtions. When set in a 50/50 supply/exhaust configuration reactivation temperatures required are relatively lower, at an average of 176ºF.

The Eco-Dry G3-HH rotor will be most beneficial to condition the humid outdoor air experienced in Orlando. The option of setting the Rotor in the 50/50 (half moon) setup provides significant advantages for solar regeneration. The Eco-Dry desiccant program obtained from the manufacturer was used for calculations along with both Rotor Source and Eco-Fresh total enthalpy recovery wheels. These calculations were first performed for RHP3 and can be found in the index.

EVACUATED-TUBE SOLAR REACTIVATION

The most common technology that can accommodate the high temperatures needed for desiccant reactivation is evacuated-tube or vacuum tube solar technology. Evacuated-tube collectors consist of a row of evacuated glass tubes. These tubes absorb direct and indirect solar energy and convert it to heat. Each tube consists of an inner and outer tube made from strong borosilicate glass. The outer tube is transparent, while the inner tube is coated with a selective coating for maximum radiation absorption and minimal reflection properties. These tubes are fused together, and a vacuum is created between the two tubes (evacuating the gasses). Evacuated-tubes can maintain internal temperatures of up to 304ºF, while the outer tube is cool to the touch.





A heat pipe filled with fluid is sealed in the evacuated-tube. When the fluid becomes hot, hot vapor rises to the pipe tip, which is connected to the water supply via a heat exchanger. As the fluid gets cooler, it settles to the bottom of the tube where it repeats the cycle. The heated water is then circulated to a hot water storage tank requiring temperatures of above 180 ºF. There are many configurations available for tank placement and water pumping. If the tank is located above the solar collector panes, this will create a thermosiphon effect. As hot water rises off the evacuated tubes, it naturally travels up the pipe while cooler water naturally travels down the pipe to the collector units. This may not be applicable for The Waverly.

In 1978 Nelson et al. simulated seasonal operation of a Munters Environmental Control (MEC) cycle, similar to the one being implemented in this report. This was done in the Miami climate, so estimates for the total collector area needed for this buildings implementation will be based on results from that study. Using less efficient solar flat-plate collectors, Nelson found that 93% of the total energy requirement of the system was met by solar energy. A solar factor (SF) of 0.93 means that 93% of the reactivation energy required for the desiccant wheel was collected via solar panels. A chart summarizing his data was found in Solar Engineering of the Thermal Process.

	Collector Area			
	7.5	15	30	45
Collector mass flow reate, kg/s	0.104	0.208	0.417	0.625
Tank heat exchanger mass flow rate, kg/s	0.167	0.333	0.67	1
Tank volume, cubic meters	0.56	1.13	2.25	3.38
Sensible load met, GJ	20.8	20.8	20.8	20.8
Latent Load met, GJ	15.7	15.7	15.9	16.7
Solar energy collected, GJ	12.2	23	41	54.4
Solar energy dumped, GJ	0	0	0.026	2.4
Auxiliary energy supplied to system, GJ	33.6	24.2	11.4	4.2
Fraction of total energy requiremtn met by solar	0.27	0.49	0.78	0.93

Nelsons total load analyzed for the cooling season considered from April through September. The flat-plate collector system had a total square area of 45m^2 that conditioned of 93% of this load.

Total load on Waverly's rooftop heat pumps:

	CFM	Ql (kBtu)	Qs (kBtu)	Total
RHP 1	5610	1529350	1216026	2745376
RHP 2	4830	1316713	1046953	2363666
RHP 3	9520	2595260	2063560	4658820
			Total	9,767,862

These rooftop heat pumps have 170 times the load of the Nelson system. However, since more efficient evacuated-tube system will be used, only half the fraction used in Nelson's design need be used. This means that in order to have a SF of 0.93, The Waverly will need 3825 m^2 (41,171 ft^2). These numbers match up with data collected from a Retscreen analysis of the project. The rooftop of The Waverly on Lake Eola has an area of 19,600 square feet. With the mechanical equipment already up on the roof, this less then half of the room that is needed for the evacuated-tube collectors available for use.

Using SolMaxx SKU16145 evacuated-tube collectors at 30° angle with appropriate spacing to account for shading, 160 collectors can fit on roof. This will give a total collector area of 462.4 m^2 (4977 ft^2). This is not nearly enough room for the amount of solar collection needed to use solar air conditioning on The Waverly. Since the solar load associated with reactivation cannot met, it seems that solar air conditioning is not applicable for this building.

CONSTRUCTION MANAGEMENT BREADTH

Florida codes for maximum U-values and Solar Heat Gain Characteristics of different types of glass are located in Table 13-601.1 of the Florida Building Code:

Table 13-601.1

Type	U-factor	SHGC
Single pane clear	1.3	0.75
single pane tint	1.3	0.64
double pane clear	0.87	0.66
double pane tint	0.87	0.55

Architects specific data on window selection for The Waverly was unavailable. Florida code data was used as an assumed base case condition. Double pane glass was assumed used as a typical building standard. From a responsible engineering perspective double pane glass for this application is mandatory. However, glass that exceeds Florida Building Code may substantially reduce the annual mechanical system costs. Many aspects of window technology can be analyzed:

Tinted glass has the potential to absorb a substantial amount of the suns energy in comparison to clear. A colorant is added to the glass during the production run. This keeps much of the light from entering the zone. These windows reduce solar heat gain and should reduce the loads on the HVAC system.

Reflective glass absorbs and reflects more light than tinted glass. A metallic coating is added to the outside of the glass at the last stages of production. Reflective glass is preferred in situations where a solar heat gain reduction is needed. The outer coating also creates an interesting addition to the architecture of the building. This system should reduce annual costs to the HVAC system.

Low-e glass is coated with a thin, transparent layer of silver or tin oxide. This allows visible light to pass through, but reflects infrared heat radiation back into the room creating an effect similar to the “greenhouse effect” typically associated with global warming. This reduces the heat loss through the windows in the winter. Low-e glass has a tendency to create a greater cooling load during summer conditions on account of the infrared radiation that reflects back into the room. While this is an amazing energy saving technology, low-e glass would not be useful in Orlando’s hot and humid climate.

Triple glazing is a technique of adding yet another layer of glass to the double glazing scheme. This creates a scenario involving two air spaces to be filled with either air of low conductivity gas. This layer of protection decreases the U-value of the glass allowing less heat transfer.

The most common considerations in specifying glass are the U-value and the Solar Heat Gain Coefficient (SHGC). U-value determines the heat loss or heat gain due to temperature differences on either side of the window. The SHGC is a measurement determining the amount of heat transferred through direct, reflected, and diffused radiation. The following table indicates typical design and specifications for window systems based on HAP inputs.

	Outer Glazing	Glazing #2	Glazing #3	U-value	SHGC
Base Case	1/8" clear	1/8" clear	not used	0.87	0.811
Blu-Grn tint	1/4" B/G tint	1/8" clear	not used	0.565	0.6
Blu-Grn Reflective	1/4" B/G reflective	1/8" clear	not used	0.565	0.401
Triple Pane	1/4" B/G reflective	1/8" clear	1/8" clear	0.381	0.39

Advantages and Disadvantages

Base Case Window system:

Advantages:
- Lowest price available satisfying Florida Building code
- All visible light enters room, for maximum daylight penetration

Disadvantages:
- High interior heat gain during cooling season
- High interior heat loss during heating season
- High radiation heat gain during cooling season

Tinted Glass:

Advantages:
- Lower price than reflective and triple pane glass
- absorbs many wavelengths of sunlight creating lower radiation heat gains
- Provides privacy to residents
- Decreases harsh interior lighting during peak sunlight hours

Disadvantages:
- Higher cost than traditional glass systems
- Lower radiation heat gain during heating seasons
- Less daylight penetration for residents

Reflective Glass:

Advantages:
- Lower price than triple pane glass

- Reflects and absorbs many wavelengths of sunlight creating lower radiation heat gains
- Provides privacy to residents
- Decreases harsh interior lighting during peak sunlight hours
- Adds to Architectural Appeal

Disadvantages:

- Higher cost than traditional glass systems and tinted glass
- Lower radiation heat gain during heating seasons
- Less daylight penetration for residents

Triple Pane Reflective Glass:

Advantages:

- Creates low heat loss/gain per square foot with low U-value
- Reflects many wavelengths of sunlight creating lower radiation heat gains
- Provides privacy to residents
- Decreases harsh interior lighting during peak sunlight hours
- Adds to Architectural Appeal

Disadvantages:

- Higher cost than double pane glass systems
- Heavier weight than double pane glass

Carrier's Hourly Analysis Program was used to study the potential energy savings associated with these different glazing technologies. The base case was first studied with Florida's code values for double glazing entered for all window data in The Waverly. This model was then simulated to find annual costs. Excess reflection of the lake cannot be put into the program, so this was assumed as a minimal load improvement. However, in true design, this would be taken into account, and reflective windows may be a necessity.

Next, the same building set-up was modified so that the exterior glazings were tinted with a Blue-Green Reflective film. This decreased the U-value of the window, and decreased the SHGC substantially.

Finally, triple pane glass was considered for the building. Although triple pane glass is rarely used due to cost, the benefits can sometimes be worthwhile. Again, the U-value and SHGC were decreased during this simulation.

Results of these analyses are summarized in the following table:

	Cooling Load (MBTU)	Heating Load	Total Load	Annual Cost($)
Base Case	24,490.00	1,288	25,778.00	57,363
Blu-Grn tint	21,654	1,257	22,911.00	51,554
Blu-Grn Reflective	17,864	1,262	19,126.00	47,261
Triple Pane	18,561.00	1,257	19,818.00	46,645

First Cost Analysis:

First cost must go into account when selecting which glass system is most applicable for The Waverly on Lake Eola. While it would be nice to always use the most efficient glass available, budget is a crucial element to the construction process. The Waverly utilizes an aluminum floor to ceiling storefront curtain wall system for most of the exterior walls. RSMeans provides annual national and state averages for costs of different building components. The curtain wall section provides costs per square foot including aluminum framing components. Labor costs per square foot are also available.

In Technical Assignment 2, I calculated the total glazing area of The Waverly. I found that the building had 75,648 square feet of window area. This was used for the following cost analysis. The cost works program by RSMeans was used to attain the following cost data for each window system:

	Per S.F.			Total Cost		
	Materials	Installation	Total	Mat.	Inst.	Total
Base Case	12.2	7.05	19.25	922906	533318	1456224
Blu-Grn tint	15	7.05	22.05	1134720	533318	1668038
Blu-Grn Reflective	17.45	6.2	23.65	1320058	469018	1789075
Triple Pane						2184336

Prices for triple pane windows were not available, however, a multiplication factor of 1.5 times the base case would be safe. This estimate is based on the added costs associated with the extra pane of glass, extra framing needed, and excess weight problems associated with installation. This factor is most likely low, however, it will be used to provide theoretical proof that the triple pane glass is not worthwhile.

A simple payback method was used to analyze the cost effectiveness of more efficient window technologies on The Waverly on Lake Eola. The calculations for this payback analysis are summarized in the following spreadsheet.

	HVAC Annual Coast	First Cost	Savings	First Cost	Payback
Base Case	57,363	1,456,224	0	0	0
Blu-Grn tint	51,554	1,668,038	5,809	211,814	36.46314
Blu-Grn Reflective	47,261	1,789,075	10,102	332,851	32.94904
Triple Pane	46,645	2184336	10,718	728,112	67.93357

This analysis first shows that the triple pane glass would not be worthwhile for The Waverly. Buildings are not built with a 67 year payback in mind, and this is not worthwhile considering the annual savings are not substantial when compared with the savings experienced with 2 pane blue-green reflective glazing.

Although the reflective window system has a higher first cost than the tinted window system, it is apparent that the added savings realized by the decrease in HVAC load are substantial enough to make the reflective tint a better investment. The tinted windows have a payback period greater than 36 years, as opposed to the 33 year payback of the reflective window system.

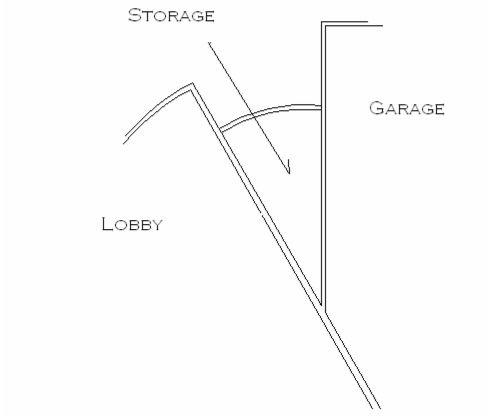
With a 33 year payback period it is hard to suggest a reflective system over the windows recommended in the Florida Building Code. Typically a payback period of more than 20 years is not recommended in the building industry. However, as energy prices continue to realize, as many experts assume they will, this payback period will see a decrease. The architectural benefits of the reflective windows, along with the increased privacy the tenants of The Waverly will see, display why the Owner chose to put up the extra investment in the reflective window system.

ACOUSTICS BREADTH:

TRANSMISSION OF SOUND BETWEEN GARAGE AND LOBBY

The first floor contains both the lobby, which serves as a tenants' first view of the building, and the first floor of the parking garage. This parking garage should not be heard from within the seating area of the lobby (located below). A storage room acting as a sound damper is between the two rooms. A study of the effectiveness of this storage room as a sound damper will be examined.

A storage room acting as a sound damper is between the two rooms. A study of the effectiveness of this storage room as a sound damper will be examined. Below is a diagram displaying the layout of the lobby/damper/garage wall system.



Noise reduction must be calculated on a room by room basis. Absorption coefficients and transmission losses must be taken into account. The garage is assumed to have a sound level about that of a busy street. This level was approximated as 80dB; 10dB higher than the value of 70dB found at www.seacoastonline.com/calender/2002/7_11coverstory.htm. The level transmitted into the lobby should be no more than 22dB. Since these values are not given with respect to sound frequency, NRC and STC data were used.

The following equation for noise reduction is used:
$NR = TL + 10\log(a_2/S)$
NR = Noise Reduction (dB)
TL = Transmission Loss (dB)
a_2 = absorption in receiving room (sabins)

Absorption coefficients were calculated for each room and summarized in the following tables:

Storage	Matl.	α	Length	SA	Sα
Wall	Concrete	0.05	17	340	17
Wall	Concrete	0.05	33	660	33
Wall	Concrete	0.05	33	660	33
Floor	Concrete	0		272	0
Ceiling	Concrete	0		272	0
				Sabins =	83

Lobby	Matl.	α	Length	SA	Sα
Walls	Concrete	0.05	40	800	40
Windows	Glass	0.05	70	1400	70
Floor	Tile	0		1438	0
Ceiling	Plaster	0.05		1438	71.9
				Sabins =	181.9

Garage	Matl.	α	Length	SA	Sα
Wall	Concrete	0.05	500	10000	500
Floor	Concrete	0		14242	0
Ceiling	Concrete	0		14242	0
				Sabins =	500

A TL level of 53 was found for concrete.

Both rooms have a shared wall area of 33 x 20 = 66 ft.

First the NR into the storage space is calculated:

NR = 53 + 10log(83/66) = 54

Therefore, Ls = 80 – 54 = 26

Next the NR into the lobby is calculated:

NR = 53 + 10log(181.9/66) = 57

Therefore, since NR > Ls : the sound from the garage is completely inaudible.

From this simple acoustical analysis, it is apparent that the storage room works well as a sound damper from the garage.

Transmission of Sound from Garage To Typical 5th Floor Bedroom Through Floor

The four-story parking garage on the bottom floors of The Waverly on Lake Eola provides a convenience for the tenants in a busy area downtown. However, the tenants living on the 5th floor would like this convenience less if they constantly heard people parking under their feet. A study of the transmission of sound from the garage into a typical bedroom on the fifth floor was analyzed.
The same equations will be used to calculate NR as were used in the previous study. NRC absorption coefficients for the bedroom are in the following table:

Bedroom	Matl.	α	Length	SA	Sα
Walls	Gypsum	0.1	49.5	445.5	44.55
Windows	Glass	0.05	70	630	31.5
Floor	Carpet	0.3		171	51.3
Ceiling	Plaster	0.05		171	8.55
				Sabins =	135.9

TL for a 6-inch reinforced concrete slab with ¾ T&G flooring is summed by an STC rating of 55.

Assuming a noise level of 80dB in the basement, and a maximum acceptable noise level transmitted into the bedroom:

NR = 55 + 10log(135.99/171) = 54

Therefore, Lb = 80 – 54 = 26

Since 26 > 22, this sound level is unacceptable.

The TL needs to be increased to at least 81 to stop the sound from entering the space. A solution to this problem is a cavity between the fourth floor ceiling and the fifth floor slab to act as a damper. Another possible solution would be sound absorbing material added to the ceiling of the fourth floor.

CONCLUSIONS:

The Waverly on Lake Eola had original HVAC requirements of taking up minimal rentable space, while giving each apartment personal heating and cooling controls. A water source heat pump system was installed to meet both of these requirements while maintaining and energy efficient design. The rooftop heat pumps supply outdoor air for all spaces in the building.

Improving on this design without affecting the amount of indoor space required for HVAC systems proved difficult. A major source of mechanical load for the building is the rooftop heat pump units. With an annual combined heating and cooling load of 9.7 million kBtu, the rooftop heat pumps make up for over 37% or the total building load. Increasing the performance of these heat pumps was taken as the best way to improve the efficiency of the building without taking up additional space due to mechanical system equipment.

Increasing the envelope efficiency was looked at as the first way to improve the efficiency of the building as a whole. The floor-to-ceiling windows located throughout The Waverly make the envelope a major source of heat loss. To account for these heat losses the mechanical system must provide extra load throughout the building. The Florida Building Code does not require windows with efficient specifications. Advanced window-systems such as tinted glass, reflective glass, and triple pane windows were examined. Triple pane glass was too expensive and heavy to be worthwhile for the building. HAP's Carrier analysis program was used to calculate the load differences influenced by different window technologies.

A Construction Management study of the new window systems was then done for my breadth study. The tinted glass saved $5,809 per year for total costs of the mechanical system. An extra total upfront window cost of $211,814 was associated with the tinted windows. This creates a payback of 36.5 years. The reflective windows save the mechanical system $10,102 per year. With an additional first cost of $332,851, this system will be paid off in 33 years. Scheduling will not be any different with these new window systems since they are pre-fabricated curtain wall. While this payback period may be too high, it is apparent that reflective windows are more efficient for the system. This may prove cost effective if energy prices continue to rise at current rates.

After analyzing the envelope, adjustments made to the mechanical system itself were studied. Since the water source heat pump system is efficient and takes up little indoor space, the goal was to improve upon this current system. The rooftop heat pump units account for approximately 40% of the total building load, either eliminating or improving upon these systems was the goal. The improvements associated with the implementation of desiccant technology were examined.

Solar air conditioning uses active desiccant technology along with solar water heating, heat exchange, and indirect evaporative cooling to cool the buildings air with no refrigeration techniques, and very little energy supplied. Desiccant wheels use exchange between exhaust air and supply air to dehumidify air and decrease the latent load. Heat recovery and evaporative cooling take care of the sensible load. Evacuated-tube solar panels heat water to temperatures in excess of 180°F in order to reactivate desiccant media. It was found that more solar paneling was needed than there was space on the roof. Since solar air conditioning would not work for the space, active desiccant technology would not be beneficial.

Passive total enthalpy wheels do not need high heats for reactivation, and thus do not need any more heat than is provided by the exhaust air. With passive systems rooftop heat pumps would still be needed, however, the load on the heat pumps could be greatly decreased. Rotor Source, EcoFresh, and SEMCO enthalpy wheels were all studied for use.

Each company had a program that was learned and implemented in order to determine exact load changes based on different wheels and configurations. These calcualations were performed using BIN data based on TMY2 numbers for Florida.The manufacturers also provided price data on these wheels. EcoFresh cartridges did not provide a substantial decrease in load on the heat pumps. .Rotor Source wheels were effective and cheap for this implementation. While SEMCO wheels cost more than twice as much, they saved more energy and would be a worthwhile purchase. The SEMCO wheels saved 5,765 MBtus per year, and had a payback of less than 4 years.

An acoustical analysis of the parking garage's effect on the indoor spaces was performed as a second breadth. The effectiveness of a storage area used as a damper between the lobby and the garage was first analyzed. A study of Noise Reduction proved that the damper worked well as a noise damper for the lobby. Next, a study of Noise Reduction was performed between the garage and a typical 5th floor apartment bedroom. The noise heard in the bedroom from the garage was found to exceed standard maximum levels. This would be remedied with noise dampening panels on the roof of the top-story of the parking garage, or a sound-dampening drop ceiling.

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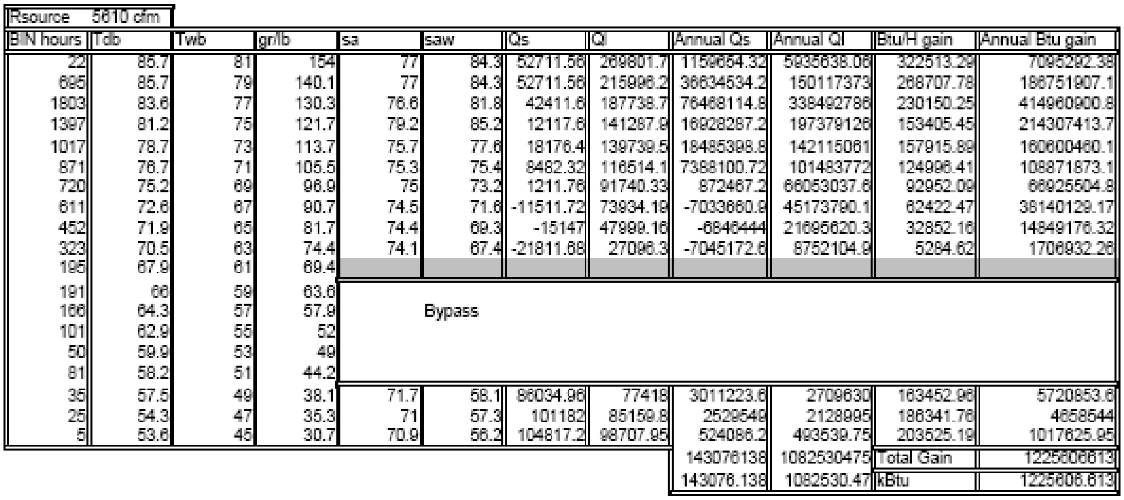
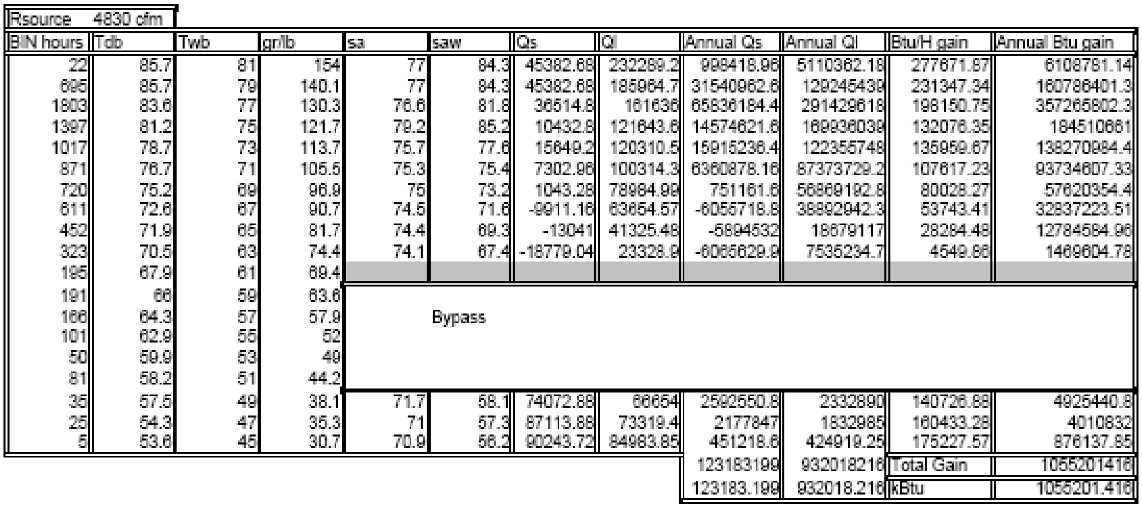
APPENDIX 1: ROTOR BIN TABLES



Rsource 5610 cfm

BIN hours	Tdb	Twb	gr/lb	sa	saw	Qs	Ql	Annual Qs	Annual Ql	Btu/H gain	Annual Btu gain
22	85.7	81	154	77	84.3	52711.56	269801.7	1159654.32	5935638.06	322513.29	7095292.38
695	85.7	79	140.1	77	84.3	52711.56	215996.2	36634534.2	150117373	268707.78	186751907.1
1803	83.6	77	130.3	76.6	81.8	42411.6	187738.7	76468114.8	338492786	230150.25	414960900.8
1397	81.2	75	121.7	79.2	85.2	12117.6	141287.9	16928287.2	197379126	153405.45	214307413.7
1017	78.7	73	113.7	75.7	77.6	18176.4	139739.5	18485398.8	142115061	157915.89	160600460.1
871	76.7	71	105.5	75.3	75.4	8482.32	116514.1	7388100.72	101483772	124996.41	108871873.1
720	75.2	69	96.9	75	73.2	1211.76	91740.33	872467.2	66053037.6	92952.09	66925504.8
611	72.6	67	90.7	74.5	71.6	-11511.72	73934.19	-7033660.9	45173790.1	62422.47	38140129.17
452	71.9	65	81.7	74.4	69.3	-15147	47999.16	-6846444	21695620.3	32852.16	14849176.32
323	70.5	63	74.4	74.1	67.4	-21811.68	27096.3	-7045172.6	8752104.9	5284.62	1706932.26
195	67.9	61	69.4								
191	66	59	63.6	Bypass							
166	64.3	57	57.9								
101	62.9	55	52								
50	59.9	53	49								
81	58.2	51	44.2								
35	57.5	49	38.1	71.7	58.1	86034.96	77418	3011223.6	2709630	163452.96	5720853.6
25	54.3	47	35.3	71	57.3	101182	85159.8	2529549	2128995	186341.76	4658544
5	53.6	45	30.7	70.9	56.2	104817.2	98707.95	524086.2	493539.75	203525.19	1017625.95
								143076138	1082530475	Total Gain	1225606613
								143076.138	1082530.47	kBtu	1225606.613



Rsource 4830 cfm

BIN hours	Tdb	Twb	gr/lb	sa	saw	Qs	Ql	Annual Qs	Annual Ql	Btu/H gain	Annual Btu gain
22	85.7	81	154	77	84.3	45382.68	232289.2	998418.96	5110362.18	277671.87	6108781.14
695	85.7	79	140.1	77	84.3	45382.68	185964.7	31540962.6	129245439	231347.34	160786401.3
1803	83.6	77	130.3	76.6	81.8	36514.8	161636	65836184.4	291429618	198150.75	357265802.3
1397	81.2	75	121.7	79.2	85.2	10432.8	121643.6	14574621.6	169936039	132076.35	184510661
1017	78.7	73	113.7	75.7	77.6	15649.2	120310.5	15915236.4	122355748	135959.67	138270984.4
871	76.7	71	105.5	75.3	75.4	7302.96	100314.3	6360878.16	87373729.2	107617.23	93734607.33
720	75.2	69	96.9	75	73.2	1043.28	78984.99	751161.6	56869192.8	80028.27	57620354.4
611	72.6	67	90.7	74.5	71.6	-9911.16	63654.57	-6055718.8	38892942.3	53743.41	32837223.51
452	71.9	65	81.7	74.4	69.3	-13041	41325.48	-5894532	18679117	28284.48	12784584.96
323	70.5	63	74.4	74.1	67.4	-18779.04	23328.9	-6065629.9	7535234.7	4549.86	1469604.78
195	67.9	61	69.4								
191	66	59	63.6	Bypass							
166	64.3	57	57.9								
101	62.9	55	52								
50	59.9	53	49								
81	58.2	51	44.2								
35	57.5	49	38.1	71.7	58.1	74072.88	66654	2592550.8	2332890	140726.88	4925440.8
25	54.3	47	35.3	71	57.3	87113.88	73319.4	2177847	1832985	160433.28	4010832
5	53.6	45	30.7	70.9	56.2	90243.72	84983.85	451218.6	424919.25	175227.57	876137.85
								123183199	932018216	Total Gain	1055201416
								123183.199	932018.216	kBtu	1055201.416

Rsource 9520 cfm

BIN hours	Tdb	Twb	gr/lb	sa	saw	Qs	Ql	Annual Qs	Annual Ql	Btu/H gain	Annual Btu gain
22	85.7	81	154	77	84.3	89449.92	444860.3	1967898.24	9786925.5	534310.17	11754823.74
695	85.7	79	140.1	77	84.3	89449.92	356143.5	62167694.4	247519733	445593.42	309687426.9
1803	83.6	77	130.3	76.6	81.8	71971.2	309551.3	129764074	558120904	381522.45	687884977.4
1397	81.2	75	121.7	79.2	85.2	20563.2	232961.3	28726790.4	325446866	253524.45	354173656.7
1017	78.7	73	113.7	75.7	77.6	30844.8	230408.3	31369161.6	234325190	261253.05	265694351.9
871	76.7	71	105.5	75.3	75.4	14394.24	192113.3	12537383	167330641	206507.49	179868023.8
720	75.2	69	96.9	75	73.2	2056.32	151265.3	1480550.4	108910980	153321.57	110391530.4
611	72.6	67	90.7	74.5	71.6	-19535.04	121905.8	-11935909	74484413.3	102370.71	62548503.81
452	71.9	65	81.7	74.4	69.3	-25704	79143	-11618208	35772636	53439	24154428
323	70.5	63	74.4	74.1	67.4	-37013.76	44677.5	-11955444	14430832.5	7663.74	2475388.02
195	67.9	61	69.4								
191	66	59	63.6								
166	64.3	57	57.9		Bypass						
101	62.9	55	52								
50	59.9	53	49								
81	58.2	51	44.2								
35	57.5	49	38.1	71.7	58.1	145998.7	131376	5109955.2	4598160	277374.72	9708115.2
25	54.3	47	35.3	71	57.3	171702.7	144513.6	4292568	3612840	316216.32	7905408
5	53.6	45	30.7	70.9	56.2	177871.7	167504.4	889358.4	837522	345376.08	1726880.4
								242795871	1785177643	Total Gain	2027973514
								242795.871	1785177.64	kBtu	2027973.514

				Saved kBtu				
SEMCO	CFM	Model	fpm	Ql	Qs	Total	%	Cost
RHP 1	5610	TA-60	700	932018.2	123183.2	1055201	0.384356	5,850
RHP 2	4830	TA-60	600	1082530	143076.1	1225607	0.518519	5,850
RHP 3	9520	TA-84	600	1785178	242795.9	2027974	0.435298	10,300
					Total	4308782	0.441118	22,000

SEMCO 5610 cfm

BIN hours	Tdb	Twb	gr/lb	sa	saw	Qs	Ql	Annual Qs	Annual Ql	Btu/H gain	Annual Btu gain
22	85.7	81	154	80.2	93.3	33323.4	234963.6	733114.8	5169199.86	268287.03	5902314.66
695	85.7	79	140.1	80.2	89.8	33323.4	194706.3	23159763	135320858	228029.67	158480620.7
1803	83.6	77	130.3	79.7	87	23629.32	167610	42603664	302200776	191239.29	344804439.9
1397	81.2	75	121.7	79.1	85.4	12723.48	140513.7	17774701.6	196297597	153237.15	214072298.6
1017	78.7	73	113.7	78.2	83.3	3029.4	117675.4	3080899.8	119675841	120704.76	122756740.9
871	76.7	71	105.5	77.6	81.1	-5452.92	94449.96	-4749493.3	82265915.2	88997.04	77516421.84
720	75.2	69	96.9	77.5	79.2	-13935.24	68514.93	-10033373	49330749.6	54579.69	39297376.8
611	72.6	67	90.7	76.9	77.4	-26052.84	51482.97	-15918285	31456094.7	25430.13	15537809.43
452	71.9	65	81.7								
323	70.5	63	74.4								
195	67.9	61	69.4								
191	66	59	63.6								
166	64.3	57	57.9		Bypass						
101	62.9	55	52								
50	59.9	53	49								
81	58.2	51	44.2								
35	57.5	49	38.1	75.5	72.1	109058.4	131610.6	3817044	4606371	240669	8423415
25	54.3	47	35.3	67.8	52.7	81793.8	67353.66	2044845	1683841.5	149147.46	3728686.5
5	53.6	45	30.7	67.3	34.4	83005.56	14322.33	415027.8	71611.65	97327.89	486639.45
								62927908.6	928078855	Total Gain	991006763.7
								62927.9086	928078.855	kBtu	991006.7637

SEMCO 4830 cfm

BIN hours	Tdb	Twb	gr/lb	sa	saw	Qs	Ql	Annual Qs	Annual Ql	Btu/H gain	Annual Btu gain
22	85.7	81	154	80.2	93.3	28690.2	202294.9	631184.4	4450487.58	230985.09	5081671.98
695	85.7	79	140.1	80.2	89.8	28690.2	167634.8	19939689	116506193	196325.01	136445882
1803	83.6	77	130.3	79.7	87.3	20343.96	143306.1	36680159.9	258380898	163650.06	295061058.2
1397	81.2	75	121.7	79.1	85.2	10954.44	121643.6	15303352.7	169936039	132597.99	185239392
1017	78.7	73	113.7	78.4	83.2	1564.92	101647.4	1591523.64	103375355	103212.27	104966878.6
871	76.7	71	105.5	77.9	81.1	-6259.68	81317.88	-5452181.3	70827873.5	75058.2	65375692.2
720	75.2	69	96.9	77.5	79	-11997.72	59655.33	-8638358.4	42951837.6	47657.61	34313479.2
611	72.6	67	90.7	76.9	77.4	-22430.52	44324.91	-13705048	27082520	21894.39	13377472.29
452	71.9	65	81.7								
323	70.5	63	74.4								
195	67.9	61	69.4								
191	66	59	63.6								
166	64.3	57	57.9		Bypass						
101	62.9	55	52								
50	59.9	53	49								
81	58.2	51	44.2								
35	57.5	49	38.1	75.7	72.1	94938.48	113311.8	3322846.8	3965913	208250.28	7288759.8
25	54.3	47	35.3	67.8	52.8	70421.4	58322.25	1760535	1458056.25	128743.65	3218591.25
5	53.6	45	30.7	67.6	34.4	73029.6	12330.99	365148	61654.95	85360.59	426802.95
								51798852	798996828	Total Gain	850795680.4
								51798.852	798996.828	kBtu	850795.6804

SEMCO 9520 cfm

BIN hours	Tdb	Twb	gr/lb	sa	saw	Qs	Ql	Annual Qs	Annual Ql	Btu/H gain	Annual Btu gain
22	85.7	81	154	80.2	93.3	57024	402076.8	1254528	8845689.6	459100.8	10100217.6
695	85.7	79	140.1	80.2	89.8	57024	333187.2	39631680	231565104	390211.2	271196784
1803	83.6	77	130.3	79.5	87.3	40435.2	284832	72904665.6	513552096	325267.2	586456761.6
1397	81.2	75	121.7	79.2	85.2	21772.8	241776	30416601.6	337761072	263548.8	368177673.6
1017	78.7	73	113.7	78.4	83.2	3110.4	202032	3163276.8	205466544	205142.4	208629820.8
871	76.7	71	105.5	77.9	81.1	-12441.6	161625.6	-10836634	140775898	149184	129939264
720	75.2	69	96.9	77.5	79	-23846.4	118569.6	-17169408	85370112	94723.2	68200704
611	72.6	67	90.7	76.9	77.4	-44582.4	88099.2	-27239846	53828611.2	43516.8	26588764.8
452	71.9	65	81.7								
323	70.5	63	74.4								
195	67.9	61	69.4								
191	66	59	63.6								
166	64.3	57	57.9		Bypass						
101	62.9	55	52								
50	59.9	53	49								
81	58.2	51	44.2								
35	57.5	49	38.1	75.7	72.1	188697.6	225216	6604416	7882560	413913.6	14486976
25	54.3	47	35.3	67.8	52.8	139968	115920	3499200	2898000	255888	6397200
5	53.6	45	30.7	67.6	34.4	145152	24508.8	725760	122544	169660.8	848304
								102954240	1588068230	Total Gain	1691022470
								102954.24	1588068.23	kBtu	1691022.47

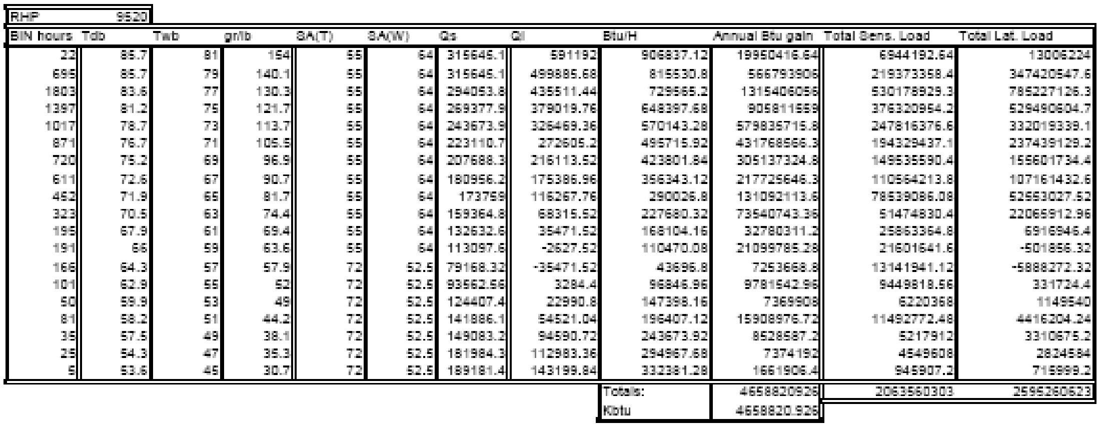
				Saved kBtu				
SEMCO	CFM	Model	fpm	Ql	Qs	Total	%	Cost
RHP 1	5610	TE-9	700	928078.9	62927.91	991006.8	0.360973	13,015
RHP 2	4830	TE-9	600	798996.8	798996.8	1597994	0.676066	13,015
RHP 3	9520	TE18	600	1588068	1588068	3176136	0.681747	22,086
					Total	5765137	0.590215	48,116

EcoDry	5610										
BIN hours	Tdb	Twb	gr/lb	sa	saw	Qs	Ql	Annual Qs	Annual Ql	Btu/H gain	Annual Btu gain
22	85.7	81	154	80.9	100.2	29062.24	206254.4	639809.28	4581597.2	237336.66	5221406.52
695	85.7	79	140.1	79.9	95.9	35141.04	171093.8	24423023	118910177	206234.82	143333199.9
1803	83.6	77	130.3	78	92.9	33929.28	144771.7	61174492	261023303	178700.94	322197794.8
1397	81.2	75	121.7	78.2	90.2	18176.4	121933.4	25392431	170340690	140109.75	195733320.8
1017	78.7	73	113.7	77.5	87.8	7270.56	100256.3	7394159.5	101960667	107526.87	109354826.8
871	76.7	71	105.5	76.9	85.2	-1211.76	78579.27	-1055443	68442544	77367.51	67387101.21
720	75.2	69	96.9	76.9	85.2	-10299.96	45289.53	-7415971.2	32608462	34989.57	25192490.4
611	72.6	67	90.7	75.8	80.6	-19388.16	39096.09	-11846166	23887711	19707.93	12041545.23
452	71.9	65	81.7	75.6	77.9	-22417.56	14709.42	-10132737	6648657.8	-7708.14	-3484079.28
323	70.5	63	74.4	75.2	75.6	-28476.36	-4645.08	-9197864.3	-1500360.8	-33121.44	-10698225.12
195	67.9	61	69.4								
191	66	59	63.6		Bypass						
166	64.3	57	57.9								
101	62.9	55	52								
50	59.9	53	49	72.7	69.1	77552.64	77805.09	3877632	3890254.5	155357.73	7767886.5
81	58.2	51	44.2	72.1	66.3	84217.32	85546.89	6821602.9	6929298.1	169764.21	13750901.01
35	57.5	49	38.1	72.1	66.3	88458.48	109159.4	3096046.8	3820578.3	197617.86	6916625.1
25	54.3	47	35.3	71.2	65.8	102393.7	118062.5	2559843	2951561.3	220456.17	5511404.25
5	53.6	45	30.7	71.1	64.4	106029	130449.3	530145	652246.65	236478.33	1182391.65
								96261003	805147587	Total	901408589.7
								96261.003	805147.59	kBtu	901408.5897

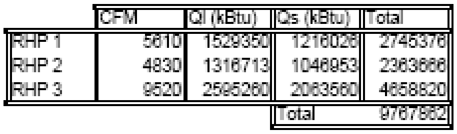
EcoDry	4830										
BIN hours	Tdb	Twb	gr/lb	sa	saw	Qs	Ql	Annual Qs	Annual Ql	Btu/H gain	Annual Btu gain
22	85.7	81	154	80.9	100.2	25038.72	179299.3	550851.84	3944583.7	204337.98	4495435.56
695	85.7	79	140.1	80.1	95.9	29211.84	147305.3	20302229	102377211	176517.18	122679440.1
1803	83.6	77	130.3	78	92.9	29211.84	124643	52668948	224731293	153854.82	277400240.5
1397	81.2	75	121.7	78	90.2	16692.48	104980.1	23319395	146657130	121672.53	169976524.4
1017	78.7	73	113.7	77.5	87.8	6259.68	86316.93	6366094.6	87784318	92576.61	94150412.37
871	76.7	71	105.5	77.1	85.2	-2086.56	67653.81	-1817393.8	58926469	65567.25	57109074.75
720	75.2	69	96.9	76.9	85.2	-8867.88	38992.59	-6384873.6	28074665	30124.71	21689791.2
611	72.6	67	90.7	75.9	80.6	-17214.12	33660.27	-10517827	20566425	16446.15	10048597.65
452	71.9	65	81.7	75.4	77.9	-18257.4	12664.26	-8252344.8	5724245.5	-5593.14	-2528099.28
323	70.5	63	74.4	75.2	75.6	-24517.08	-3999.24	-7919016.8	-1291754.5	-28516.32	-9210771.36
195	67.9	61	69.4								
191	66	59	63.6		Bypass						
166	64.3	57	57.9								
101	62.9	55	52								
50	59.9	53	49	72.9	69.1	67613.2	66987.27	3390660	3349363.5	134600.47	6740023.5
81	58.2	51	44.2	72.3	66.9	73551.24	75652.29	5957650.4	6127835.5	149203.53	12085485.93
35	57.5	49	38.1	72.1	66.5	76159.44	94648.68	2665580.4	3312703.8	170808.12	5978284.2
25	54.3	47	35.3	71.2	65.8	88157.16	101647.4	2203929	2541183.8	189804.51	4745112.75
5	53.6	45	30.7	71.1	64.4	91287	112312	456435	561559.95	203598.99	1017994.95
								82990316	693387231	Total	776377547.2
								82990.316	693387.23	kBtu	776377.5472

EcoDry	9520										
BIN hours	Tdb	Twb	gr/lb	sa	saw	Qs	Ql	Annual Qs	Annual Ql	Btu/H gain	Annual Btu gain
22	85.7	81	154	80.9	100.2	49351.68	356371.2	1085737	7840166.4	405722.88	8925903.36
695	85.7	79	140.1	80.1	95.9	57576.96	292780.8	40015987	203482656	350357.76	243498643.2
1803	83.6	77	130.3	77	93	67858.56	247075.2	122348984	445476586	314933.76	567825569.3
1397	81.2	75	121.7	78.2	90.2	30844.8	208656	43090186	291492432	239500.8	334582617.6
1017	78.7	73	113.7	77.7	87.6	10281.6	172886.4	10456387	175825469	183168	186281856
871	76.7	71	105.5	76.3	85.2	4112.64	134467.2	3582109.4	117120931	138579.84	120703040.6
720	75.2	69	96.9	76.7	85	-15422.4	78825.6	-11104128	56754432	63403.2	45650304
611	72.6	67	90.7	75.4	81.6	-28788.48	60278.4	-17589761	36830102	31489.92	19240341.12
452	71.9	65	81.7	75.9	77.7	-41126.4	26496	-18589133	11976192	-14630.4	-6612940.8
323	70.5	63	74.4	75.5	75.6	-51408	-7948.8	-16604784	-2567462.4	-59356.8	-19172246.4
195	67.9	61	69.4								
191	66	59	63.6		Bypass						
166	64.3	57	57.9								
101	62.9	55	52								
50	59.9	53	49	72.7	69.1	131604.5	133142.4	6580224	6657120	264746.88	13237344
81	58.2	51	44.2	72	66.4	141886.1	147052.8	11492772	11911277	288938.88	23404049.28
35	57.5	49	38.1	71.7	66.3	145998.7	186796.8	5109955.2	6537888	332795.52	11647843.2
25	54.3	47	35.3	71.2	65.8	173759	202032	4343976	5050800	375791.04	9394776
5	53.6	45	30.7	71	64.5	178899.8	223891.2	894499.2	1119456	402791.04	2013955.2
								185113011	1.376E+09	Total	1560621056
								185113.01	1375508	kBtu	1560621.056

				Saved kBtu				
EcoFresh	CFM	Model	fpm	Ql	Qs	Total	%	Cost
RHP 1	5610	HRW1600-200	600	805147.6	96261	901408.6	0.328337	?
RHP 2	4830	HRW1400-200	700	693387.2	82990.32	776377.5	0.328463	?
RHP 3	9520	HRW1900-200	700	1375508	185113	1560621	0.334982	?



RHP	9520										
BIN hours	Tdb	Twb	gr/lb	SA(T)	SA(W)	Qs	Ql	Btu/H	Annual Btu gain	Total Sens. Load	Total Lat. Load
22	85.7	81	154	55	64	315645.1	591192	906837.12	19950416.64	6944192.64	13006224
695	85.7	79	140.1	55	64	315645.1	499885.68	815530.8	566793906	219373358.4	347420547.6
1803	83.6	77	130.3	55	64	294053.8	435511.44	729565.2	1315406056	530178929.3	785227126.3
1397	81.2	75	121.7	55	64	269377.9	379019.76	648397.68	905811559	376320954.2	529490604.7
1017	78.7	73	113.7	55	64	243673.9	326469.36	570143.28	579835715.8	247816376.6	332019339.1
871	76.7	71	105.5	55	64	223110.7	272605.2	495715.92	431768566.3	194329437.1	237439129.2
720	75.2	69	96.9	55	64	207688.3	216113.52	423801.84	305137324.8	149535590.4	155601734.4
611	72.6	67	90.7	55	64	180956.2	175386.96	356343.12	217725646.3	110564213.8	107161432.6
452	71.9	65	81.7	55	64	173759	116267.76	290026.8	131092113.6	78539086.08	52553027.52
323	70.5	63	74.4	55	64	159364.8	68315.52	227680.32	73540743.36	51474830.4	22065912.96
195	67.9	61	69.4	55	64	132632.6	35471.52	168104.16	32780311.2	25863364.8	6916946.4
191	66	59	63.6	55	64	113097.6	-2627.52	110470.08	21099785.28	21601641.6	-501856.32
166	64.3	57	57.9	72	52.5	79168.32	-35471.52	43696.8	7253668.8	13141941.12	-5888272.32
101	62.9	55	52	72	52.5	93562.56	3284.4	96846.96	9781542.96	9449818.56	331724.4
50	59.9	53	49	72	52.5	124407.4	22990.8	147398.16	7369908	6220368	1149540
81	58.2	51	44.2	72	52.5	141886.1	54521.04	196407.12	15908976.72	11492772.48	4416204.24
35	57.5	49	38.1	72	52.5	149083.2	94590.72	243673.92	8528587.2	5217912	3310675.2
25	54.3	47	35.3	72	52.5	181984.3	112983.36	294967.68	7374192	4549608	2824584
5	53.6	45	30.7	72	52.5	189181.4	143199.84	332381.28	1661906.4	945907.2	715999.2
								Totals:	4658820926	2063560303	2595260623
								Kbtu	4658820.926		



	CFM	Ql (kBtu)	Qs (kBtu)	Total
RHP 1	5610	1529350	1216026	2745376
RHP 2	4830	1316713	1046953	2363666
RHP 3	9520	2595260	2063560	4658820
			Total	9767862

APPENDIX 2: WINDOW HAP CALCULATIONS

Base Case:

Table 1. Annual Costs

Component	WSHP ($)
Air System Fans	25,347
Cooling	1,041
Heating	169
Pumps	27,335
Cooling Tower Fans	3,470
HVAC Sub-Total	**57,363**
Lights	235,016
Electric Equipment	0
Misc. Electric	0
Misc. Fuel Use	0
Non-HVAC Sub-Total	**235,016**
Grand Total	**292,379**

Table 2. Annual Cost per Unit Floor Area

Component	WSHP ($/ft²)
Air System Fans	0.088
Cooling	0.004
Heating	0.001
Pumps	0.095
Cooling Tower Fans	0.012
HVAC Sub-Total	**0.199**
Lights	0.817
Electric Equipment	0.000
Misc. Electric	0.000
Misc. Fuel Use	0.000
Non-HVAC Sub-Total	**0.817**
Grand Total	**1.017**
Gross Floor Area (ft²)	287584.0
Conditioned Floor Area (ft²)	287584.0

Note: Values in this table are calculated using the Gross Floor Area.

Table 3. Component Cost as a Percentage of Total Cost

Component	WSHP (%)
Air System Fans	8.7
Cooling	0.4
Heating	0.1
Pumps	9.3
Cooling Tower Fans	1.2
HVAC Sub-Total	**19.6**
Lights	80.4
Electric Equipment	0.0
Misc. Electric	0.0
Misc. Fuel Use	0.0
Non-HVAC Sub-Total	**80.4**
Grand Total	**100.0**

1. Annual Coil Loads

Component	Load (kBTU)	(kBTU/ft²)
Cooling Coil Loads	24,589,650	85.504
Heating Coil Loads	1,267,536	4.408
Grand Total	**25,857,182**	**89.912**

2. Energy Consumption by System Component

Component	Site Energy (kBTU)	Site Energy (kBTU/ft²)	Source Energy (kBTU)	Source Energy (kBTU/ft²)
Air System Fans	1,015,470	3.531	3,626,679	12.611
Cooling	41,719	0.145	148,997	0.518
Heating	6,777	0.024	24,203	0.084
Pumps	1,095,080	3.808	3,911,000	13.600
Cooling Towers	139,026	0.483	496,522	1.727
HVAC Sub-Total	**2,298,072**	**7.991**	**8,207,401**	**28.539**
Lights	9,415,216	32.739	33,625,772	116.925
Electric Equipment	0	0.000	0	0.000
Misc. Electric	0	0.000	0	0.000
Misc. Fuel Use	0	0.000	0	0.000
Non-HVAC Sub-Total	**9,415,216**	**32.739**	**33,625,772**	**116.925**
Grand Total	**11,713,288**	**40.730**	**41,833,173**	**145.464**

Tinted Glass:

Table 1. Annual Costs

Component	WSHP ($)
Air System Fans	19,533
Cooling	1,052
Heating	164
Pumps	27,335
Cooling Tower Fans	3,470
HVAC Sub-Total	**51,554**
Lights	235,018
Electric Equipment	0
Misc. Electric	0
Misc. Fuel Use	0
Non-HVAC Sub-Total	**235,018**
Grand Total	**286,572**

Table 2. Annual Cost per Unit Floor Area

Component	WSHP ($/ft²)
Air System Fans	0.068
Cooling	0.004
Heating	0.001
Pumps	0.095
Cooling Tower Fans	0.012
HVAC Sub-Total	**0.179**
Lights	0.817
Electric Equipment	0.000
Misc. Electric	0.000
Misc. Fuel Use	0.000
Non-HVAC Sub-Total	**0.817**
Grand Total	**0.997**
Gross Floor Area (ft²)	287584.0
Conditioned Floor Area (ft²)	287584.0

Note: Values in this table are calculated using the Gross Floor Area.

Table 3. Component Cost as a Percentage of Total Cost

Component	WSHP (%)
Air System Fans	6.8
Cooling	0.4
Heating	0.1
Pumps	9.5
Cooling Tower Fans	1.2
HVAC Sub-Total	**18.0**
Lights	82.0
Electric Equipment	0.0
Misc. Electric	0.0
Misc. Fuel Use	0.0
Non-HVAC Sub-Total	**82.0**
Grand Total	**100.0**

1. Annual Coil Loads

Component	Load (kBTU)	(kBTU/ft²)
Cooling Coil Loads	21,653,520	75.295
Heating Coil Loads	1,256,917	4.371
Grand Total	**22,910,439**	**79.665**

2. Energy Consumption by System Component

Component	Site Energy (kBTU)	Site Energy (kBTU/ft²)	Source Energy (kBTU)	Source Energy (kBTU/ft²)
Air System Fans	782,507	2.721	2,794,666	9.718
Cooling	42,165	0.147	150,588	0.524
Heating	6,568	0.023	23,456	0.082
Pumps	1,095,080	3.808	3,911,000	13.600
Cooling Towers	139,026	0.483	496,522	1.727
HVAC Sub-Total	**2,065,345**	**7.182**	**7,376,233**	**25.649**
Lights	9,415,216	32.739	33,625,772	116.925
Electric Equipment	0	0.000	0	0.000
Misc. Electric	0	0.000	0	0.000
Misc. Fuel Use	0	0.000	0	0.000
Non-HVAC Sub-Total	**9,415,216**	**32.739**	**33,625,772**	**116.925**
Grand Total	**11,480,561**	**39.921**	**41,002,005**	**142.574**

Reflective Glass:

Table 1. Annual Costs

Component	WSHP ($)
Air System Fans	15,244
Cooling	1,046
Heating	166
Pumps	27,335
Cooling Tower Fans	3,470
HVAC Sub-Total	**47,261**
Lights	235,019
Electric Equipment	0
Misc. Electric	0
Misc. Fuel Use	0
Non-HVAC Sub-Total	**235,019**
Grand Total	**282,280**

Table 2. Annual Cost per Unit Floor Area

Component	WSHP ($/ft²)
Air System Fans	0.053
Cooling	0.004
Heating	0.001
Pumps	0.095
Cooling Tower Fans	0.012
HVAC Sub-Total	**0.164**
Lights	0.817
Electric Equipment	0.000
Misc. Electric	0.000
Misc. Fuel Use	0.000
Non-HVAC Sub-Total	**0.817**
Grand Total	**0.982**
Gross Floor Area (ft²)	287584.0
Conditioned Floor Area (ft²)	287584.0

Note: Values in this table are calculated using the Gross Floor Area.

Table 3. Component Cost as a Percentage of Total Cost

Component	WSHP (%)
Air System Fans	5.4
Cooling	0.4
Heating	0.1
Pumps	9.7
Cooling Tower Fans	1.2
HVAC Sub-Total	**16.7**
Lights	83.3
Electric Equipment	0.0
Misc. Electric	0.0
Misc. Fuel Use	0.0
Non-HVAC Sub-Total	**83.3**
Grand Total	**100.0**

1. Annual Coil Loads

Component	Load (kBTU)	(kBTU/ft²)
Cooling Coil Loads	17,864,830	62.120
Heating Coil Loads	1,261,666	4.387
Grand Total	**19,126,496**	**66.508**

2. Energy Consumption by Energy Source

Component	Site Energy (kBTU)	Site Energy (kBTU/ft²)	Source Energy (kBTU)	Source Energy (kBTU/ft²)
HVAC Components				
Electric	1,893,335	6.584	6,761,909	23.513
Natural Gas	0	0.000	0	0.000
Fuel Oil	0	0.000	0	0.000
Propane	0	0.000	0	0.000
Remote Hot Water	0	0.000	0	0.000
Remote Steam	0	0.000	0	0.000
Remote Chilled Water	0	0.000	0	0.000
HVAC Sub-Total	**1,893,335**	**6.584**	**6,761,909**	**23.513**
Non-HVAC Components				
Electric	9,415,216	32.739	33,625,772	116.925
Natural Gas	0	0.000	0	0.000
Fuel Oil	0	0.000	0	0.000
Propane	0	0.000	0	0.000
Remote Hot Water	0	0.000	0	0.000
Remote Steam	0	0.000	0	0.000
Non-HVAC Sub-Total	**9,415,216**	**32.739**	**33,625,772**	**116.925**
Grand Total	**11,308,551**	**39.323**	**40,387,681**	**140.438**

Triple Pane:

Table 1. Annual Costs

Component	WSHP ($)
Air System Fans	14,622
Cooling	1,054
Heating	164
Pumps	27,335
Cooling Tower Fans	3,470
HVAC Sub-Total	**46,645**
Lights	235,019
Electric Equipment	0
Misc. Electric	0
Misc. Fuel Use	0
Non-HVAC Sub-Total	**235,019**
Grand Total	**281,664**

Table 2. Annual Cost per Unit Floor Area

Component	WSHP ($/ft²)
Air System Fans	0.051
Cooling	0.004
Heating	0.001
Pumps	0.095
Cooling Tower Fans	0.012
HVAC Sub-Total	**0.162**
Lights	0.817
Electric Equipment	0.000
Misc. Electric	0.000
Misc. Fuel Use	0.000
Non-HVAC Sub-Total	**0.817**
Grand Total	**0.980**
Gross Floor Area (ft²)	287584.0
Conditioned Floor Area (ft²)	287584.0

Note: Values in this table are calculated using the Gross Floor Area.

Table 3. Component Cost as a Percentage of Total Cost

Component	WSHP (%)
Air System Fans	5.2
Cooling	0.4
Heating	0.1
Pumps	9.7
Cooling Tower Fans	1.2
HVAC Sub-Total	**16.6**
Lights	83.4
Electric Equipment	0.0
Misc. Electric	0.0
Misc. Fuel Use	0.0
Non-HVAC Sub-Total	**83.4**
Grand Total	**100.0**

1. Annual Coil Loads

Component	Load (kBTU)	(kBTU/ft²)
Cooling Coil Loads	18,571,010	64.576
Heating Coil Loads	1,256,917	4.371
Grand Total	**19,827,931**	**68.947**

2. Energy Consumption by System Component

Component	Site Energy (kBTU)	Site Energy (kBTU/ft²)	Source Energy (kBTU)	Source Energy (kBTU/ft²)
Air System Fans	585,784	2.037	2,092,085	7.275
Cooling	42,218	0.147	150,777	0.524
Heating	6,569	0.023	23,462	0.082
Pumps	1,095,080	3.808	3,911,000	13.600
Cooling Towers	139,026	0.483	496,522	1.727
HVAC Sub-Total	**1,868,677**	**6.498**	**6,673,846**	**23.207**
Lights	9,415,216	32.739	33,625,772	116.925
Electric Equipment	0	0.000	0	0.000
Misc. Electric	0	0.000	0	0.000
Misc. Fuel Use	0	0.000	0	0.000
Non-HVAC Sub-Total	**9,415,216**	**32.739**	**33,625,772**	**116.925**
Grand Total	**11,283,893**	**39.237**	**40,299,618**	**140.132**

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