SENIOR THESIS DESIGN PROJECT

RIVER VUE APARTMENTS

4/4/2012

Pittsburgh, Pennsylvania

Laura Pica – Mechanical Option

Adviser: Stephen Treado

RIVER VUE APARTMENTS

PITTSBURGH, PENNSYLVANIA

http://www.engr.psu.edu/ae/thesis/portfolios/2012/LQP5013/index.html

PROJECT TEAM

* Owner: River Vue Associates, LP
* General Contractor & CM: Turner
* Architects: Design 4 Studio, Inc. / IDG LLP
* Structural Engineer: Whitney, Bailey, Cox & Magnani, Inc.
* MEP Engineer: Claitman Engineering Associates Inc.

BUILDING STATISTICS

* Dates of Construction: June 2011-April 2012
* Project Delivery Method: Design-Bid-Build
* Cost: $28 Million
* Size: 16 stories, 295,000 square feet

ARCHITECTURE

* 16 story structure curved-cornered, aluminum and glass façade with white marble accents
* Units include multiple bedrooms, bathroom, kitchen, and living space with retail space on the ground floor.
* Two levels of valet parking for residents
* Spectacular views of city landmarks and access to Point State Park

LIGHTING/ELECTRICAL

* Day lighting achieved through new bronze glazing and balconies on upper levels
* LED bollards and up-lights used for exterior accents
* Three Phase, 120/208 V electrical system
* Four main transformers serve 2000A switchboard which distributes power to 400, 225, & 100A panel boards throughout the units
* Separate emergency and fire alarm electric system

MEHANICAL

* Several simple occupancy zones including apartment units, lobby/retail, parking, and corridors for energy modeling
* Two 200 GPM boilers, a 1024 GPM plate heat exchanger and a single air handling unit with enthalpy wheel serve building
* All existing duct, registers, grilles, and piping to be replaced in renovation
* Natural ventilation achieved through operable windows

STRUCTURE

* Steel frame supporting metal decking with lightweight concrete slab topping
* Double curtain wall system comprised of aluminum panels and glazing
* Additional bracing to be installed between column lines on ground floor

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MECHANICAL OPTION, DEPARTMENT OF ARCHITECTURAL ENGINEERING

FALL 2011

ADVISER: STEPHEN TREADO

- TABLE OF CONTENTS -

LIST OF FIGURES AND TABLES

EXECUTIVE SUMMARY

River Vue Apartments is a renovation project to turn the Old State Office Building located downtown Pittsburgh, Pennsylvania into a high rise multifamily apartment complex. The site is tightly constrained by neighboring buildings and historic sites and most of the existing structure will remain with the exception of fenestration which will be replaced to lighten the solar gains.

Preliminary research of the existing mechanical system indicated that ventilation is provided by the single make up air handling unit whereas heating and cooling is supplied by heat pumps located in each apartment unit. Ventilation does not meet current minimum values recommended by ASHRAE Standard 62.1. Loop water serves the heat pumps and a chilled water loop provides water for domestic use and minimal floor space is lost on each floor due to mechanical equipment and shafts.

A formal research project was conducted to understand design alternatives to the mechanical system that may improve occupant comfort or energy savings. It was found that in order to improve ventilation to meet current ASHRAE Standard 62.1 minimums, a larger air system would consume more annual electricity and create more emissions. However, energy savings can be found through the use of demand control ventilation coupled with carbon dioxide sensors to monitor building occupancy. Further energy savings was achieved through the addition of an economizer rather than other energy recovery techniques discussed. The capital cost is greatly reduced when implementing this design because of the removal of hydronic piping, heat pumps and fittings which are expensive and labor intensive.

An electrical study was conducted to analyze if use of a photovoltaic array could be used to either supplement the annual electric requirement of the building or power internal shading devices that could lower the solar sensible heat gains to the spaces. Research proved that the available space for an array would not provide enough electricity to power the desired shades and the electricity harvested off of the array would only offset the building's energy use by three percent, making the proposed design invaluable for its high capital cost. Payback would not occur in the expected life cycle of the building's operation. An array of 100 times the size of the available space is required to make a significant impact on annual electric use.

Schedule changes would be significant if the proposed mechanical system replaced the existing one because the labor required for duct installation is much less. 27% of the original time dedicated to rough-in can be decreased to 340 days of working time and MEP finishing can be reduced by 24% with the elimination of heat pumps. Punch list and inspection time was almost fully maintained from the original schedule because of the new air system's testing and balancing requirements during start up procedures.

The reduction in water usage, improvement of indoor air quality and other attributes of the proposed mechanical design assist the improvement of the LEED score to nearly 40 points, making LEED Silver certification a possibility for River Vue Apartments, an improvement over the original desire for LEED Certified.

BUILDING OVERVIEW & INTRODUCTION

BUILDING ARCHITECTURE

Modern, high-profile apartment living is the goal for the renovation of Pittsburgh's Old State Office Building. Two new levels of valet parking will welcome residents to enjoy multiple bedrooms, a kitchen, bathroom, and living space within their unit. Upper levels of the building feature two-story apartments with exceptional views of the city. Café and retail spaces are featured on the ground floor to attract business and provide convenient food service for tenants. The building currently has two curtain wall systems that create its dark, modern appearance along the shoreline, similar to the style of buildings popularized by Mies van der Rohe. The outer dark glass and aluminum panels were installed at the time of initial construction in 1955, and the inner curtain wall system, was added during a renovation project in the 1980's. There is a steel frame supporting the building's sixteen floors, two stairwells and six existing elevator shafts.

BUILDING CODES & ZONING

Since the building was originally constructed in the 1950's, there are many aspects of construction that do not meet today's current building codes. Most of the construction work occurring throughout the summer of 2011 is asbestos abatement and testing of interior building surfaces for lead paint levels. Although most interior surfaces are being completely demolished, the interior stairwells, which are lined with tile, are under review to determine if the existing materials conform to IBC section 800 requirements for interior finishes.

The few pieces of existing mechanical equipment will be replaced to meet ASHRAE 62.1 and 90.1 code standards for ventilation and indoor air quality while additional boilers, pumps, and cooling towers will also be added during new construction.

The building's original electrical equipment and panel boards are still in use for temporary power to the site; however, new equipment listed in the renovation plans will be installed to meet the current National Electric Code. As of August 2011, the only existing functioning equipment in the building is elevator gears and several electrical panels.

All of the services for the building, including gas, sanitary, storm, and fire protection piping are to be replaced in the renovation process to meet the national Plumbing Code, International building Code Chapters 9 and 29, the City of Pittsburgh Code of Ordinances, and the National Fire Protection Code. Each floor of the building will be fully sprinkled in the new design.

Pittsburgh zoning requires an occupancy permit for all structures other than single family dwellings. This building is located in section C5, the Golden Triangle District, of the Pittsburgh Urban Zoning code and since the project is a renovation of the existing structure with no major architectural or height changes, there is no conflict with its current zoning status.

River Vue Apartments is located across Commonwealth Place from the historical Point State Park, where Fort Pitt and Fort Duquesne were constructed in the mid 1700's. Although it is not directly located on this historical site, it must respect the landscape and will be noticed in all views from the park as seen here.

Figure 1: Point State Park

Photo courtesy www.wikipedia.com

BUILDING ENCLOSURE & ROOF

As previously mentioned, the existing structure consists of a steel frame with existing bays of about 20' x 25' using mostly W14x34 beams for spans within bays. The two curtain wall systems are hung parallel to each other, 1 ½' apart. The outer curtain wall consists of 6'x4' gray aluminum panels and dark gray glass with interior bearing walls comprised of concrete masonry units. The outer gray glass is to be replaced with new bronze-colored window panes. The interior aluminum panel curtain wall acts as an insulator by maintaining an air gap between it and the outer layer.

Current roofing materials are being replaced in the proposed renovation plans to include a sealant, flashing, ½" cementitous back board and a latex plaster finish along the vertical edges. The horizontal plane of the roof is comprised of several layers, including a Dex-o-Tex traffic surface, membrane, slip sheet, 6 ½" light weight concrete layer (3500 psi) with fiber reinforcement and a 1 ½" extruded insulation board. The roof deck is galvanized 20 gauge, 1 ½" thick steel with wide rib configurations.

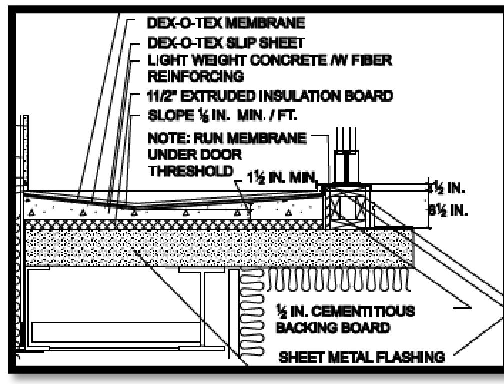


Figure 2: Detail from Contract Drawing

SUSTAINABILITY FEATURES

LEED Certification is the goal of this renovation project. This certification will be achieved through using regional materials, recycled content, low emitting materials, and weather proofing materials. Each apartment unit within the building will have individual temperature controls, electric panels, and a heat pump to promote energy conscious living. The glazing on the exterior façade will also be replaced to change the current building loads that are influenced by sunlight.

SITE/CIVIL WORK

Existing site boundaries cannot be altered due to the proximity of River Vue Apartments to its surrounding buildings, streets, and Point State Park. However, renovation work includes the removal of existing underground electric feeders, addition of concrete loading dock, ramp, curbs, and asphalt pavement at building entrances. All sidewalks are to have a broom finish with 2 coats of boiled linseed oil finish. Renovation of the site's manhole will proceed with precast manhole sections and class "AAA" concrete. Grading of the site will remain except for the excavation of a new ramp to underground parking at the rear (south east side) of the building. Additionally, there will be a 450 gallon, precast concrete storm water detention tank added outside the foundation of the building near the new parking garage entrance. New landscaping materials include a six inch topsoil layer, ryegrass and Kentucky bluegrass, limestone, and mulch.

CONSTRUCTION METHODS

Project management will be conducted directly from the first floor of the building by Turner staff members while all engineering and architectural work will be conducted by outside firms. There are two on-site Turner project engineers and a project manager to handle daily reports and track job progress. The site provides little space to store materials or equipment outside the structure; therefore most staging will require seamless planning to coordinate deliveries to and from the site. Substantial completion is scheduled for April 2012, where the first five floors are expected to be complete for turnover to the owner. After this time, two additional floors will be required to be finished each month until the entire building is completed.

ELECTRICAL

The existing 300 kW generator located on the ground floor is to remain as well as the existing emergency power feeders, which will serve as a source for temporary power throughout the demolition and renovation phases. All starters, disconnects and general use feeders shall be removed and replaced with new electric wiring in the form of copper bus bars to meet the current National Electric Code. The building operates on a three phase, 120/208 V system, stemming from a main electrical room located on the ground floor. Electric power is supplied to this room's 2000A switchboard by Duquesne Light Company through four main transformers on the North West side of the site and serves panel boards of 400, 225 and 100 amps. Each apartment within the building has typical load requirements for appliances such as refrigerators, hot water heaters, washer-dryer combinations, electric ranges, dishwashers, heat pumps along with lighting and has access to its own panel board. There is a separate electric service for emergency power and fire alarms for safety.

LIGHTING

Existing gray stationary window glazing and associated gaskets are to be removed during the renovation and replaced with new, operable bronze colored panels to allow for additional day lighting. Apartments on upper levels 15 and 16 will incorporate new balcony areas to allow additional natural light and outdoor living space for the tenants. Wall sconces and pendant fixtures hung from acoustic tile ceilings will be installed in interior corridors for guided lighting to each unit. The façade will be lit with white LED flood and spot lights as well as several metal halides. LED bollards and up-lights will be used for pathway lighting and to accent the landscape.

MECHANICAL

All existing chilled & hot water supply and return piping, hangers and associated insulation will be removed during the demolition phase as well as unit ventilators, ductwork, grilles, registers, diffusers, unit heaters, pumps and the existing air handling unit, chiller, and pumps. Two new 200 GPM boilers will be used to heat water for the building and associated pumps will distribute it to individual apartment units while a 1024 GPM heat exchanger will be used to collect residual heat and re-use it to conserve energy. A 350 ton cooling tower will be disguised by three new, 66' diameter curved, perforated stainless steel curved panels on the roof. Plumbing and sanitary piping will serve typical water closets, lavatories, showers, and kitchen appliances throughout the building.

A single 17,000 CFM air handling unit with energy recovery wheel located on the roof will be used to condition air for the building through two supply risers and two exhaust risers located in the north-east corner of the building. Tenants will also have the option to use their operable windows for additional ventilation to individual units. The building can easily be divided into several simple zones for conditioning: tenant apartment units, corridors, lobby retail space, and parking garage space, which will allow for simple energy modeling at a later date.

STRUCTURAL

Two types of concrete are used throughout the building, lightweight concrete (107-116 pcf) for topping on metal decks and normal weight (145pcf) for exterior applications, footings, piers and foundation walls, and interior slab on grade applications. The building is designed per IBC 2006 with the following load conditions:

- Roof Live Load of 20 PSF
- Snow Load of 21 PSF
- Roof Dead Load of 30 PSF
- Floor Live Load
  - Stairs/Slab-On-Grade at 100 PSF
  - First Floor Parking at 40 PSF
  - First Floor Lobby at 100 PSF
  - Condos at 40 PSF
- Floor Dead Load
  - Existing: 1st Floor at 115 PSF + steel beam framing
  - Existing 2-16th Floors at 98 + steel beam framing
  - New Composite Floor at 75 + steel beam framing
- Wind Load category B
- Seismic design category B

Temporary bracing of the existing structure will be provided by Turner and will remain in place until the structure is completely enclosed and all floor and roof systems are completely installed. Permanent steel beam bracing will be inserted between nine different column lines in the ground floor parking area with ½" steel filler plates, as required for extra bracing.

The existing foundation is reinforced concrete, 3'-6" below finished grade. Metal composite floor deck is 20 gauge galvanized steel with varying rib dimensions, as per plans, and roof deck is 1-1/2" 20 gauge steel deck with wide rib configurations. Wide flange steel beams are used for internal bays of about 20'x25' along with hollow structural sections, channels and steel plates, conforming to ASTM standards A36 and A500.

There are two existing curtain walls creating the exterior building envelope, which are hung 1-1/2' apart on the building's steel frame. The exterior layer consists of 6' by 4' dark gray aluminum panels and dark glass panels to protect the interior structure from the environment, whereas the interior curtain wall of aluminum panels acts as an insulator, trapping a layer of air between the two sets of panels.

FIRE PROTECTION

Each floor will be fully sprinkled in the renovation design to provide fire protection to all occupants. New sanitary and storm piping lines are being added to each floor of the building to allow for proper drainage. Dry pipe standpipes will be installed in each stairwell with fire alarms connected to the emergency power system.

TRANSPORTATION

River Vue Apartments' location near Point State Park and notable golden triangle buildings leaves little room on its site for transportation access. To accommodate for this, the renovation plans incorporate two floors of double-level valet parking using loading lifts for resident's automobiles. Structural plans for the building show a modified drainage trench on the ground floor as well as 4" of added concrete under the lift legs where loads are transferred to the structure, as seen in this structural detail.

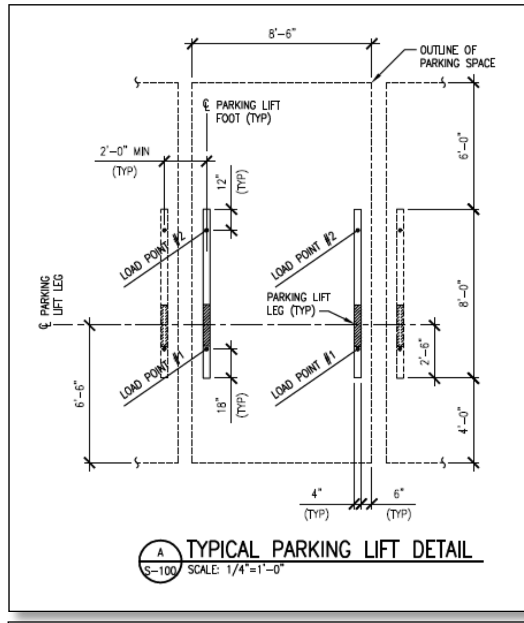


Figure 3: Detail taken from contract drawing S-100

The Gateway Center Parking garage is also a convenient parking structure, located directly east of the site underground. In addition, city bus routes travel alongside the building site routinely throughout the week.

SPECIAL SYSTEMS

Since River Vue Apartments is a renovation project, most work occurring in the early stages of the job is stripping of the interior surfaces and removal of existing conditions. A large portion of the original surfaces contain harmful materials like asbestos and lead, and therefore require special attention when they are removed and disposed of. Ceramic tile lining the interior stairwells is to be tested for lead levels and if the product does not meet current code, it will be removed. All laborers working with these materials are asked to use extra caution and wear proper personal protective equipment (PPE).

Existing marble panels on the east exterior façade are to remain throughout the renovation, however, like all other marble surfaces on the building, will be cleaned and restored to their original state.

TECHNICAL RESEARCH SUMMARY

ENERGY SOURCES

The United States has several different regions within electricity is generated and distributed. Pittsburgh, Pennsylvania is located in the RFC (Eastern) region which is typically known for producing most of its electricity by burning bituminous and sub-bituminous coal, since it is the natural resource most prevalent in that region. Mechanical equipment like the generator and boilers in this building also consume natural gas for operation.

ENERGY RATES

River Vue Apartments uses Duquesne Light as an electricity provider, Equitable Gas Company for natural gas, and the Pittsburgh Water & Sewer Authority for water. Each company's typical utility rate was used to calculate monthly and annual utility costs, based on usage predicted by a Trane TRACE 700 energy model.

Type of Service	Provider	Rate ($)
Electricity	Duquesne Light	0.0896
Natural Gas	Equitable Gas Company	0.0622
Water	Pittsburgh Water & Sewer Authority	13.7656

Table 1: Utility Rate Structure

FACTORS INFLUENCING DESIGN

SITE

River Vue Apartments is located across Commonwealth Place from the historical Point State Park, where Fort Pitt and Fort Duquesne were constructed in the mid 1700's. Although it is not directly located on this historical site, it must respect the landscape and will be noticed in all views from the park. As noted in the project's Historic Sites Map in the geotechnical report, the project site is located within walking distance to many other historic sites and federal historic areas as well. It is important for the project to not disturb these city landmarks.

As with most urban construction projects, the building footprint utilizes much of the site's area, making for tight spacing for the storage of construction materials and waste. No additional space is available for the addition of a campus utility plant. Deliveries must be highly coordinated to avoid prolonged street closures and noise levels must be observed so nearby businesses and residents are not disturbed.

COST

Since this project is in the form of a contract plus construction costs and has a guaranteed maximum price, there was little room in the project budget for detailed energy modeling or energy usage tracking after operation of the facility begins. Strict budgeting also constrains the design team and construction managers to completing the project on time and without additional costs. The project will be financed through the HUD 220 program created by the United States Department of Housing and Urban Development and will require payment of prevailing wage rates, which are listed in the project's contract documents. HUD 220 is a mortgage insurance program for rental housing for urban renewal and concentrated development areas that insures lenders against loss on mortgage defaults.

REBATES/TAX RELIEF

No rebate or tax relief information was available at the time this report was completed.

OTHER

Since the building was originally constructed in the 1950's, there are many aspects of construction that do not meet today's current building codes. Most of the construction work occurring throughout the summer of 2011 is asbestos abatement and testing of interior building surfaces for lead paint levels. Although most interior surfaces are being completely demolished, the interior stairwells, which are lined with tile, are under review to determine if the existing materials conform to IBC section 800 requirements for interior finishes.

FENESTRATION

Each exterior wall has a significant amount of glazing which heavily influences the cooling load of the building, especially during summer months when solar radiation is high. Percentage of glass per floor was tabulated in Technical Report 1 to understand River Vue Apartments' compliance with ASHRAE Standard 90.1 for fenestration. Each floor exceeded the maximum allowance of 40% as seen below:

Level	Glass Area	Wall Area	% Glass	Compliance
G	3992	6336	63.01	N
1	3600	6336	56.82	N
2	3600	6336	56.82	N
3	3600	6336	56.82	N
4	3600	6336	56.82	N
5	3600	6336	56.82	N
6	3600	6336	56.82	N
7	3600	6336	56.82	N
8	3600	6336	56.82	N
9	3600	6336	56.82	N
10	3600	6336	56.82	N
11	3600	6336	56.82	N
12	3600	6336	56.82	N
13	3600	6336	56.82	N
14	3600	6336	56.82	N
15	3600	6336	56.82	N
16	3000	6336	47.35	N
TOTAL	60992	107712	56.63	N

Table 2: Fenestration Analysis

OUTDOOR DESIGN CONDITIONS

Design day weather conditions for Pennsylvania provided by the ASHRAE Handbook of Fundamentals 2009 are as follows:

- Winter Design Dry Bulb Temperature: 61 degrees F (15 degrees Celsius)
- Summer Design Dry Bulb Coincident Temperature: 88 degrees F (31 degrees Celsius)
- Summer Design Wet Bulb Temperature: 86 degrees F (30 degrees Celsius)
- Mean Daily Range of Temperatures: 11 degrees
- Typical Prevailing Winds: West at 6 mph

INDOOR DESIGN CONDITIONS

The single make up air handling unit provides two operational modes, summer and winter, and these design conditions are detailed below. An ASHRAE psychometric chart was used in Technical Report 1 to specify what relative humidity exists at each state point.

	Winter Months	**Summer Months**
Dry Bulb Temperature (degrees)	78	58
Wet Bulb Temperature (degrees)	54	55
Relative Humidity (percent)	17	82

Table 3: Design Conditions

LOADS & ENERGY

As stated in Technical Report 2, much of the load for this building comes from its occupants, ventilation, infiltration, lighting and mechanical equipment as well as significant solar gains. Tenants will likely be using the most energy early in the morning and later in the evening during dinner hour since this is a residential facility. The mechanical equipment like boilers, pumps, air handling unit and the generator will be in constant use whereas lighting loads and solar gains will vary throughout the day and year.

VENTILATION REQUIREMENTS

The Ventilation Rate Calculation Procedure from ASHRAE Standard 62.1 was used to calculate outdoor ventilation rates for typical spaces inside River Vue Apartments based on space dimensions and occupancy in Technical Report 1. "As Designed" airflow rates were read directly from contract drawings and a comparison was made to determine if spaces within the complex require further attention and potential redesign. The table below summaries these calculations and it can be seen that most occupied spaces do receive enough ventilation air.

Space	ASHRAE Outdoor Airflow (cfm)	As Designed Outdoor Airflow (cfm)	Requires Redesign
Common Corridor	933	5250	
Stairwells	346	3200	
Main Entry Lobby	42	570	
Stair Lobby	81	150	
Elect Equip Room	48	0	YES
Bsmt Machine Room	96	0	YES
Elevator Machine Room	150	0	YES
Boiler Room	96	0	YES
Fire Pump Room	96	0	YES
Generator Room	96	0	YES
Dwelling Units 2nd Floor	1641	1156	YES
Dwelling Units 3-14	17504	8580	YES
Dwelling Units 15-16	2217	3107	
Fitness Center	516	500	YES
Retail Sales	365	500	
Parking Garage	2070	0	YES

Table 4: Ventilation Analysis

It was anticipated that mechanical spaces and the parking garage would not receive ventilation and therefore their comparison results are expected however, redesign for minimal ventilation would provide a healthier indoor air quality. Dwelling units on each floor seem to be provided with an extremely large amount of ventilation but it must be noted that the "As Designed" values account for not only ventilation air but also cooling supply air. Detailed comparison information and calculations for ventilation requirements is provided for reference in Appendix A.

INFILTRATION

Building infiltration occurs when envelopes allow outdoor air to leak in through cracks. Given that the system operates in two primary modes, summer operation and winter operation, the latent and sensible loads due to infiltration differ throughout the year and were calculated separately using the following simple relationships:

$$\text{Sensible Load: } Q_S = 1.10Q(\Delta T)\ (\text{BTU/hr-sqft})$$

$$\text{Latent Load: } Q_L = 4840Q(\Delta W)(\text{BTU/hr-sqft})$$

As seen by the equations above, sensible load is a direct result of temperature changes whereas latent load is affected by the humidity ratio (Δw) and moisture content. It makes sense that there is higher sensible load during the winter season because of the large temperature difference between outdoor and indoor air. In the summer operating scheme latent loads dominate due to high moisture content in the outdoor air. Overall, the summer condition sees higher loads.

	Summer Condition	**Winter Condition**
Sensible Load	925,514	1,735,338
Latent Load	2,163,388	381,775
Total	3,088,902	2,117,113

Table 5: Infiltration Loads

ENERGY MODELING

A comparison between ASHRAE design specifications and the Trane TRACE energy model created is shown in the table below. As previously described, it can be seen that assumptions used for the model were almost always conservative compared to typical design values from ASHRAE for high rise apartment complexes. However, most values seen in the model are within reason given the knowledge that many simplifications to space loads, construction materials, occupancy and equipment schedules were made in the modeling process.

High Rise Apartment			**River Vue Apartments**
occupancy sqft/person			*occupancy sqft/person*
Lo	Av	Hi	Model
325	175	100	200
lights watts/sqft			*lights watts/sqft*
Lo	Av	Hi	Model
1	2	4	1
refrigeration sqft/ton			*refrigeration sqft/ton*
Lo	Av	Hi	Model
450	400	350	90
supply air rate (east-south-west) cfm/sqft			*supply air rate (east-south-west) cfm/sqft*
Lo	Av	Hi	Model
0.8	1.2	1.7	0.63
supply air rate (north) cfm/sqft			*supply air rate (north) cfm/sqft*
Lo	Av	Hi	Model
0.5	0.8	1.3	0.63

Table 6: Original Energy Model Results

ANNUAL ENERGY CONSUMPTION

Annual energy consumption was calculated based on an energy model created with Trane TRACE 700 in the second technical report. A summary of this data is provided below.

Monthly Utility Usage			
Month	Electric (kW)	Gas (therms)	Water (gal)
1	722	36776	16
2	717	35939	13
3	722	26060	17
4	849	15040	104
5	839	4558	263
6	845	1307	411
7	846	46	509
8	844	1717	350
9	839	4782	238
10	842	17417	96
11	749	20845	83
12	726	33222	17
TOTAL	9540	197709	2117

Table 7: Original Design Utility Usage

It is important to note that the energy usage calculated with the Trane TRACE 700 energy model only accounts for the HVAC equipment, solar gains, lighting and plug loads. No miscellaneous kitchen appliances or other apartment equipment was included. The loads vary depending on the occupancy schedules outlined in Technical Report 2, where most load occurs during times when occupants are likely to be present. This energy model predicts that most energy consumed at River Vue Apartments will be in the form of natural gas.

EXISTING SYSTEM OPERATION

HVAC flow diagrams are simple graphic representations of the fluid or thermal systems in a building and are used to easily convey how the system works without referring to other plans or elevations.

WATER SIDE

Water is circulated throughout two distinct loops in River Vue Apartments, the first being the chilled water loop, noted by CS and CR on Figure 3. This loop is controlled by two 1024 GPM condensing water pumps in the basement. Water is delivered to each floor for use by small appliances, bathroom faucets, showers, and lavatories and once it is consumed, it is drained through the sanitary sewage piping down to basement level where it is fed into Pittsburgh's sanitary sewer system. Excess water moves to the cooling tower located on the roof where it is then fed down through risers to its starting point.

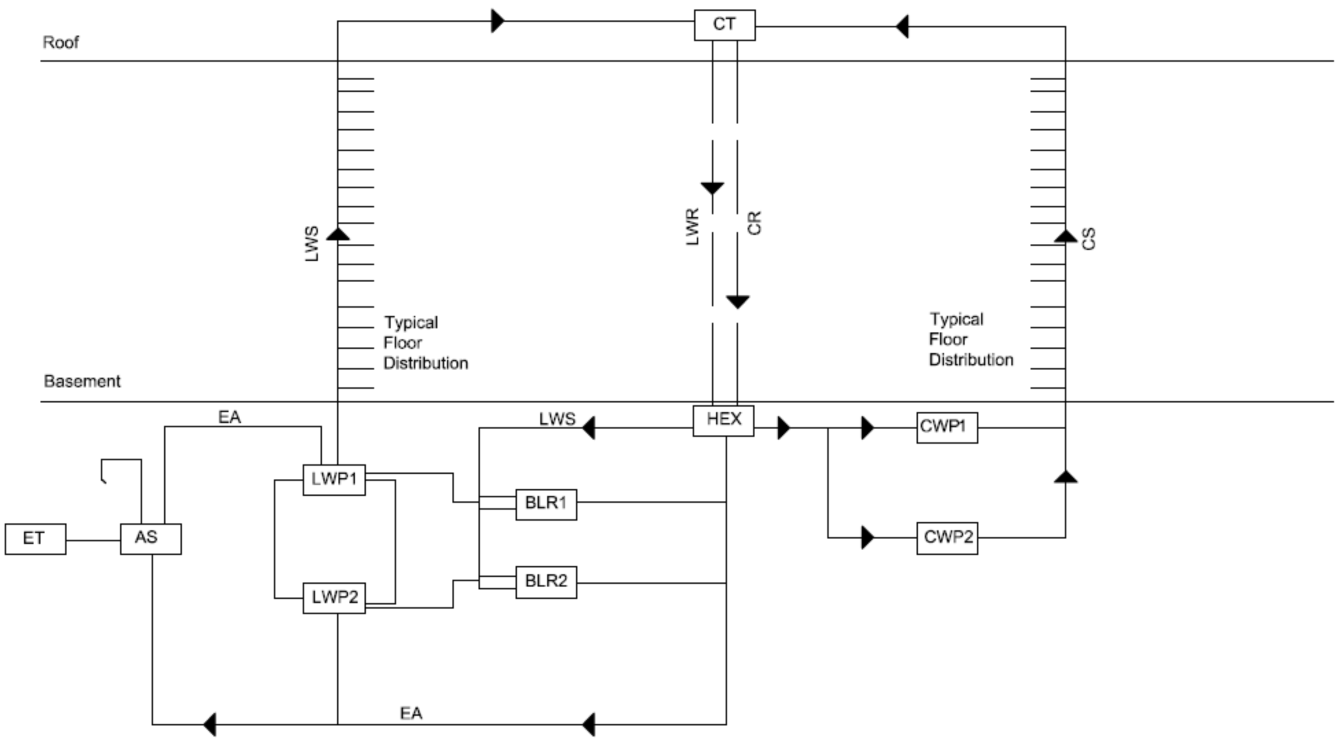


Figure 4: Existing System Water Diagram

The second loop water system is heated by two natural gas fired boilers and circulated by two corresponding loop water pumps, also located in the basement. Loop water is circulated to each apartment unit and fed into individual heat pumps that condition the spaces. Water source heat pumps can facilitate heating in one zone and cooling in another at the same time making it an attractive option for a high-rise residential complex where solar gains and occupancy fluctuate throughout the day. The cooling tower and boilers act as a heat rejecter and heat supplements during extreme weather conditions. A diagram of the building's repetitive heat pumps is shown in Appendix B for reference.

Loop water piping follows the chilled water piping through the same risers when it is returned to the basement. It is then moved through the plate and frame heat exchanger which transfers unwanted heat from the chilled water return stream to the loop water supply stream, conserving energy and freeing the boilers from a heavy load.

AIR SIDE

A single make-up air handling unit sitting on the roof of River Vue Apartments, shaded by curved aluminum panels, incorporates outdoor air into the return air stream to supply air to the apartment units. As these air streams are mixed, they pass through an enthalpy wheel in the air handling unit where latent and sensible energy from the return air is transferred to the supply stream. This preheats the air in the winter and cools it in the summer, allowing the heat pumps to run less often. Two separate exhaust risers exist to evacuate exhaust air from stacked trash and mechanical rooms on each typical floor, as seen in Figure 4.

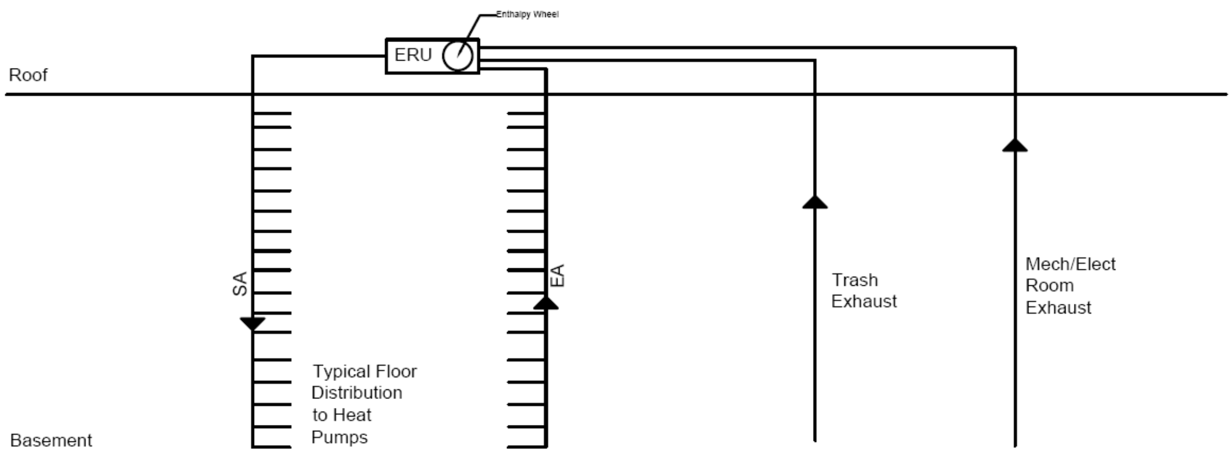


Figure 5: Air Flow Diagram

CONTROL LOGIC

As described in Technical Report 1, there is a direct-digital control system with 48 hour battery backup prescribed for River Vue Apartments which will act to automatically control temperature, control valves, dampers and their operators, interface equipment and accessories for the make-up air unit, ventilation systems, unit heaters, and plumbing equipment. The sequence of operation for control of the equipment is described explicitly in the contract document specification section 0230993.

EQUIPMENT

Due to the simplicity of the complex, River Vue Apartments is served by only one 26,300 CFM air handling unit with an energy recovery wheel located on the roof serving two supply risers and two exhaust risers located in the north-east corner of the building. Two 200 GPM boilers and a 1024 GPM plate heat exchanger are located in the basement mechanical space and a 350 ton cooling tower located behind stainless steel curved panels on the roof serve the plumbing system's risers. The building can be divided into several simple zones requiring ventilation and conditioned air from the air handling unit, including residential apartment units, corridors, lobby/retail space, and the parking garage. Much of the building's ventilation will be provided by operable windows in the façade. Fire protection will be supplied through sprinklers on each floor, which will be new to the building in the current renovation project.

LOST USABLE SPACE

A floor-by-floor breakdown of lost usable space was done to understand how much floor space is consumed due to mechanical equipment and vertical shafts. The basement and roof had the most floor area lost to mechanical equipment since major equipment rooms are located on those floors. Every typical apartment floor has a loss of about 5.5% due to shafts and a small mechanical room near each elevator lobby. The building as a whole has a loss of 6.5% with an average of 6.21% of floor space per floor. A detailed breakdown of lost usable floor space is provided in Appendix C.

COSTS

River Vue Apartments renovation project has a guaranteed maximum price of $28,248,910 which, with a total building area of 297,000 square feet, equates to approximately $95 per square foot. A complete breakdown of project costs is provided in the figure below.

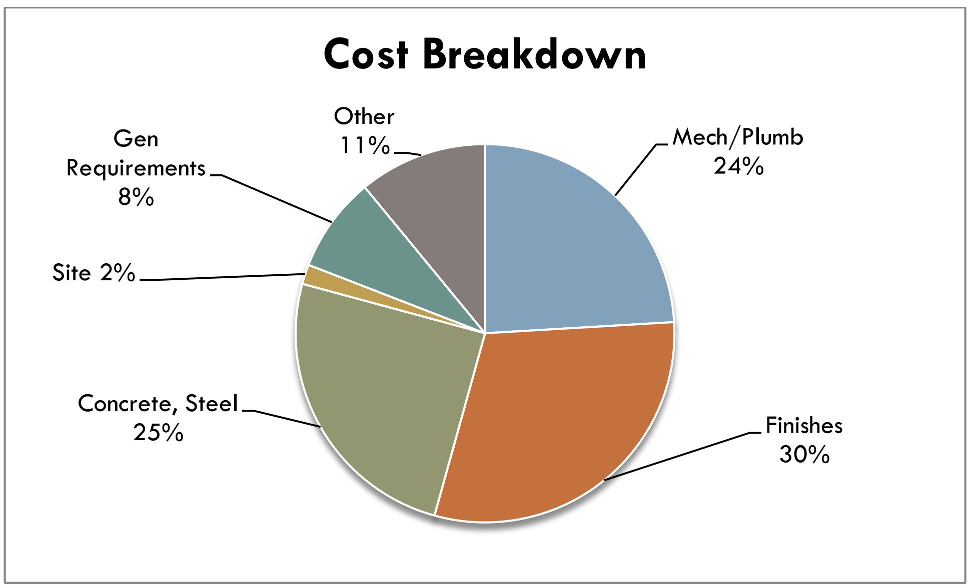


Figure 6: Original Project Cost Breakdown

The mechanical, plumbing, and fire protection systems equate to approximately 24 percent of the total construction cost. It makes sense that the percentage is relatively high because most of the work being performed through the renovation is to replace mechanical, electrical, and plumbing services as well as install all new finishes throughout the building.

METER DATA & UTILITY BILLS

As noted in Technical Report 2, no operational data or current utility bills were available for River Vue Apartments. The costs associated with a commercial office building do not correspond to those of a residential facility since the building function is different, therefore old operational data would not be directly applicable given the future residential application of the facility. Since the project has an initial substantial completion date of April 2012, operational data may become available later in the development of this senior thesis. If this is the case, data will be provided at that time as a supplement to this report.

The energy analysis produced in Technical Report 2 detailed the expected monthly utility consumption and predicted an annual operational cost of nearly $153,000 for electricity, natural gas and water for the large mechanical equipment. This equates to roughly $0.57 per square foot.

SUSTAINABILITY

In today's energy-conscious world, building labeling for sustainability has become one of the biggest trends in new construction and large-scale renovation projects. A major leader in this field is the United States Green Building Council, (USGBC) which publishes guidelines for ranking buildings' sustainable design, construction, and operation.

LEED-NC Green Building Rating System for New Construction and Major Renovations, Version 2.2 was used as a benchmark for the renovation of River Vue Apartments. This method evaluates site selection and use, water efficiency, energy use, materials and resources as well as indoor environmental quality and innovative design.

Figure 7: USGBC logo.

Image courtesy: http://ecosalon.com/wp-content/uploads/Leed-Logo.jpg

Type of Certification	Points Range
Certified	26-32
Silver	33-38
Gold	39-51
Platinum	52-69

Table 8: LEED Certifications

The project scored 31 out of a possible 69 points, categorizing the building as LEED Certified. Most points came from repurposing the site and building, using regional and low-emitting materials, and managing the construction process with recycling and commissioning. There was a lack of points associated with lighting control, ventilation, materials reuse, renewable energy and energy monitoring. A complete breakdown of the LEED scorecard is provided in Appendix D for reference.

DESIGN PROPOSAL

A formal design proposal will serve as a guide and schedule to modify the current design of River Vue Apartments throughout the Spring 2012 semester. A large depth study will be conducted in the area of mechanical systems design while two breadth studies will focus on other areas of the Architectural Engineering program, such as lighting/electrical and construction management, to emphasize the importance of integrated design.

As noted in Technical Reports 1, 2, and 3, there are several aspects of the current design that do not meet current ventilation or energy standards and therefore prevent River Vue Apartments from being a leading building in energy performance. The building receives low amounts of ventilation air, uses highly repetitive heat pumps in each of the apartment units and suffers from high solar gains due to excessive glazing on the façade. Although the construction process will be highly organized and implement regional materials and recycling programs, River Vue Apartments barely achieves LEED Certified status and may contribute to the urban heat island effect.

In order to improve the building's energy usage, the building's current heat pumps will be removed to allow for re-zoning of the interior spaces. Demand control ventilation will be implemented using high velocity air streams and CO_2 sensors to monitor occupancy and regulate ventilation more accurately. The current make-up air handling unit will be resized to manage this system and small supply air ducts will be designed for central corridor distribution.

The first breadth study will examine the installation of a photovoltaic array for the roof and if the net electric consumption for the building can be reduced. These panels may improve the energy usage and sustainability points of River Vue apartments while allowing for internal shading devices to be implemented to reduce solar gains. Cost analysis and payback time will be studied to examine the benefit of this option.

A second breadth study will focus on the scheduling and cost impacts of changing the mechanical system and controls, as well as the addition of the photovoltaic array and corresponding electrical components. A bid package with material and equipment take-offs will be prepared and supplemented with construction schedule updates.

NOTE: This study is an educational exercise in preparation for my career as a mechanical engineer at a design firm and as a project manager later in my career. All calculations and design proposals are solely my work and are not meant to be a replacement for the current project design.

MECHANICAL DEPTH STUDY

MECHANICAL REDESIGN NECESSITY

It was seen throughout the investigation of the existing mechanical system that minimum ventilation requirements prescribed by ASHRAE Standard 62.1 are not met for all apartment units within River Vue Apartments. The building suffers from high solar sensible gains in summer months due to the large amount of fenestration in the façade while it sees large heating loads throughout the rest of the year due to the climate of Pittsburgh, PA.

Therefore, an air system was designed to meet the sensible and latent loads of the building. Knowing that a significant increase in energy use would come with the additional ventilation, energy recovery techniques were also researched in order to provide the most efficient system while still meeting ventilation needs. Analyses of these design alternatives follow the description of the base air handling unit design below.

BASE AHU DESIGN

The base air handling unit was sized by adding the lighting, equipment, occupancy and solar sensible loads seen by each room within the building. A total number of Btu/h was found for each component of the total load and then summed. A complete spreadsheet for these calculations can be found in the appendix however, a brief summary follows.

COOLING LOADS (Btu/h)					
lighting	equipment	occupancy	solar	TOTAL Btu/h	TOTAL cfm
318096	7278258	352800	948365	8.90E+06	411922

Table 9: Cooling Load Calculation Summary

Lighting densities for each space were calculated based on the existing lighting plan's wattage per floor area, since the lighting plan will not change with this redesign. A typical apartment has a lighting density of approximately 0.6 Watts per square foot.

Each apartment has several domestic appliances such as a dishwasher, oven, refrigerator, television, and others according to project drawing specifications. Expected energy consumption for each piece of equipment was found in ASHRAE Fundamentals and used as a benchmark for design.

The Ventilation Rate Procedure prescribed by ASHRAE Standard 62.1 was used to understand the minimum ventilation rates required for this application. The procedure, based on occupancy and square footage, was used to calculate the necessary airflow (in CFM) for each room in the building and these values were summed, translated into Btu/h and added to the other building loads.

Finally, solar loads were calculated according to ASHRAE Fundamentals method for approximating solar gains. Direct beam, diffuse and ground reflected radiation were calculated for Pittsburgh, PA on a typical June design day and added to the conductive effects of the façade's material properties. Again, the total solar load was computed to Btu/h and added to the lighting, equipment, ventilation, and occupancy loads.

DEMAND CONTROL VENTILATION

Demand Control Ventilation is a type of control strategy that monitors a building's operation or occupancy to supply only the necessary ventilation air. This is an attractive strategy when a building has varying occupancy throughout the day, ventilation requirements are high, and energy use is of concern.

Ratings for applications of DCV given by the Carrier DCV Guide are given as:

Application	Rating
Hotels, Resorts, Dormitories	
Bedrooms	B
Lobbies	A
Conference Rooms	A
Gym	A

Table 10: Assessment of DCV Application

Applications with a rating of "A" are recommended for DCV and ratings of B are possible uses. All spaces within River Vue Apartments can therefore be considered for demand control ventilation.

It is important to note that ASHRAE Standard 62.1 advises that the HVAC system size be reduced no more than half of its original size when adjusting for variable occupancy.

A thorough study of demand control ventilation was conducted by the International Energy Agency in the mid 1990's so that the mechanical systems design industry could become more familiar with the control strategy and its benefits. This report outlines how contaminant levels can be used to indicate occupancy at given times and therefore could relay information about corresponding necessary ventilation rates.

Several contaminants can be monitored to employ demand control ventilation including water vapor, carbon dioxide, carbon monoxide, nitrogen dioxide, formaldehyde and other hydrocarbons. The detection of carbon dioxide was selected for River Vue Apartments because it is directly given off by occupants and can be detected within 2-3 minutes.

This study outlines the following equation that specifies the concentration of carbon dioxide in a space at a given time:

$$\mathbf{c(t+\Delta t) = c(t) * e\text{^}(-n*\Delta t) + (cb + (N*q)/(n*V)) * (1-e\text{^}(-n*\Delta t)}$$

where

$c(t+\Delta t)$	concentration at time $(t+\Delta t)$ (vol/vol)
$c(t)$	concentration at time t (vol/vol)
n	air change rate between time t and $(t+\Delta t)$
cb	background concentration (vol/vol) **ASSUME 400 ppm
q	CO2 production rate per person (cubic meter per hour) **assume q=0.02
N	number of occupants
V	volume of room (cubic meters)
Δt	**Let Δt be in minutes

This equation was used to model the behavior of a typical apartment unit over a 24 hour period to assess the need for demand control ventilation and it resulted in positive feedback. Four ventilation strategies were modeled in this study:

Strategy A
Natural Ventilation with constant air change rate
n = 2*h^(-1) represents leaky bldg under average weather conditions

Strategy B
Natural Ventilation with intensive ventilation during recreation times
n=10*h^(-1)

Strategy C
Classical Mechanical Ventilation
n=0.1*h^(-1) between 8 am-5 pm

Strategy D
Ideal Demand Control Ventilation
Assume: Perfect mixing, DCV system with continuously variable air flow, set point of 1000 or 1400 ppm

Occupancy was assumed to vary between 1 and 4 occupants, where most of the occupants are not in the apartment during the middle of the day, to represent a typical working family's schedule. Figure 8 shows this pattern.

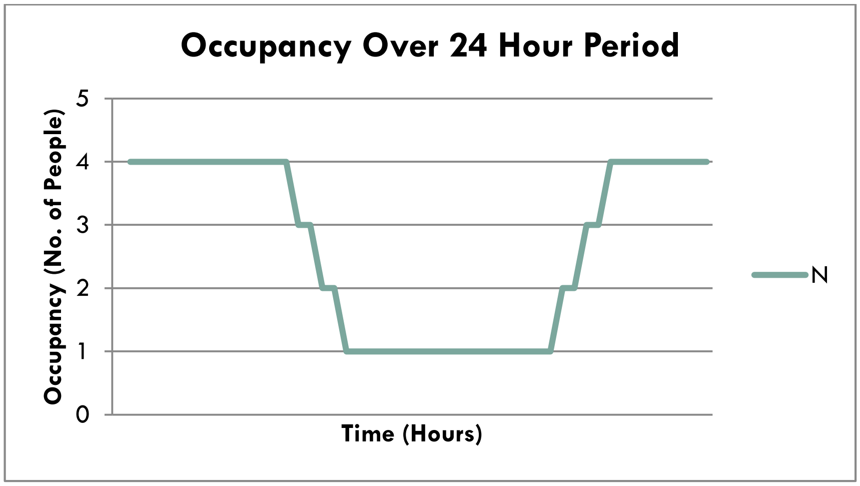


Figure 8: Daily Occupancy Schedule

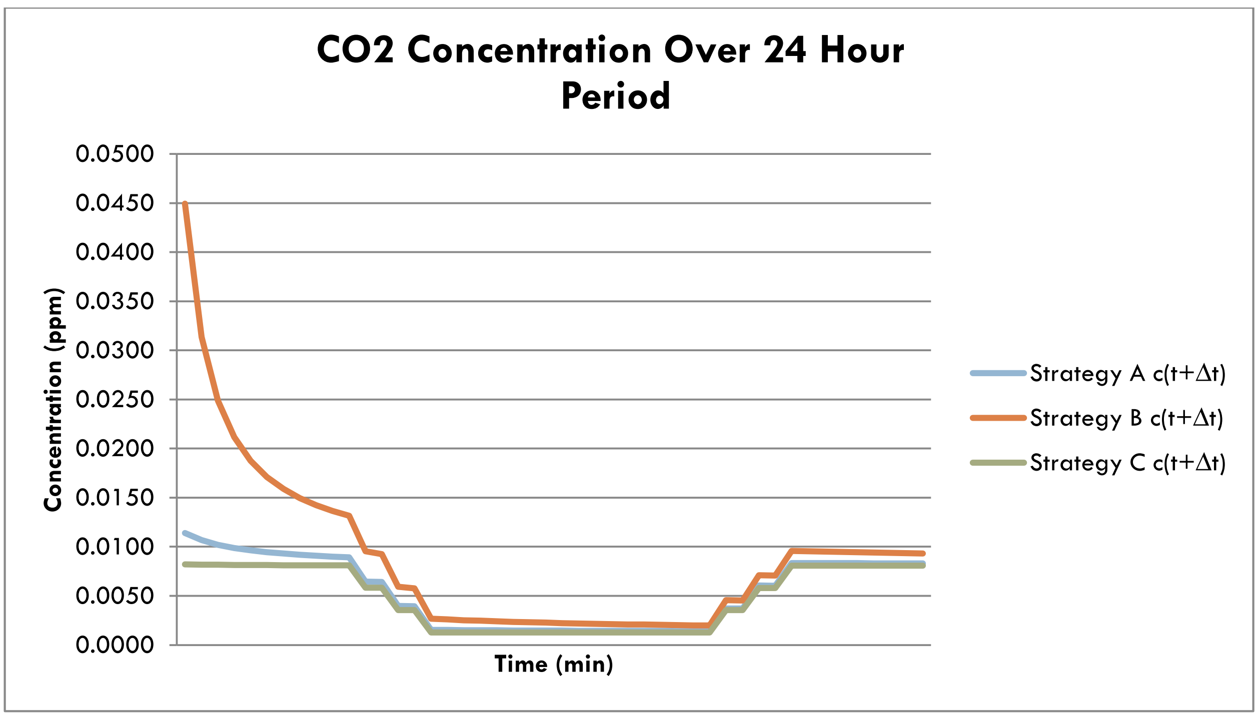


Figure 9: 24-Hour CO_2 Concentration Represented by Strategies A, B, C

It was found that the carbon dioxide sensors (and Demand Control Ventilation) best articulated the occupancy and therefore would provide the necessary ventilation without over ventilating and wasting energy.

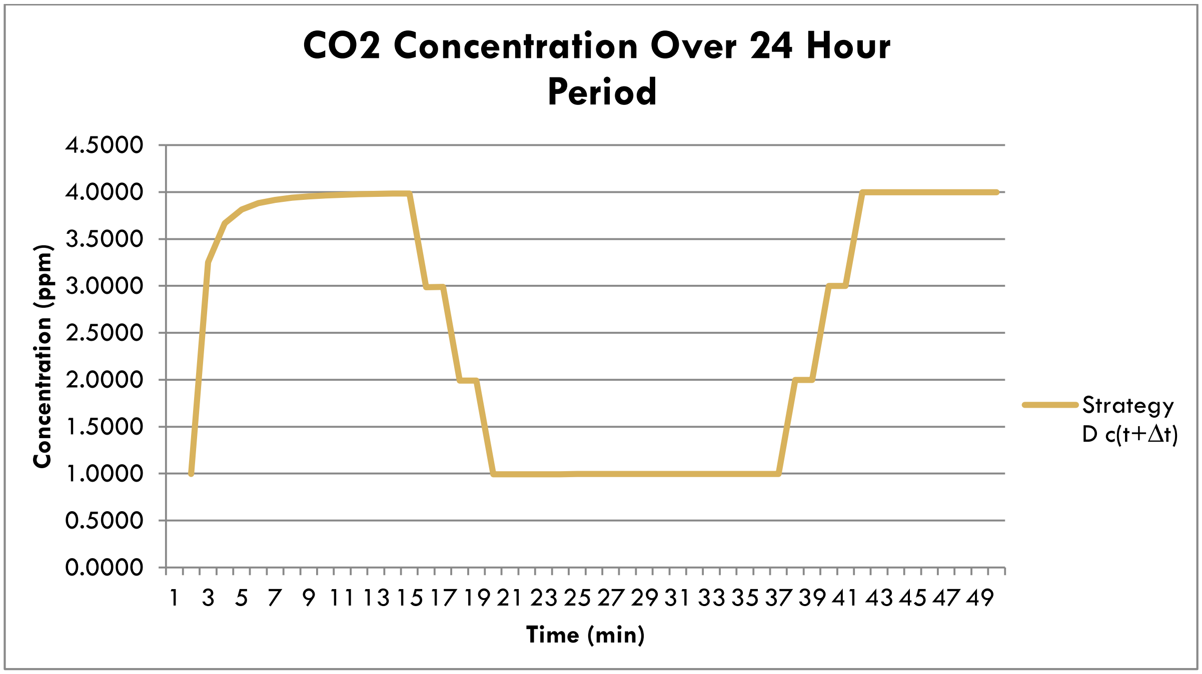


Figure 10: 24-Hour CO2 Concentration Represented by Strategy D

To further prove the necessity for demand control ventilation, Trane TRACE 700 was used to create a simple model of River Vue Apartments where various air handling systems could be evaluated. The first test was to examine if the basic air handling system would have increased ventilation and satisfy the need for system redesign. The first test showed that, indeed, the air handling unit did improve the airflow to the building from the original system.

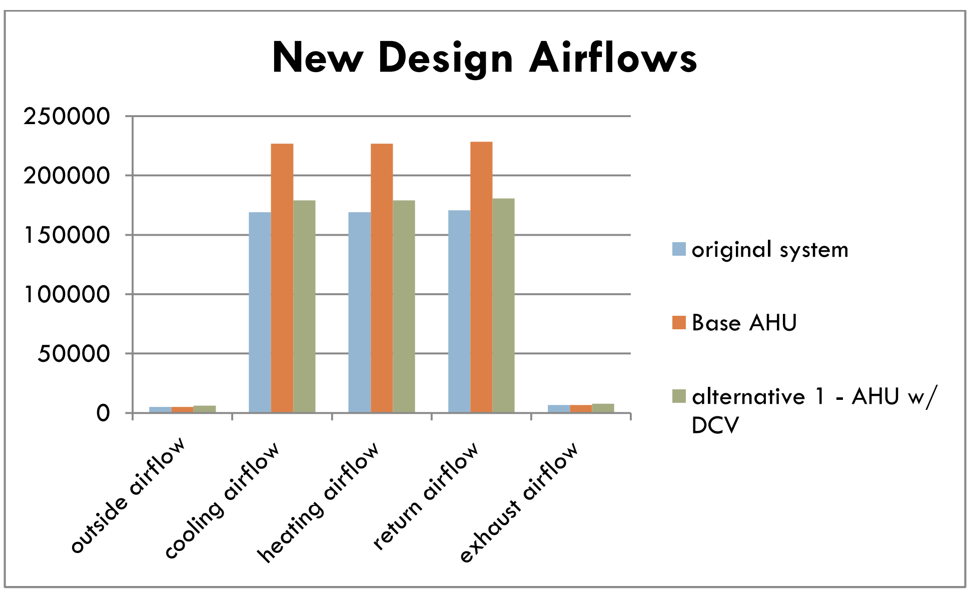


Figure 11: Design Airflow Comparison with DCV

The second test was to assess the value of using demand control ventilation with the base air handling unit. It was found that a significant energy savings of nearly 20% can be achieved with this strategy while the airflow can be limited to only the necessary amount. Thus, the addition of demand control ventilation is useful and justified.

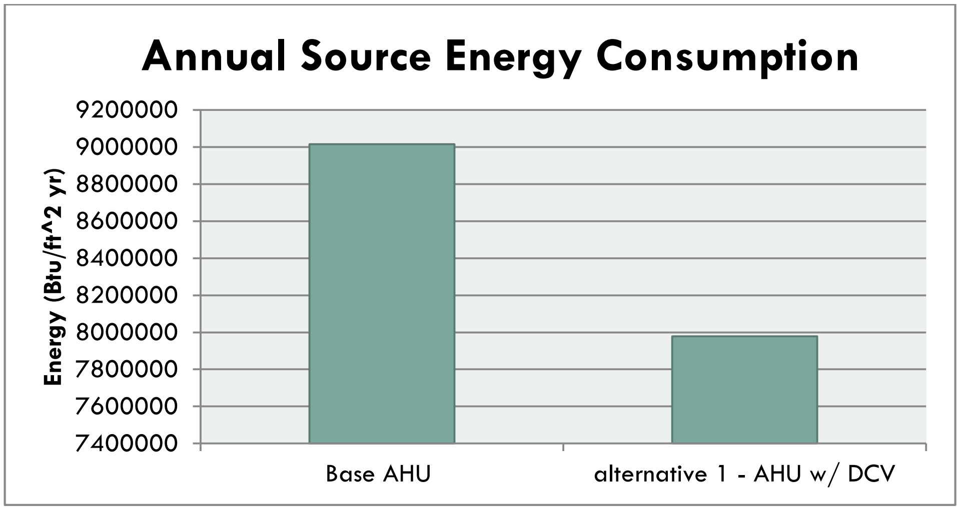


Figure 12: Source Energy Reduction with DCV

Factors influencing the design of this new demand control ventilation system include the following:

Design Occupancy	4 occupants per apartment unit with 197 units = 788 occupants total
Expected actual occupancy	2 occupants per apartment unit with 197 units = 394 occupants total
How predictable occupancy will be	Full design occupancy expected from midnight – 6 am, half occupancy expected from 6 am – 6 pm and full occupancy expected from 6pm – midnight
Time to fill and empty spaces	Approximately 1 minute

Space contaminates and their variability	Smoking, cooking, bathroom odors which would depend on occupants as well as emitting surfaces like carpets
System maintenance requirements	Low maintenance desired
Occupant behavior	Office type behavior (Light) = about 1.25 MET
Building use and potential for change of use	Residential apartment use with low potential for change within the next 10-20 years

Table 11: DCV Design Factors

DCV SENSOR SELECTION & IMPLEMENTATION

Carbon dioxide sensors measure buildup of carbon dioxide in a given space as occupants breathe. One sensor will be installed on each floor to monitor the occupancy and the highest sensor reading of concentration will be used to operate the demand control ventilation system. Carbon dioxide sensors were selected because they can measure a wide range of occupancies and respond accordingly. Single room or zone monitoring is easy because with doubling of occupancy comes doubling of CO2.

The appropriate sensor can be selected from ASHRAE Standard 62.1 Appendix C. River Vue apartments will have relatively light activity levels for each apartment unit, corresponding to a MET level of 1.5 according to the figure below.

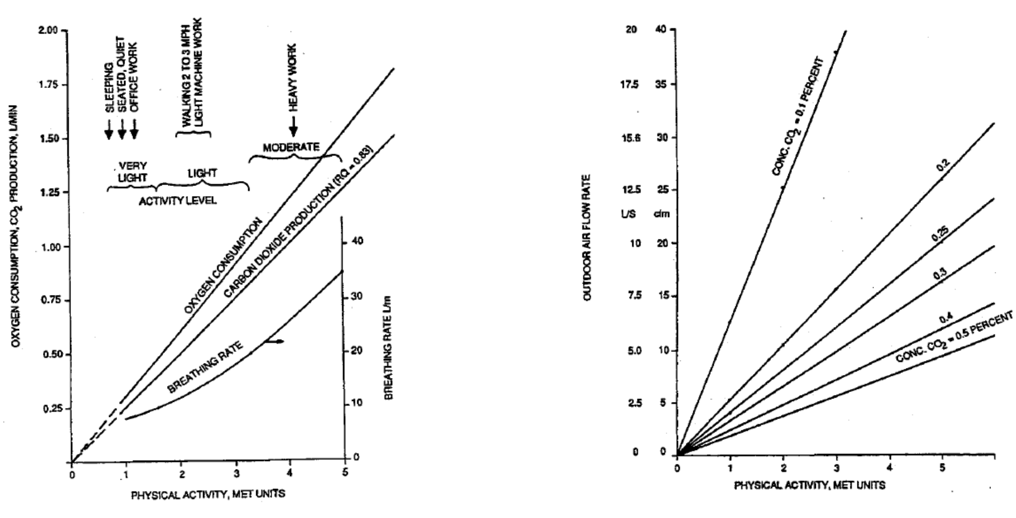


Figure 13: ASHRAE Sensor Selection Graphs, ASHRAE Standard 62.1, Appendix C

According to the figure above, with MET =1.5 and 15 cfm of outside airflow, the expected CO2 concentration will be about 0.13 percent. Sensors can be calibrated to detect when CO2 concentrations raise above this expected value by 10% or more and when this point is reached more ventilation will be provided to the space than the minimum rate since occupancy has increased.

Sensors will be connected directly to an economizer (if used) and/or to the Direct Digital Control System that already exists in the contract specifications for River Vue Apartments. It is important to program the control logic to accept the sensor's signal and use it to control dampers on the air handling unit. Simple control logic can be formed using an analog input and analog output from the carbon dioxide sensors.

GE Measurement and Control Division produces carbon dioxide sensors for demand control ventilation strategy that are wall mounted in their Telair Ventostate 8000 series, as advertised in the February 2012 ASHRAE Journal. These sensors can be ordered without a display to be discrete in residential applications like River Vue Apartments. The sensors have self-calibration capabilities so that manual maintenance is avoided and they are manufactured in two components so that if replacement is required during the equipment's lifetime, rewiring will not be necessary.

Product information for the Telair Ventostate 8000 series sensors is provided in the appendix for reference and it was made available through GE. The sensor specifications indicate that these sensors are accurate within 3% and can detect 400-1250 ppm of CO2 within the space. The Carrier Demand Control Ventilation Design Guide illustrates that outdoor atmospheric carbon dioxide levels in 2008 ranged from 450-500 ppm in areas of high population and industry. Expected indoor contaminent levels for typical residential applications range between 900-1000 ppm due to occupancy. Therefore, this sensor meets the needs of the application and can be used.

It is important to note that carbon dioxide concentrations above 1000 ppm can cause people to become drowsy and uncomfortable and because of this the Occupational Safety and Health Administration (OSHA) has placed limits on the levels people can be exposed to over certain periods of time.

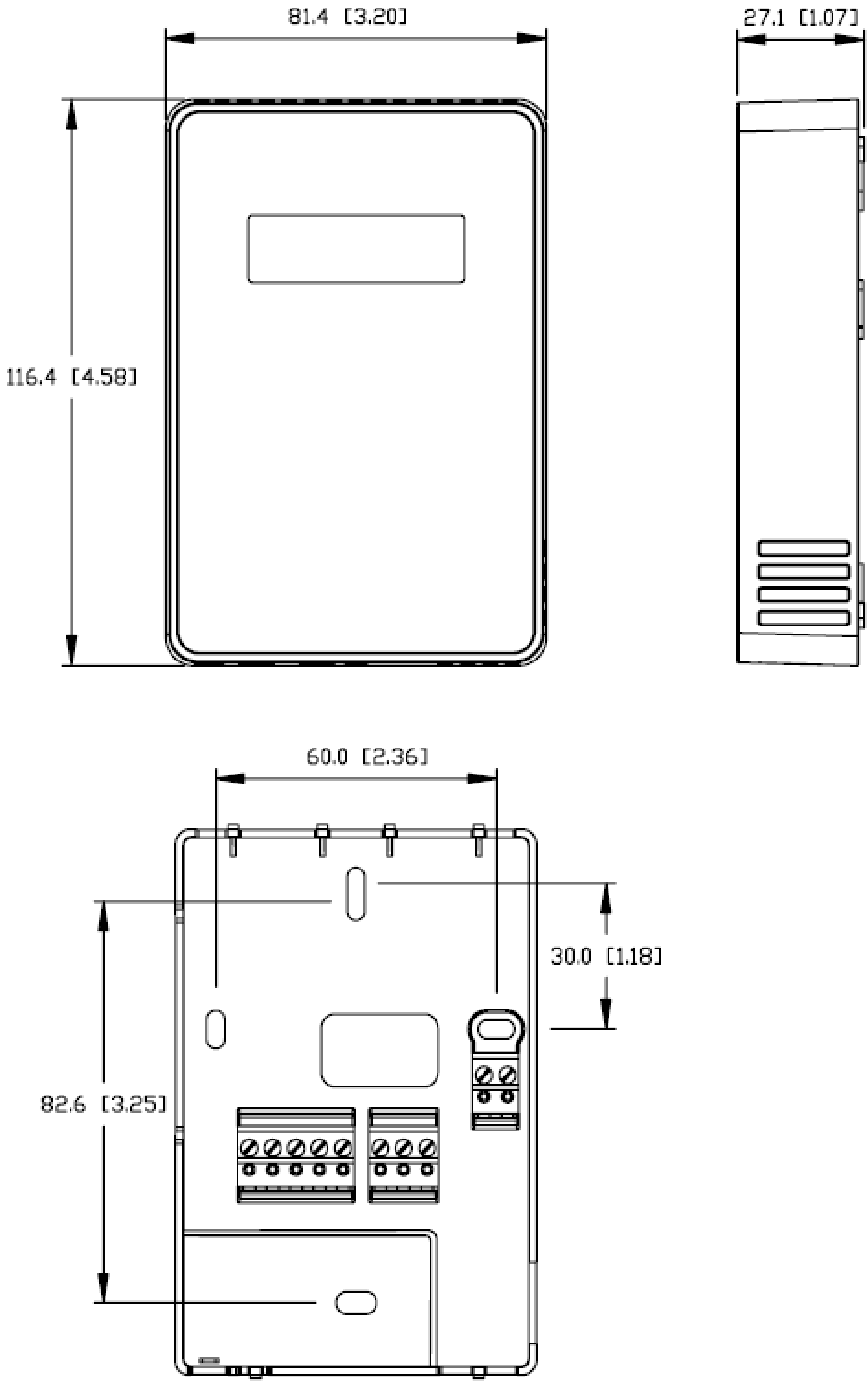


Figure 14: CO2 Sensor Details

DESIGN ALTERNATIVES

Knowing that demand control ventilation strategy is an appropriate addition to the base air handling unit, the following design alternatives were studied to assess their energy consumption, cost, and life cycle. The analyses produce a final suggested mechanical system design for River Vue Apartments.

The four design alternatives studied include:

1. Base AHU
2. AHU w/ DCV
3. AHU w/ DCV and Economizer
4. AHU w/ DCV and 1 Stage of Energy Recovery via Fixed Plate HX (OA Preconditioning)
    - Fixed Plate HX 65% efficient with a static pressure drop of 0.85 in wg on both the supply and exhaust sides
    - has modulated controls and frost protection with a set point of 40 degrees F.

5. AHU w/ DCV and 2 Stages of Energy Recovery: Fixed Plate HX & Runaround Coil Loop
    - Fixed plate HX has same properties as Alternative 3
    - Runaround Coil Loop is 50% efficient, has 5 in wg static pressure drop on supply and return sides, has modulated control and exhaust air preheat for frost protection

In order to model the annual energy consumption, airflow rates, and expected operation of the design alternatives Trane TRACE 700, Version 6.2 was used. A simplified, single zone version of the building was created and all internal equipment, occupancy and lighting loads used in earlier energy modeling simulations were applied to the space.

A second model detailing each room within the building was also created using Trane TRACE 700 to assess the appropriateness of the first model's simplicity. It was found that the simplistic model reflected the results within 10% and therefore could be deemed acceptable for this study.

NOTE: Personal experience with the Trane TRACE 700 program and previous energy analysis projects were factors in the outcome of the energy model's results.

RESULTS OF STUDIES

Each of the four design alternatives are affected by the same internal loads. It can be seen in the figure below that solar gains, window transmission, and occupancy contribute to most of the sensible gains. These results were expected because of the large area of fenestration in the building's façade.

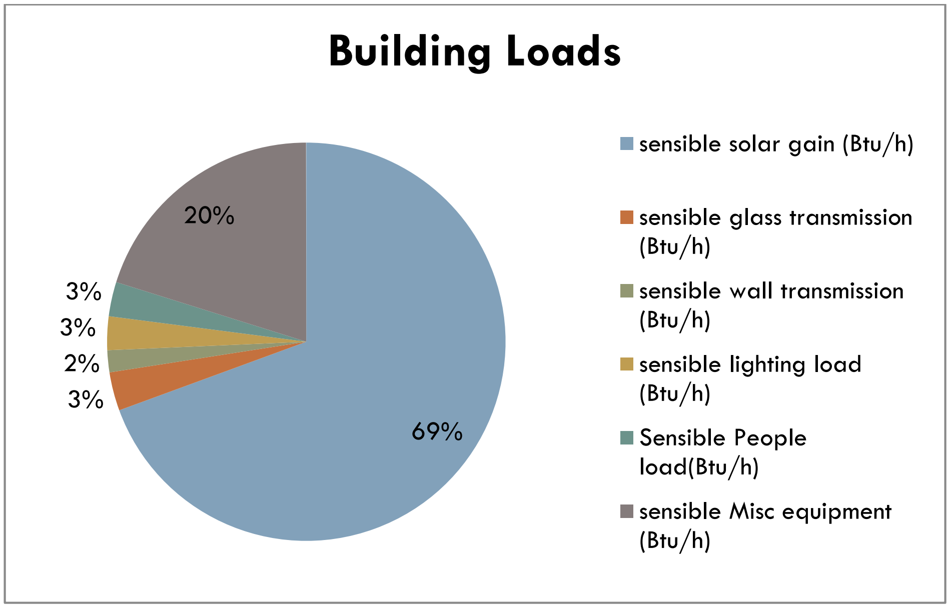


Figure 15: Building Loads

It is obvious that adding demand control ventilation reduces the need for excessive airflow and therefore saves fan energy by the figure below. Adding an economizer increases the amount of exhaust air while adding energy recovery reduces the exhaust air.

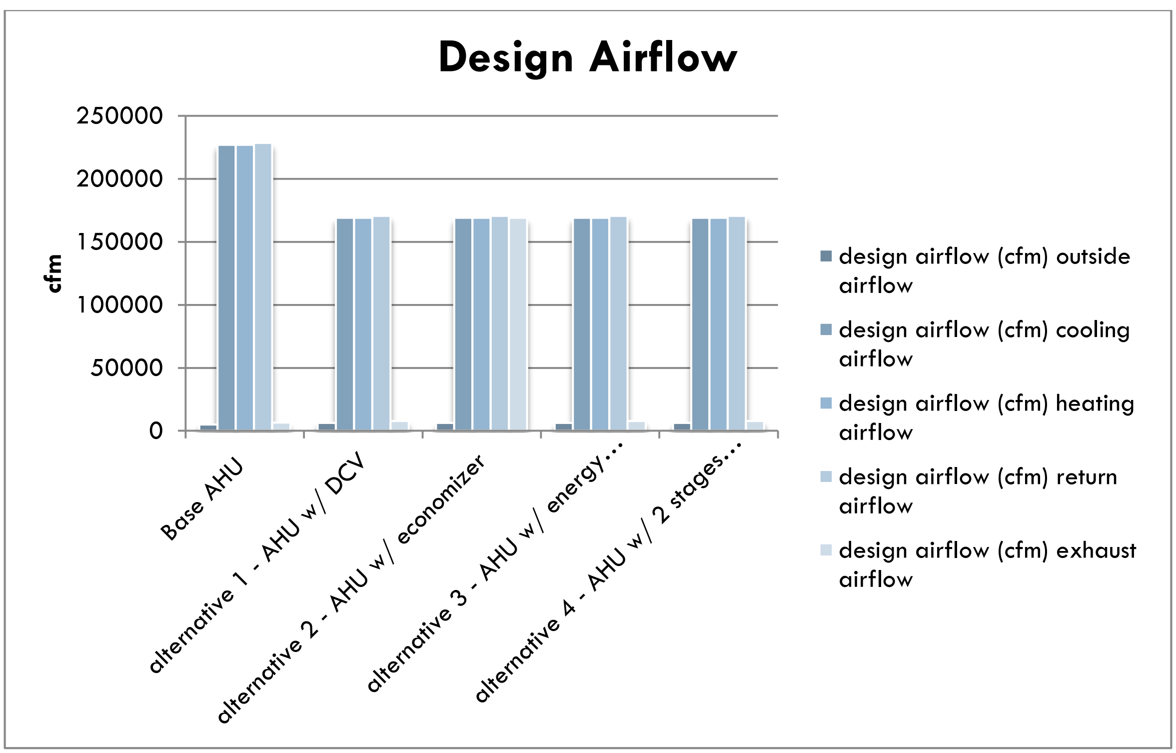


Figure 16: Design Airflow Comparisons

It can be seen that the base air handling unit requires the largest cooling coil out of all the design alternatives. Adding an economizer reduces the size of the coil by 136 tons whereas adding a fixed plate heat exchanger for energy recovery reduces the size of the coil by 130 tons. The runaround coil reduces the coil size by 125 tons.

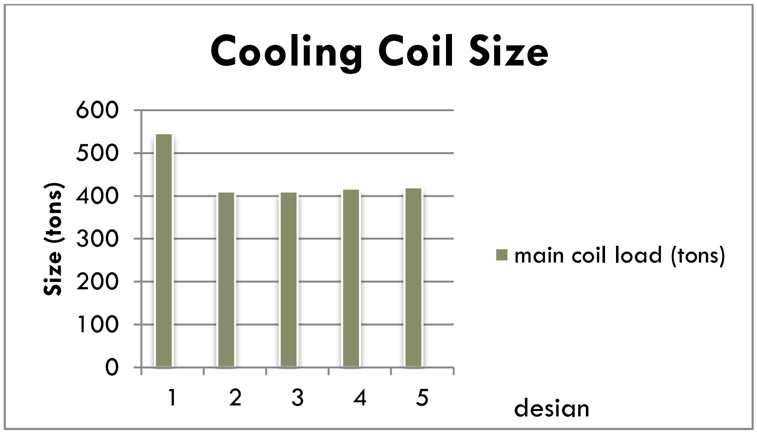


Figure 17: Design Cooling Coil Sizes

It is important to understand how often equipment is running at its specified efficiency because it will consume the least amount of energy in this type of operation. Therefore, an analysis of the system load profile was completed to assess how many hours each design alternative runs at 25% efficiency or higher. The graph below shows that the base air handling unit runs the most efficiently however, the design alternative with two stages of energy recovery runs over 7600 hours at expected efficiency.

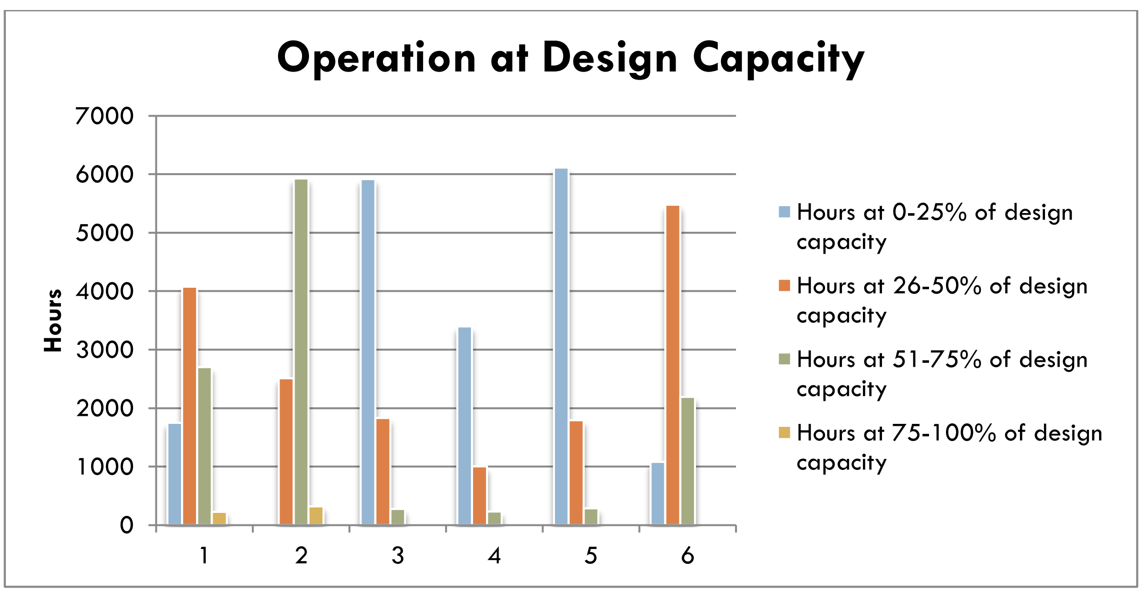


Figure 18: System Operation Hours

ENERGY & EMISSIONS

Source energy is a valuable commodity in today's energy conscious world and therefore it is an important design factor to consider. Since more ventilation was added with the redesigned air handling system, it was expected that building energy usage (and therefore source energy usages) would increase proportionately. Adding the demand control ventilation strategy reduces the amount of source energy by 11.5% and adding an economizer reduces that usage another 2%.

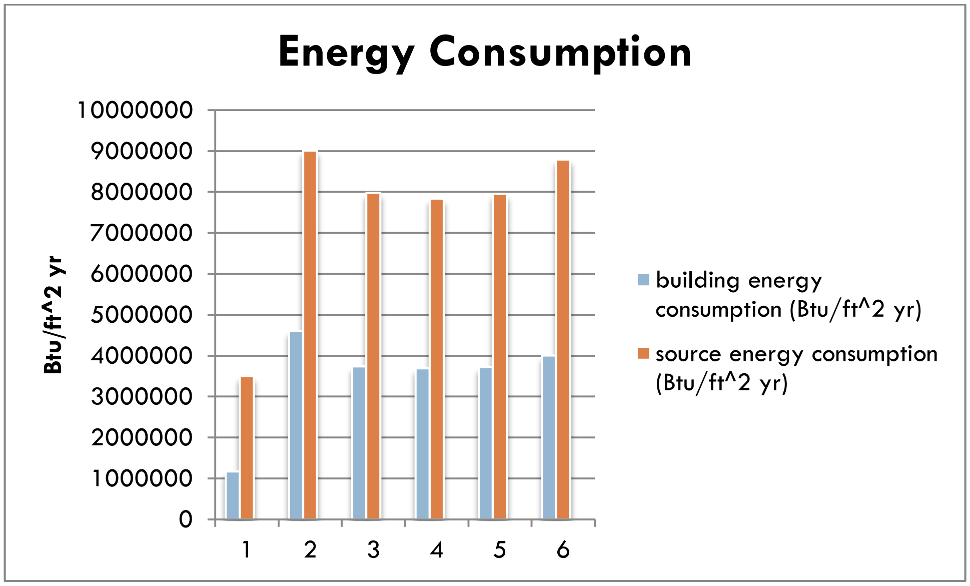


Figure 19: Annual Energy Consumption of Proposed Designs

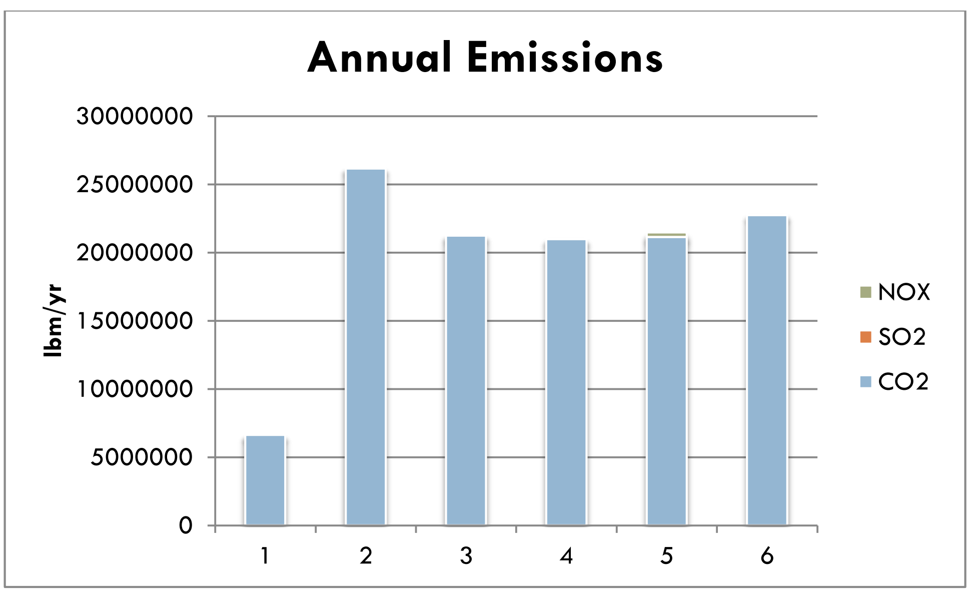


Figure 20: Annual Emissions of Proposed Designs

It was also expected that emissions would increase since building energy and source energy increased. Carbon dioxide is of most concern since so much more of it is produced by each design alternative. The air handling unit with an economizer has the leas emissions, followed closely by the air handling unit with a fixed plate heat exchanger for energy recovery. The base air handling unit produces the most emissions, as expected, since it consumes the most source energy per year.

ECONOMICS

To further understand which design alternative poses the most value, an economic study was completed based on 20 year life cycle costs as well as initial capital cost. The twenty year life cycle cost analysis utilizes discount rates and utility escalation rates from the Energy Price Indices and Discount Factors for Life Cycle Cost Analysis 2011 Guide, an annual supplement to the NIST Handbooks. This reference is a reliable source of cost inflation data from the United States Department of Commerce and helps to better predict net present value of utility costs. An example calculation using this data is provided in the appendix.

Capital cost includes the equipment only; piping, duct, insulation and accessories are not included for simplicity. Pricing for each design alternative was obtained from RS Means Mechanical Cost Data 2010 reference manual. As expected, as more energy recovery techniques are added to the base air handling system the capital cost increases. RS Means cost data for each design alternative and the original design is provided in the appendix for reference.

The original heat pump system has the lowest life cycle cost out of all design options (as seen in the table above) proving why the original design team chose this option. Having low life cycle cost and low maintenance is the preference for any building developer. Of course, by adding ventilation the energy consumed by all of the new design alternatives will be higher over the life of the building.

The figure below shows that the twenty year life cycle cost of the air handling unit with demand control ventilation and an economizer addition has the lowest expected life cycle cost out of all the new designs. When analyzing energy recovery, adding a second stage increases the capital cost and therefore also increases the life cycle cost. Thus, only one stage of energy recovery should be used if this option is to be implemented.

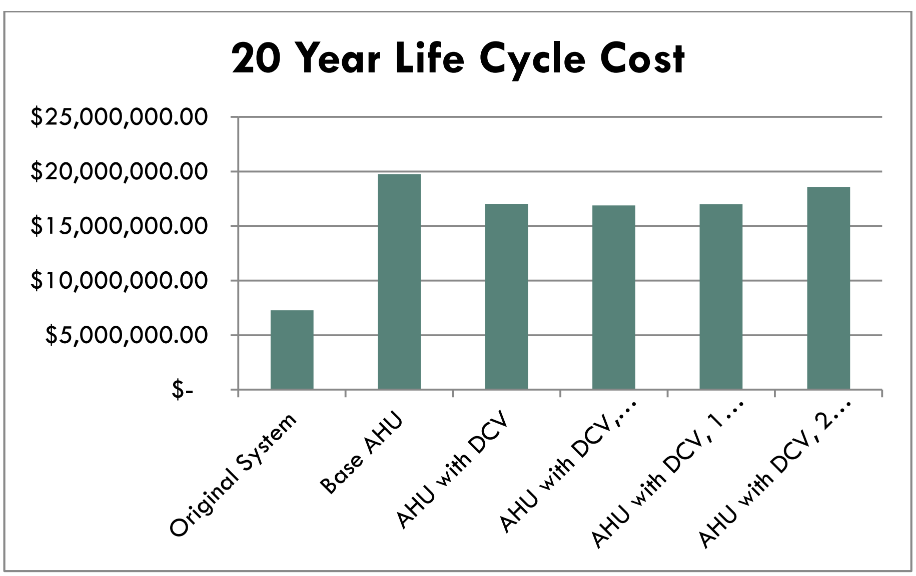


Figure 21: Life Cycle Cost of Proposed Designs

Utilities each have their own rate structures and escalation rates throughout the twenty year period. It can be seen that electricity has the highest cost and will therefore be the governing utility. Each of the new design alternatives use nearly the same amount of natural gas and little chilled water. Again, the air handling unit with demand control ventilation and an economizer addition proves to be the least expensive option.

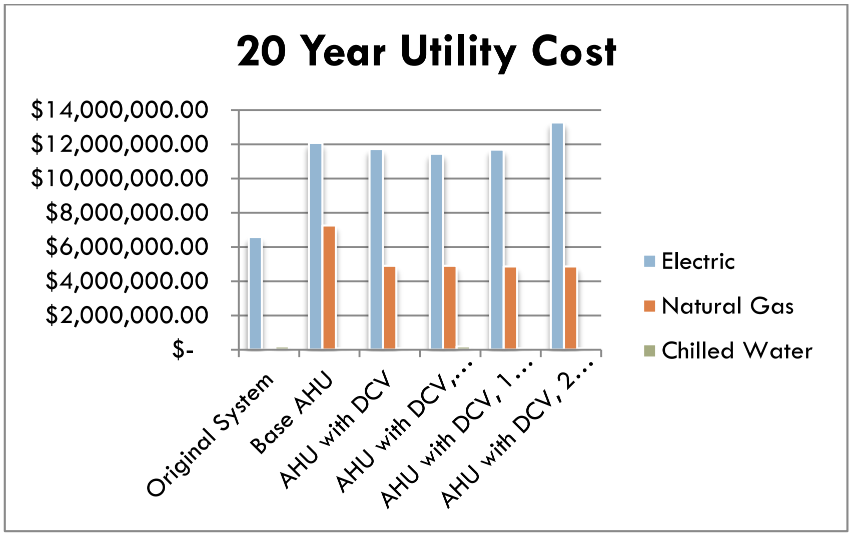


Figure 22: 20 Year Utility Costs for Proposed Designs

It can be seen that the base air handling unit has the lowest capital cost of all options and that all new design alternatives have lower capital costs than the original design with heat pumps. The new design alternatives nearly cost the same up front when demand control ventilation is applied, therefore making the building developer able to choose energy recovery or an economizer addition without much hesitation.

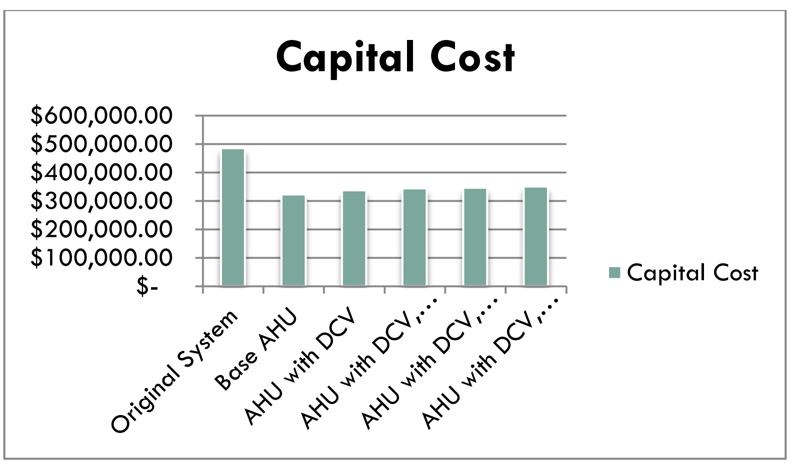


Figure 23: Capital Cost of Proposed Designs

SELECTION SUMMARY

It has been proven that implementing demand control ventilation is a worthwhile control strategy for monitoring carbon dioxide concentrations within River Vue Apartments. This strategy will reduce excessive energy spent over ventilating with a basic air handing unit while increasing tenant and building owner interest in energy conservation. An air handling unit fit with this control strategy and an economizer for energy recovery should therefore be selected. It has the lowest life cycle cost and lowest capital cost out of all design alternatives that have demand control ventilation.

The system size information is provided in the table below:

Airflow	169,033 cfm
Coil Size	434 tons
Total Btu/h	8.9MBtu/h
Annual CO2 Emissions	20,981,096 lbm/yr
Capital Cost	$363,600
20 Year Life Cycle Cost	$16.9 Million

Table 12: Proposed Mechanical Design

A schematic of the economizer cycle with demand controls is provided below for clarity of operation and control techniques implemented in this new design. This schematic was produced using AutoCAD 2011 to show how damper position is controlled by damper motors, outdoor temperature, supply temperature and carbon dioxide level readings from the conditioned space. Another schematic of the overall mechanical system is provided below to show the operation of the design alternative to the original design. It can be seen that the larger air handling unit works with the control system, heating and cooling equipment to provide comfortable indoor conditions for occupants.

Figure 24: Economizer Cycle Schematic

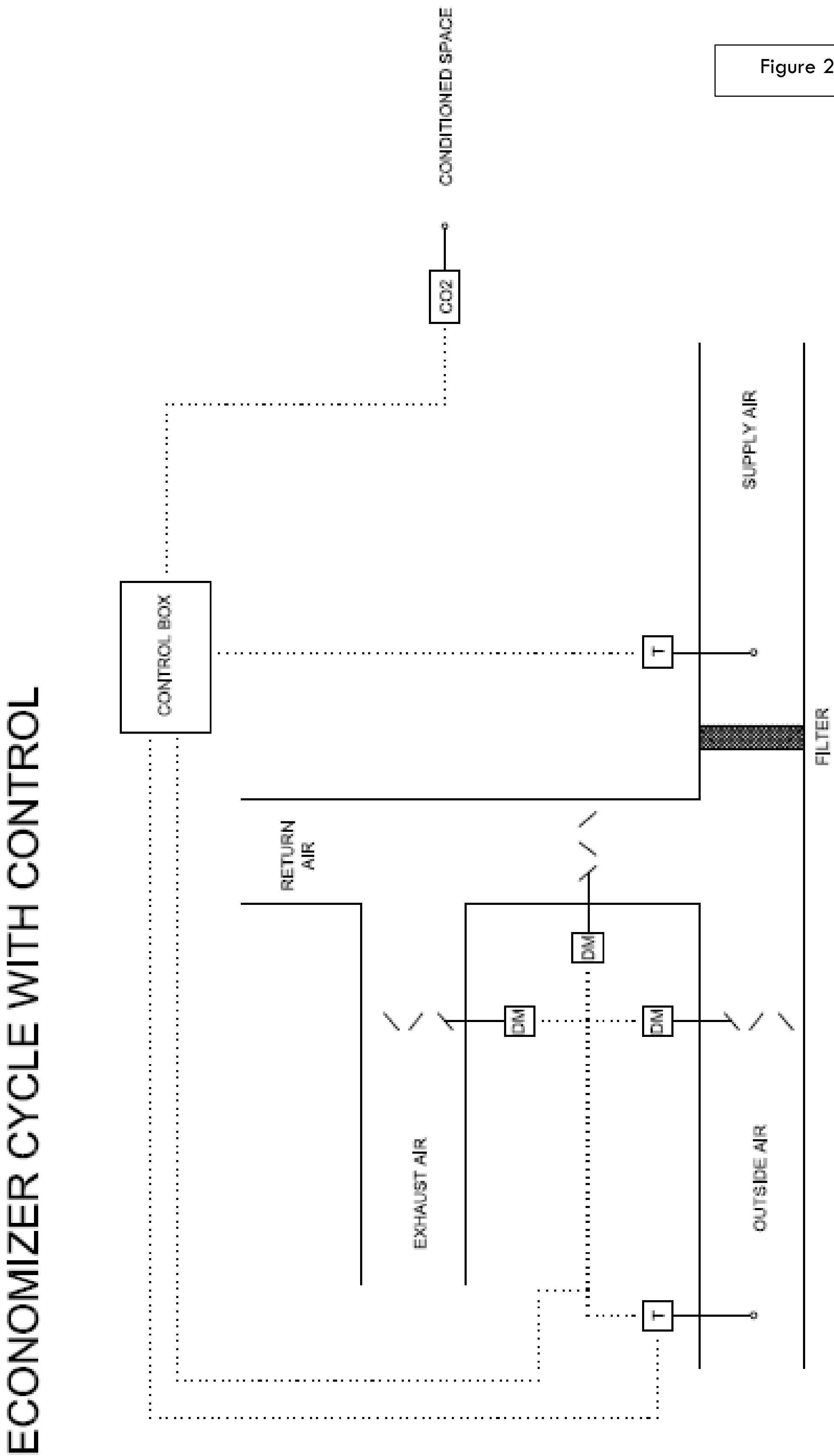
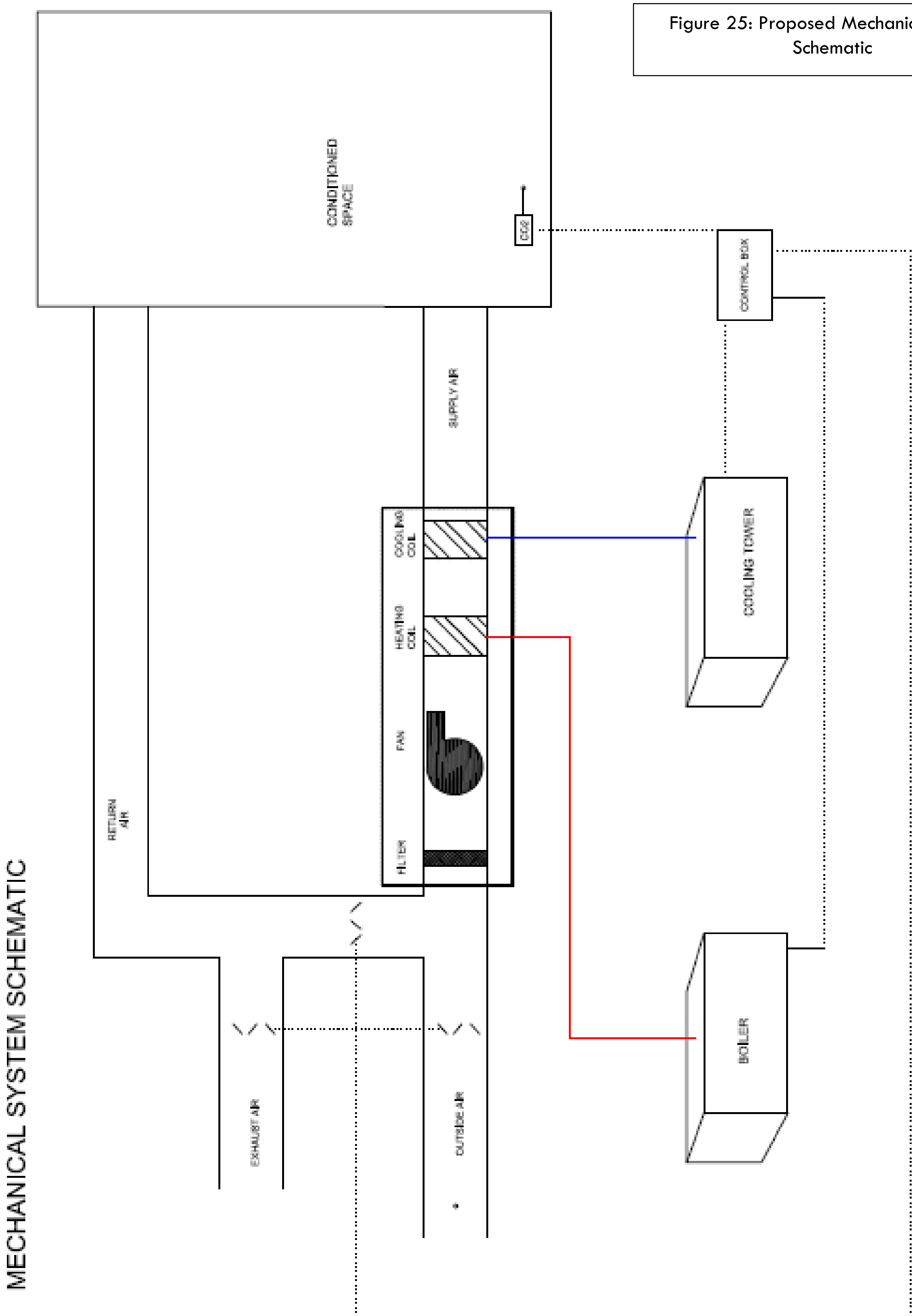


Figure 25: Proposed Mechanical System Schematic



DUCT SIZING, DIFFUSER SELECTION & LAYOUT

Another investigation of duct sizing and layout as well as diffuser selection was completed to assess if air handling system would fit in the existing plenum space of River Vue Apartments. Hand calculations were performed to follow duct sizing methods specified in "Heating, Ventilating, and Air Conditioning Analysis and Design, 6th Edition" by McQuiston, Parker and Spitler.

A type "C" diffuser, a sill grille, is preferred for this type of application because it works well in heating applications where significant glass area exists in the wall. The diffuser would be mounted in the floor to discharge vertically and a return grille would be mounted on the opposite wall near the ceiling.

Knowing the necessary airflow (in cfm) for a typical apartment, the expected air flow for a typical floor can be simply calculated by multiplying the number of rooms on a floor by that flow rate. An NC level of 30-35 is desired for apartment living spaces. The appropriate throw distance and pressure drop is found by knowing the characteristic room length and cooling load.

Sample hand calculations are provided in the appendix for reference however, the selection is as follows:

Size	Capacity	Throw	NC	Pressure Drop
2x12 sill grille	62 cfm	9.45 feet	20	0.073 in wg

Table 13: Diffuser Selection

After assessing the diffuser size and placement, duct runs can be sized and laid out for a typical floor plan as well. Knowing that a typical floor will require 10,640 cfm with a pressure drop of 1.387 in wg, the typical corridor supply duct will need to be a 20" round duct. With 1" insulation wrapped on the outside of the duct the total dimension will be 22", leaving only 2" gap throughout the two foot plenum. Using a round duct would be ideal because it is quick to produce and has low production and installation costs. Although this supply and return duct would take up most of the plenum height, there is still two feet of horizontal space left for other utilities and therefore this air system is an acceptable design alternative.

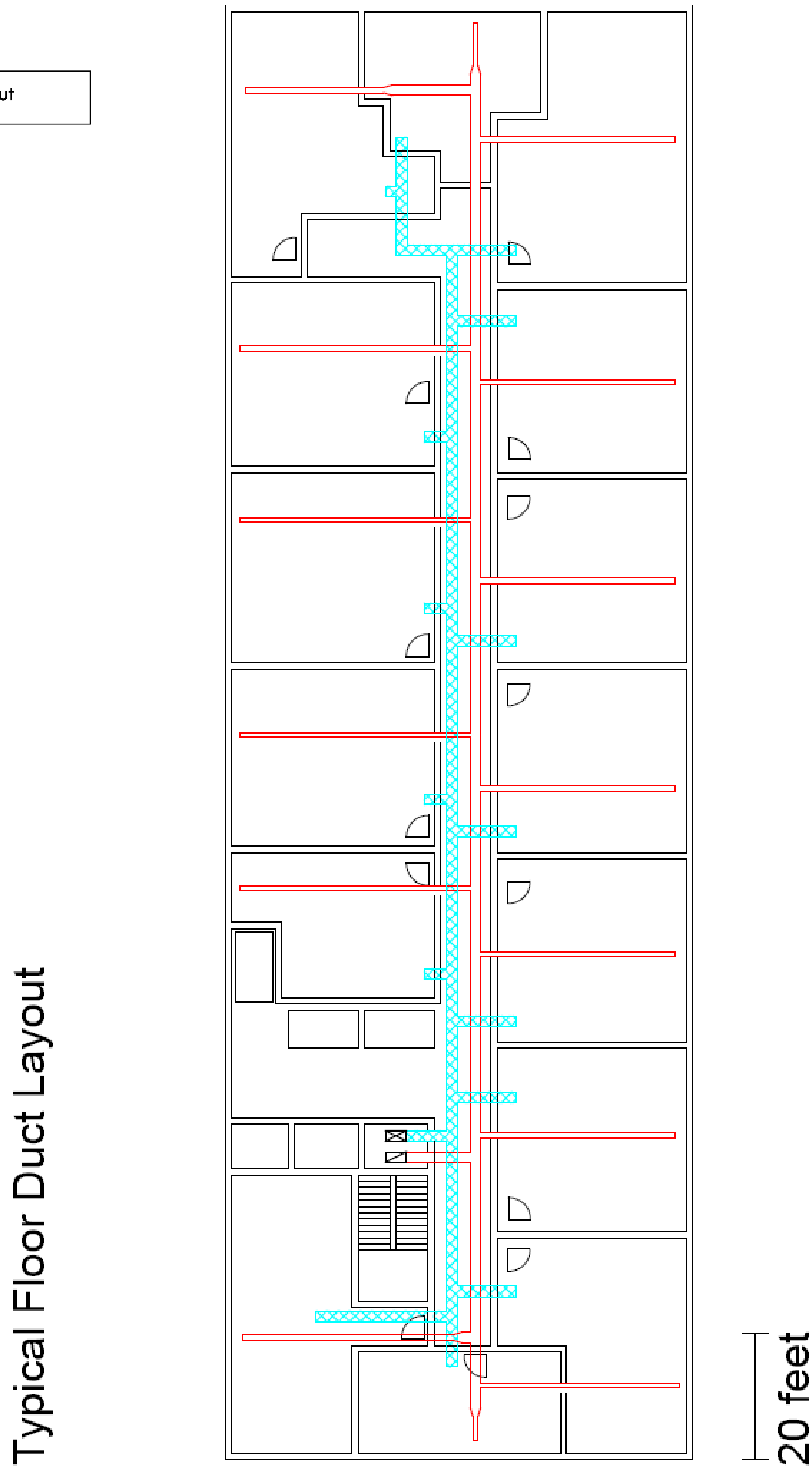
AutoCAD 2012 was used to produce a typical apartment floor plan with supply and return duct layouts. Of course, there will be special requirements for unique spaces like lobbies, the fitness center, and other high occupancy zones however; this floor plan represents the 13 floors of typical apartments.

Figure 26: Proposed Duct Layout

KEY

Red – Supply

Blue - Return



CONTROL LOGIC

Electronic control of mechanical systems is often the least considered portion of a proposed design when it should be heavily integrated into the system. Having controls that run a system properly will decrease wasted heating/cooling hours and therefore operational costs and fuel consumption while increasing occupant comfort at the same time.

EIKON Logic Builder, a computer program by Automated Logic for studying and laying out the details of mechanical system controls, was used to create a schematic of the proposed air handling unit's control logic. A variable air volume system with carbon dioxide monitoring and an economizer was created with the program's Equipment Builder application and microblocks. A full layout of the microblocks, controls, and wiring schematics is provided in the appendix for reference however, the sequence of operation follows for details on operation and set points.

SEQUENCE OF OPERATION:

<u>Run Conditions - Requested:</u>
The unit will run whenever:

- Any zone is occupied.
- OR a definable number of unoccupied zones need heating or cooling.

<u>Freeze Protection:</u>
The unit will shut down and generate an alarm upon receiving a freezestat status.

<u>High Static Shutdown:</u>
The unit will shut down and generate an alarm upon receiving a high static shutdown signal.

<u>Supply Air Smoke Detection:</u>
The unit will shut down and generate an alarm upon receiving a supply air smoke detector status.

<u>Supply Fan:</u>
The supply fan will run anytime the unit is commanded to run, unless shutdown on safeties. To prevent short cycling, the supply fan will have a user definable (adj.) minimum runtime.

Alarms will be provided as follows:

- Supply Fan Failure: Commanded on, but the status is off.
- Supply Fan in Hand: Commanded off, but the status is on.
- Supply Fan Runtime Exceeded: Status runtime exceeds a user definable limit (adj.).

<u>Supply Air Duct Static Pressure Control:</u>
The controller will measure duct static pressure and will modulate the supply fan VFD speed to maintain a duct static pressure setpoint of 1.5 in H_2O (adj.). The supply fan VFD speed will not drop below 30 % (adj.).

Alarms will be provided as follows:

- High Supply Air Static Pressure: If the supply air static pressure is 25 % (adj.) greater than setpoint.
- Low Supply Air Static Pressure: If the supply air static pressure is 25 % (adj.) less than setpoint.
- Supply Fan VFD Fault.

<u>Supply Fan VFD Feedback Monitor:</u>
The controller will monitor the supply fan speed as feedback from the variable frequency drive.

<u>Return Fan:</u>
The return fan will run whenever the supply fan runs.

Alarms will be provided as follows:

- Return Fan Failure: Commanded on, but the status is off.
- Return Fan in Hand: Commanded off, but the status is on.
- Return Fan Runtime Exceeded: Status runtime exceeds a user definable limit (adj.).
- Return Fan VFD Fault.

<u>Building Static Pressure Control:</u>
The controller will measure building static pressure and modulate the return fan VFD speed to maintain a building static pressure setpoint of 0.05 in H_2O (adj.). The return fan VFD speed will not drop below 20 % (adj.).

Alarms will be provided as follows:

- High Building Static Pressure: If the building air static pressure is 25 % (adj.) greater than setpoint.
- Low Building Static Pressure: If the building air static pressure is ____ % (adj.) less than setpoint.

<u>Return Fan VFD Feedback Monitor:</u>
The controller will monitor the return fan speed as feedback from the variable frequency drive.

<u>Supply Air Temperature Setpoint - Optimized:</u>
The controller will monitor the supply air temperature and will maintain a supply air temperature setpoint reset based on zone cooling and heating requirements

The supply air temperature setpoint will be reset for cooling based on zone cooling requirements as follows:

- The initial supply air temperature setpoint will be 55 °F (adj.).
- As cooling demand increases, the setpoint will incrementally reset down to a minimum of 53 °F (adj.).
- As cooling demand decreases, the setpoint will incrementally reset up to a maximum of 72 °F (adj.) .

If more zones need heating than cooling, then the supply air temperature setpoint will be reset for heating as follows:

- The initial supply air temperature setpoint will be 82 °F (adj.).
- As heating demand increases, the setpoint will incrementally reset up to a maximum of 85 °F (adj.).
- As heating demand decreases, the setpoint will incrementally reset down to a minimum of 72 °F (adj.).

Cooling Coil Valve:
The controller will measure the supply air temperature and modulate the cooling coil valve to maintain its cooling setpoint.

The cooling will be enabled whenever:

- Outside air temperature is greater than 60 °F (adj.).
- AND the economizer (if present) is disabled or fully open.
- AND the supply fan status is on.
- AND the heating (if present) is not active.

The cooling coil valve will open to 50 % (adj.) whenever the freezestat (if present) is on.

Alarms will be provided as follows:

- High Supply Air Temp: If the supply air temperature is 5 °F (adj.) greater than setpoint.

Heating Coil Valve:
The controller will measure the supply air temperature and modulate the heating coil valve to maintain its heating setpoint.

The heating will be enabled whenever:

- Outside air temperature is less than 65 °F (adj.).
- AND the supply fan status is on.
- AND the cooling (if present) is not active.

The heating coil valve will open whenever:

- Supply air temperature drops from 40 °F to 35 °F (adj.).
- OR the freezestat (if present) is on.

Alarms will be provided as follows:

- Low Supply Air Temp: If the supply air temperature is 5 °F (adj.) less than setpoint.

Economizer:
The controller will measure the mixed air temperature and modulate the economizer dampers in sequence to

maintain a setpoint [2] °F (adj.) less than the supply air temperature setpoint. The outside air dampers will maintain a minimum adjustable position of [20] % (adj.) open whenever occupied.

The economizer will be enabled whenever:

- Outside air temperature is less than [65] °F (adj.).
- AND the outside air temperature is less than the return air temperature.
- AND the supply fan status is on.

The economizer will close whenever:

- Mixed air temperature drops from [40] °F to [35] °F (adj.).
- OR the freezestat (if present) is on.
- OR on loss of supply fan status.

The outside and exhaust air dampers will close and the return air damper will open when the unit is off. If Optimal Start Up is available the mixed air damper will operate as described in the occupied mode except that the outside air damper will modulate to fully close.

<u>Minimum Outside Air Ventilation - Fixed Percentage:</u>
The outside air dampers will maintain a minimum adjustable position during building occupied hours and be closed during unoccupied hours.

<u>Mixed Air Temperature:</u>
The controller will monitor the mixed air temperature and use as required for economizer control (if present) or preheating control (if present).

Alarms will be provided as follows:

- High Mixed Air Temp: If the mixed air temperature is greater than [90] °F (adj.).
- Low Mixed Air Temp: If the mixed air temperature is less than [45] °F (adj.).

<u>Return Air Carbon Dioxide (CO2) Concentration Monitoring:</u>
The controller will measure the return air CO2 levels.

Alarms will be provided as follows:

- High Return Air Carbon Dioxide Concentration: If the return air CO2 concentration is greater than [1000] ppm (adj.) when in the unit is running.

<u>Return Air Temperature:</u>
The controller will monitor the return air temperature and use as required for setpoint control or economizer control (if present).

Alarms will be provided as follows:

- High Return Air Temp: If the return air temperature is greater than [90] °F (adj.).

- Low Return Air Temp: If the return air temperature is less than 45 °F (adj.).

Supply Air Temperature:
The controller will monitor the supply air temperature.

Alarms will be provided as follows:

- High Supply Air Temp: If the supply air temperature is greater than 120 °F (adj.).
- Low Supply Air Temp: If the supply air temperature is less than 45 °F (adj.).

BREADTH 1 – PHOTOVOLTAIC ARRAY STUDY

Solar energy is the most plentiful energy source on earth however the logistics of capturing it efficiently and using it for building loads is a common design dilemma when solar radiation usually occurs at opposite times of peak building loads. In River Vue Apartments the peak load times will be early in the morning and late in the evening when residents are occupying the apartment units. Solar radiation peaks in the middle of the day and therefore would be of little use for heating domestic hot water or supplementing air heating.

It is known that River Vue Apartments has significant glazing area in each of the four exterior walls and therefore suffers from high sensible solar loads throughout the day. Solar radiation can be collected to power internal shading devices to lower the cooling load of the building during the hottest hours of the day through a photovoltaic array on the roof of the building. A study was conducted by Carrier in 2006 using their HAP program to model the effect of internal shading devices on cooling loads for a single pane, 1/8 inch thick window. The figure below proves that using light solar shading will reduce and shift the peak sensible load on the mechanical system, making internal shading a valuable design tool.

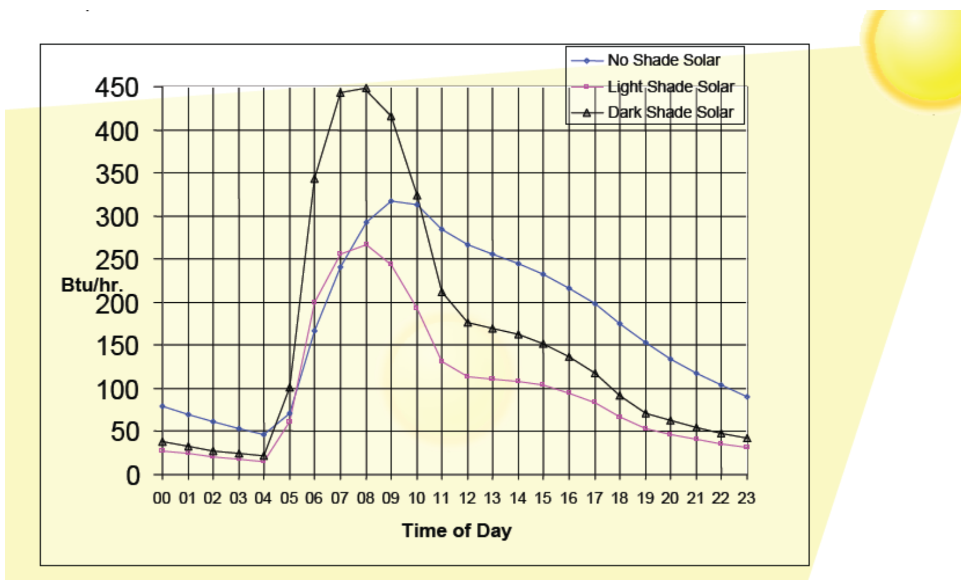


Figure 27: Carrier's "Effect of Internal Shades on Cooling Loads" study, page 2.

Photovoltaic panels are used to convert part of the incident solar radiation on a surface directly to electricity, which, in this study will be directed to power electric blinds. A photovoltaic array is comprised of modules of cells, each with their own efficiency, that contain thin barriers to recombine and build up electrons. When these cells are connected to an electric circuit the electrons can flow, producing electricity.

The figure below shows the average solar irradiance (1991-1993) for the world obtained from weather satellites. It can be seen that Pittsburgh, Pennsylvania receives around 175 W/m^2 of solar irradiation each day. The plot also shows several areas around the world (noted by the dark circles) that are estimated to receive enough daily solar radiation to meet the electricity needs of the world, assuming the photovoltaic panels have a conversion efficiency of around eight percent.

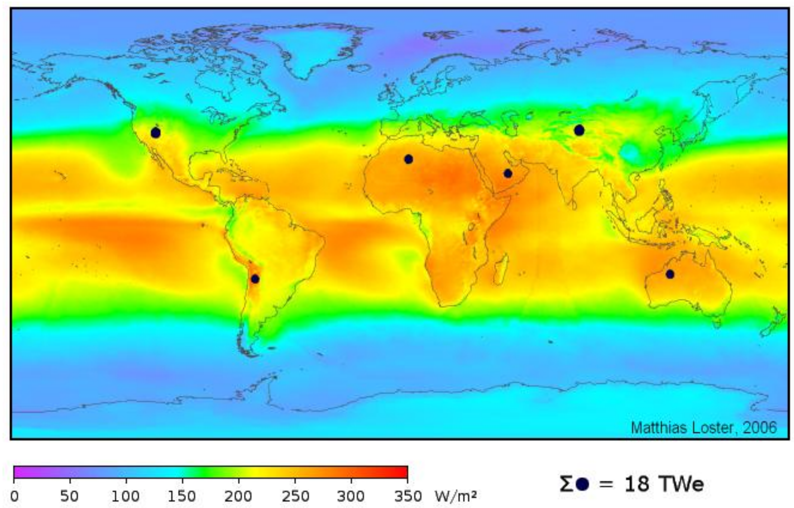


Figure 28: Global Solar Radiation Image courtesy www.wikipedia.com

INCENTIVE PROGRAMS

Incentive programs, grants and loans are available for financial support of photovoltaic systems and their installation from many sources. A few of the options available for River Vue Apartments include:

1. Pennsylvania Federal Investment Tax Credit 2009-2016
   - "Purchases of qualifying solar electric systems may claim up to 30% of the full cost of installing a system, including making changes or improvements in roofs to which solar panel arrays are to be installed."
   - There is no upper limit to the funding available
2. Power Purchase Agreement (PPA)
   - Some companies that do energy auditing offer PPAs (Purchase Power Agreement) as an incentive for building developers to install solar systems. In this scheme, a company like Standard Solar will pay to design and install it for the developer, eliminating the capital cost of the system. Although the building developer can expect relatively uniform operational costs, he must continually pay a "design fee" over some pre-established period of time for this service in order for the company to profit.
3. West Penn Power Sustainable Energy Fund
   - Typical grant for sustainable energy and demand response technologies $25,000-$50,000
4. Pennsylvania Sunshine Solar Rebate Program
   - $0.50/W for the first 100kW available for small businesses with systems greater than 90kW but all applicants after August 2011 seeking funding for PV systems will be put on a waiting list due to the limited funding

DESIGN & ANALYSIS

Weather and solar data was obtained from the National Solar Radiation Database, 2005 Update. This technical report summaries the solar radiation seen by national radiation stations throughout the United States (shown in the figure below) on each day of the year. Class 1 stations collect measured data whereas Class 2 stations produce modeled data, based on information of surrounding Class 1 stations. Information for this photovoltaic array study was taken from the Class 1 Station located at Pittsburgh International Airport in Allegheny County, Pennsylvania.

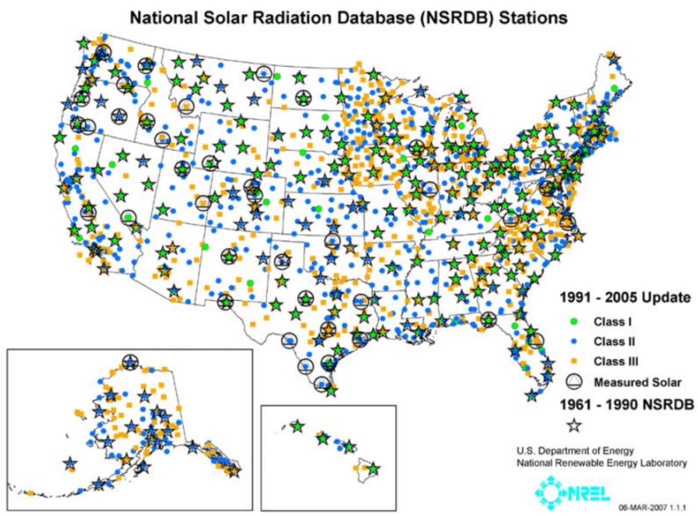


Figure 29: National Solar Radiation Database Stations

Given the dimensions of the air handling equipment and chiller required for the mechanical system, there is approximately 5500 square feet of available space on the roof for a photovoltaic array.

A spreadsheet was created to analyze this photovoltaic array's electric output by allowing user changeable inputs such as latitude, solar collector area, angle of tilt from horizontal installation and ground reflectance. Each hour of the 15th day of each month was analyzed in this study to examine the hourly solar radiation versus the hourly electric output. The total electric output for each day was summed and translated to obtain monthly and annual expected electric outputs. A summary of these calculations is provided in the table below and full calculations are provided in the Appendix for reference.

Month	Daily Radiation	Monthly Radiation	Daily Electric Output (W)	Monthly Electric Output (W)	Monthly kWh
1	2038	63178	179873	5576074	133826
2	3903	109284	90390	2530908	60742
3	5462	169322	51874	1608079	38594
4	7009	210270	58112	1743346	41840
5	6079	188449	58596	1816491	43596
6	4311	129330	142001	4260020	102240

7	4682	145142	103100	3196086	76706
8	3082	95542	111187	3446787	82723
9	4591	137730	57869	1793940	43055
10	3811	118141	154221	4780850	114740
11	1235	38285	591	17735	426
12	507	15717	3289	101966	2447
TOTAL		1420390	1011102	30872282	740935

Table 14: Summary of Radiation Calculations

It can be seen that solar radiation peaks during the summer months and has its lowest magnitude during winter months. The average solar radiation seen at River Vue Apartments is 118,365W/m^2 each month.

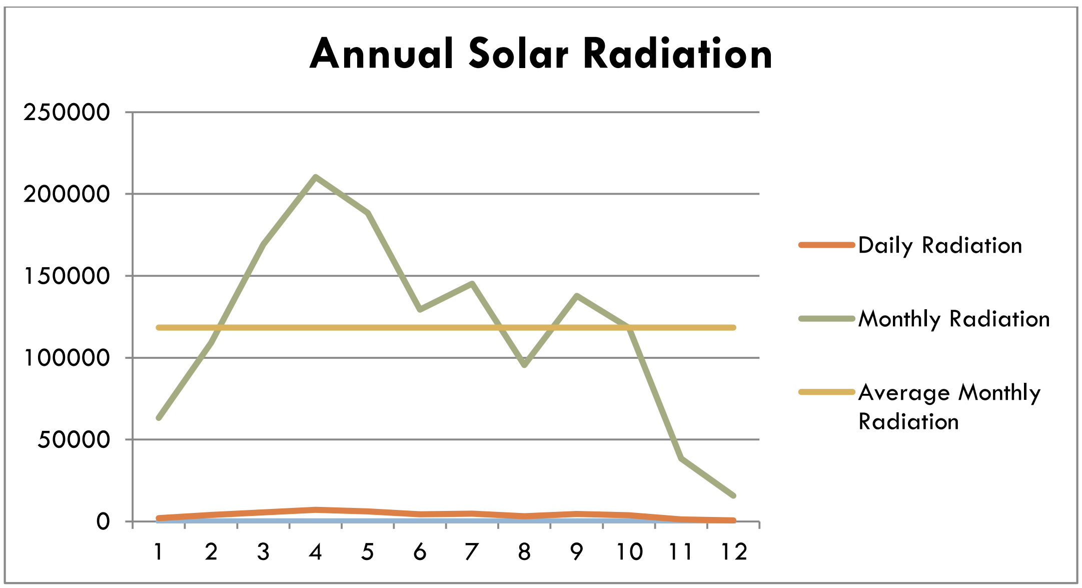


Figure 30: Annual Solar Radiation in Pittsburgh, PA

Electric output corresponds to the available solar radiation directly. When more solar radiation is available during summer months, more electricity can be produced by the panel array, as seen in the figure below. Monthly values are a direct multiple of the daily values.

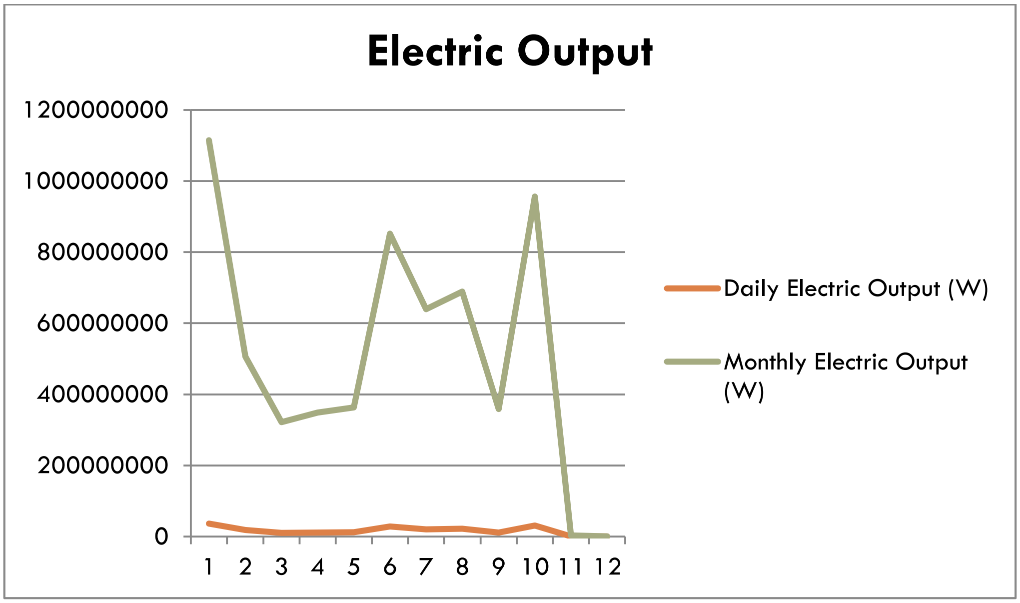


Figure 31: Annual Electric Output

Another study was conducted to find what angle the photovoltaic panels should be mounted in order to collect the highest possible amount of radiation (and electricity) each year. It was found that a tilt angle of thirty degrees would yield the highest electric output annually.

β	Monthly Electric Output
0	1.401E+18
5	1.389E+22
10	9.904E+20
15	4.487E+20
20	1.722E+20
25	3.564E+20
30	1.177E+24
35	1.044E+21
40	6.104E+20
45	3.497E+20

Table 15: Panel Tilt Study

This solar system will contain several components including photovoltaic panels, solar batteries with battery enclosures, solar power charge controllers, solar inverters, solar panel mounts, and power distribution components (wiring). Photovoltaic panels were researched to find the best equipment for this study's application. Silicon Solar, a solar company based in New York, provided the best cost and panel specification data and was chosen as the vendor for this project.

A 660 Watt DC Offgrid Power Kit was chosen for a price of $6790.91 for each kit, which includes a 55 Watt SolMaxx Solar Panel, A Xantrex C35 Charge Controller, 300 volt DC lighting arrestor, T series Batteries with enclosure and a ground/roof low profile tilt mount. Each panel selected has an area of 58.8 ft^2 and a nominal voltage of 24 V. Each panel is expected to produce 3.3 Kwh/day, based on 5 average sun hours. Each kit will also contain 48 feet of 10 AWG wiring for connection to feeder wiring. Knowing that there is 5500 square feet of space available on the roof of River Vue Apartments, this project can accommodate 90 panels that will have a total purchase price of $611181.90.

INTERNAL SHADING

Window blinds that move vertically up and down will be powered by the electricity harvested through the photovoltaic array chosen above. It is known that River Vue Apartments has no interior zones and therefore each apartment suffers from solar gains throughout the year. Solar radiation translates to sensible space loads almost immediately upon striking the building unlike space loads that appear later from transmission through building envelope materials or due to the increase in occupancy. Therefore, this shading will have control logic programmed to a schedule to release the shades down during the expected hours of peak solar radiation each day and pull it back up during off-peak hours and nighttime.

MechoSystems lighting design firm offers internally mounted motorized shades that are appropriate for this application. Their Electro/1 shades are available in sizes up to 15x18 ft and are powered by a 50 mm tubular motor which accepts the 12 V DC power from the photovoltaic array. The cut sheet for this product is included in the appendix for reference. Two shades will be necessary for each apartment to cover the 30' window span, making for 400 shades in total.

A vendor from MechoSystems was contacted to design and price the internal shading system with the following specifications:

- A shading fabric or shade cloth to enhance the current U-value of the window from 0.49 (Btu/h ft^2) to around 0.2 (Btu/h ft^2)
- dark color preferred so that occupants can still see out of the window
- polyester material preferred for durability
- solar control but not blackout to allow some natural day lighting in the space
- automated system – programmed to shade the space during certain hours of the day

ELECTRICAL ANALYSIS

A simple analysis was conducted to understand how worthwhile a photovoltaic system would be to install based on a comparison of the available electricity from the photovoltaic array and the requirement of the internal shades. If any positive difference remained, it was compared to the mechanical system's annual electric requirement (as predicted by the Trane TRACE 700 model earlier) to understand if that need could be supplemented by the array's output. Results are tabulated below.

# Shades	Shade (kW) requirement per year	Annual PV Array (kW) output	Δ (PV Output-Shading Requirement)	Annual Mechanical System Requirement (kW)	Mech Syst Need - PV Power Available	
1	2102.4	**30872**	28770	9491826	**9460954**	
					0	
400	840960		-810088	9491826	**9460954**	0.33%

Table 16: Internal Shading Electric Analysis

This data proves that the array designed above will not provide enough power to operate the desired 400 internal shading devices. Also, the electric output of the photovoltaic array can only be used to offset less than one percent of the electrical requirements of the mechanical system, appliances, and other equipment within the building, making this design alternative an even less attractive option.

If the photovoltaic array *could* provide enough power to serve the internal shading required, the following electrical design would be implemented:

Each photovoltaic kit comes with 48 feet of wiring that would be sufficient to connect the panels on the roof however, additional wiring is necessary to distribute the power to each floor of the building. The 2008 National Electric Code was used to size the appropriate wiring and conduit needed with the following system information:

Internal Shading Analysis						
# Shades	**volts**	**amps**	**VA**	**PF**	**Watts**	**Full load amps**
1	120	20	2400	1	2400	12
400	120	8000	960000	1	960000	4624

Table 17: Theoretical Electrical Analysis

Knowing that the system requires 4624 full load amps, there will need to be 14 sets of 400 kcmil copper wire inside four 3 ½ inch EMT conduit lines. This setup would require a 1/0 copper grounding electrode and a 3000 amp circuit breaker. This system is intended to be independent of the building's existing electrical system because power will not be sold back to the grid.

ENERGY ANALYSIS

The simplified Trane TRACE 700 model was modified so that the solar U-value would represent a shaded window rather than a transparent one in order to understand the energy effects of adding shading. It was seen that the sensible solar gain decreased by ten percent when internal shading was added from 2,750,676 Btu/h to 2,507127 Btu/h annually. Not all appliances, equipment and internal loads were represented in this simple model so the expected annual electric consumption and space loads would only increase from the modeled scenario. Therefore, the photovoltaic array would not be a worth-while design proposal from an energy perspective.

ECONOMIC ANALYSIS

An analysis was completed to understand the capital cost of installing a photovoltaic array as designed above as well as the internal shading system as separate entities.

Category	Equipment	Quantity	Cost Per Item (Inc O&P)	Total Capital Cost
Photovoltaic Array	photovoltaic panel kit	94	$ 6,790.91	$ 638,345.54
	additional wiring (ft)	212	$ 140.00	$ 29,680.00
	conduit	212	$ 44.00	$ 9,328.00
	conduit cutting/drilling	64	$ 200.00	$ 12,800.00
	grounding electrode	1	$ 120.00	$ 120.00
	circuit breaker	1	$ 22,000.00	$ 22,000.00
Shading	internal shades & motors	400	$ 2,500.00	$ 1,000,000.00
	Photovoltaic TOTAL			$ 712,273.54
	System TOTAL			**$ 1,712,273.54**

Table 18: Solar Study Economics

Clearly, the internal shading and corresponding motors and equipment comprise the majority of the capital cost for this design system.

Next, government incentives and funding programs discussed previously were included to examine if their effect will make a photovoltaic array more attractive.

	Original Photovoltaic TOTAL		$	**712,273.54**
Solar Funding	PA Federal Investment Tax Credit	30% of total installation cost	$	213,682.06
	West Penn Power Sustainable Energy Fund	one time grant	$	25,000.00
	New Photovoltaic TOTAL		$	473,591.48

Table 19: Solar Incentive Program Contributions

It can be seen that the price of the photovoltaic array can be reduced by 34% with government incentives and funding but the internal shading cost remains high.

A twenty year life cycle cost and simple payback period analysis was completed to understand the value of the photovoltaic array over time. The value of the electricity collected from the array was found by multiplying the expected annual electricity (in Watts) by the cost of electricity and its expected escalation rate. Electricity was valued at $0.087 per kWh.

Photovoltaic Array Study

Date	Year	Capital	Other Mat.	Elect. Escalation	Elect. Value
2011	1	$ 1,712,274	$ 100	1.00	$ 64,461
2012	2	$ -	$ 100	0.96	$ 61,883
2013	3	$ -	$ 100	0.93	$ 59,949
2014	4	$ -	$ 100	0.91	$ 58,660
2015	5	$ -	$ 100	0.91	$ 58,660
2016	6	$ -	$ 100	0.90	$ 58,015
2017	7	$ -	$ 100	0.90	$ 58,015
2018	8	$ -	$ 100	0.90	$ 58,015
2019	9	$ -	$ 100	0.91	$ 58,660
2020	10	$ -	$ 100	0.92	$ 59,304
2021	11	$ -	$ 100	0.93	$ 59,949
2022	12	$ -	$ 100	0.94	$ 60,594
2023	13	$ -	$ 100	0.94	$ 60,594
2024	14	$ -	$ 100	0.94	$ 60,594
2025	15	$ -	$ 100	0.94	$ 60,594
2026	16	$ -	$ 100	0.94	$ 60,594
2027	17	$ -	$ 100	0.94	$ 60,594
2028	18	$ -	$ 100	0.94	$ 60,594
2029	19	$ -	$ 100	0.93	$ 59,949
2030	20	$ -	$ 100	0.93	$ 59,949
	Column NPV	$ 1,712,274	$ 1,589		$ 953,086
		Total NPV			**$2,666,974**

Table 20: Photovoltaic Life Cycle Cost

The simple payback period for the photovoltaic array and internal shading system is approximately 26.6 years, almost 7 years longer than the expected occupancy of the building, proving that it is not a worthwhile investment for the building developer. When internal shading is removed from the capital cost the payback period shrinks to 11 years with a total net present value of $1.67 million, but knowing that solely harvesting electricity to offset the building's annual needs is not effective, the photovoltaic array itself becomes a poor design concept.

The study of solar radiation, a photovoltaic array and internal shading was very educational and worthwhile. If the photovoltaic array could be 100 times larger than the proposed design area of 5500 square feet (550,000 square feet) then it could offset the building's annual electric consumption by 24% while powering all 400 shades and motors. If no internal shading was used the photovoltaic array of this size could offset the building's annual electric requirement by 35%. However, with River Vue Apartments being within strict building site limits this area is not possible and therefore the proposal cannot be considered.

BREADTH 2 – CONSTRUCTION MANAGEMENT STUDY

Some of the most important design considerations are the cost and schedule impacts of changing the original design therefore; a construction management study was conducted to assess each of the proposed design alternatives. The two parts of this study included understanding the original design and comparing that to the new design proposals- air system design and photovoltaic array design. It is important to note that only changes to the original design were considered in takeoffs and scheduling. Mechanical equipment, sanitary piping, fire protection piping and other elements that exist in both designs are not factored into the following assessment.

First, equipment and material takeoffs for the proposed air handling unit with demand control ventilation and economizer addition were compiled. RS Means Mechanical Cost Data 2010 was used to assign pricing and labor rates for each item as follows:

Category	Equipment	Quantity	Cost Per Item (Inc. O&P)		Total Cost	
Mechanical System Design Alternative	AHU – VAV for 100,000 cfm, not incl duct & accessories	2	$	161,000.00	$	322,000.00
	DCV Direct-Digital CO2 Detector System, incl panel & sensor	1	$	1,650.00	$	1,650.00
	DCV sensor	200	$	950.00	$	190,000.00
	DCV Wiring (ft)	212	$	50.00	$	10,600.00
	Economizer Add-on	1	$	25,000.00	$	25,000.00
	supply duct (lb) – 20”	16299.75	$	5.67	$	92,338.08
	supply duct (lb) – 10”	16268.1	$	2.83	$	45,989.92
	return duct (lb) – 20”	24604	$	5.67	$	139,382.37
	supply elbows	225	$	18.55		$4173.75
	return elbows	255	$	37.00		$9435
	supply transitions	60		$35		$2100
	diffusers	225		$65.5		$14737.5
	modulating dampers for AHU	2		$161		$322
TOTAL					**$**	**857,728.62**

Table 21: Proposed Mechanical System Take-off

As expected, the major equipment will have the highest capital cost whereas repetitive components like duct and diffusers will be lower cost.

Category	Equipment	Crew Size	$ Per crew member	Total Labor $	Labor Hours per unit	Total installation hours
Mechanical System Design Alternative	AHU – VAV for 100,000 cfm, not incl duct & accessories	1	$ 14,400.00	$ 14,400.00	290	580
	DCV Direct-Digital CO2 Detector System, incl panel & sensor	2	$ 104.00	$ 208.00	2	2
	DCV sensor	2	$ 57.00	$ 114.00	1.1	220
	DCV Wiring (ft)	1	$ 16.00	$ 16.00	0.2	42
	Economizer Add-on	1	$ 590.00	$ 590.00	13	13
	supply duct (lb) – 20"	2	$ 16.90	$ 33.80	0.369	6015
	supply duct (lb) – 10"	2	$ 4.42	$ 8.84	0.1	1627
	return duct (lb) – 20"	2	$ 16.90	$ 33.80	0.369	9079
	supply elbows	2	$ 10.00	$ 20.00	0.5	113
	return elbows	2	$ 10.00	$ 20.00	0.5	128
	supply transitions	2	$ 10.00	$ 20.00	0.5	30
	diffusers	4	$ 12.30	$ 49.20	0.25	56
	modulating dampers for AHU	1	$ 49.00	$ 49.00	1	2
	TOTAL			**$ 15,562.64**		**17906**

Table 22: Proposed Mechanical System Labor Estimate

Again, it can be seen that the most labor costs and installation time will be required for the air handling unit with economizer addition because it is not repetitive work and requires special attention to connections and set up. Duct installation will go quickly as workers move through the building and gain experience on each floor.

Next, the photovoltaic array was priced using cost data from the vendor's website. A single cost was provided for each photovoltaic array kit. Corresponding electrical wiring, conduit, grounding and accessories were priced using RS Means Electrical Cost Data 2010 and pricing information for the internal shades and their motors was obtained from vendor recommendations, industry professionals, and research of equipment available at local home improvement stores, i.e. Home Depot.

Category	Equipment	Quantity	Cost Per Item (Inc O&P)	Total Cost
Photovoltaic Array	photovoltaic panel kit	94	$ 6,790.91	$ 638,345.54
	additional wiring (ft)	212	$ 140.00	$ 29,680.00
	conduit	212	$ 44.00	$ 9,328.00
	conduit cutting/drilling	64	$ 200.00	$ 12,800.00
	grounding electrode	1	$ 120.00	$ 120.00
	circuit breaker	1	$ 22,000.00	$ 22,000.00
	internal shade& motor	400	$ 2500	$ 1,000,000.00
	TOTAL			**$ 1,712,273.54**

Table 23: Photovoltaic Array Take-off

The cost of the internal shades, motors and corresponding mounting equipment is what makes this portion of the bid package extremely pricey. Quotes from several vendors were taken into consideration when forming the final internal shading cost estimate. For more information on these vendors please see the appendix.

Category	Equipment	Crew Size	$ Per crew member	Total Labor $	Labor Hours per unit	Total installation hours
Photovoltaic Array	photovoltaic panel kit	2	$ 25.00	$ 50.00	0.75	70.5
	additional wiring (ft)	2	$ 16.00	$ 32.00	1	212
	conduit	2	$ 9.40	$ 18.80	0.2	42.4
	conduit cutting/drilling	1	$ 114.00	$ 114.00	2.4	153.6
	grounding electrode	1	$ 68.50	$ 68.50	1.45	1.45
	circuit breaker	1	$ 1,175.00	$ 1,175.00	25	25
	internal shade	4	$ 15.00	$ 60.00	0.25	100
	shade motor	4	$ 15.00	$ 60.00	0.2	80
	TOTAL			**$ 1,578.30**		**685**

Table 24: Photovoltaic Array Labor Estimate

Next, information was gathered about the original mechanical design as specified by the contract drawings and specifications. 0.5”-2.5” piping is specified to be copper, 3”-6” piping is specified to be schedule 80 threaded steel and all fittings are brass. Duct and piping sizes were read directly from contract drawings and all fittings, elbows and valves for HVAC and plumbing were also directly taken from contract drawings. Cost and labor data was obtained from RS Means Mechanical Cost Data 2010.

Category	Equipment	Quantity	Cost Per Item (Inc O&P)	Total Cost
Mechanical system	Water Source Heat Pump @ 2 ton cooling, not incl piping	200	$ 2,500.00	$ 500,000.00
	schedule 40 piping	4920	$ 24.50	$ 120,540.00
	elbows	450	$ 68.00	$ 30,600.00
	1.25" ball valves	400	$ 87.50	$ 35,000.00
	1.25" shut off valve	200	$ 133.00	$ 26,600.00
	1.25" unions	400	$ 113.00	$ 45,200.00
	2.5" tee	400	$ 164.00	$ 65,600.00
	3" tee	400	$ 360.00	$ 144,000.00
	2.5" piping for hps (ft)	2400	$ 24.50	$ 58,800.00
	3" piping for hps (ft)	2400	$ 74.00	$ 177,600.00
	1.25" piping for hps (ft)	2400	$ 22.00	$ 52,800.00
	make up AHU	1	$ 14,200.00	$ 14,200.00
	duct - 12x12 rect. (lb)	17381.25	$ 4.72	$ 82,022.12
	elbows	405	$ 5.24	$ 2,121.43
	diffusers	225	73	$ 16,425.00
	TOTAL			**$ 1,371,508.55**

Table 25: Mechanical Specialties Take-off

The table above shows that piping fittings and specialties are the most costly item in the mechanical and plumbing takeoff. Usually these items are most time consuming to install, as well and will have a significant effect on the labor cost and installation hours. Straight piping runs will be relatively low cost because they are repetitive on many of the floors, as are the heat pump units. Once the crew members can master the installation process, it will get quicker and save time and money.

Category	Equipment	Quantity	Crew Size	Labor Hours per unit	Total installation hours	Labor Cost Per Unit	Total Labor Cost
Mechanical system	Water Source Heat Pump @ 2 ton cooling, not incl piping	200	4	9.42	1884	440	$ 1,760.00
	schedule 40 piping	4920	4	0.5	2460	9.35	$ 37.40
	elbows	450	2	0.8	360	37.5	$ 75.00
	1.25" ball valves	400	2	0.533	213.2	28	$ 56.00
	1.25" shut off valve	200	2	0.533	106.6	28	$ 56.00
	1.25" unions	400	2	0.571	228.4	29.5	$ 59.00
	2.5" tee	400	2	1.778	711.2	83.5	$ 167.00
	3" tee	400	2	2.667	1066.8	125	$ 250.00
	2.5" piping for hps (ft)	2400	2	0.5	1200	10	$ 20.00
	3" piping for hps (ft)	2400	2	0.421	1010.4	19.75	$ 39.50
	1.25" piping for hps (ft)	2400	2	0.143	343.2	7.45	$ 14.90
	make up AHU	1	2	100	100	350	$ 700.00
	duct - 12x12 rect. (lb)	17381.25	4	0.84	14600.25	3.86	$ 15.44
	elbows	405	2	0.9324	377.622	4.2846	$ 8.57
	diffusers	225	2	0.667	150.075	32.5	$ 65.00
	TOTAL				**24812**		**$ 3,323.81**

Table 26: Mechanical Specialties Labor Estimate

Finally, a comparison was made between the original mechanical design and the proposed design alternative as follows. It was found that the new design proposal saves over $500,000 in capital cost. These savings can be contributed to the elimination of hundreds of piping fittings, valves and copper heat pump piping with an air system. A larger portion of the construction cost has shifted to labor rather than material cost in the new design however.

The new mechanical system also saves almost 7000 hours of construction time and this is a significant factor in this project. The original project schedule calls for mechanical finishes to be completed on the first through fifth floors by February 17 2012 with two more floors being completed every two weeks thereafter until all mechanical work is finished by July 27 2012. With the new proposed design, the hours to complete all mechanical work is reduced by 26%

Category	Cost for Equipment & Materials	Total installation hours	Total installation days	Total Labor Cost
New Mech System	$ 865,728.62	18306	763	$ 15,610.64
Old Mechanical System	$ 1,371,508.55	24812	1034	$ 3,323.81
Mech System Cost Difference	$ 505,779.92	6506	271	$ (12,286.83)

Table 27: Mechanical System Cost & Schedule Comparison

When the photovoltaic system with internal shading is added to the construction costs and schedule the total duration of the new design remains less than the original design but the capital cost and labor costs exceed that of the original design significantly, making it an unattractive addition.

Category	Cost for Equipment & Materials	Total installation hours	Total installation days	Total Labor Cost
New Mech System with Photovoltaic and Shading Systems TOTAL	$ 2,578002.16	18911	788	$ 17,128.94
Old Mechanical System	$ 1,371,508.55	24812	1034	$ 3,323.81
Overall System Difference	**$ (1,206,493.62)**	**5901**	246	**$ (13,805.13)**

Table 28: Complete Proposed Design Cost & Schedule Comparison

Since it was proven that the overall schedule for the mechanical portion of the renovation project could be significantly reduced, a further breakdown of labor was completed to understand where time savings can be maximized. It was found that a 24% overall reduction in schedule days can result from significant savings in rough-in and finishing as seen in the table below. Most of these savings occur because air duct is installed by attaching metal hangers to structural elements and sampling hanging the duct below floor slabs whereas piping requires significant drilling and boring. Pipe fittings also take much more time to install than do duct fittings, making the "MEP Finishes' " duration less.

Project Schedule					
	Original Schedule			Adjusted Schedule	
Zone	Duration	Start	Finish	Duration	Decrease in Time
TOTAL	840	7/25/2011	8/31/2012	640	24%
MEP Rough In	465	7/25/2011	2/10/2012	340	27%
Elevator Lobbies & Stair Towers Rough In	100	8/15/2011	12/9/2011	85	
Basement and Level 1 Underground Rough In	80	10/24/2011	2/10/2012	70	
Level 2, 3, 4, 5 Rough In	60	7/25/2011	10/14/2011	40	
Level 6 & 7 Rough In	30	8/1/2011	9/9/2011	15	
Level 8 & 9 Rough In	30	8/22/2011	9/30/2011	15	
Level 10 & 11 Rough In	30	9/12/2011	10/21/2011	15	
Level 12 & 13 Rough In	30	10/3/2011	11/11/2011	15	
Level 14, 15 & 16 Rough In	45	10/24/2011	12/23/2011	30	
Penthouse and Roof Rough In	60	8/8/2011	10/28/2011	55	
MEP Finishes	250	11/21/2011	7/27/2012	190	24%
Elevator Lobbies & Stair Towers	60	11/21/2011	2/10/2012	45	
Basement and Level 1 Underground	20	1/30/2012	2/24/2012	15	
Level 2, 3, 4, 5	60	11/28/2011	2/17/2012	45	
Level 6 & 7	20	2/27/2012	3/23/2012	15	
Level 8 & 9	20	3/19/2012	4/13/2012	15	
Level 10 & 11	20	4/30/2012	5/25/2012	15	
Level 12 & 13	20	5/28/2012	6/22/2012	15	
Level 14, 15 & 16	30	6/18/2012	7/27/2012	25	
Punch list & Inspections	125	2/27/2012	8/31/2012	110	12%
Basement and Level 1, 2, 3, 4, 5	20	2/27/2012	3/23/2012	18	
Level 6 & 7	20	3/26/2012	4/20/2012	18	
Level 8 & 9	20	4/23/2012	5/18/2012	18	
Level 10 & 11	20	5/28/2012	6/22/2012	18	
Level 12 & 13	20	7/2/2012	7/27/2012	18	
Level 14, 15 & 16	25	7/30/2012	8/31/2012	20	

Table 29: Schedule Changes

Much of the original project's expected duration for punch list items and inspections was maintained in the adjusted schedule since the proposed air system will require significant testing and balancing during start up. The proposed air handling unit will change the roof work so most of the original rough in time for that zone was kept, too.

SUSTAINABILITY

Finally, the sustainability and LEED score was re-evaluated to assess the performance of River Vue Apartments with a larger air system and removed hydronic system. Many of the original points remained the same for sustainable sites, materials and resources categories; however, points were gained with a water use reduction, heat island effect reduction and green power addition through the use of the photovoltaic array. More points were obtained with increased ventilation and thermal comfort as well as innovation in design. As a result, the building now can achieve a Silver Rating with a total of 37 points in the LEED-NC Green Building Rating System for New Construction & Major Renovations, Version 2.2. A complete breakdown of points can be seen in the appendix.

Figure 32: Site Photo of River Vue Apartments, Photo by Laura Pica, August 2011

SUMMARY

As seen in the research of River Vue Apartment's existing mechanical system, there is a need for further study and design alternatives to improve annual energy usage as well as occupant comfort and indoor air quality. Energy efficiency, sustainable design and easy, long-term operation are hot topics in the United States today as energy sources become jeopardized and renovation projects become the "norm."

This design study, used primarily for educational purposes and student training in the field of mechanical systems design, proved to be a worthwhile adventure. Demand Control Ventilation strategy coupled with carbon dioxide sensors was applied to an enlarged air handling unit with economizer addition for added ventilation during times of heightened occupancy levels. It was seen that in order to meet ASHRAE Standard 62.1 minimum ventilation rates additional energy would be needed each year to power larger mechanical equipment however; success is measured in occupant comfort, energy savings with an economizer, and reduced construction schedule.

Studying a photovoltaic array for River Vue Apartments showed that its use would not provide sufficient electricity to power internal shading devices. The intention was that sensible solar gains could be reduced through this design by over ten percent allowing the mechanical system to work less throughout the year to heat and cool the vulnerable exterior zones. Government and state funding makes this venture financially possible for applications where power harvested through the array can supplement building requirements.

The conversion between hydronic and air systems allows for a significant reduction in project schedule, upwards of 25% overall with significant savings in rough in and installation time due to the elimination of hundreds of piping fittings. The air system also saves over $500,000 in capital cost but the addition of a photovoltaic array to power internal shading devices drives the capital cost far beyond the original project cost.

Sustainable credits achieved through improved indoor air quality and ventilation, reduction in water consumption improves the LEED score to 35 points, which qualifies River Vue Apartments for Silver certification. The addition of a photovoltaic array would have would have helped improve the LEED score further in the categories of green power and urban heat island effect reduction.

APPENDIX

LOAD CALCULATIONS FOR BASE AIR HANDLING UNIT

					Occupancy		Area		TOTAL	
Room No	Space Type	Area (**Az**)	Expected # of occupants	Occupant Density (#/sqft)	OA Rate per person (**Rp**)	OA Rate (cfm)	OA rate per unit area (**Ra**)	OA Rate (cfm)	(CFM)	Btu/h
B-10	lobby	100	5	0.050	5	25	0.06	6	31	1.435185
B-11	elevator	40	2	0.050	0	0	0.12	4.8	5	0.222222
B-12	elevator	40	2	0.050	0	0	0.12	4.8	5	0.222222
B-13	corridor	136	5	0.037	0	0	0.06	8.16	8	0.377778
B-14	janitor	25	0	0.000	0	0	1	25	25	1.157407
B-15	boiler room	284	0	0.000	0	0	0.12	34.08	34	1.577778
B-16	electrical	178	0	0.000	0	0	0.12	21.36	21	0.988889
B-17	emergency power	32	0	0.000	0	0	0.12	3.84	4	0.177778
B-18	mechanical	196	0	0.000	0	0	0.12	23.52	24	1.088889
B-18A	telecom	20	0	0.000	0	0	0.12	2.4	2	0.111111
B-19	parking garage basement	4836	20	0.004	0	0	0.75	3627	3627	167.9167
B-20	fire pump	140	0	0.000	0	0	0.12	16.8	17	0.777778
B-21	generator	130	0	0.000	0	0	0.12	15.6	16	0.722222
100	parking garage first flr	4664	20	0.004	0	0	0.75	3498	3498	161.9444
101	west lobby	107	5	0.047	5	25	0.06	6.42	31	1.45463
102	elevator	40	2	0.050	0	0	0.12	4.8	5	0.222222
103	central lobby	164	5	0.030	5	25	0.06	9.84	35	1.612963
104	elevator	40	2	0.050	0	0	0.12	4.8	5	0.222222
105	north lobby	30	5	0.167	5	25	0.06	1.8	27	1.240741
106	east lobby	60	5	0.083	5	25	0.06	3.6	29	1.324074
200	lobby	120	5	0.042	5	25	0.06	7.2	32	1.490741
201	apartment	498	4	0.008	5	20	0.06	29.88	50	2.309259
202	apartment	496	4	0.008	5	20	0.06	29.76	50	2.303704
203	apartment	900	4	0.004	5	20	0.06	54	74	3.425926
204	apartment	520	4	0.008	5	20	0.06	31.2	51	2.370

											37
	205	apartment	540	4	0.007	5	20	0.06	32.4	52	2.425926
	206	apartment	520	4	0.008	5	20	0.06	31.2	51	2.37037
	207	apartment	540	4	0.007	5	20	0.06	32.4	52	2.425926
	208	apartment	520	4	0.008	5	20	0.06	31.2	51	2.37037
	209	apartment	540	4	0.007	5	20	0.06	32.4	52	2.425926
	210	apartment	808	4	0.005	5	20	0.06	48.48	68	3.17037
	211	apartment	546	4	0.007	5	20	0.06	32.76	53	2.442593
	212	apartment	1142	4	0.004	5	20	0.06	68.52	89	4.098148
	213	apartment	666	4	0.006	5	20	0.06	39.96	60	2.775926
	214	apartment	520	4	0.008	5	20	0.06	31.2	51	2.37037
	215	apartment	540	4	0.007	5	20	0.06	32.4	52	2.425926
	216	apartment	520	4	0.008	5	20	0.06	31.2	51	2.37037
	217	apartment	540	4	0.007	5	20	0.06	32.4	52	2.425926
	218	apartment	520	4	0.008	5	20	0.06	31.2	51	2.37037
	219	corridor	250	5	0.020	0	0	0.06	15	15	0.694444
	220	janitor	36	0	0.000	0	0	0.12	4.32	4	0.2
	221	mechanical	36	0	0.000	0	0	0.12	4.32	4	0.2
	222	trash	40	0	0.000	0	0	0.12	4.8	5	0.222222
	223	party/media	240	10	0.042	5	50	0.06	14.4	64	2.981481
	226	corridor	150	5	0.033	0	0	0.06	9	9	0.416667
	227	fitness center	392	10	0.026	20	200	0.06	23.52	224	10.34815
	228	bathroom	64	1	0.016	5	5	0.06	3.84	9	0.409259
	229	central corridor	480	5	0.010	0	0	0.06	28.8	29	1.333333
	230	corridor	112	1	0.009	0	0	0.06	6.72	7	0.311111
	231	corridor	180	1	0.006	0	0	0.06	10.8	11	0.5
	232	storage	120	0	0.000	0	0	0.12	14.4	14	0.666667
3-14 alike	300	lobby	180	2	0.011	5	10	0.06	10.8	250	11.55556
	301	apartment	352	4	0.011	5	20	0.06	21.12	493	22.84444
	302	apartment	306	4	0.013	5	20	0.06	18.36	460	21.31111
	303	apartment	258	4	0.016	5	20	0.06	15.48	426	19.71111
	304	apartment	450	4	0.009	5	20	0.06	27	564	26.11111
	305	apartment	450	4	0.009	5	20	0.06	27	564	26.11111
	306	apartment	450	4	0.009	5	20	0.06	27	564	26.11

											111
	307	apartment	450	4	0.009	5	20	0.06	27	564	26.11111
	308	apartment	450	4	0.009	5	20	0.06	27	564	26.11111
	309	apartment	570	4	0.007	5	20	0.06	34.2	650	30.11111
	310	apartment	380	4	0.011	5	20	0.06	22.8	514	23.77778
	311	apartment	310	4	0.013	5	20	0.06	18.6	463	21.44444
	312	apartment	450	4	0.009	5	20	0.06	27	564	26.11111
	313	apartment	450	4	0.009	5	20	0.06	27	564	26.11111
	314	apartment	450	4	0.009	5	20	0.06	27	564	26.11111
	316	corridor	720	5	0.007	5	25	0.06	43.2	818	37.88889
	317	janitor	42	0	0.000	0	0	0.12	5.04	60	2.8
	318	mechanical	42	0	0.000	0	0	0.12	5.04	60	2.8
	319	trash	40	0	0.000	0	0	0.12	4.8	58	2.666667
	1500	lobby	180	2	0.011	5	10	0.06	10.8	21	0.962963
	1501	stairwell	32	0	0.000	1	0	0.06	1.92	2	0.088889
	1502	apartment	624	4	0.006	5	20	0.06	37.44	57	2.659259
	1503	apartment	660	4	0.006	5	20	0.06	39.6	60	2.759259
	1505	apartment	510	4	0.008	5	20	0.06	30.6	51	2.342593
	1506	apartment	360	4	0.011	5	20	0.06	21.6	42	1.925926
	1507	apartment	450	4	0.009	5	20	0.06	27	47	2.175926
	1509	apartment	450	4	0.009	5	20	0.06	27	47	2.175926
	1511	apartment	544	4	0.007	5	20	0.06	32.64	53	2.437037
	1512	apartment	600	4	0.007	5	20	0.06	36	56	2.592593
	1513	apartment	510	4	0.008	5	20	0.06	30.6	51	2.342593
	1515	apartment	330	4	0.012	5	20	0.06	19.8	40	1.842593
	1517	apartment	420	4	0.010	5	20	0.06	25.2	45	2.092593
	1518	apartment	480	4	0.008	5	20	0.06	28.8	49	2.259259
	1520	apartment	512	4	0.008	5	20	0.06	30.72	51	2.348148
	1521	central corridor	744	5	0.007	5	25	0.06	44.64	70	3.224074
	1522	janitor	42	0	0.000	0	0	0.12	5.04	5	0.233333
	1523	mechanical	42	0	0.000	0	0	0.12	5.04	5	0.233333
	1524	trash	40	0	0.000	0	0	0.12	4.8	5	0.222222

	TOTAL	18407	852

LIGHTING CALCULATIONS

Room No	Space Type	Area (Az)	(Watts)	Density (W/sqft)	Btu/h
B-10	lobby	100	256	2.560	874
B-11	elevator	40	0	0.000	0
B-12	elevator	40	0	0.000	0
B-13	corridor	136	448	3.294	1530
B-14	janitor	25	0	0.000	0
B-15	boiler room	284	768	2.704	2622
B-16	electrical	178	448	2.517	1530
B-17	emergency power	32	128	4.000	437
B-18	mechanical	196	704	3.592	2404
B-18A	telecom	20	64	3.200	219
B-19	parking garage basement	4836	7128	1.474	24338
B-20	fire pump	140	320	2.286	1093
B-21	generator	130	256	1.969	874
100	parking garage first flr	4664	7128	1.528	24338
101	west lobby	107	256	2.393	874
102	elevator	40	0	0.000	0
103	central lobby	164	375	2.287	1280
104	elevator	40	0	0.000	0
105	north lobby	30	256	8.533	874
106	east lobby	60	192	3.200	656
200	lobby	120	280	2.333	956
201	apartment	498	322	0.647	1099
202	apartment	496	322	0.649	1099
203	apartment	900	322	0.358	1099
204	apartment	520	322	0.619	1099
205	apartment	540	322	0.596	1099
206	apartment	520	322	0.619	1099
207	apartment	540	322	0.596	1099
208	apartment	520	322	0.619	1099
209	apartment	540	322	0.596	1099
210	apartment	808	322	0.399	1099
211	apartment	546	322	0.590	1099
212	apartment	1142	322	0.282	1099

213	apartment	666	322	0.483	1099
214	apartment	520	322	0.619	1099
215	apartment	540	322	0.596	1099
216	apartment	520	322	0.619	1099
217	apartment	540	322	0.596	1099
218	apartment	520	322	0.619	1099
219	corridor	250	52	0.208	178
220	janitor	36	0	0.000	0
221	mechanical	36	64	1.778	219
222	trash	40	64	1.600	219
223	party/media	240	336	1.400	1147
226	corridor	150	52	0.347	178
227	fitness center	392	448	1.143	1530
228	bathroom	64	64	1.000	219
229	central corridor	480	1100	2.292	3756
230	corridor	112	52	0.464	178
231	corridor	180	52	0.289	178
232	storage	120	0	0.000	0
300	lobby	180	280	1.556	11472
301	apartment	352	322	0.915	13193
302	apartment	306	322	1.052	13193
303	apartment	258	322	1.248	13193
304	apartment	450	322	0.716	13193
305	apartment	450	322	0.716	13193
306	apartment	450	322	0.716	13193
307	apartment	450	322	0.716	13193
308	apartment	450	322	0.716	13193
309	apartment	570	322	0.565	13193
310	apartment	380	322	0.847	13193
311	apartment	310	322	1.039	13193
312	apartment	450	322	0.716	13193
313	apartment	450	322	0.716	13193
314	apartment	450	322	0.716	13193
316	corridor	720	52	0.072	2131
317	janitor	42	64	1.524	2622
318	mechanical	42	64	1.524	2622
319	trash	40	64	1.600	2622
1500	lobby	180	280	1.556	956
1501	stairwell	32	64	2.000	219
1502	apartment	624	312	0.500	1065
1503	apartment	660	312	0.473	1065
1505	apartment	510	312	0.612	1065
1506	apartment	360	312	0.867	1065

1507	apartment	450	312	0.693	1065
1509	apartment	450	312	0.693	1065
1511	apartment	544	312	0.574	1065
1512	apartment	600	312	0.520	1065
1513	apartment	510	312	0.612	1065
1515	apartment	330	312	0.945	1065
1517	apartment	420	312	0.743	1065
1518	apartment	480	312	0.650	1065
1520	apartment	512	312	0.609	1065
1521	central corridor	744	1100	1.478	3756
1522	janitor	42	64	1.524	219
1523	mechanical	42	64	1.524	219
1524	trash	40	64	1.600	219
		TOTAL	37811.000		318096

EQUIPMENT CALCULATIONS

Equipment	Quantity	BTU/h per unit	Watts per unit	TOTAL Btu/h
dishwasher	199	800	234	159200
stove & oven	199	2,200	644	437800
microwave	199	1,000	293	199000
refrigerator	199	300	88	59700
washer	199	1,195	350	237813
dryer	199	6,146	1800	1223038
television	199	324	95	64549
radio	199	14	4	2718
computer	199	1,639	480	326143
vehicle lift	150	30,047	8800	4507008
trash compactor	1	2,561	750	2561
elevator	2	19120.64	5600	38241
treadmill	4	2560.8	750	10243
elliptical machine	4	2560.8	750	10243
				7278258

Table 5: Infiltration Loads

OCCUPANCY CALCULATIONS

Room No	Space Type	Expected # of occupants	occupant load (Btu/h)	CFM
B-10	lobby	5	1750	81
B-11	elevator	2	700	32
B-12	elevator	2	700	32
B-13	corridor	5	1750	81
B-14	janitor	0	0	0
B-15	boiler room	0	0	0
B-16	electrical	0	0	0
B-17	emergency power	0	0	0
B-18	mechanical	0	0	0
B-18A	telecom	0	0	0
B-19	parking garage basement	20	7000	324
B-20	fire pump	0	0	0
B-21	generator	0	0	0
100	parking garage first flr	20	7000	324
101	west lobby	5	1750	81
102	elevator	2	700	32
103	central lobby	5	1750	81
104	elevator	2	700	32
105	north lobby	5	1750	81
106	east lobby	5	1750	81
200	lobby	5	1750	81
201	apartment	4	1400	65
202	apartment	4	1400	65
203	apartment	4	1400	65
204	apartment	4	1400	65
205	apartment	4	1400	65
206	apartment	4	1400	65
207	apartment	4	1400	65
208	apartment	4	1400	65
209	apartment	4	1400	65
210	apartment	4	1400	65
211	apartment	4	1400	65
212	apartment	4	1400	65

213	apartment	4	1400	65
214	apartment	4	1400	65
215	apartment	4	1400	65
216	apartment	4	1400	65
217	apartment	4	1400	65
218	apartment	4	1400	65
219	corridor	5	1750	81
220	janitor	0	0	0
221	mechanical	0	0	0
222	trash	0	0	0
223	party/media	10	3500	162
226	corridor	5	1750	81
227	fitness center	10	3500	162
228	bathroom	1	350	16
229	central corridor	5	1750	81
230	corridor	1	350	16
231	corridor	1	350	16
232	storage	0	0	0
300	lobby	2	8400	389
301	apartment	4	16800	778
302	apartment	4	16800	778
303	apartment	4	16800	778
304	apartment	4	16800	778
305	apartment	4	16800	778
306	apartment	4	16800	778
307	apartment	4	16800	778
308	apartment	4	16800	778
309	apartment	4	16800	778
310	apartment	4	16800	778
311	apartment	4	16800	778
312	apartment	4	16800	778
313	apartment	4	16800	778
314	apartment	4	16800	778
316	corridor	5	21000	972
317	janitor	0	0	0
318	mechanical	0	0	0
319	trash	0	0	0
1500	lobby	2	700	32
1501	stairwell	0	0	0
1502	apartment	4	1400	65
1503	apartment	4	1400	65
1505	apartment	4	1400	65

1506	apartment	4	1400	65
1507	apartment	4	1400	65
1509	apartment	4	1400	65
1511	apartment	4	1400	65
1512	apartment	4	1400	65
1513	apartment	4	1400	65
1515	apartment	4	1400	65
1517	apartment	4	1400	65
1518	apartment	4	1400	65
1520	apartment	4	1400	65
1521	central corridor	5	1750	81
1522	janitor	0	0	0
1523	mechanical	0	0	0
1524	trash	0	0	0
		TOTAL	352800	16333

OCCUPANCY SENSOR SPECIFICIATIONS

Sensing Method	**Non-dispersive infrared (NDIR) absorption**	
	Gold-plated optics	
	Patented ABC Logic self calibration algorithm	
CO2 Measurement Range	T8100/T8300 - Single Channel	0 to 2000 ppm
		0 ppm = 0 V, 4 mA
	T8200 - Dual Channel	0 to 2000 ppm
		0 ppm = 0 V, 4 mA
CO2 Accuracy	T8100/T8300 - Single Channel	400-1250 ppm ±30 ppm or 3% of reading, whichever is greater*,** 1250-2000 ppm ±5% of reading + 30ppm *, ** T8200 - Dual Channel 75 ppm or 10% of reading (whichever is greater)
Power Supply Requirements	18-30 VAC RMS 50/60 Hz	
Power Consumption	Typical 0.7 W at nominal voltage of 24V AC RMS	
Stability	T8100/T8300 - Single Channel	<2% of FS over life of sensor (15 years)
	T8200 - Dual Channel	<5% of FS or <10% reading annual over life of sensor (10 years)
Pressure Dependence	0.135% of reading per mm Hg	
Warranty	One year on mechanical defects	
Certifications	CE and RoHS compliant	
Signal Update	Every 5 seconds	
CO2 Warm-up Time	< 2 minutes (operational) 10 minutes (maximum accuracy)	
Operating Conditions	0°C to 50°C 0 to 95% RH, non-condensing	
Storage Conditions	-40°C to 70°C	
Flammability Classification	UL94 5VA	
Thermistor Type	NTC 10 K W thermistor	
Thermistor Accuracy	±1°C (15° to 35°C)	
Output	Analog	0 to 10 V (100 W output impedance) and 4 to 20mA (RL maximum 500 W) available
simultaneously	Digital to Analog error ±1%	

SOLAR CALCULATIONS

Calculated according to ASHRAE Fundamentals 2009, Chapter 14

Direct Beam (qb)		Diffuse (qd)		Conductive (qc)		
A	60992	A	60992	U	0.49	
Et,b	299.3647674	Et,b + Et,r	341.533384	A	60992	
SHGC(Θ)	0.39	SHGC D	0.54	Tout	75	
IAC(Θ,Ω)	1	IAC D	1	Tin	55	
TOTAL	7120954		11248634		597722	18967310

Eo	δ	β	*m*	ab	ad	Eb	Ed
433.3333333	-23.381143	26.61886	0.23720426	0.782291	0.3101417	324.7783	249.3523

Et,b	Et,d	Et,r
299.3647674	112.2085357	42.16862

LIFE CYCLE COST CALCULATION

AHU with DCV Control

	ELECTRIC		NATURAL GAS		CHILLED WATER			
Ann. Use	9711651	kWh	264,643	therms	3203.172	therms	0	1000 gal.
Unit Cost	$ 0.08	$/kWh	$ 1.14	$/therm	$ 1.40	$/therm	$ 2.16	/1000 gal.
Ann. Cost	$ 776,932		$ 301,693		$ 4,484		$ -	
	Discount Rate	2.10	%	(OMB 20 Year)				
Date	Year	Capital	Other Mat.	Elect. Escalation	Natural Gas Escalation	Elect. Cost	Natural Gas	Chilled Water Cost
2011	1	$ 337,200	$ 2,000	1.00	1.00	$ 776,932	$ 301,693	$ 4,484
2012	2	$ -	$ 2,000	0.96	0.98	$ 745,855	$ 301,693	$ 4,484
2013	3	$ -	$ 2,000	0.93	0.95	$ 722,547	$ 301,693	$ 4,484
2014	4	$ -	$ 2,000	0.91	0.91	$ 707,008	$ 301,693	$ 4,484
2015	5	$ -	$ 2,000	0.91	0.90	$ 707,008	$ 301,693	$ 4,484
2016	6	$ -	$ 2,000	0.90	0.90	$ 699,239	$ 301,693	$ 4,484
2017	7	$ -	$ 2,000	0.90	0.91	$ 699,239	$ 301,693	$ 4,484
2018	8	$ -	$ 2,000	0.90	0.92	$ 699,239	$ 301,693	$ 4,484
2019	9	$ -	$ 2,000	0.91	0.93	$ 707,008	$ 301,693	$ 4,484
2020	10	$ -	$ 2,000	0.92	0.94	$ 714,778	$ 301,693	$ 4,484
2021	11	$ -	$ 2,000	0.93	0.95	$ 722,547	$ 301,693	$ 4,484
2022	12	$ -	$ 2,000	0.94	0.97	$ 730,316	$ 301,693	$ 4,484
2023	13	$ -	$ 2,000	0.94	0.98	$ 730,316	$ 301,693	$ 4,484
2024	14	$ -	$ 2,000	0.94	0.99	$ 730,316	$ 301,693	$ 4,484
2025	15	$ -	$ 2,000	0.94	1.00	$ 730,316	$ 301,693	$ 4,484
2026	16	$ -	$ 2,000	0.94	1.01	$ 730,316	$ 301,693	$ 4,484
2027	17	$ -	$ 2,000	0.94	1.07	$ 730,316	$ 301,693	$ 4,484
2028	18	$ -	$ 2,000	0.94	1.08	$ 730,316	$ 301,693	$ 4,484
2029	19	$ -	$ 2,000	0.93	1.09	$ 722,547	$ 301,693	$ 4,484
2030	20	$ -	$ 2,000	0.93	1.09	$ 722,547	$ 301,693	$ 4,484
	Column NPV	$ 337,200	$ 32,389			$ 11,708,961	$ 4,885,842	$72,624
		Total NPV						**$ 17,037,017**

RS MEANS COST DATA FOR DESIGN ALTERNATIVES

RS Means Cost Data - RS Means Mechanical Cost Data 2010				
Equipment	**Quantity**	**Cost Per Item (Inc O&P)**	**Total Cost**	**page # in reference book**
Water Source Heat Pump @ 2 ton cooling, not incl piping	200	$ 2,425.00	$ 485,000.00	386
AHU - VAV for 100,000 cfm, not incl duct & accessories	2	$ 161,000.00	$ 322,000.00	375
AHU - VAV for 100,000 cfm, not incl duct & accessories	2	$ 161,000.00	$ 322,000.00	375
DCV Direct-Digital CO2 Detector System, incl panel & sensor	16	$ 950.00	$ 15,200.00	257
Economizer Add-on	1	$ 7,000.00	$ 7,000.00	373
Energy Recovery Add - 2000 cfm Energy Recovery Wheel	1	$ 8,850.00	$ 8,850.00	374
Energy Recovery Add - Runaround Coil - 100 MBH, 1700 cfm	1	$ 4,700.00	$ 4,700.00	375

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Variable Air Volume - AHU

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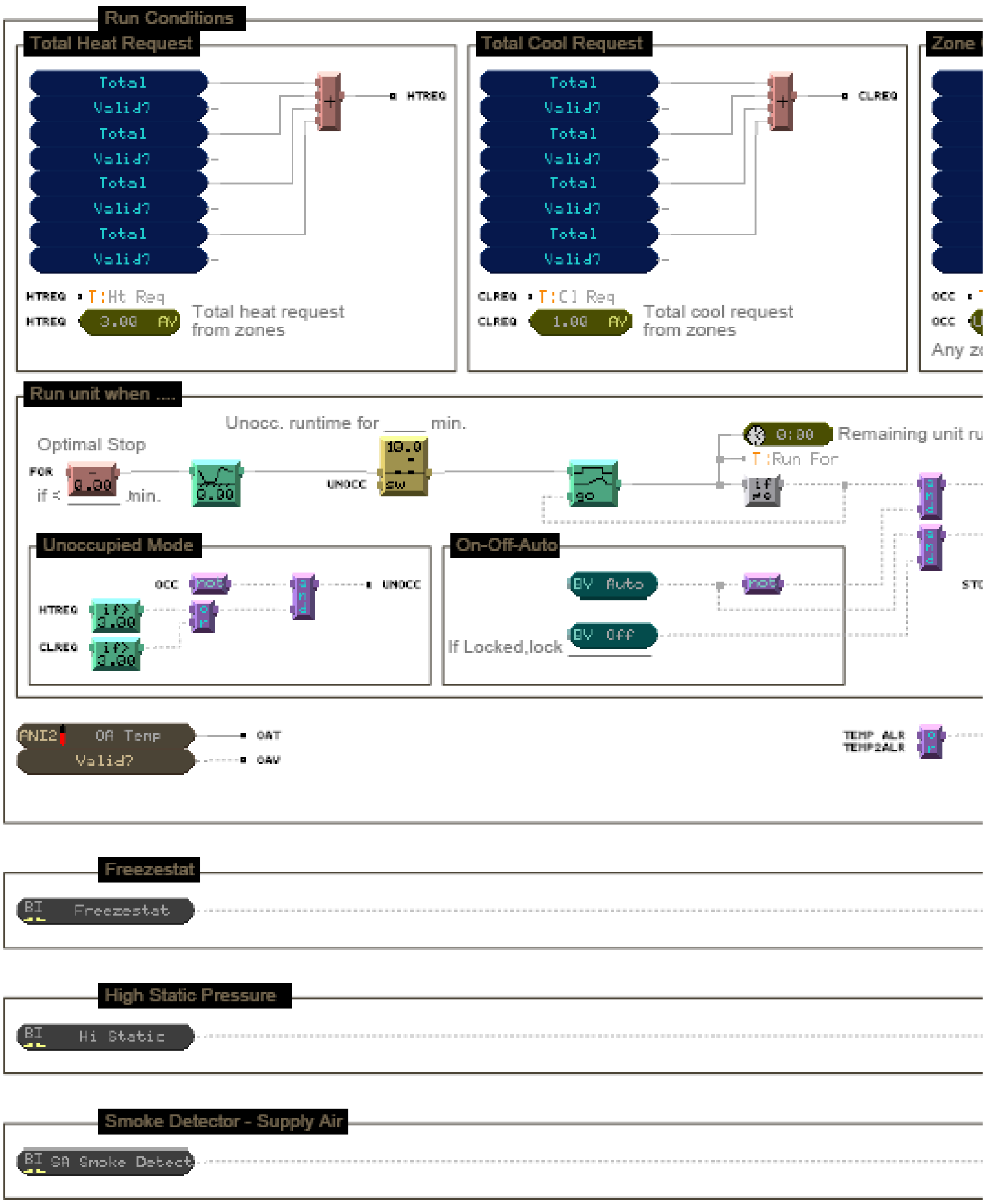

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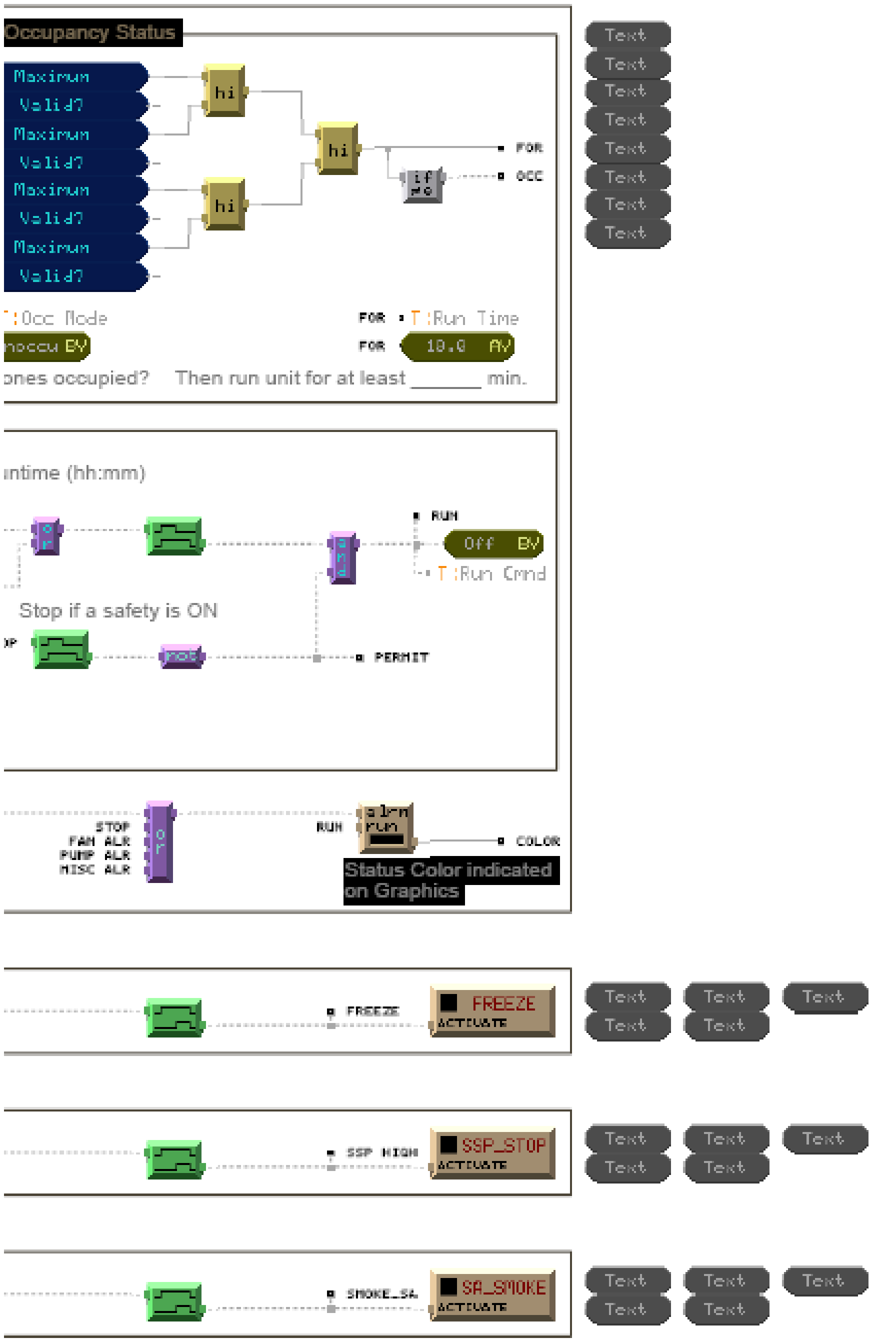

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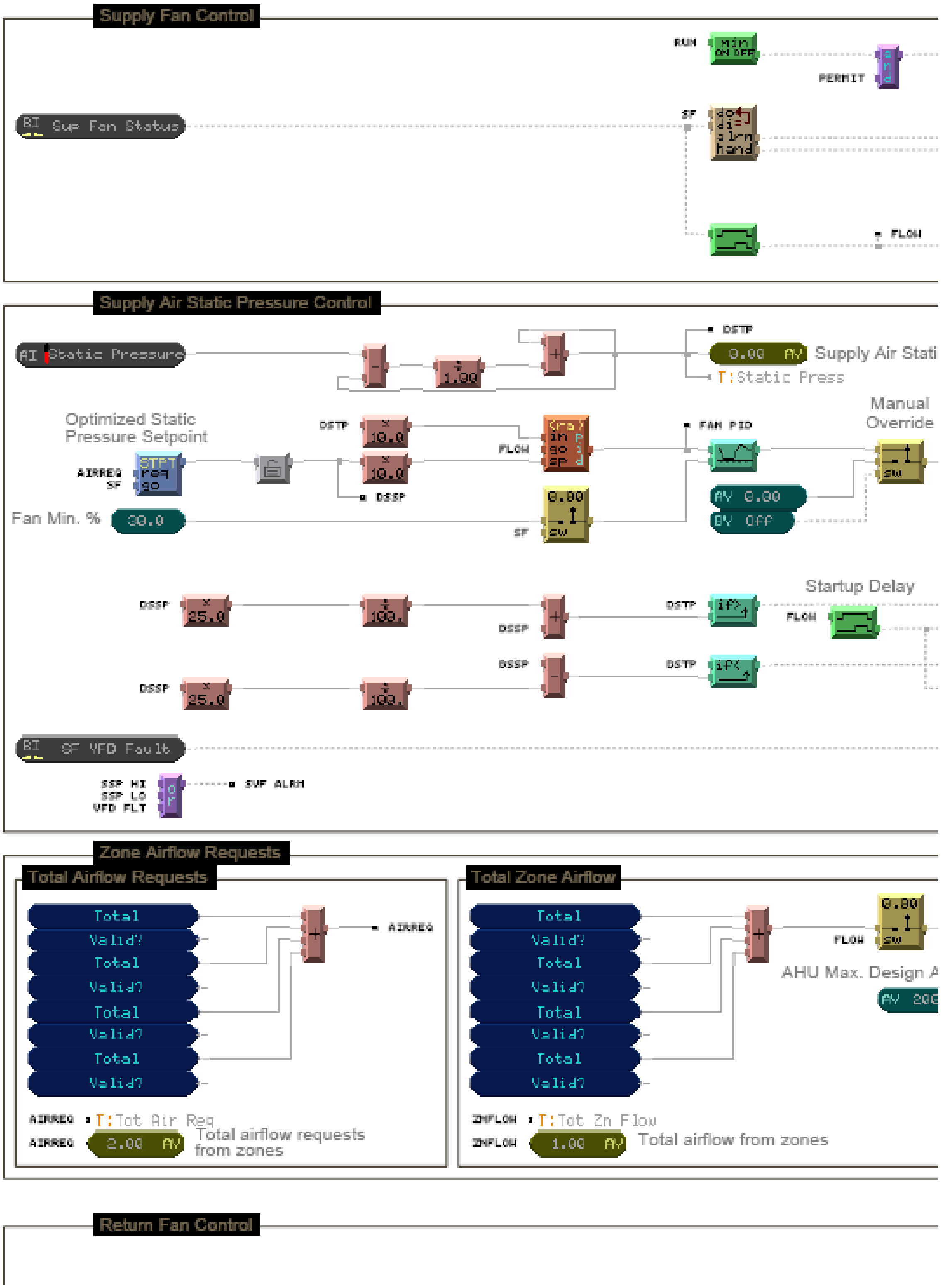

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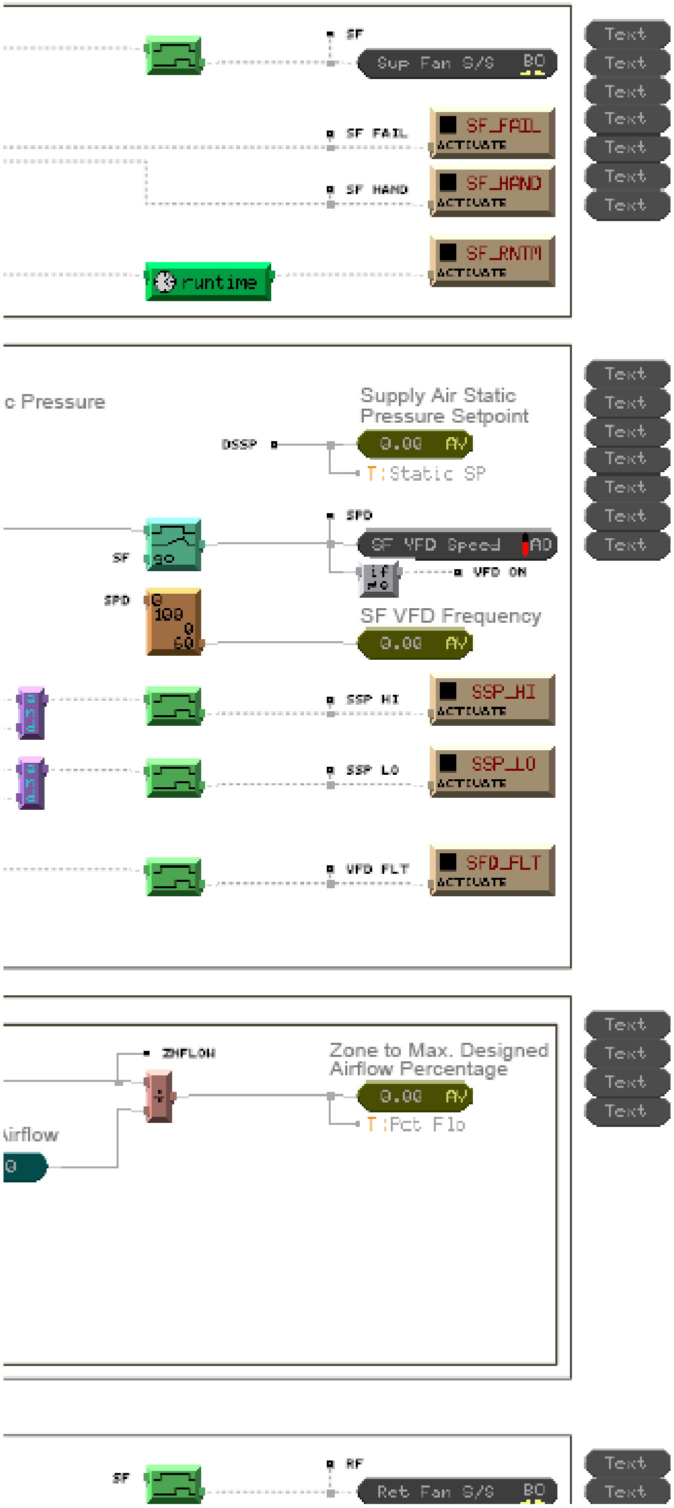

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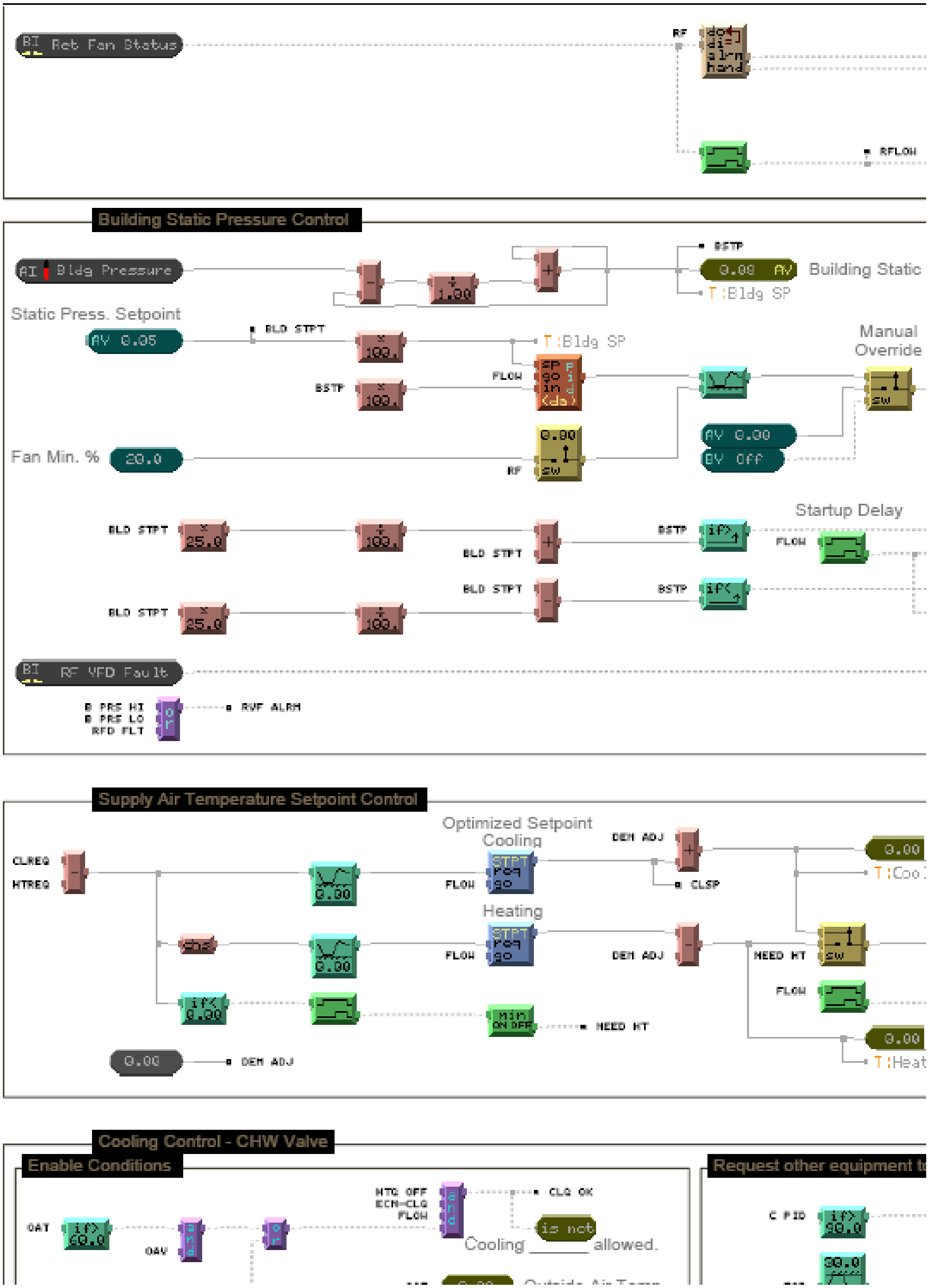

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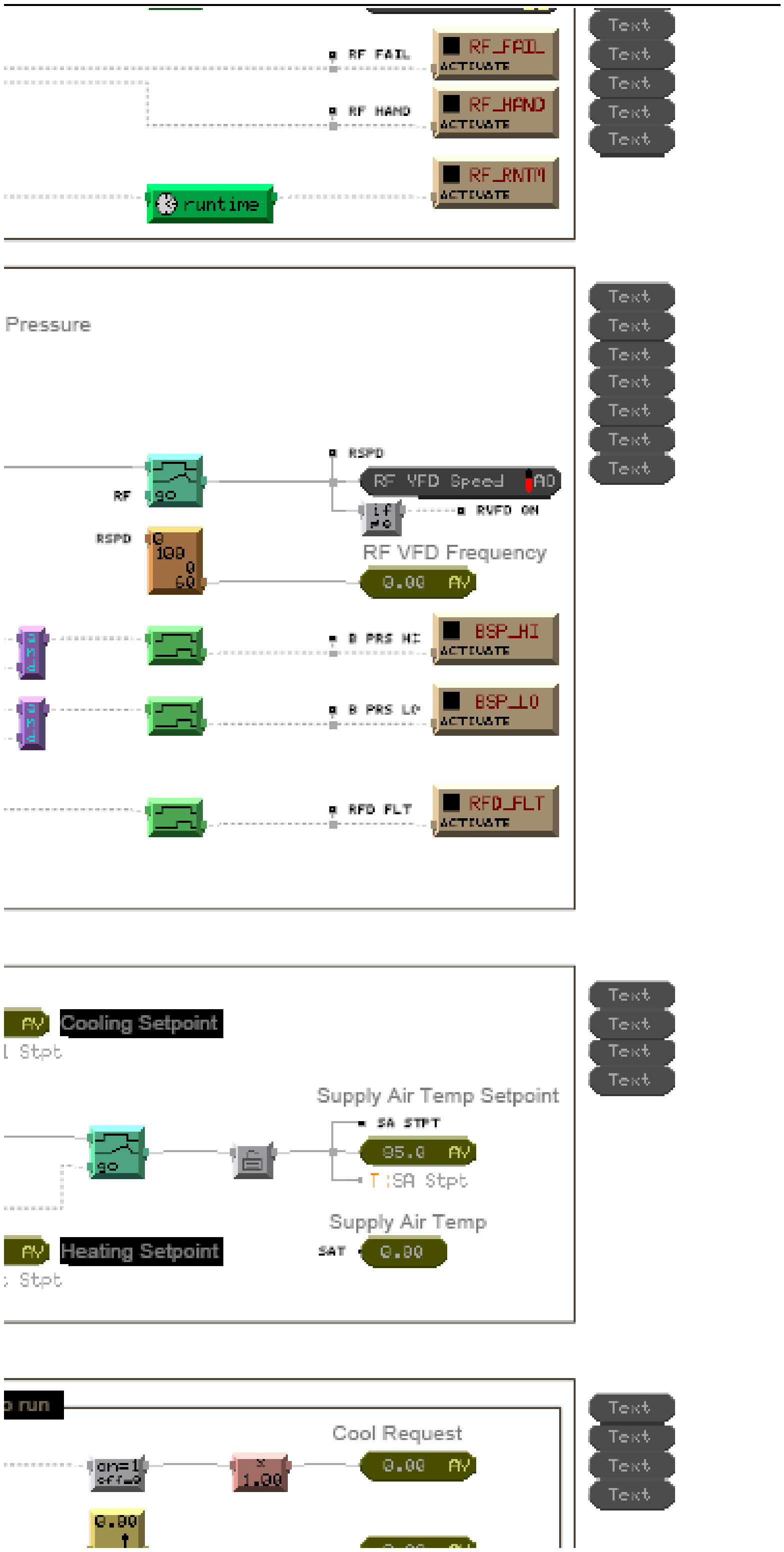

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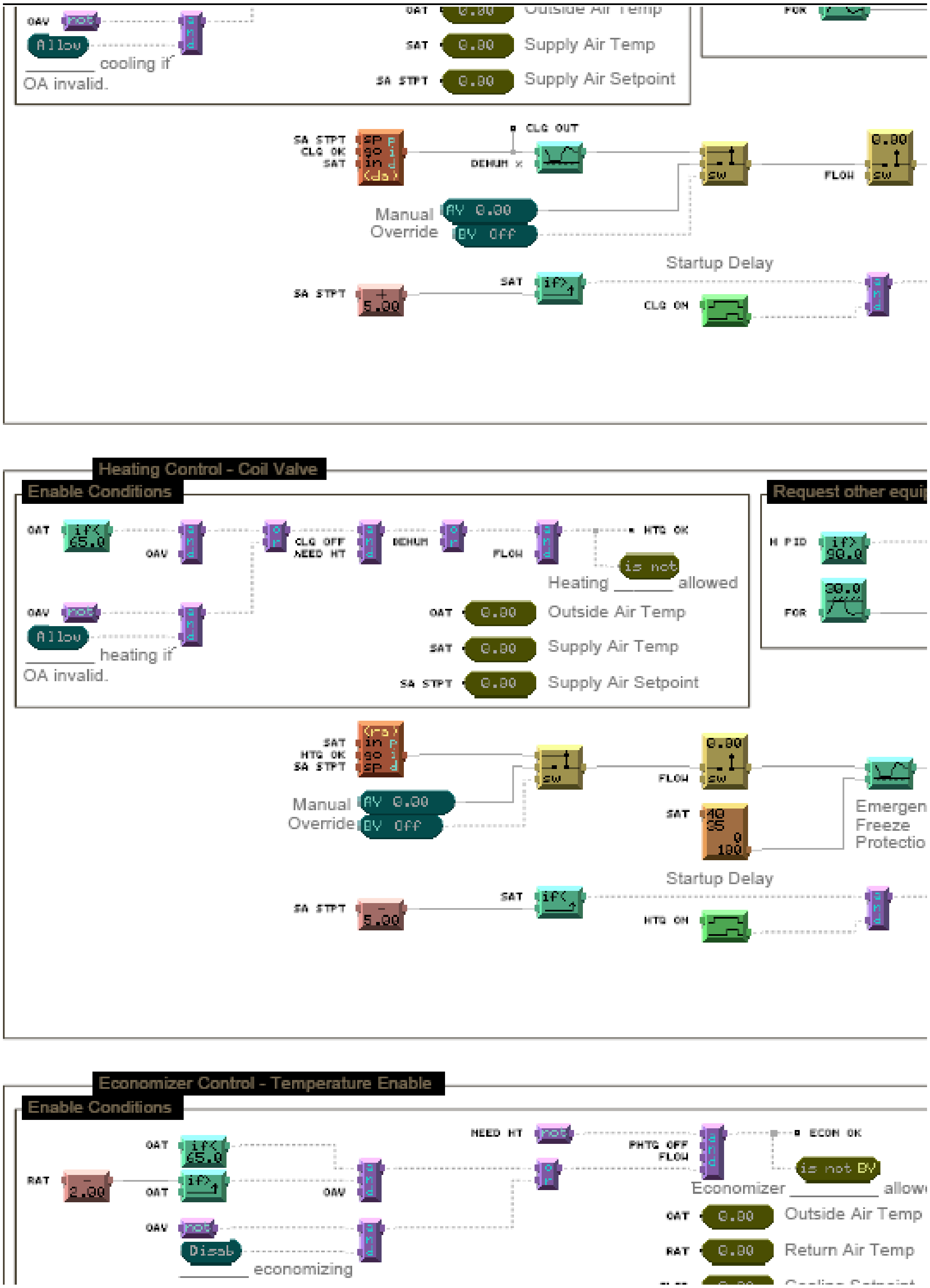

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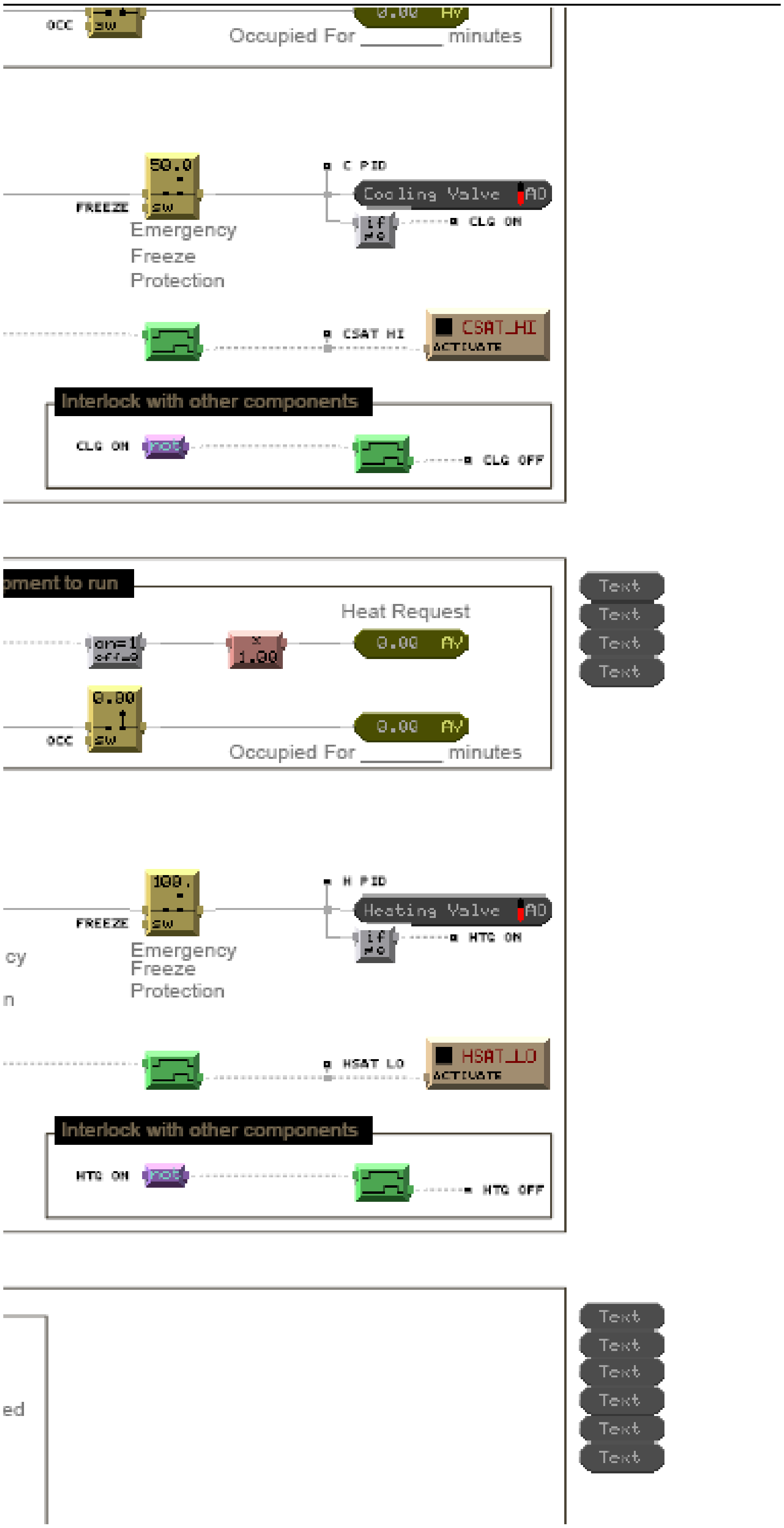

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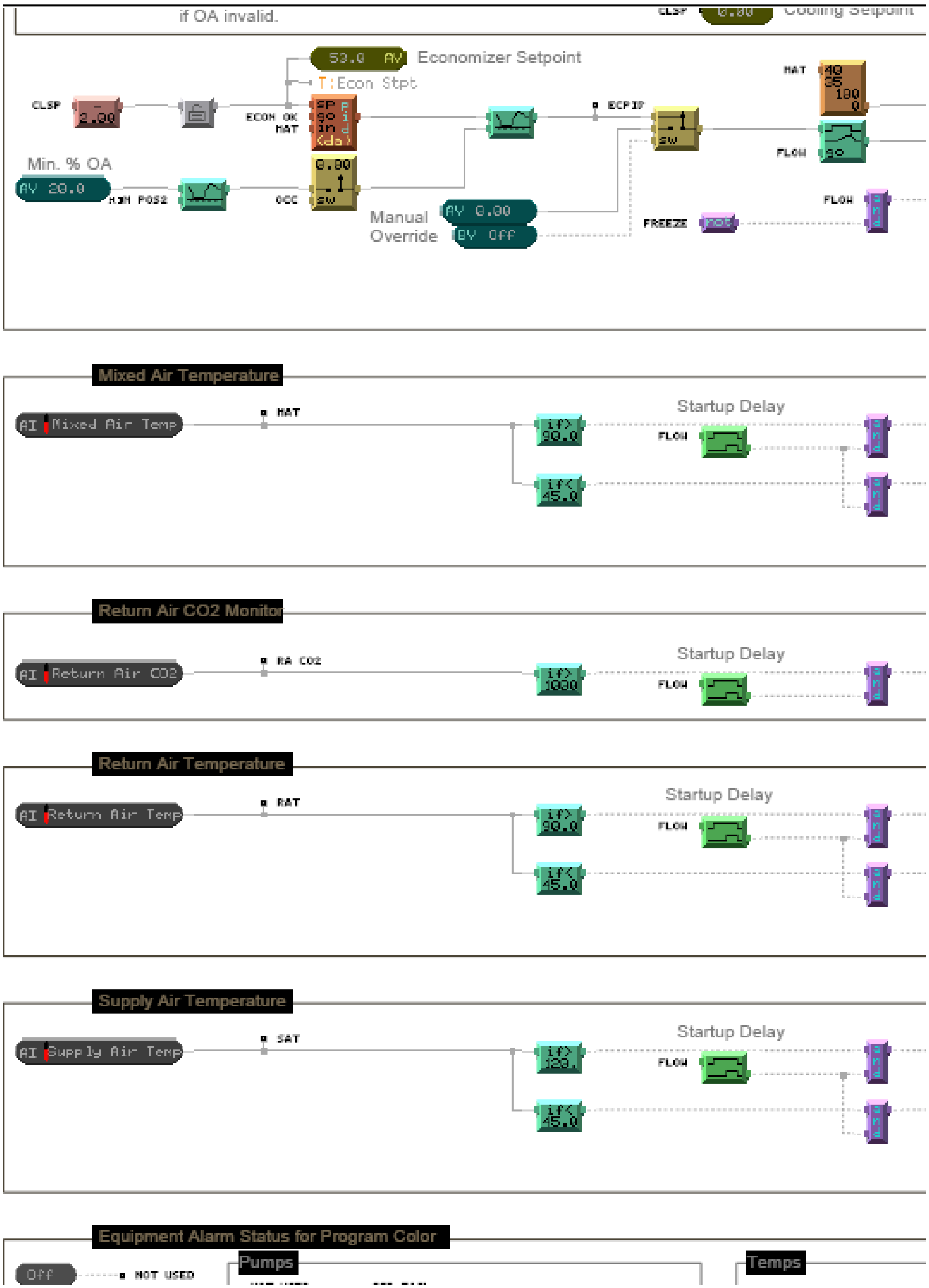

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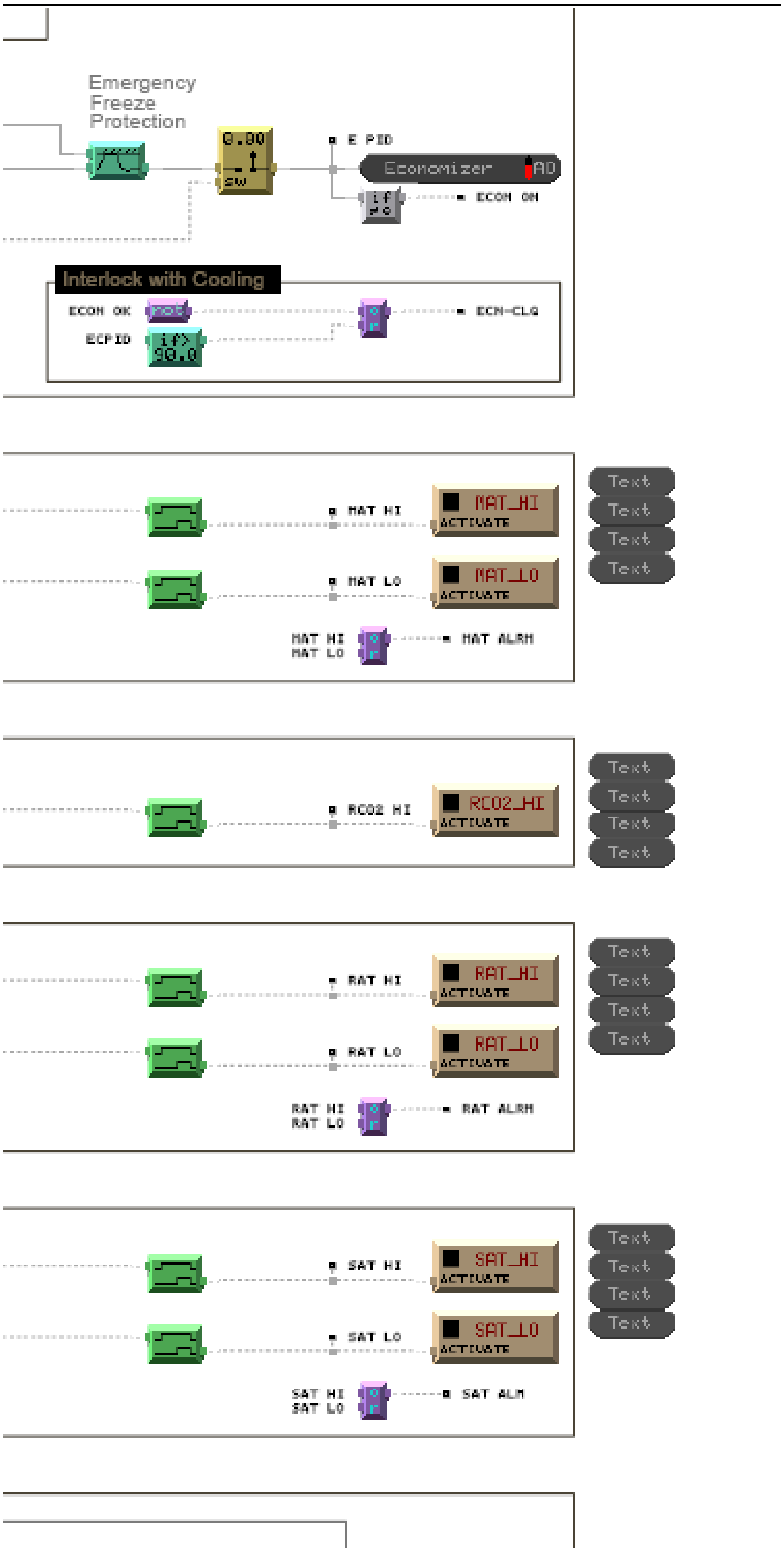

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Page 11 of 12 - Mar 13, 2012 at 3:02:12 PM.

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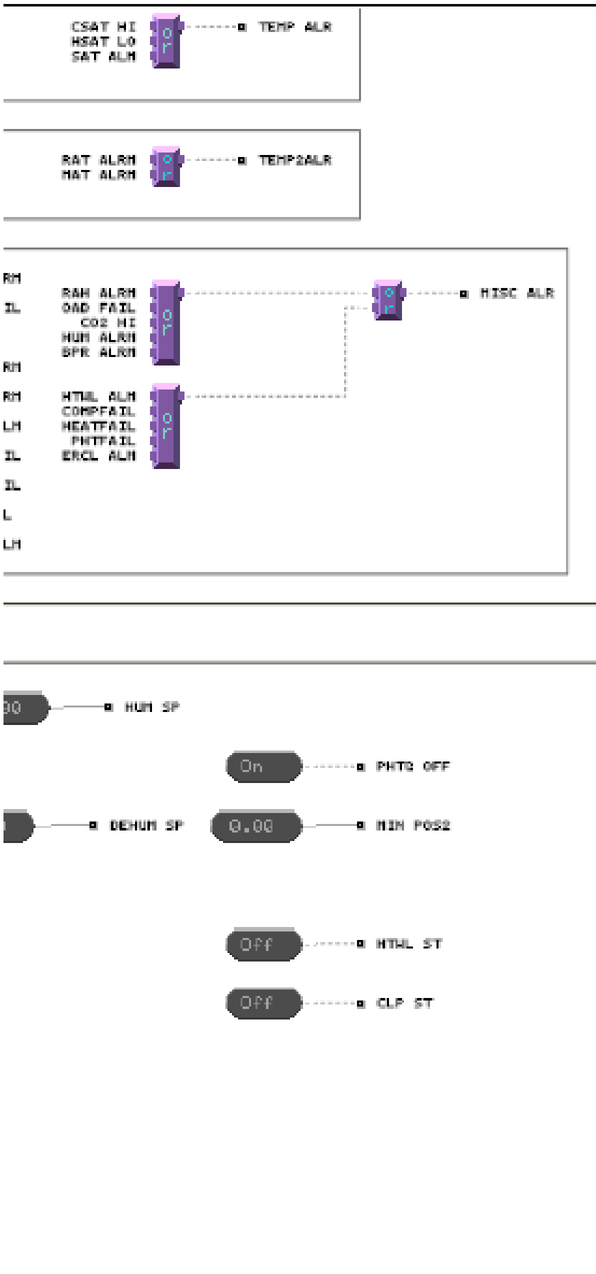

Page 12 of 12 - Mar 13, 2012 at 3:02:13 PM.

SAMPLE SOLAR RADIATION CALCULATIONS

SOLAR RADIATION CALCULATIONS

Month	Day (n)	Hour	(ω)	Latitude ϕ	β	ρg	δ	γ	cosθ	θ	cosθz	θz	a	b	rt	rd	Gsc	Io	Weather Data I v I
1	15	12	-180	40	30	0.2	-9.25267	20	0.50055	59.9635	-0.52085	121.389	-0.06524	1.11159			1367		0
	15	1	-165	40	30	0.2	-9.25267	20	-0.88672	152.464	-0.1712	99.8575	0.87554	0.21752	0.08081	0.02485	1367	22387218.12	0
	15	2	-150	40	30	0.2	-9.25267	20	0.93952	20.0291	0.33186	70.6185	0.17439	0.88386	0.02415	0.10688	1367	20112391.55	0
	15	3	-135	40	30	0.2	-9.25267	20	-0.44795	116.612	-0.78212	141.455	0.29892	0.76551	0.01108	0.22489	1367	10336648.4	0
	15	4	-120	40	30	0.2	-9.25267	20	-0.1661	99.5613	0.40738	65.9599	0.81086	0.27899	0.11921	0.03644	1367	6572722.855	0
	15	5	-105	40	30	0.2	-9.25267	20	0.79313	37.5208	-0.28594	106.615	-0.0915	1.13655	0.07135	0.24261	1367	18157499.62	0
	15	6	-90	40	30	0.2	-9.25267	20	-0.94616	161.113	-0.42203	114.963	0.76758	0.32012	0.04036	0.07996	1367	23180928.11	0
	15	7	-75	40	30	0.2	-9.25267	20	0.73724	42.503	0.47806	61.4413	0.36467	0.70303	0.01181	0.04804	1367	14897457.18	0
	15	8	-60	40	30	0.2	-9.25267	20	-0.08118	94.6567	-0.75343	138.888	0.11777	0.93768	0.00743	0.25919	1367	1619493.189	8
	15	9	-45	40	30	0.2	-9.25267	20	-0.52109	121.405	0.21757	77.4336	0.89582	0.19825	0.13141	0.02971	1367	14602423.38	172
	15	10	-30	40	30	0.2	-9.25267	20	0.96572	15.0462	-0.02625	91.5044	-0.03943	1.08707	0.07299	0.19808	1367	21640477.27	378
	15	11	-15	40	30	0.2	-9.25267	20	-0.85339	148.583	-0.62679	128.814	0.60351	0.47604	0.01196	0.14088	1367	20443179.64	537
	15	12	0	40	30	0.2	-9.25267	20	0.42372	64.9306	0.52947	58.0301	0.56189	0.5156	0.04221	0	1367	7254810.678	638
	15	1	15	40	30	0.2	-9.25267	20	0.30242	72.3972	-0.62679	128.814	-0.01781	1.06653	0.01852	0.27126	1367	7254810.678	672
	15	2	30	40	30	0.2	-9.25267	20	-0.79039	142.222	-0.02625	91.5044	0.9046	0.18991	0.10439	0	1367	20443179.64	639
	15	3	45	40	30	0.2	-9.25267	20	0.9913	7.56538	0.21757	77.4336	0.08282	0.97089	0.04323	0.14088	1367	21640477.27	540
	15	4	60	40	30	0.2	-9.25267	20	-0.62295	128.532	-0.75343	138.888	0.409	0.6609	0.00572	0.19808	1367	14602423.38	382
	15	5	75	40	30	0.2	-9.25267	20	0.04801	87.2484	0.47806	61.4413	0.73518	0.35091	0.09534	0.02971	1367	1619493.189	177
	15	6	90	40	30	0.2	-9.25267	20	0.64282	49.9978	-0.42203	114.963	-0.0866	1.13189	0.05592	0.25919	1367	14897457.18	9
	15	7	105	40	30	0.2	-9.25267	20	-0.93188	158.73	-0.28594	106.615	0.83581	0.25527	0.06173	0.04804	1367	23180928.11	0
	15	8	120	40	30	0.2	-9.25267	20	0.86587	30.0183	0.40738	65.9599	0.25611	0.8062	0.01383	0.07996	1367	18157499.62	0
	15	9	135	40	30	0.2	-9.25267	20	-0.29089	106.911	-0.78212	141.455	0.21449	0.84576	0.01199	0.24261	1367	6572722.855	0
	15	10	150	40	30	0.2	-9.25267	20	-0.33109	109.335	0.33186	70.6185	0.85743	0.23473	0.13011	0.03644	1367	10336648.4	0
	15	11	165	40	30	0.2	-9.25267	20	0.88675	27.5329	-0.1712	99.8575	-0.07782	1.12355	0.07674	0.22489	1367	20112391.55	0
	15	12	180	40	30	0.2	-9.25267	20	-0.9234	157.429	-0.52085	121.389	0.70023	0.38412	0.02616	0.10688	1367	22387218.12	0
Day Total																			4152
Month TOTAL																			128712

PHOTOVOLTAIC ARRAY OUTPUT CALCULATIONS

Kt	Id	Ib	Ig	Rb	It	Hd/H	a1	a2	a3	b1	b2	b3	AREA (M^2)	Zi	ηi	Ei (W)	M
	0	0	0	-0.96103	0	0.99	0.77079	-2.69626	1.9152	-0.1551	#NUM!	0	705.57433	#DIV/0!	#DIV/0!	#DIV/0!	
0	0	0	0	5.17949	0	0.99	27.7129	-48.4542	22.6253	-0.1551	#NUM!	0	705.57433	#DIV/0!	#DIV/0!	#DIV/0!	
0	0	0	0	2.8311	0	0.99	8.50376	-13.1437	5.79955	-0.1551	#NUM!	0	705.57433	#DIV/0!	#DIV/0!	#DIV/0!	
0	0	0	0	0.57274	0	0.99	0.43467	0.00577	0.02246	-0.1551	#NUM!	0	705.57433	#DIV/0!	#DIV/0!	#DIV/0!	
0	0	0	0	-0.40774	0	0.99	0.10704	-0.63655	0.68992	-0.1551	#NUM!	0	705.57433	#DIV/0!	#DIV/0!	#DIV/0!	
0	0	0	0	-2.77377	0	0.99	7.23437	-18.0224	10.2185	-0.1551	#NUM!	0	705.57433	#DIV/0!	#DIV/0!	#DIV/0!	
0	0	0	0	2.24191	0	0.99	5.41513	-7.74618	3.30889	-0.1551	#NUM!	0	705.57433	#DIV/0!	#DIV/0!	#DIV/0!	
0	0	0	0	1.54216	0	0.99	2.64887	-3.13971	1.2528	-0.1551	#NUM!	0	705.57433	#DIV/0!	#DIV/0!	#DIV/0!	
4.94E-06	6.4	1.6	1.6	0.10775	4.54261	0.99	0.0396	0.18055	0.0993	-0.1551	-0.51907	1.4E-06	705.57433	-1.3E+10	9.3E+07	3.63003E+13	
1.178E-05	137.6	34.4	34.4	-2.39502	11.5706	0.99	5.34078	-13.734	7.94054	-0.15509	-0.4718	3.3E-06	705.57433	9E+12	-6.6E+10	2.57437E+16	
1.747E-05	302.4	75.6	75.6	-36.7837	-2574.36	0.99	1346.83	-2742.22	1384.33	-0.15508	-0.45036	4.8E-06	705.57433	7.3E+10	-5.3E+08	2.07385E+14	
2.627E-05	429.6	107.4	107.4	1.36153	439.579	0.99	2.09384	-2.26868	0.88108	-0.15508	-0.42817	7.3E-06	705.57433	1.4E+09	-1E+07	4.00026E+12	
8.794E-05	510.4	127.6	127.6	0.80026	450.637	0.99	0.78554	-0.39487	0.14242	-0.15502	-0.36243	2.4E-05	705.57433	5531754	-40363.9	15822053564	
9.263E-05	537.6	134.4	134.4	-0.48249	302.251	0.99	0.16094	-0.84326	0.81968	-0.15501	-0.35961	2.6E-05	705.57433	1.6E+08	-1169946	4.58602E+11	
3.126E-05	511.2	127.8	127.8	30.1058	4196.59	0.99	911.461	-1782.96	881.076	-0.15507	-0.41871	8.7E-06	705.57433	1.4E+10	-1E+08	4.10756E+13	
2.495E-05	432	108	108	4.5562	787.058	0.99	21.5394	-36.9319	17.0844	-0.15508	-0.43096	6.9E-06	705.57433	9.5E+09	-6.9E+07	2.71921E+13	
2.616E-05	305.6	76.4	76.4	0.82682	271.847	0.99	0.83326	-0.45515	0.16317	-0.15508	-0.42839	7.2E-06	705.57433	1.9E+08	-1384522	5.42713E+11	
0.0001093	141.6	35.4	35.4	0.10042	100.246	0.99	0.03683	0.17637	0.10398	-0.155	-0.35061	3E-05	705.57433	-1.8E+07	128623	50418413767	
6.041E-07	7.2	1.8	1.8	-1.52315	2.17481	0.99	2.0721	-6.04279	3.787	-0.1551	-0.63338	1.7E-07	705.57433	1.6E+14	-1.2E+12	4.70513E+17	
0	0	0	0	3.259	0	0.99	11.1821	-17.9341	8.04362	-0.1551	#NUM!	0	705.57433	#DIV/0!	#DIV/0!	#DIV/0!	
0	0	0	0	2.12547	0	0.99	4.88692	-6.84384	2.89884	-0.1551	#NUM!	0	705.57433	#DIV/0!	#DIV/0!	#DIV/0!	
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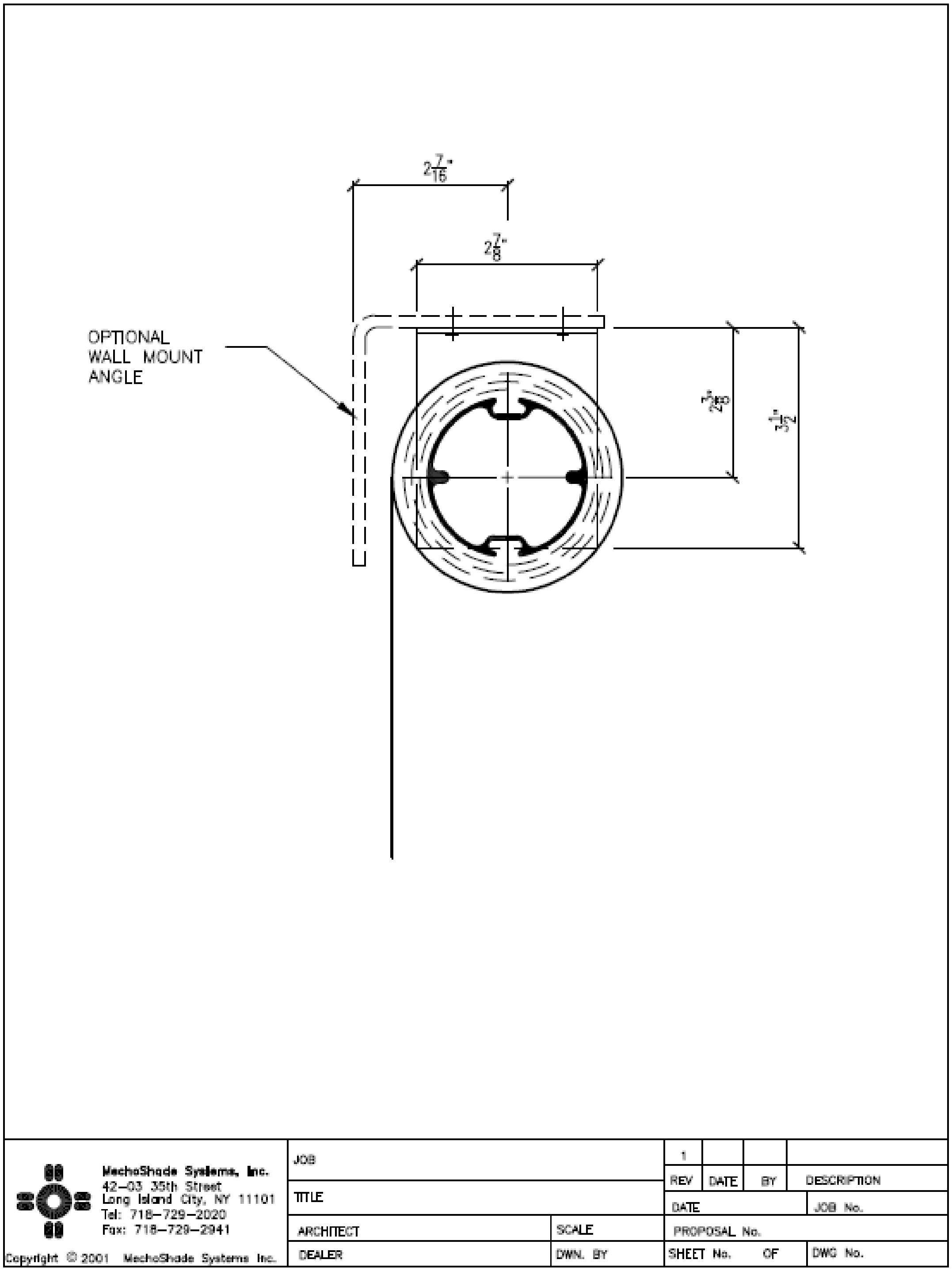
0	0	0	0	-5.17962	0	0.99	25.9621	-58.6617	31.3879	-0.1551	#NUM!	0	705.57433	#DIV/0!	#DIV/0!	#DIV/0!	
0	0	0	0	1.77288	0	0.99	3.45275	-4.44213	1.82252	-0.1551	#NUM!	0	705.57433	#DIV/0!	#DIV/0!	#DIV/0!	
																4.96574E+17	
																1.53938E+19	

MECHOSYSTEMS INTERNAL SHADE CUT SHEET

http://mechoshade.com/motorizedshades/pdf/electro1_standard.pdf



REVISED LEED SCORECARD

LEED-NC Green Building Rating System for New Construction & Major Renovations, Version 2.2			
		Possible Points	River Vue Apartments
Sustainable Sites			
Prereq 1	Construction Activity Pollution Prevention		YES
Credit 1	Site Selection	1	1
Credit 2	Development Density & Community Connectivity	1	1
Credit 3	Brownfield Redevelopment	1	
Credit 4.1	Alternative Transportation - Public Transportation Access	1	1
Credit 4.2	Alternative Transportation - Bicycle Storage & Changing Rooms	1	
Credit 4.3	Alternative Transportation - Low Emitting & Fuel Efficient Vehicles	1	
Credit 4.4	Alternative Transportation - Parking Capacity	1	
Credit 5.1	Site Development - Protect or Restore Habitat	1	1
Credit 5.2	Site Development - Maximize Open Space	1	
Credit 6.1	Storm water Design - Quantity Control	1	1
Credit 6.2	Storm water Design - Quality Control	1	
Credit 7.1	Heat Island Effect - Non-Roof	1	1
Credit 7.2	Heat Island Effect - Roof	1	1
Credit 8	Light Pollution Reduction	1	
Water Efficiency			
Credit 1.1	Water Efficient Landscaping, Reduce by 50%	1	
Credit 1.2	Water Efficient Landscaping, No Potable Use or No Irrigation	1	1
Credit 2	Innovative Wastewater Technologies	1	1
Credit 3.1	Water Use Reduction by 20%	1	1
Credit 3.2	Water Use Reduction by 30%	1	

Energy & Atmosphere			
Prereq 1	Fundamental Commissioning of the Building Energy Systems		YES
Prereq 2	Minimum Energy Performance		YES
Prereq 3	Fundamental Refrigerant Management		YES
Credit 1	Optimize Energy Performance	10	5
Credit 2	On-Site Renewable Energy	3	
Credit 3	Enhanced Commissioning	1	1
Credit 4	Enhanced Refrigerant Management	1	1
Credit 5	Measurement & Verification	1	
Credit 6	Green Power	1	1
Materials & Resources			
Prereq 1	Storage & Collection of Recyclables		YES
Credit 1.1	Building Reuse, Maintain 75% of Existing Walls, Floors, & Roof	1	1
Credit 1.2	Building Reuse, Maintain 95% of Existing Walls, Floors, & Roof	1	1
Credit 1.3	Building Reuse, Maintain 50% of Interior Non-Structural Elements	1	
Credit 2.1	Construction Waste Management, Divert 50% from Disposal	1	1
Credit 2.2	Construction Waste Management, Divert 75% from Disposal	1	
Credit 3.1	Materials Reuse of 5%	1	1
Credit 3.2	Materials Reuse of 10%	1	
Credit 4.1	Recycled Content, 10% (post-consumer + 1/2 pre-consumer)	1	1
Credit 4.2	Recycled Content, 20% (post-consumer + 1/2 pre-consumer)	1	
Credit 5.1	Regional Materials, 10% Extracted, Processed & Manufactured Regionally	1	1
Credit 5.2	Regional Materials, 20% Extracted, Processed & Manufactured Regionally	1	
Credit 6	Rapidly Renewable Materials	1	
Credit 7	Certified Wood	1	
Indoor Environmental Quality			
Prereq 1	Minimum IAQ Performance		YES
Prereq 2	Environmental Tobacco Smoke (ETS) Control		YES
Credit 1	Outdoor Air Delivery Monitoring	1	1
Credit 2	Increased Ventilation	1	1
Credit 3.1	Construction IAQ Management Plan, During Construction	1	1
Credit 3.2	Construction IAQ Management Plan, Before Occupancy	1	1
Credit	Low-Emitting Materials, Adhesives & Sealants	1	1

4.1			
Credit 4.2	Low-Emitting Materials, Paints & Coatings	1	1
Credit 4.3	Low-Emitting Materials, Carpet Systems	1	1
Credit 4.4	Low-Emitting Materials, Composite Wood & Agrifiber Products	1	
Credit 5	Indoor Chemical & Pollutant Source Control	1	1
Credit 6.1	Controllability of Systems, Lighting	1	
Credit 6.2	Controllability of Systems, Thermal Comfort	1	1
Credit 7.1	Thermal Comfort, Design	1	1
Credit 7.2	Thermal Comfort, Verification	1	1
Credit 8.1	Daylight & Views, Daylight 75% of Spaces	1	1
Credit 8.2	Daylight & Views, Views for 90% of Spaces	1	1
Innovation & Design Process			
Credit 1.1	Innovation in Design	1	
Credit 1.2	Innovation in Design	1	
Credit 1.3	Innovation in Design	1	
Credit 1.4	Innovation in Design	1	
Credit 2	LEED Accredited Professional	1	
TOTAL		69	37

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- Environmental Protection Agency's website www.epa.gov.
- "Source Energy and Emission Factors for Energy Use in Buildings." M. Deru and P. Torcellini. National Renewable Energy Laboratory. June 2007.

Utility Cost Data was gathered from:

- http://www.puco.ohio.gov/puco/index.cfm/apples-to-apples/columbia-gas-of-ohio-apples-to-apples-chart/
- http://inflationdata.com/Inflation/images/charts/Annual_Inflation/annual_inflation_chart.htm

General building and site information was found at:

- http://www.city.pittsburgh.pa.us/cp/html/land_use_control_and_zoning.html
- Color photos taken by Laura Pica, August 2011
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- ANSI/ASHRAE (2007), Standard 62.1-2007, Ventilation for Acceptable Indoor Air Quality. American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., Atlanta, GA, 2007.
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- "CO2 Based Ventilation Control." ASHRAE Journal, February 2012. Published by W. Comstock. Atlanta, GA.
- GE CO2 Sensors :http://www.ge-mcs.com/en/co2/wall-mount/ventostat-8000-series.html

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- Vendor Information : http://www.siliconsolar.com/off-grid-solar-systems.html
- Photovoltaic array design guide by PV Watts:http://rredc.nrel.gov/solar/calculators/PVWATTS/version1/system.html

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