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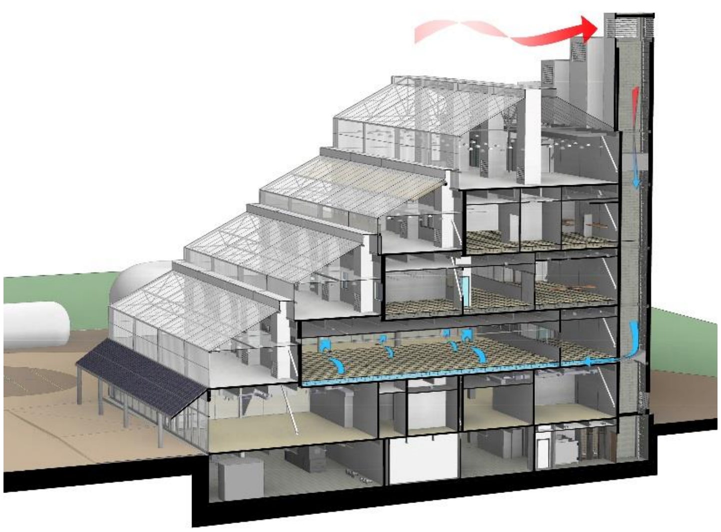


APPENDIX A – REFERENCES

Software:

IES Virtual Environment 2014

Autodesk Revit 2015

Google Sketchup 2014

Trane TRACE 700

Engineering Equation Solver

Microsoft Word, PowerPoint, Excel 2013

Codes:

Wisconsin Commercial Buildings – Administrative Code

Florida Building Codes

International Mechanical Code 2012

International Fuel Gas Code 2012

International Plumbing Code 2012

Handbooks and Standards:

ASHRAE 90.1-2013: Energy Standard Except for Low-Rise Residential Buildings

ASHRAE 62.1-2013: Ventilation for Acceptable Indoor Air Quality

2007 ASHRAE Handbook – HVAC Applications

2013 ASHRAE Handbook – Fundamentals

2009 ASHRAE Pocket Guide

ASHRAE UFAD Design Guide- 2013

Advanced Energy Design Guide for K-12 School Buildings

HVAC Equations, Data, and Rules of Thumb

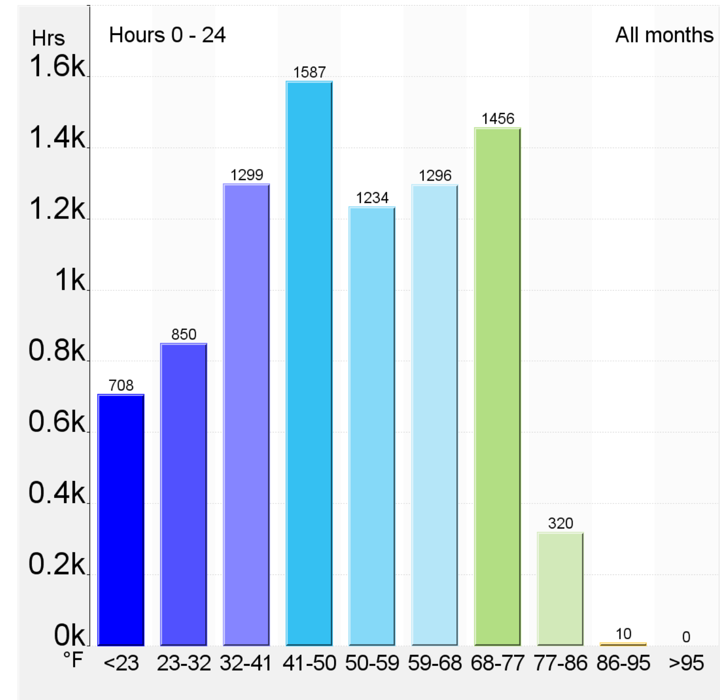
References:

1. "Building Technologies Group." *U.S Department of Energy* (n.d.): n. pag. Web.
2. Eisenmann. "Sustainability in an Urban Environment through Anaerobic Digestion." *An Overview of How One Urban Farm Is Fighting the Food Desert Epidemic by Utilizing Anaerobic Digestion to Create a Net-Zero Energy System* (n.d.): n. pag. Web.Eisenmann
3. Noren, Corfitz. "Evaluation of CO2-fertilization of a Greenhouse with Flue Gases from a Microturbine." *Arbetsrapport SGC A32* (2002): n. pag. Web.
4. Matthey, Johnson. *Gas Turbine Oxidation Catalyst* (n.d.): n. pag. Web.
5. "Water Detail - Lincoln Creek, Milwaukee River South Watershed (MI02)."Water Detail - Lincoln Creek, Milwaukee River South Watershed (MI02). N.p., n.d. Web. 8 Nov. 2014.
6. "Plant Growth Factors: Temperature." Plant Growth Factors: Temperature. N.p., n.d.
7. "Transpiration - The Water Cycle." *, from USGS Water-Science School*. N.p., n.d. Web.
8. Salazar, Tomas, and Dr. Cecilia Stanghellini. "An Estimate of Greenhouse Transpiration, Condensation and Natural Ventilation Fluxes." *Thesis Farm Technology Group* (2010). Print.
9. "TABLE Z-1 Limits for Air Contaminants. - 1910.1000 TABLE Z-1." *TABLE Z-1 Limits for Air Contaminants. - 1910.1000 TABLE Z-1*. N.p., n.d. Web.
10. Mediterranean Workshop On New Technologies, Of Recycling Non Conventional Water, and In Protected Cultiv. *The Watergy Greenhouse: Improved Productivity and Water Use Efficiency Using a Closed Greenhouse* (n.d.): n. pag. Web.
11. Sheaffer, Craig C., and Kristine M. Moncada. Introduction to Agronomy. Clifton Park, NY: Delmar, 2009

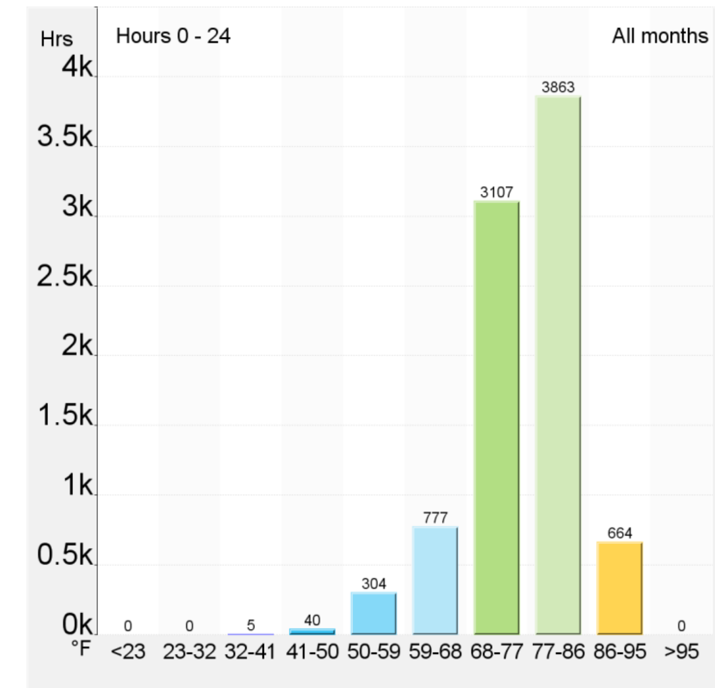
APPENDIX B – CLIMATE & WEATHER DATA

Climate Data: A detailed climatic analysis of both Milwaukee and Miami climates was performed in order to determine the cooling and heating loads present and to properly size mechanical equipment. The graphs displayed represent the climate for Milwaukee, WI.

Temperature Distribution: A side by side comparison of the Milwaukee climate to the Miami climate. The Milwaukee climate features an evenly distributed temperature range over the course of a year. Hot stresses dominate the Miami climate for most of the year. The airside mechanical systems are designed to perform in both climates.

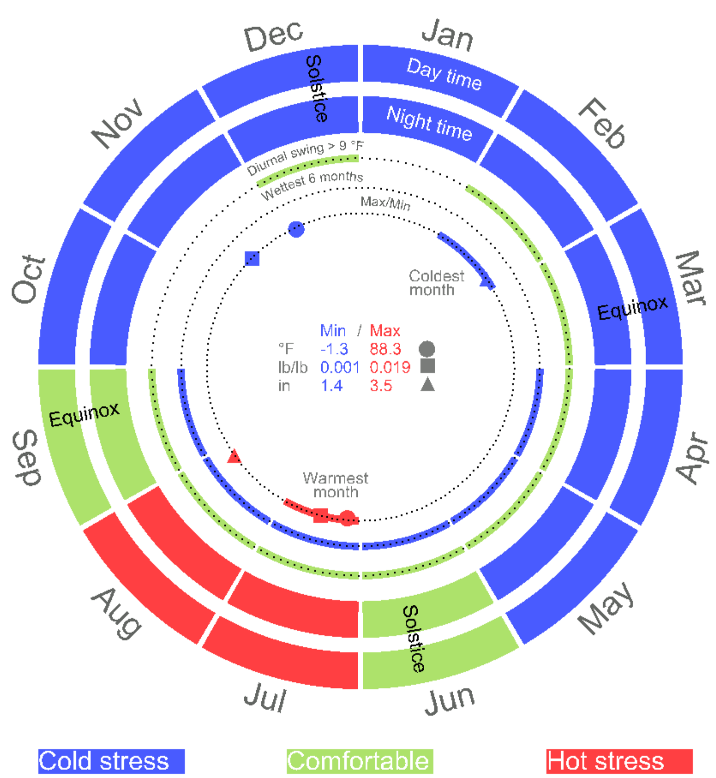


Milwaukee, WI

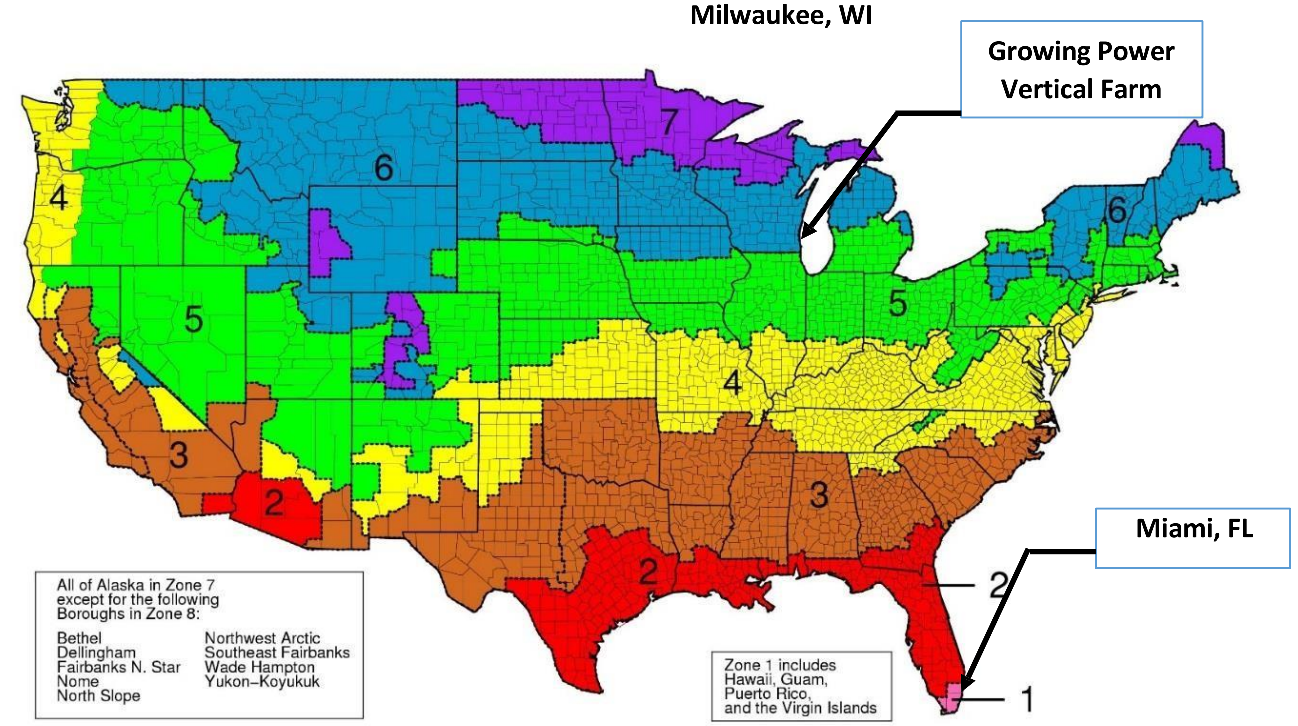


Miami, FL

Milwaukee, WI Climate Summary Metrics



IES VE Climatic Conditions: A graphical representation of the Milwaukee climate displays when the hot and cold stresses occur during a typical meteorological year. Weather conditions are comfortable in June and September, while July and August need comfort cooling. The heating loads dominate the majority of the year for Milwaukee.



Weather Data:

Milwaukee, WI

CDD(50.0) = 2654.3
HDD(65.0) = 6159.7
Annual Average Wind Speed = 13.15 mph
Annual Rainfall = 34 inches

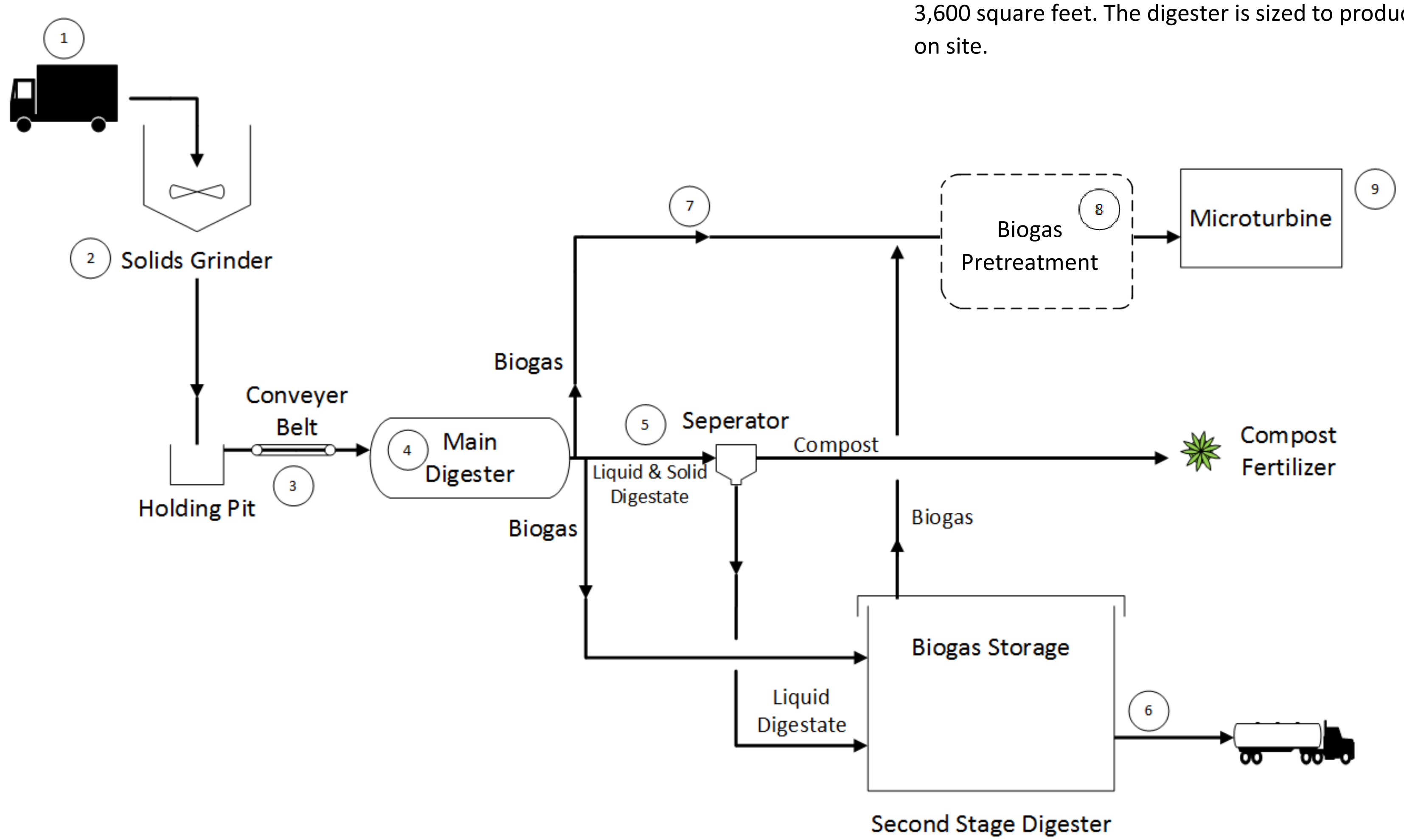
Miami, FL

CDD(50.0) = 9403.8
HDD(65.0) = 130.3
Annual Average Wind Speed = 9.68 mph
Annual Rainfall = 56 inches

Figure M4: Department of Energy Climate Map of United States. Milwaukee, WI is located in Zone 6 and Miami, FL is located in Zone 1

APPENDIX C – ANAEROBIC DIGESTION ANALYSIS

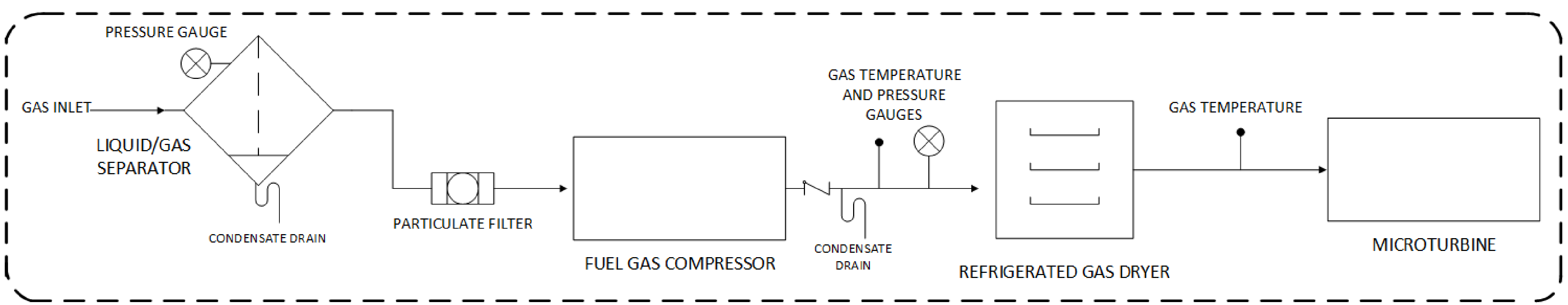
Anaerobic Digester Selection: A plug-flow mesophilic anaerobic digester was selected to create usable biogas for the Vertical Farm. The digester produces approximately 2.2 million BTU/hr of usable biogas and has a total footprint of 3,600 square feet. The digester is sized to produce enough energy for both the Vertical Farm and existing greenhouses on site.



Anaerobic Digestion Process:

1. Single garbage truck delivers 14 tons of food waste per day into a solids grinder
2. Solids grinder breaks down food and sends it to a holding pit
3. Conveyer belt delivers waste to main digester at constant rate
4. Main stage digester converts food into biogas, solid, and liquid fertilizer
5. Solid and liquid digester sent to a separator where liquid digestate is filtered out and sent to second stage digester, where it will continue to be broken down into biogas. Solid digestate is converted to compost.
6. Liquid digestate stored is delivered as usable biofertilizer
7. Usable biogas is sent to a biogas pretreatment system and excess biogas is sent to second stage digester for future use.
8. Biogas pretreatment system completely eliminates liquid from biogas through a fuel gas compressor and gas dryer.
9. Treated biogas is sent to microturbine to produce heat and electricity

Biogas Pretreatment System

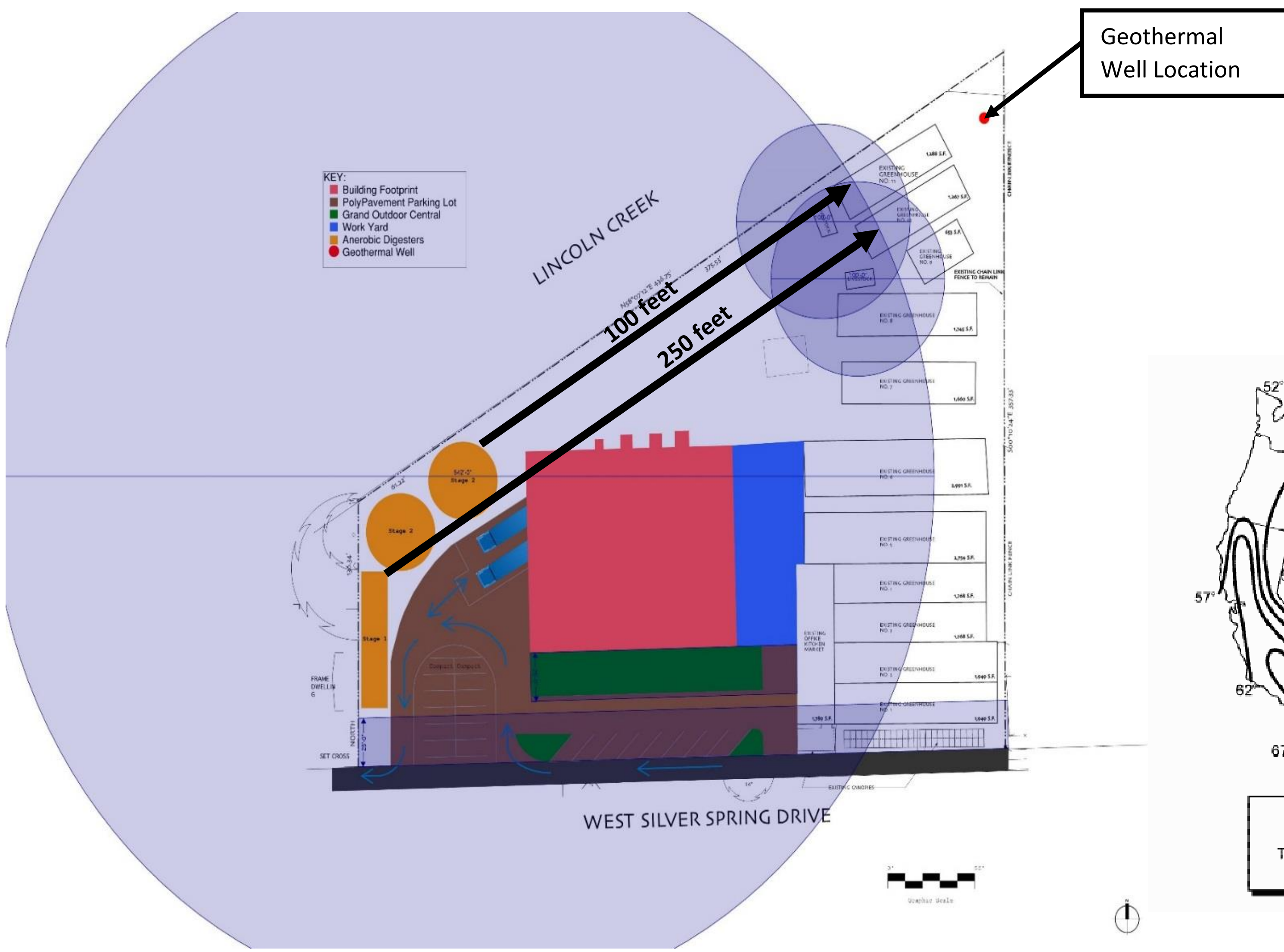


Biogas Pretreatment System: A pretreatment system is needed to eliminate all water from the biogas.

- *Liquid/Gas Separator* – Separate usable biogas from liquid. Condensate is drained out of system.
- *Fuel Gas Compressor* – Compress biogas to a cool temperature. Produces condensate and eliminate all water within the biogas
- *Refrigerated Gas Dryer* – A dryer is used to increase the cool biogas in order to raise the temperature above the dew point of the microturbine

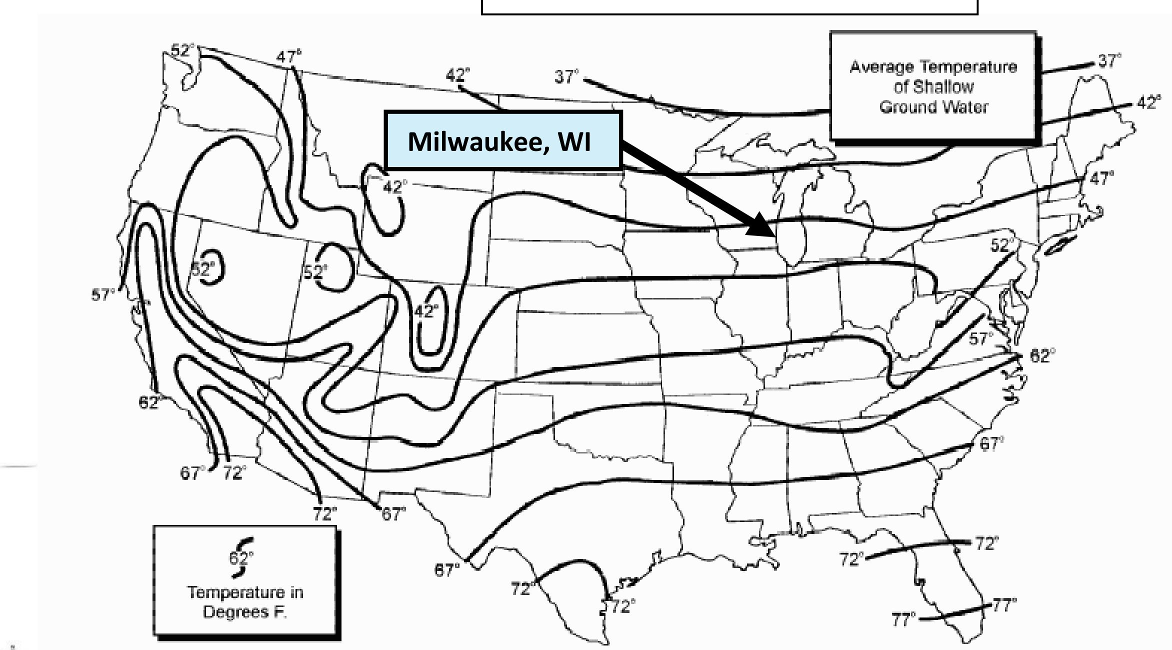
APPENDIX D – GEOTHERMAL WELL ANALYSIS

Geothermal Location: The hybrid condenser water system consists of a geothermal well that will pump a maximum of 450 gallons per minute of groundwater that will be used in conjunction with the condenser water loop. An extensive code analysis was done to ensure that the geothermal can be implemented and installed on the site. The *Wisconsin State Legislature NR 812: Well Construction and Pump Installation* was carefully reviewed to determine the placement of the geothermal well. The optimal location was for the well to be placed in the northeast corner of the site due to the large distance separation it needs to be from the anaerobic digester (orange). The purple circles denote the minimum distance that is required from the well.



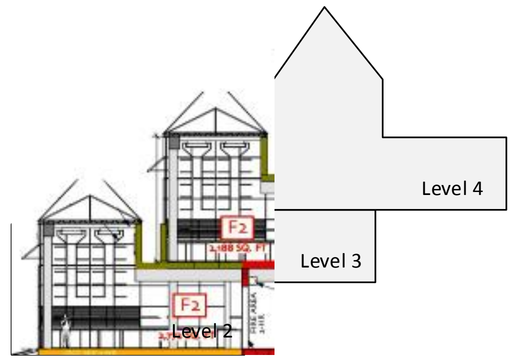
Geothermal Well Location Parameter Checklist		
Item	**Distance Separation**	**Parameter Met [Yes/No]**
buried gravity flow sanitary building drain	8 feet	Yes
buried gravity flow sanitary building sewer	8 feet	Yes
buried storm collector sewer or stormwater culvert	8 feet	Yes
buried sanitary building drain or sanitary building sewer	25 feet	Yes
buried pressurized sanitary building sewer	25 feet	Yes
animal barn or animal shelter	50 feet	Yes
animal yard	50 feet	Yes
animal barn pen	50 feet	Yes
bulk surface storage tank or other container with a capacity greater than 1500 gallons or any bulk buried storage tank including, for both surface or buried tanks, regardless of capacity, any associated buried piping, for any solid, semi-solid, or liquid product, including any associated above ground piping	100 feet	Yes
solid waste processing facility	250 feet	Yes
solid waste transfer facility	250 feet	Yes

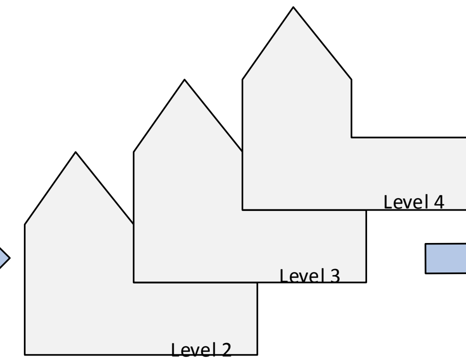
Average Groundwater Temperatures

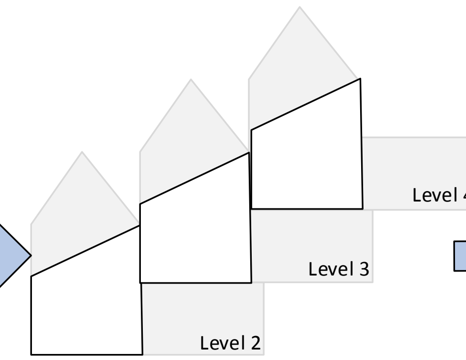


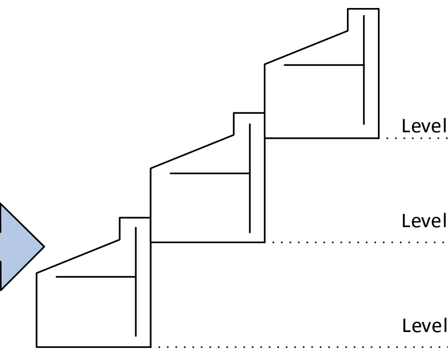
Average Groundwater Temperatures: The EPA publishes a map displaying the average shallow groundwater temperatures around the country. The Mechanical Team took advantage of the 47°F average groundwater temperature in Milwaukee, WI by providing a hybrid condenser water system.

APPENDIX E– GREENHOUSE TRANSFORMATION









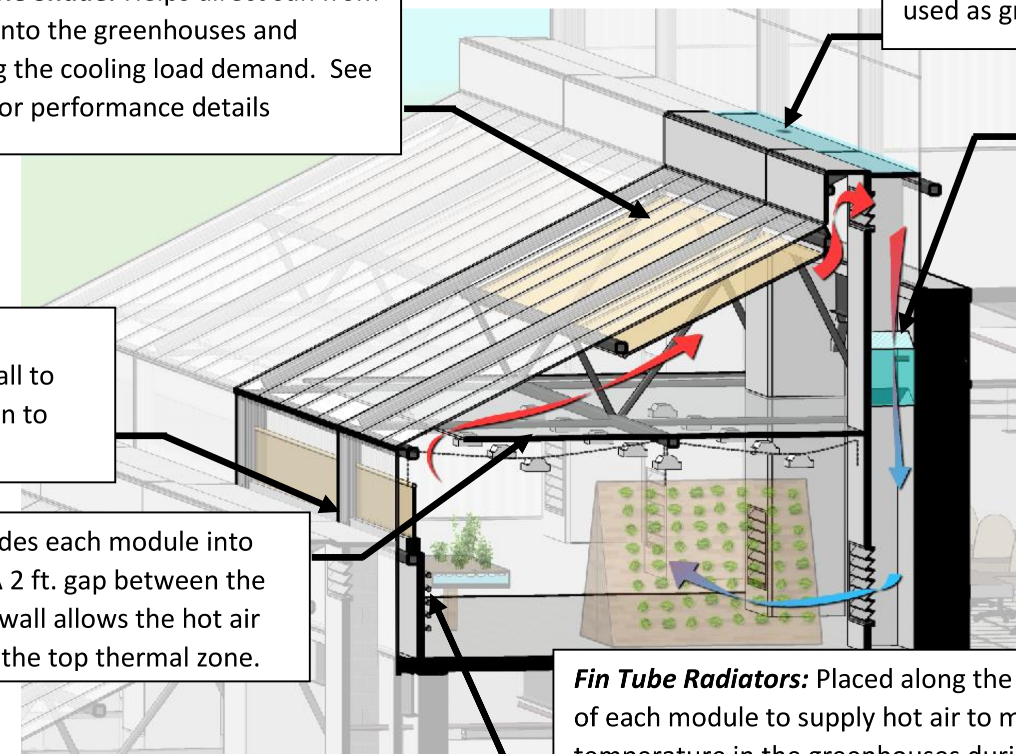
	TKWA Design	Cavity Removal	Eliminate Unused Space	Synthesis Design
Changes that Occured	Original design from competition provided drawings by TKWA Architects.	Greenhouses were adjusted so that there is no longer a large rain/snow collection gap between each tier.	Transition to a single slope glazing system with a smaller growing volume. North portion received very little daylight and therefore was eliminated from the greenhouse.	Utilize similar single slope design however stagger tiers and coordinate heights by floor in order to decrease shading.
Daylight Delivery	Large glazing area will provide ample daylight to top plants, although the large volume will create shading issues for lower crops.	Similar daylight issues as initial design. The north facing sloped glazing lets in diffuse light. North covered areas in the rear do not receive adequate daylight for sustained plant growth.	Decreased growing area is optimal for limiting self shading between crops. Back of greenhouse spaces that did not receive light have been removed and used elsewhere.	Module design creates optimum lighting requirements for specific carbon three plants. Steel structural system minimizes shading and shade mounted system has adequate support.
Ventilation	Open loop system, 100% Outside Air	Open loop system, 100% Outside Air	Open loop system, 100% Outside Air	Closed loop heating and cooling system. Lots of benefits including lower loads and increased controllability
Adaptability	Angle of glazing is not optimized	Snow accumulation between greenhouses will become an issue.	Single slope glazing is optimal for Miami but works well in Milwaukee as well. Reduced heating and cooling in all climates due to reduced glazing area.	Cooling system, pest control, and carbon dioxide fertilization is sized for Miami. The exact same module can be used anywhere.
Constructability	Tall structure requires concrete and steel system with precast beams. Not ideal. Snow and Rain gutter between greenhouses will cause problems	Similar issues as initial design. Shared walls between greenhouses are difficult to coordinate and construct.	Simple to construct but large top slant poses logistic issues.	Optimal due to consistent and reasonable sized steel and glazing. Allows trusses to be preassembled and trucked to site.
Heating and Cooling	Height of greenhouse will cause stratification resulting in a non-homogenous growing environment	Height of greenhouse will cause stratification resulting in a non-homogenous growing environment. Less glazing than initial design helps.	Less glazing. Reduced stratification resulting in a more homogenous growing enviornment.	Refer to Mechanical Report
Operation Maintenance	Greenhouse is 20' high. This will require a rotational plant system that may have failures and maintenance issues	Similar issues as initial design. Tall growing area will pose problems.	Easier maintenance issues with regards to farming operations. Angled slope is still difficult to maintain	Easier maintenance issues with regards to farming operations. Angled slope is still difficult to maintain
Cost (construction and operation)	Cost of construction will be high due to large floor to ceiling heights	Cost of construction will be high due to large floor to ceiling heights	Reasonable cost due to repeatability	Cost is decreased due to prefabrication offsite and waste is decreased.

APPENDIX F– GREENHOUSE DESIGN

The greenhouse design provided in the original drawings transitioned from an open, ventilated greenhouse to a closed greenhouse. The closed greenhouse provides four advantages:

1. Reduced Water Usage
2. Increased CO_2 concentration
3. Pest Control
4. Temperature and humidity control

The major components of the closed greenhouse are illustrated and explained.



Retractable Shade: Helps direct sun from entering into the greenhouses and increasing the cooling load demand. See Figure X for performance details

Stormwater Drain: Located on top of each greenhouse module to collect stormwater that is used as greywater for the Vertical Farm.

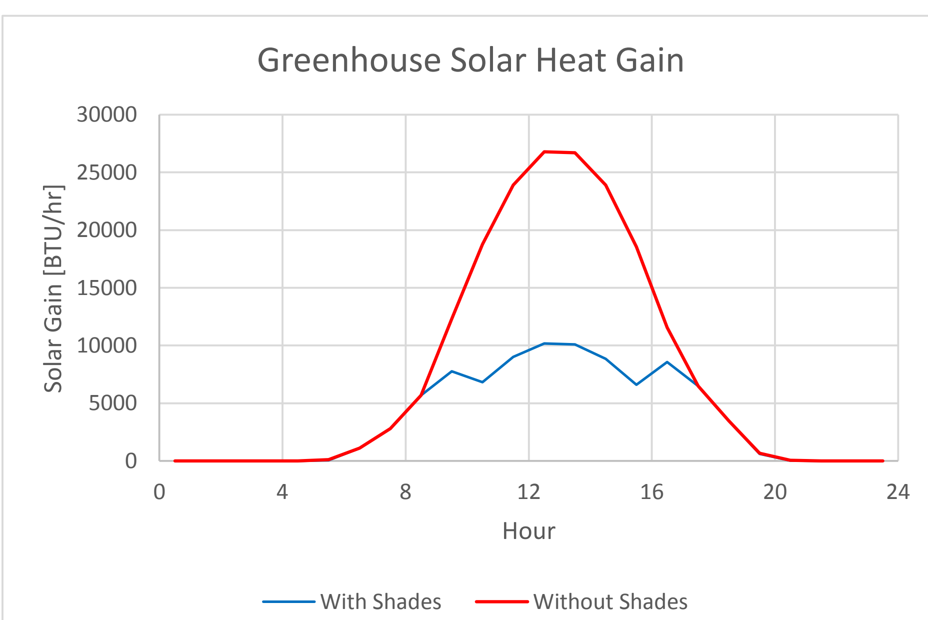
Cooling Coil: Located in the shaft of each greenhouse module. The condenser water loop supplies 50F water to cool the air to 65F. The cool, dense air falls and maintains the greenhouses at a temperature of 85F and 90% RH.

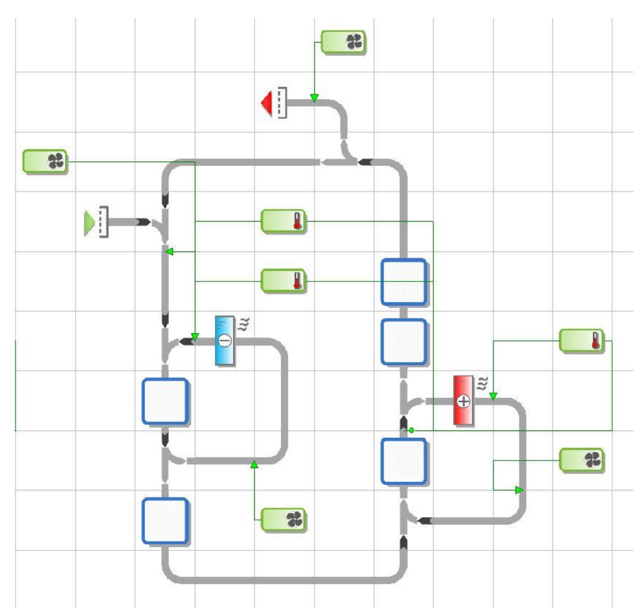
Aluminum Mullion: A thermal bridge mullion is placed at each southern wall to create a cold surface for condensation to collect and to be used as greywater.

Thermal Divider: Divides each module into two thermal zones. A 2 ft. gap between the divider and southern wall allows the hot air to rise and enter into the top thermal zone.

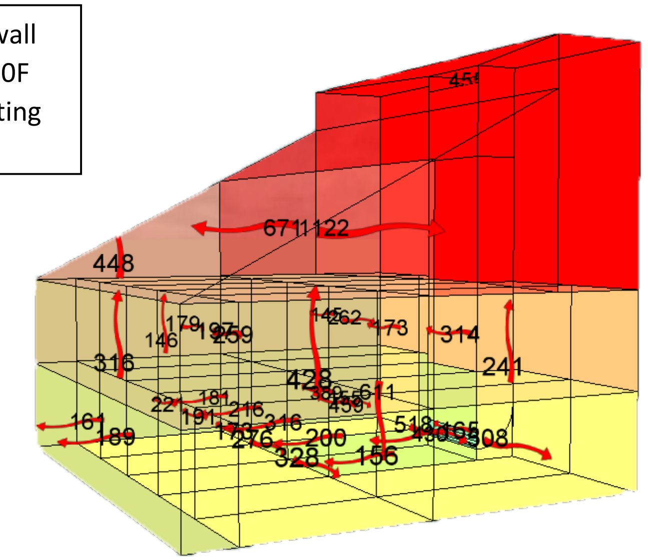
Fin Tube Radiators: Placed along the southern wall of each module to supply hot air to maintain a 70F temperature in the greenhouses during the heating season.

Greenhouse Solar Heat Gain: The greenhouse retractable shades not only ensure that plants receive the correct amount of light, but significantly reduce the cooling load in the greenhouses. The figure below displays the reduction in solar heat gain as a result of the shades.





IES ApacheHVAC Custom Greenhouse Control System: Temperature and humidity sensors monitor conditions in the lower greenhouse zone. The cooling system is activated when the temperature exceeds 85°F or RH exceeds 90%. Heating is provided via fin tube convectors when temperatures fall below 70°F



IES MacroFlo Simulation: A bulk airflow model was performed for both Milwaukee and Miami locations to determine if the cooling system was able to maintain the temperature set points needed in each module throughout the cooling season. From simulations, it was determined that the necessary amount of airflow needed to cool the space is supplied. The arrows and numbers indicate the direction of airflow movement and the flow rate (cfm), respectively. As expected, air is funneled out into the top thermal zone dividing the cool air supplied from the hot stratified air.

APPENDIX G – TRANSPIRATION

Transpiration Model (*Stanghellini*)

$$Rn - S - LE = 0$$

(1) Energy balance on a leaf

$$E = \frac{\frac{\varepsilon r_b Rn}{L} + 2LAI(X_{in}^* - X_{in})}{(1+\varepsilon) r_b + r_s}$$

(2) Canopy transpiration through the Penman-Monteith approach

$$R_n = 0.86[1 - \exp(-0.7LAI)]I_{rad}$$

(3) Net radiation at crop level can be estimated as function of global radiation and LAI

$$r_s = 82\frac{\frac{Rn}{2LAI}+4.3}{\frac{Rn}{2LAI}+0.54}[1 + 0.023(T_{in} - 24.5)^2]$$

(4) Stomatal resistance as a function of net radiation at crop level and greenhouse temperature

$$E = g_c(X_{crop} - X_{in})$$

(5) Equation (2) rearranged as a transfer equation

$$g_e = \frac{2LAI}{(1+\varepsilon) r_b - r_s}$$

(6) Transpiration conductance

$$E = \frac{\varepsilon r_b[0.86(1-\exp(-0.7LAI))I_{rad}] + 2LAI(\chi_{in}^* - \chi_{in})}{(1+\varepsilon)R_b + [82\frac{\frac{0.86(1-\exp(-0.7LAI))I_{rad}}{2LAI}+4.3}{\frac{0.86(1-\exp(-0.7LAI))I_{rad}}{2LAI}+5.4}[1+0.023(T_{in}-24.5)^2]]}$$

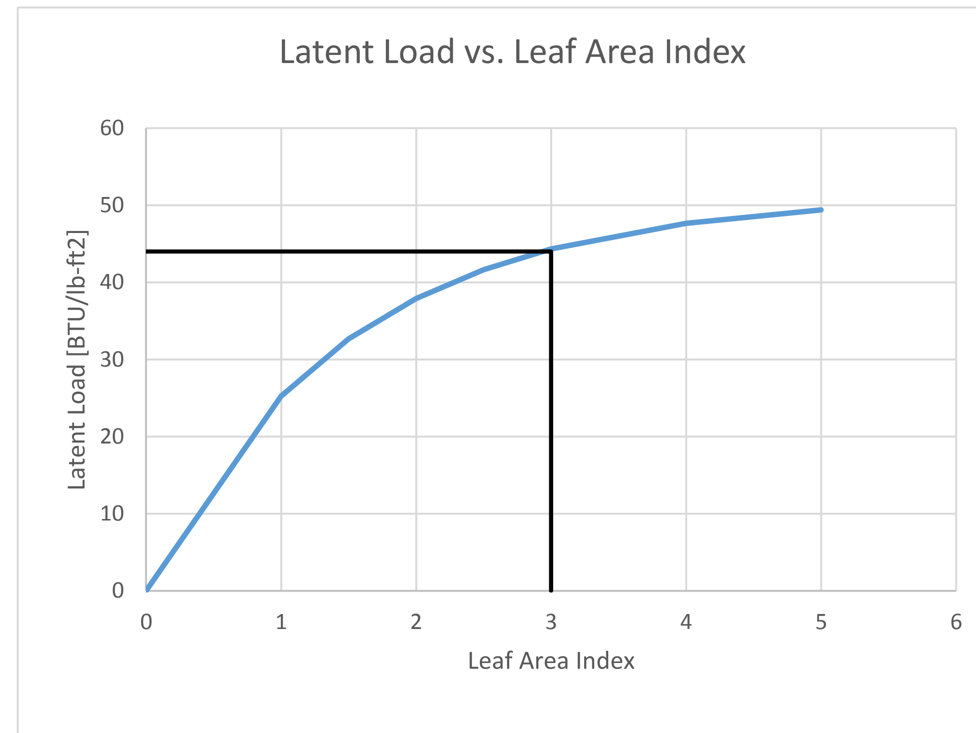
(7) Substitute terms

Variable	Variable Name	Units
R_n	Net Radiation	W/m^2
L	Latent Heat of Vaporization of Water	J/g
S	Sensible Heat Flux	W/m^2
E	Transpiration Flux Density	g/m^2-s
r_s	Stomatal Resistance	s/m
r_b	Boundary Layer Resistance to Heat	s/m
LAI	Leaf Area Index	m^2/m^2
X_{in}	Greenhouse Water Vapor Concentration	g/m^3
X^*_{in}	Saturated Greenhouse Water Vapor Concentration	g/m^3

Transpiration Model: The amount of transpiration produced by plants was calculated to account for the latent load in each greenhouse. The Stanghellini model accounts for the transpiration rate produced given a certain Leaf Area Index (LAI) of a greenhouse. The amount of transpiration is then used to calculate the amount of sensible cooling that is happening due to the evaporation of water. The closed greenhouse prevents the transpiration produced to escape out into the atmosphere.

Latent Load vs. Leaf Area Index: The Mechanical Team assumed a Leaf Area Index of 3 to compute the amount of transpiration produced in the greenhouses. The Leaf Area Index describes the ratio of leaf area to ground surface area. The LAI for a Vertical Farm produces would be characterized as slightly higher

Latent Load in Greenhouses [BTU/hr]									
		02 Greenhouse		03 Greenhouse		04 Greenhouse		05 Greenhouse	
LAI	E [BTU/hr-ft^2]	Latent Load [BTU/hr]	# of People	Latent Load [BTU/hr]	# of People	Latent Load [BTU/hr]	# of People	Latent Load [BTU/hr]	# of People
1	76	56595	283	56746	284	53616	268	122101	611
1.5	98	73198	366	73394	367	69346	347	157922	790
2	114	84981	425	85209	426	80508	403	183343	917
2.5	125	93331	467	93580	468	88419	442	201356	1007
3	133	99359	497	99625	498	94130	471	214362	1072
4	142	106781	534	107067	535	101161	506	230374	1152
5	147	110748	554	111044	555	104919	525	238932	1195
6	150	112999	565	113301	567	107051	535	243789	1219
7	151	114397	572	114703	574	108376	542	246806	1234
8	152	115373	577	115681	578	109300	547	248910	1245
9	153	116137	581	116448	582	110025	550	250560	1253
10	153	116797	584	117110	586	110650	553	251984	1260



APPENDIX H- GREENHOUSE CO_2 CONCENTRATIONS AND EMISSIONS

CO_2 Greenhouse Concentrations

Rate of Accumulation of Contaminant = Flow in – Flow Out

c_a = Concentration of Incoming CO_2

c = Concentration of CO_2 absorbed from plants

$V\Delta c = (Qca - Qc)\Delta t$

$c = 0.12\,\frac{kg}{hr-100m^2} = 2\,\frac{lbm}{hr}$ Concentration of CO_2 absorbed by plants for all greenhouses

$c_a = 625\,\frac{lbm}{MWh} * \frac{200kW}{1000} = 125\,\frac{lbm}{hr}$ Concentration released from 200kW microturbine

Heat Exchanger Capacity: $\dot{q} = \dot{m}C_p(T_1 - T_2) = 160\,\frac{BTU}{hr}$

Carbon Dioxide:

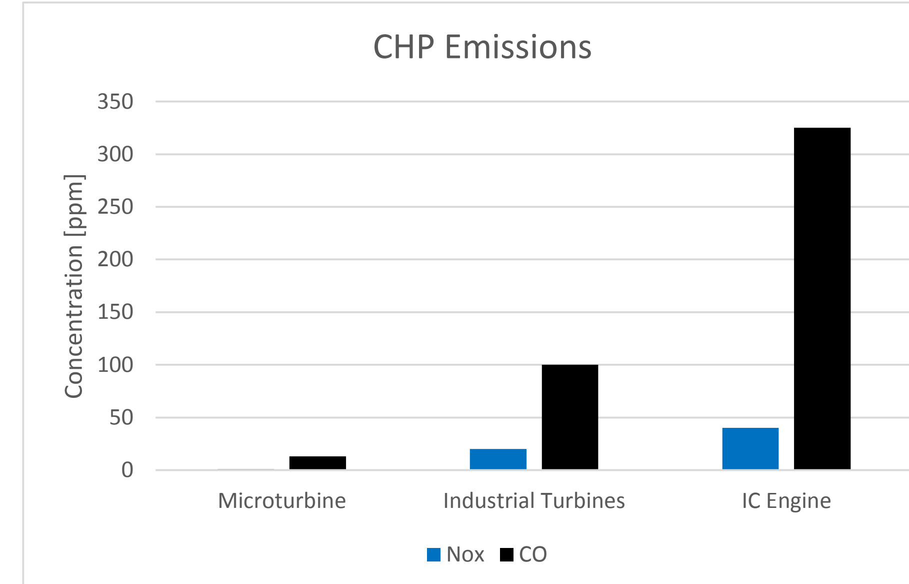
$\dot{m} = 2\,\frac{lbm}{hr}$

$C_p = 0.20\,\frac{BTU}{lbm - °F}$

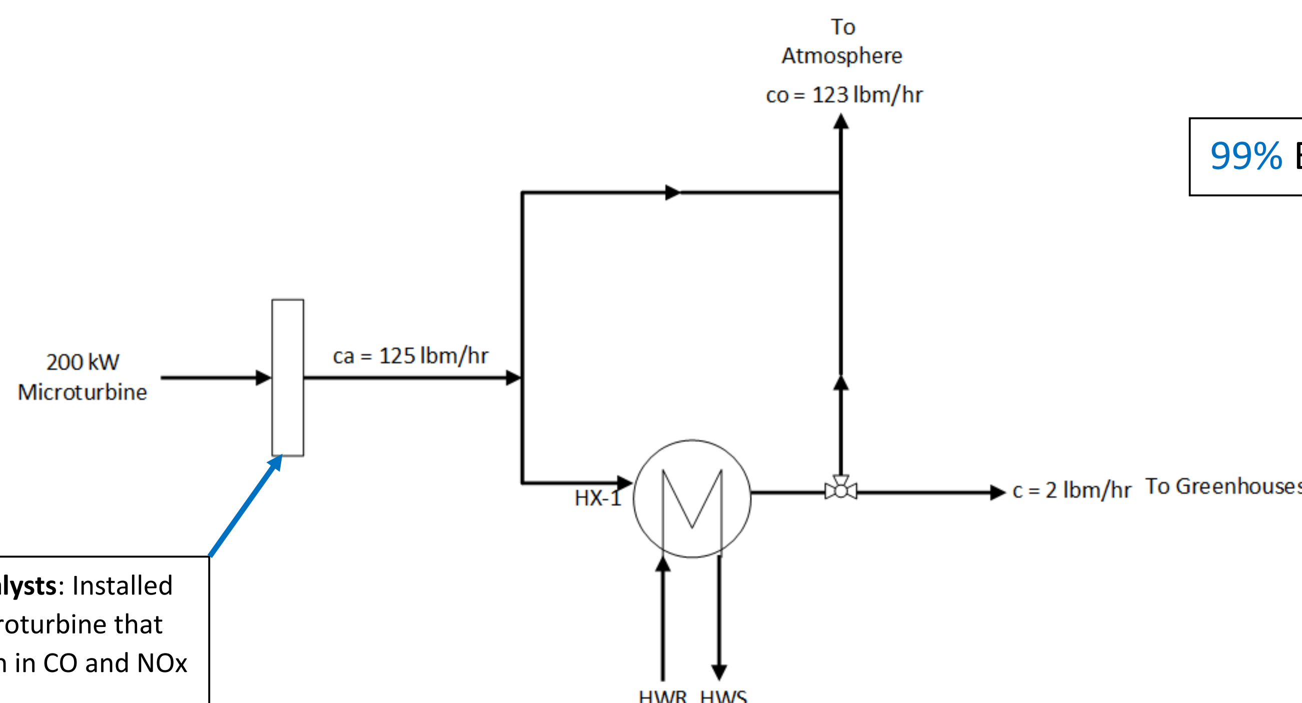
$T_1 = 535°F$

$T_2 = 135°F$

Carbon Dioxide Concentrations: The amount of CO_2 needed to supply the greenhouses was determined from the rate of CO_2 absorbed by plants in each greenhouse. The temperature of the exhaust gas must also be reduced in order to supply the exhaust gases to the greenhouses.



Carbon Dioxide Flow Schematic



Oxidation and SCR Catalysts: Installed downstream of the microturbine that provide a 90% reduction in CO and NOx emissions

99% Emissions Reduction

Microturbine Emissions: An advantage of the microturbine is that it produces ultra-low emissions compared to other CHP turbines and engines. An oxidation and SCR catalyst are also installed downstream of the microturbine to reduce CO and NOx emissions by 90%. The concentration of CO and NOx produced is well below the OSHA 8-hour exposure limit making it acceptable to enrich the greenhouses with CO_2.

Exhaust Gas Bypass: To distribute the required amount of carbon dioxide to the greenhouses, the following schematic is used. During start-up, it will be positioned in a by-pass mode to avoid unburned methane entering the greenhouses. Once the CO_2 concentration target of 1000 ppm is reached, the exhaust gases will be diverted to the atmosphere.

Exhaust Gas Heat Exchanger: Converts waste heat from the microturbine exhaust into hot water for space heating. Parameters of the heat exchanger are listed below.

Exhaust Gas Heat Exchanger	
Exhaust Gas Flow [lbm/hr]	10,440
Hot Water Flow [GPM]	120
T1 [F]	535
T2 [F]	180
T3 [F]	135
T4 [F]	160

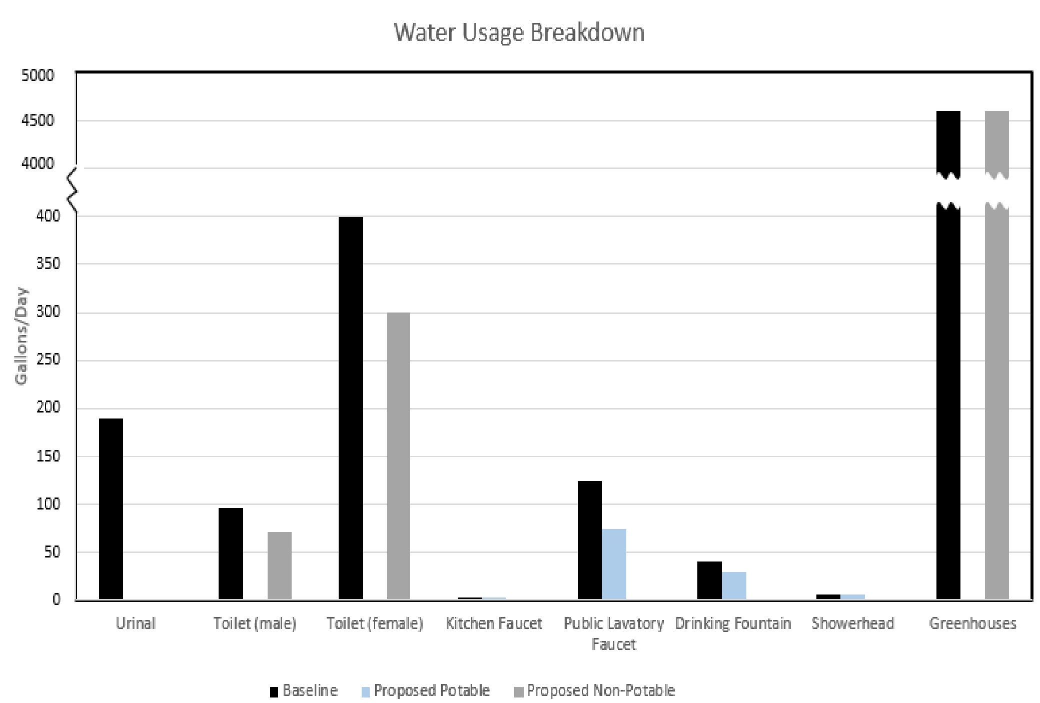
Polar Power Exhaust Gas Heat Exchanger

APPENDIX I – WATER USAGE

Fixture Information		Duration		Flow Rate			Uses per Day						Total Daily Uses		Total Daily Water Use	
Fixture ID	Fixture Type	Default (sec)	Non-default (sec) (Optional)	Baseline Flow Rate (gpm/gpc)	Design Flow Rate (gpm/gpc)	Percent of Occupants (%)	Employees (FTE)	Visitors	Retail Customers	Students (K-12)	Residential	Other	Default	Non-default (Optional)	Baseline (gallons)	Design (gallons)
	Kitchen faucet	15		2.20	1.8	10	1.0	0.0	0.0	0.0	0.0		50.0		2.75	2.25
	Showerhead	300		2.50	2.2	10	0.1	0.0	0.0	0.0	0.0		5.0		6.25	5.5
	Public lavatory (restroom) faucet	30		0.50	0.3	100	3.0	0.5	0.0	0.0	0.0		500.0		125.00	75
							0.0	0.0	0.0	0.0	0.0		0.0		0.00	0
							0.0	0.0	0.0	0.0	0.0		0.0		0.00	0
Baseline case annual flow volume (gallons/year)						48,910.00										
Design case annual flow volume (gallons/year)						30,203.75										

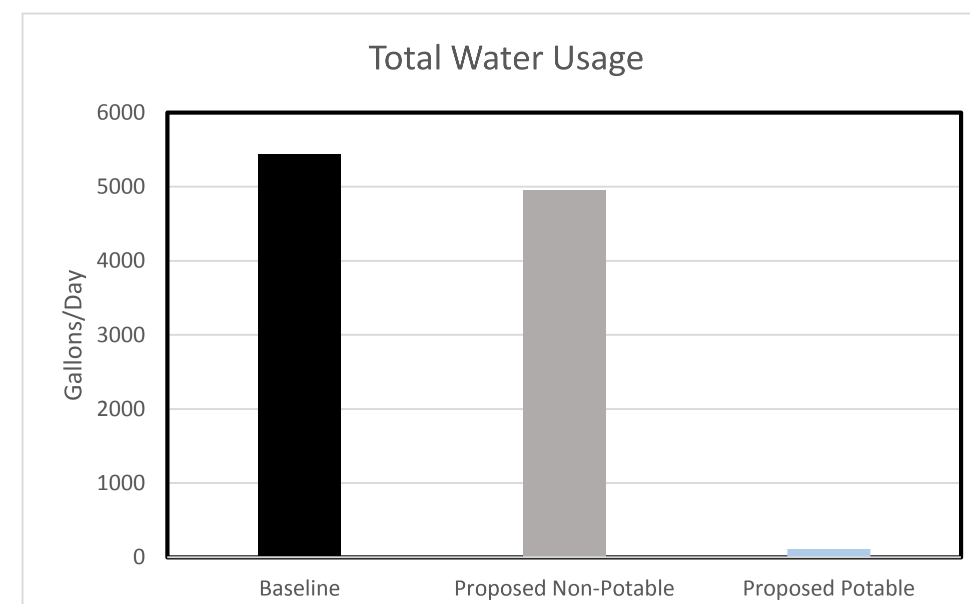
An indoor water usage calculator determined the number of gallons of water used in the baseline model compared to the proposed. Efficient plumbing fixtures helped reduce the amount of potable water used.

Fixture Information			Flush Rate			Uses per Day						Total Daily Uses		Total Daily Water Use	
Fixture ID	Fixture Family	Fixture Type	Baseline Flush Rate (gpf)	Design Flush Rate (gpf)	Percent of Occupants (%)	Employees (FTE)	Visitors	Retail Customers	Students (K-12)	Residential	Other	Default	Non-default (Optional)	Baseline (gallons)	Design (gallons)
	Urinal	Non-Water Urinal	1.00	0	100	2.0	0.4	0.00	0.0	0.0		190.0		190.00	0
	Toilet (male)	Low-Flow Water Closet	1.60	1.2	100	1.0	0.1	0.00	0.0	0.0		60.0		96.00	72
	Toilet (female)	Low-Flow Water Closet	1.60	1.2	100	3.0	0.5	0.00	0.0	0.0		250.0		400.00	300
						0.0	0.0	0.00	0.0	0.0		0.0		0.00	0
						0.0	0.0	0.00	0.0	0.0		0.0		0.00	0
Baseline case annual flush volume (gallons/year)					250,390.00										
Design case annual flush volume (gallons/year)					135,780.00										



Baseline water fixture flow rates and uses per day were calculated per LEED NC-2009 Water Use Reduction. Water efficient fixtures were selected to reduce flow rates. Figure MX displays a water usage breakdown by source. The greenhouses use the majority of the water in the building; however, with a closed greenhouse, all of the water is collected and reused as greywater for plants. This explains why the Vertical Farm uses 98% less potable water than the baseline building.

98% Potable Water Reduction



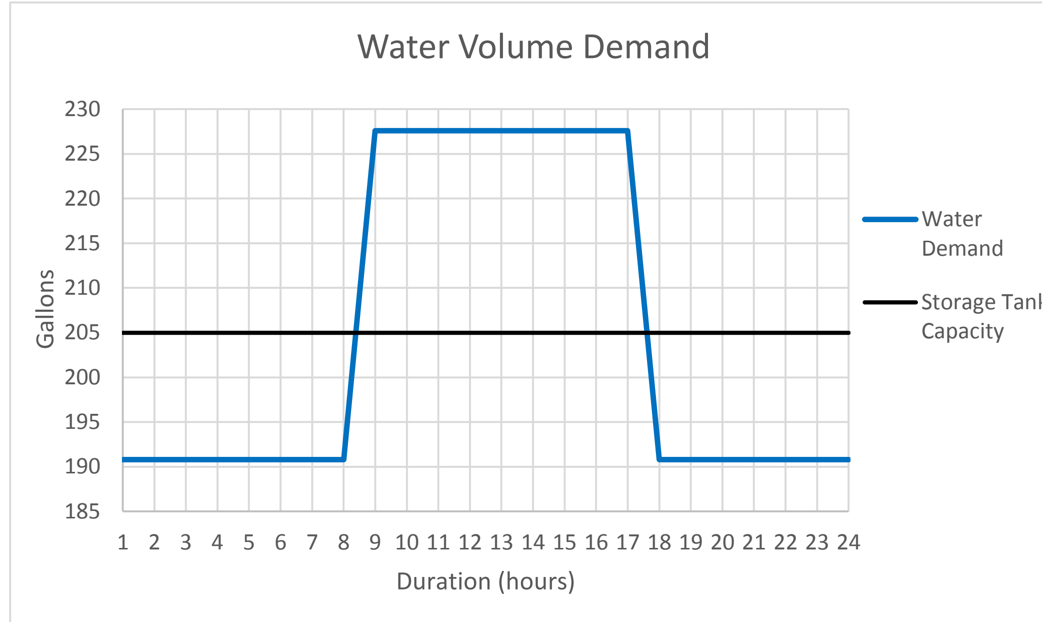
APPENDIX J – WATER COLLECTION

Rainfall Collected

Month	Average Rainfall (in)
January	1.8
February	1.7
March	2.1
April	3.5
May	3.2
June	3.9
July	3.7
August	3.9
September	3.1
October	2.7
November	2.8
December	2
Total	**34.4**

4,500 Gallon Water Storage Tank

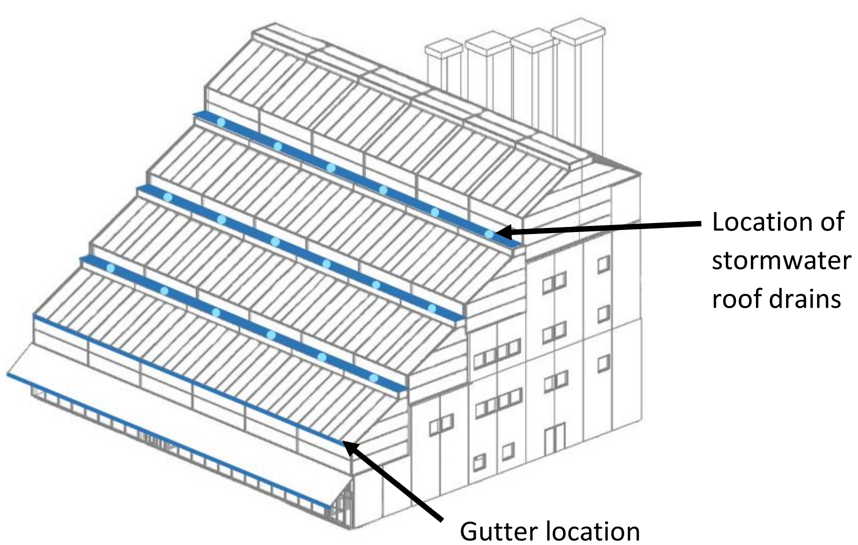
Rainwater Collection	
Total Annual Rainfall [inches/year]	34.4
Total Roof Area [square feet]	12360
Total Annual Rainfall Collection [gallons/year]	265031
Total Daily Rainfall Collection [gallons/day]	**726**



The grey water storage tank was sized based off the amount of rainwater collected annually, water from condensation in greenhouses, and from the amount of condensation on the cooling coils located in each supply tower. The Mechanical Team calculated the total amount of water collected from all sources and sized a tank that could hold the maximum amount of water collected. The graph above displays the displays a water usage profile during a typical day and the capacity the storage tank will need to hold.

Storage Tank Demand

Hour	Demand [Gallons]	Storage Tank
1	190.8	205
2	190.8	205
3	190.8	205
4	190.8	205
5	190.8	205
6	190.8	205
7	190.8	205
8	190.8	205
9	227.61	205
10	227.61	205
11	227.61	205
12	227.61	205
13	227.61	205
14	227.61	205
15	227.61	205
16	227.61	205
17	227.61	205
18	190.8	205
19	190.8	205
20	190.8	205
21	190.8	205
22	190.8	205
23	190.8	205
24	190.8	205



Greenhouse Water Collected

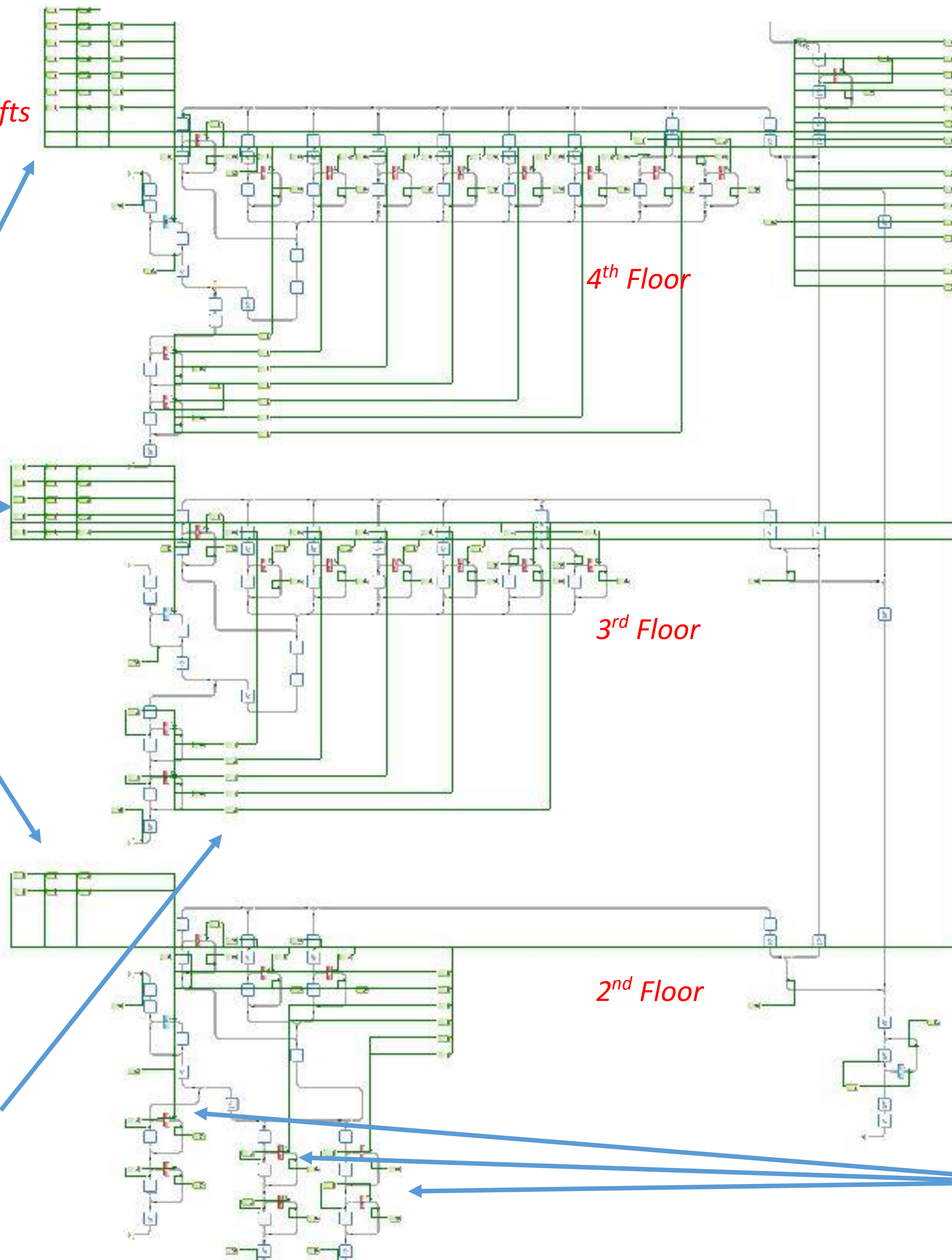
Greenhouse Water Usage				
Floor	Zone Name	Area [ft^2]	Water Usage per Area [Gallons/ft^2-day]	Water Usage Per Day [Gallons/day]
2	02 Greenhouse	2242	0.4	897
3	03 Greenhouse	2248	0.4	899
4	04 Greenhouse	2124	0.4	850
5	05 Greenhouse	4837	0.4	1935
			Total:	**4580**

Greenhouse Water – The closed greenhouse allows for the collection of water through transpiration of plants. Condensation will occur on the coldest surface in the greenhouse (thermal bridge aluminum mullion) and will be collected from a gutter which will be sent down to the water storage tank. Condensate will also occur on the cooling coils in each greenhouse module shaft. A drip pan is there to collect and send the condensate to the storage tank.

APPENDIX K – NATURAL HVAC

Custom System and Controls for Natural HVAC System in IES Virtual Environment

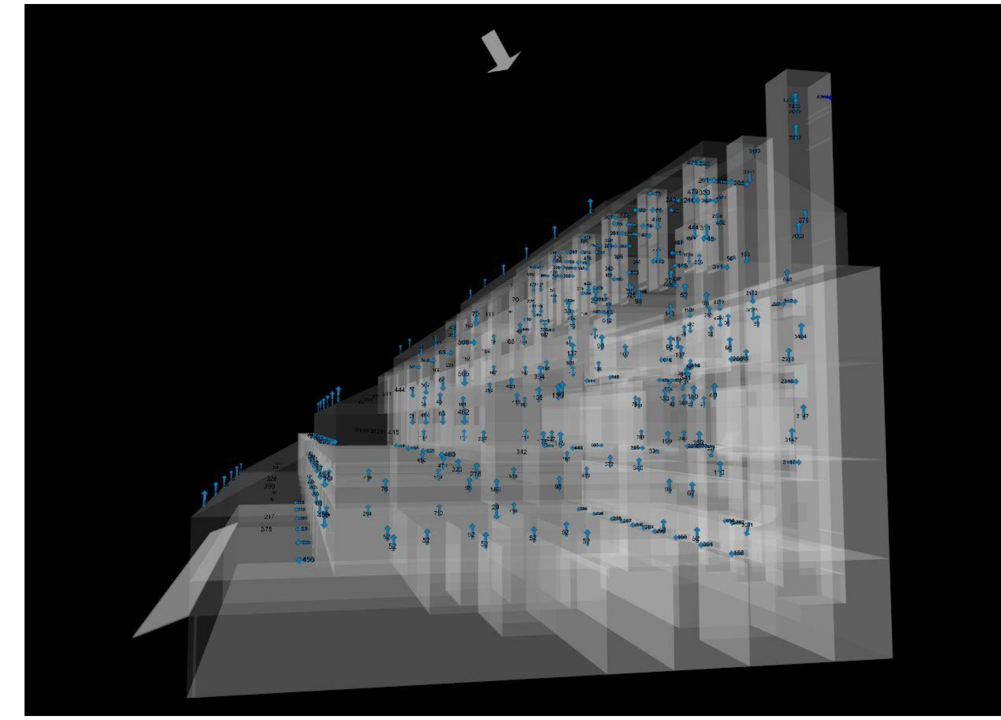
Solar chimney fan controls. The fan is turned on when a temperature exceeds 77°F or when the CO_2 concentration exceeds 1300 ppm in a space.



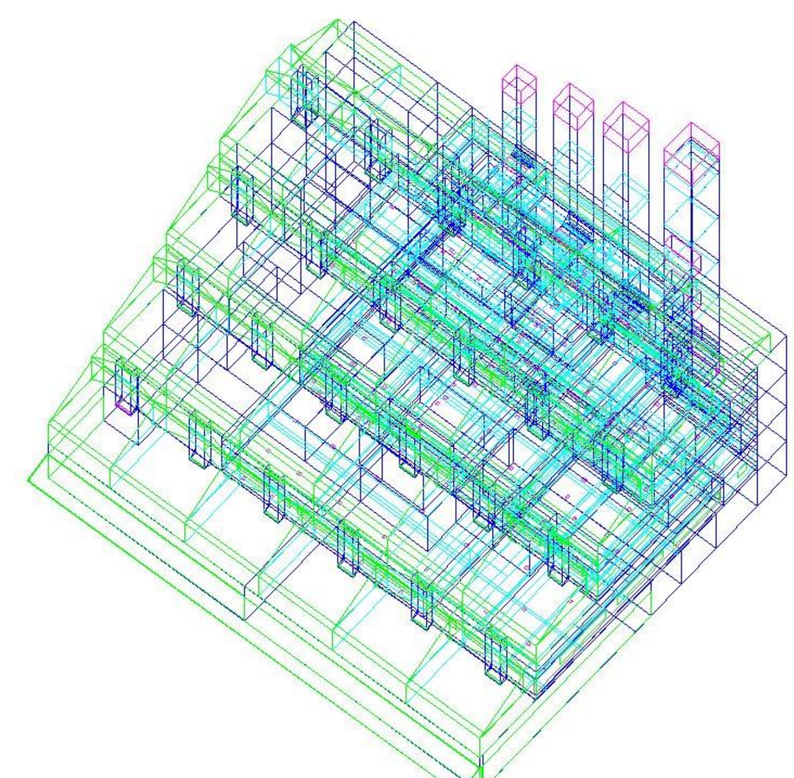
Leaving cooling coil temperature reset controls. Based on worst case room. Temperature, CO_2, and dew point in rooms with chilled beams are monitored and used to reset the leaving coil temperature.

Leaving heating coil temperature reset controls to maintain temperature and CO_2 set points. Reset based on worst case room.

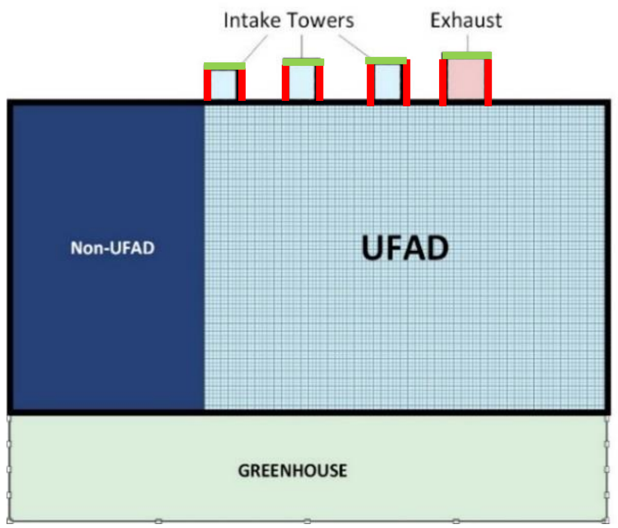
All three supply shafts contain ground level intake louvers, and serve the second floor while in updraft mode in order to meet the large ventilation requirement of the gathering room when wind blows from the South. The shafts primarily serving floors three and four contain an additional set of louvers above the second floor plenum, allowing them to serve their respective floors.



The building was divided into over 1,000 thermal zones in order to model airflow and space conditioning driven by the wind and thermal buoyancy



APPENDIX L – INTEGRATED BULK AIRFLOW/ENERGY MODEL



Exposed Wall

Sheltered Wall

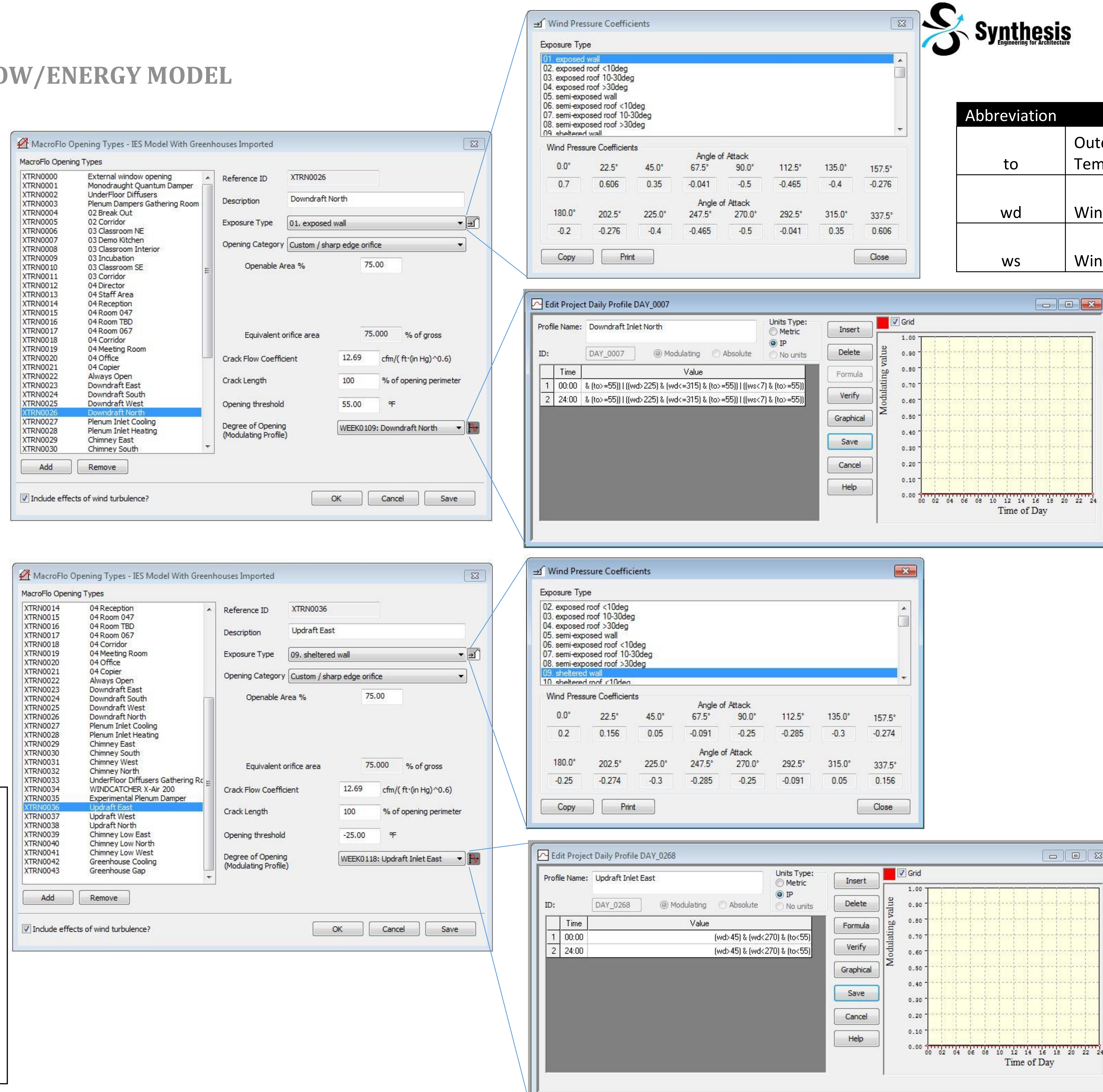
A limitation of the software used to model the natural HVAC system is that it does not include the wind shading effect of the building. Therefore, wind pressure coefficients for the natural HVAC intake dampers must be altered as a function of the angle of attack. Two classifications were used select pressure coefficients for the shaft inlets: exposed wall and sheltered wall. The coefficients and damper control algorithms are shown to the right.

Accounting for obstructions and frictional resistance: The bulk airflow tool within IES does not automatically account for obstructions and friction losses; however, they can be accounted for by creating an opening with an equivalent orifice area. The procedure used to calculate the equivalent area is described below.

$$A_o = \frac{A_d}{0.62\sqrt{k}},\ k = k_{duct} + k_{abs}$$

$$k_{abs} = (1 - \sigma + \left[\frac{(1-\sigma)}{2}\right]^{.5})^2/\sigma^2$$

$$k_{duct} = L/(8w\left\{log_{10}\left[\frac{\frac{\varepsilon}{w}}{7.4}\right]\right\}^2)$$



Abbreviation	Meaning	Units
to	Outdoor Air Temperature	Degrees Fahrenheit
wd	Wind Direction	Degrees From North
ws	Wind Speed	Feet per Second

APPENDIX M – CHILLED BEAM AND RADIANT FIN TUBE DESIGN

Design Parameters	
T_{OA} [°F]	86.2
T_{SA} [°F]	63
T_{RA} [°F]	77
Beam Length [ft.]	6
T_{RA} - T_{CWS} [°F]	14

Chilled Beam Design								
Space	Min. Outside Air [CFM]	Ventilation Sensible Cooling [BTUH]	Total Sensible Cooling Load [BTUH]	Chilled Beam Sensible Cooling [BTUH]	Sensible Cooling Capacity [BTUH/LF]	Number of Chilled Beams	Sensible Cooling Capacity [BTUH/LF]	Required Flow Rate [GPM]
Second Floor								
Break-Out Space	700	10584	39886	29302	4884	8	610	16
Gathering	3200	48384	122000	73616	12269	20	613	40
Third Floor								
Classroom	400	6048	12159	6111	1018	4	255	8
Classroom	400	6048	12300	6252	1042	4	519	14
Fourth Floor								
Director	100	1512	8670	7158	1193	2	398	6
							Total:	**84**

Passive Chilled Beam Selection Process:

1. Determine amount of sensible load to be handled by chilled beams
2. Estimate beam entering air temperature: stratified system: entering air temperature assumed to be 2°F warmer
3. Determine chilled water supply temperature – must be at least greater than the room dew point temperature to avoid condensation
4. Select beam using temperature difference between entering air and chilled water supply
5. Determine water flow rate and pressure loss associated with selected beam

Typical Chilled Beam

Greenhouse Fin Tube Design- High output finned tubes are specifically designed to heat all greenhouses. These are twice as thick as any standard base board radiators making them a viable option for greenhouse environments. The fin tubes are placed along the southern wall of the greenhouses to minimize the conduction heat loss through the glazing in the winter.

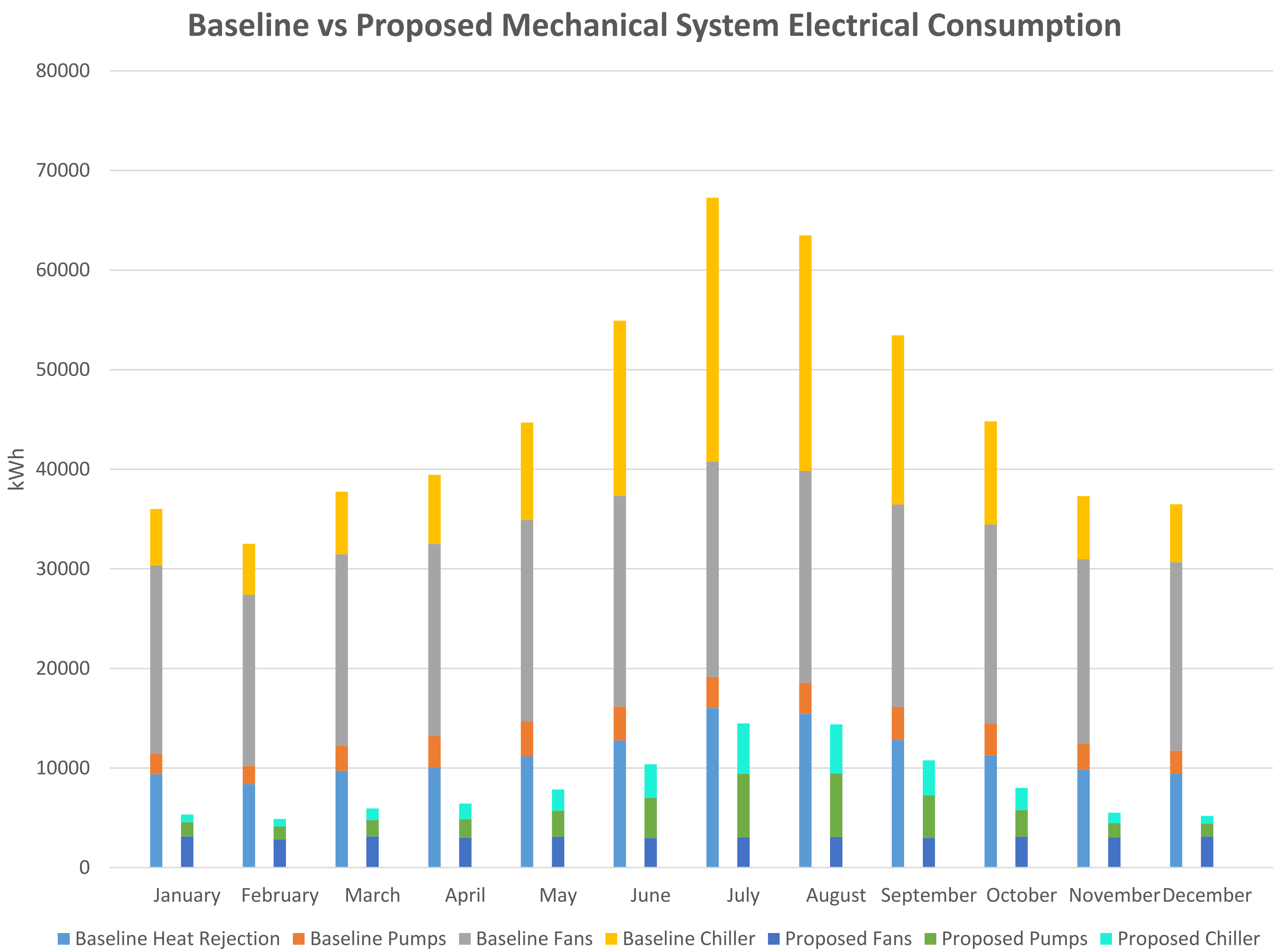
Greenhouse Fin Tube Design					
Tube Size Material	Fin Size Material	Average Water Temperature [F]	Fins/ft	No of Tiers	BTU/HR-ft
1.25 inch Sch 40 Aluminum	3.25" x 3.25" 0.025 Aluminum	180	24	2	1259

Zone Name	Total Heating Load [BTU/hr]	Total Length [ft]
Greenhouse 1	71538	57
Greenhouse 2	71477	57
Greenhouse 3	72746	58
Greenhouse 4	299668	238

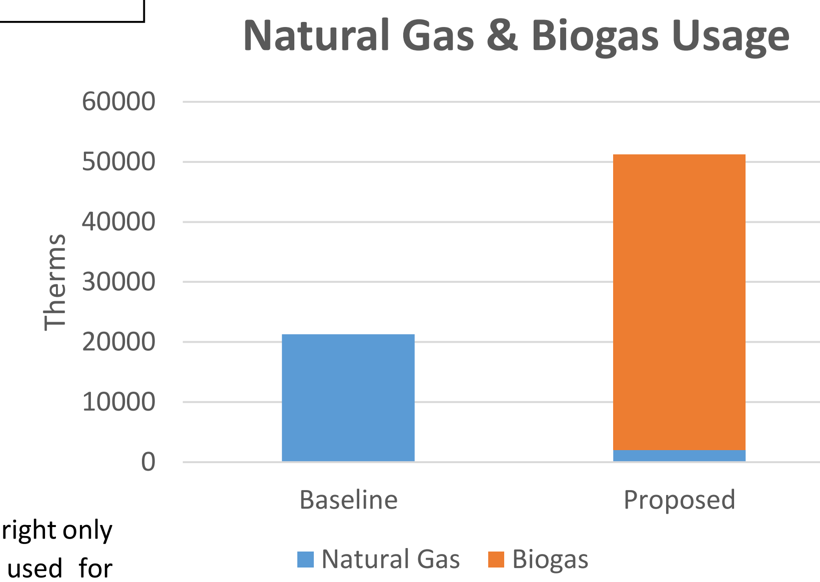
APPENDIX N– ENERGY USAGE

An energy and load simulation was performed using IES Virtual Environment software. A summary of the energy performance of the Vertical Farm in Milwaukee is displayed below.

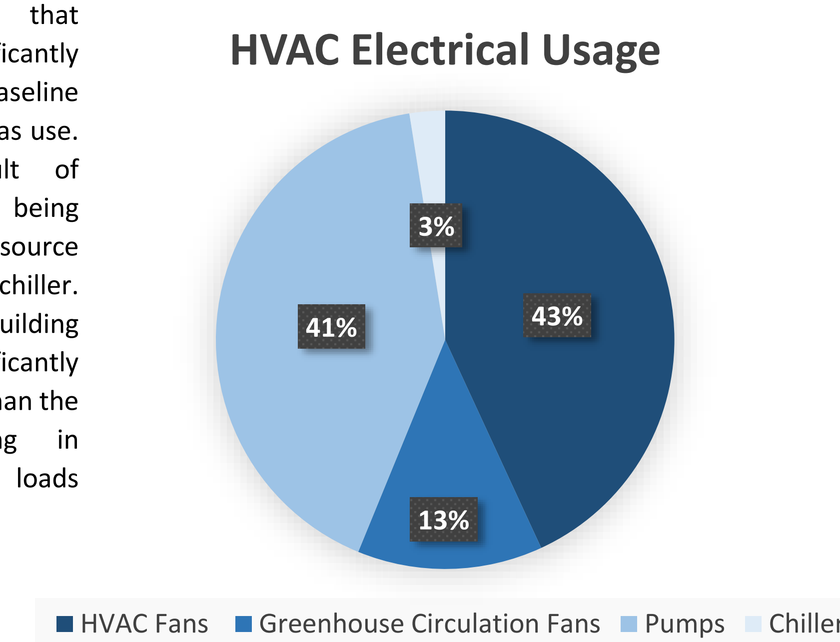
Cooling Performance: 0.3-0.4 kW/ton including pump and fan energy



The baseline building was created as prescribed by AHSRAE 90.1 Appendix G. For fairness, the baseline building was modeled with greenhouses identical to the proposed building. Unfortunately, the baseline building experiences much higher interior lighting gains and does not use operable shades, resulting in significantly higher loads than the proposed building, and rendering a comparison unproductive.



The graph to the right only includes biogas used for heating or cooling. The proposed model uses a combination of natural gas and biogas that amounts to significantly more than the baseline building's natural gas use. This is a result of combusted biogas being used as the heat source for an absorption chiller. The proposed building also provides significantly more outdoor air than the baseline, resulting in increased heating loads and gas usage.



APPENDIX O– QUAD-GENERATION COST ANALYSIS

Item	First Cost
Anaerobic Digester and Related Equipment	$1,000,000
Biogas Pretreatment	$165,000
Microturbine	$333,000
Exhaust Gas Heat Exchanger	$14,390
Oxidation & SCR Catalysts	$4,000
CO_2 Piping	$15,400
CO & NOx Sensors	$408
Total:	**$1,532,198**

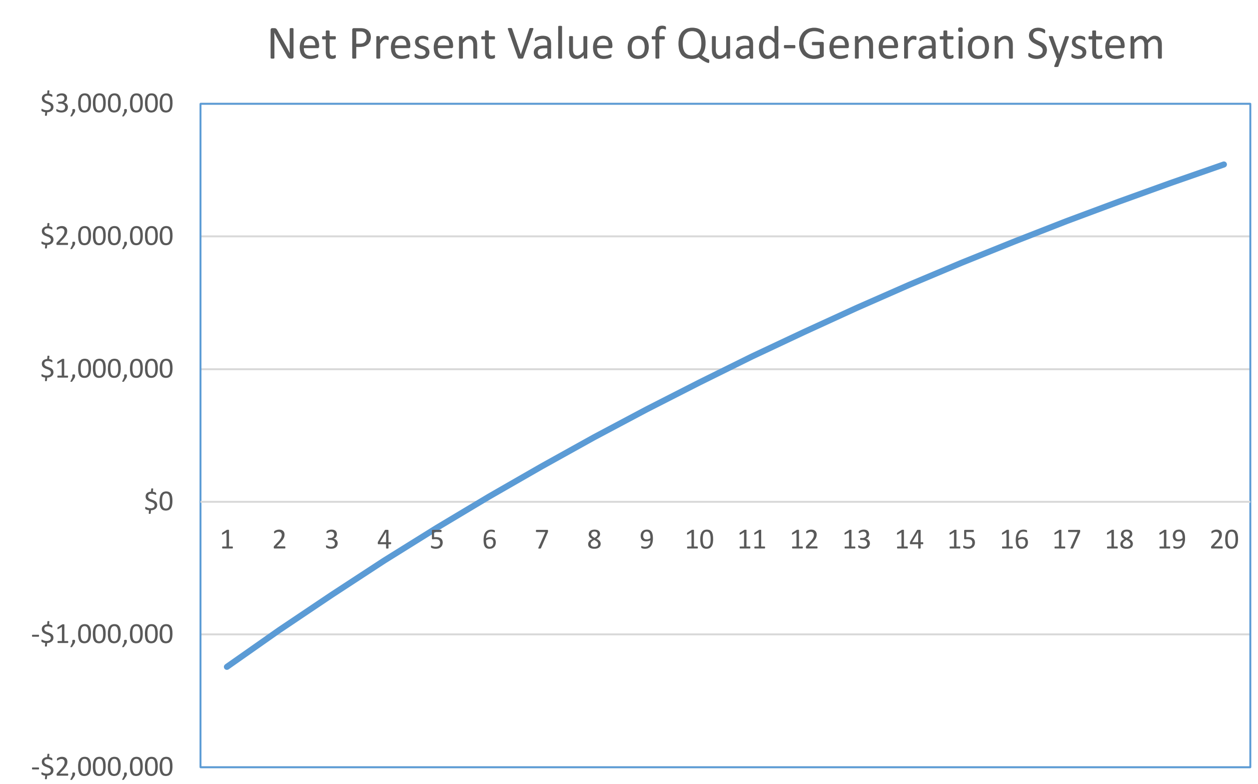
Annual Profits and Expenses		Unit	Rate	Cost
Offset Grid Electrical Usage	1,641,959	kW	$0.12	$197,035
Electricity Sold To Grid	132,041	kW	$0.04	$5,282
Natural Gas Reduction (Baseline - Proposed)	19,270	Therms	$0.60	$11,562
Solid Fertilizer	730	Yards	$65.00	$47,450
40% Increase in Crop Production	*based on $5/SF/year of greenhouse profit*			$22,456
Tipping Fees	4,599	Tons	$10.00	$45,990
Operations & Maintenance	*3% of total digester cost*			-$30,000
Total:				**$299,775**

Existing Site Electrical Load Assumptions

	Grow lights	Miscellaneous
W/SF	25	2
SF	7434	21581
kWh	186	43
% Of Year Operating	25%	100%
Hours	2190	8760
Annual kWh	407012	378099
Total:		**785111**

Years	Net Cash Flow	Net Present Value
0	-	-$1,532,198
1	$299,774.00	-$1,243,954
2	$299,774.00	-$966,796
3	$299,774.00	-$700,298
4	$299,774.00	-$444,050
5	$299,774.00	-$197,657
6	$299,774.00	$39,258
7	$299,774.00	$267,062
8	$299,774.00	$486,104
9	$299,774.00	$696,721
10	$299,774.00	$899,238
11	$299,774.00	$1,093,965
12	$299,774.00	$1,281,203
13	$299,774.00	$1,461,240
14	$299,774.00	$1,634,352
15	$299,774.00	$1,800,805
16	$299,774.00	$1,960,857
17	$299,774.00	$2,114,753
18	$299,774.00	$2,262,730
19	$299,774.00	$2,405,016
20	$299,774.00	$2,541,828

Total Investment	$ 1,532,198.00
First Year Utility Savings	$ 299,774.72
First Year Return on Investment	20%
Simple Payback Period (Years)	5.11
Assumed Escalation Rate	4%



APPENDIX P – COOLING AND HEATING LOAD CALCULATIONS

Cooling and Heating Load Calculation -Non Greenhouses Spaces, Milwaukee

Floor	Zone Name	Area [ft^2]	Cooling											Heating			
			Min. Outside Air [CFM]	Sensible				Latent			TRACE Total	Total Cooling Coil Load [Btuh]	Design Supply Air [CFM]	Outside Air [CFM]	Ventilation Load [BTUh]	Peak Sensible Room Load [BTUh]	Total Heating Coil Load [BTUh]
				Outside Air [BTUh]	Peak Sensible Room Load [BTUh]	30% more than OA	Supply Air [CFM]	Outside Air [BTUh]	Peak Latent Room Load [BTUh]	Supply Air [CFM]							
First Floor																	
1	Work Shop	951	236	2855	13750	307	637	2138	1663	107	15413	20406	637	236	17332	6633	23965
1	Mud Room	221	32	387	2521	42	117	290	1148	74	3668	4345	117	32	2350	269	2619
1	Volunteers	231	36	435	2576	47	119	326	1155	75	3731	4493	119	36	2644	465	3109
1	Office	95	11	133	1096	14	51	100	200	13	1296	1529	51	11	808	203	1011
1	Market Office	95	11	133	1096	14	51	100	200	13	1296	1529	51	11	808	203	1011
1	Market	3122	373	4512	31663	485	1466	3380	6244	404	37907	45798	1466	373	27393	36472	63865
1	Processing	1849	198	2395	38826	257	1797	1794	4623	299	43448	47637	1797	198	14541	17759	32300
1	Loading	799	139	1681	2600	181	120	1259	0	0	2600	5541	0	139	10208	1722	11930
1	Shipping/Receiving	728	112	1355	2308	146	107	1015	0	0	2308	4678	0	112	8225	1420	9645
1	Corridor	2055	123	1488	7400	160	343	1114	0	0	7400	10002	343	123	9033	15741	24774
1	Women	165	0	0	512	0	24	0	0	0	512	512	24	0	0	0	0
1	Men	165	0	0	512	0	24	0	0	0	512	512	24	0	0	0	0
		Total:	1271	15374	104859.4	1652	4855	11516	15231.6	985	120091	146981	4627	1271	93342	80887	174229
Second Floor																	
2	Corridor	2935	176	1749	18828	229	1245	877	0	0	18828	21453	1200	545	43224	3231	213332
2	Break-Out Space	1067	605	6011	61233	787	4050	3013	10850	555	72083	81107	1000	605	44431	1219	45650
2	Gathering	4080	3106	30861	128032	4038	8468	15469	59365	3037	187397	246233	4100	3106	228105	3268	231373
		Total:	3711	36872	189265	4824	12518	18482	70215	3592	259480	327340	6300	3711	272536	4487	277023
Third Floor																	
3	Corridor	825	71	705	1858	92	123	354	0	0	1858	3132	130	71	5214	0	5214
3	Classroom	635	394	3915	12159	512	804	1962	4921	252	17080	24273	800	394	28935	199	29134
3	Storage	110	13	129	0	17	0	65	0	0	0	211	20	13	955	474	1429
3	Corridor	1181	71	705	0	92	0	354	0	0	0	1151	600	71	5214	0	5214
3	Demo Kitchen	947	484	4809	23710	629	1568	2410	9250	473	32960	42377	1600	484	35545	0	35545
3	Classroom	605	375	3726	31200	488	2064	1868	4689	240	35889	44034	500	375	27540	0	27540
3	Classroom	610	378	3756	27865	491	1843	1883	4728	242	32592	40565	500	378	27760	486	28246
3	University Incubator Office	654	62	616	5761	81	381	309	1308	67	7069	8455	400	62	4553	232	4785
		Total:	1777	17656	100695	2310	6660	8850	24896	1274	125590	161066	4420	1777	130503	1391	131894
Fourth Floor																	
4	Corridor	1350	81	805	306	105	20	403	0	0	306	1640	105	81	5949	0	5949
4	Staff Area	364	62	616	9119	81	603	309	3761	192	12880	14489	600	62	4553	0	4553
4	Director	350	26	258	8670	34	573	129	200	10	8870	9865	600	26	1909	2572	4481
4	Meeting	450	100	994	12833	130	849	498	4650	238	17483	19953	600	100	7344	0	7344
4	Office Area	758	83	825	8033	108	531	413	1400	72	9433	11310	600	83	6096	0	6096
4	Reception Area	328	69	686	8830	90	584	344	3389	173	12219	13922	600	69	5067	0	5067
4	Copy	122	10	99	937	13	62	50	0	0	937	1161	70	10	734	62	796
		Total:	350	3478	48422	455	3202	1743	13400	685	61822	70700	3070	431	25704	2634	28338

Cooling Design Parameters

Air	T [°F]	W [lb/lb]
Outside Air	89	0.013986
Room Air (2-4 Floors)	77	0.012957
Supply Air (2-4 Floors)	63	0.008918
Supply Air (1st Floor)	55	0.008918
Room Air (1st Floor)	75	0.012114

Heating Design Parameters

Air	T[°F]
Outside Air	0
Room Air (2-4 Floors)	68
Supply Air (2-4 Floors)	88
Supply Air (1st Floor)	95
Room Air (1st Floor)	75

$$q_{sen} = 1.08 \cdot CFM \cdot (T_{room} - T_{supply})$$

$$q_{lat} = 4840 \cdot CFM \cdot (W_{room} - W_{supply})$$

The cooling and heating loads for the Vertical Farm shown are calculated for Milwaukee, WI. The Mechanical Team performed load calculations for Miami, FL for comparisons to Milwaukee site and equipment sizing.

Cooling and Heating Load Calculation -Greenhouses Spaces, Milwaukee

Floor	Zone Name	Area [ft^2]	Cooling						Heating
			Sensible			Latent	TRACE Total	Total Cooling Coil Load [Btuh]	Total Heating Coil Load [BTUh]
			Peak Sensible Room Load [BTUh]	New Peak Sensible Room Load [BTUh]	Supply Air [CFM]	Peak Latent Room Load [BTUh]			
Greenhouses									
2	Greenhouse 1	2242	184901	8581	265	220400	405301	228981	71538
3	Greenhouse 2	2248	207918	31118	960	221000	428918	252118	71477
4	Greenhouse 3	2124	206649	39609	1223	208800	415449	248409	72746
5	Greenhouse 4	4837	1224337	844017	26050	475400	1699737	1319417	299668
		Total:	1823805	923325	56290	1125600	2949405	2048925	515429

All greenhouses were calculated with a supply air temperature of 65 °F. A room air temperature of 85°F and 90% relative humidity were used for cooling load calculations. The peak latent load is calculated based off the amount of transpiration in the greenhouses See Appendix K for a detailed calculation. The heating calculation loads were calculated with a room air temperature of 70°F.

APPENDIX Q – VENTILATION AND EXHAUST CALCULATIONS

Ventilation Schedule

Floor	Zone Name	Classification	# Persons/1000 ft²	Area [ft²]	Outdoor Air Flow/ft² [CFM/ft²]	Zone Population [# of People]	Outdoor Airflow/Person [CFM/Person]	Breating Zone Ventilation [CFM]	Zone Air Distribution Effectiveness [%]	Minimum Outdoor Air Supply [CFM]	Design Supply Outdoor Air [CFM]
First Floor											
1	Work Shop	Manufacturing	7	945	0.18	7	10	236	100.0	236	307
1	Corridor	Corridor	-	2055	0.06	0	0	123	100.0	123	160
1	Mud Room	Laundry	10	221	0.06	2	5	24	100.0	24	32
1	Volunteers	Break Room	25	231	0.06	6	5	43	100.0	43	56
1	Office	Office	-	100	0.06	1	5	11	100.0	11	14
1	Market Office	Office	-	100	0.06	1	5	11	100.0	11	14
1	Market	Supermarket	8	3111	0.06	25	7.5	373	100.0	373	485
1	Processing	Processing	10	1801	0.06	18	5	198	100.0	198	258
1	Loading	Shipping/Receiving	0	893	0.12	0	0	107	100.0	107	139
1	Shipping/Receiving	Shipping/Receiving	0	719	0.12	0	0	86	100.0	86	112
									V_{ot}	1213	1578
Second Floor											
2	Corridor	Corridor	-	2935	0.06	0	0	176	100.0	176	229
2	Break-Out Space	Multi-Purpose	-	1328	0.06	70	7.5	605	100.0	605	786
2	Gathering	Auditorium	-	3884	0.06	383	7.5	3106	100.0	3106	4037
									V_{ot}	3710	4823
Third Floor											
3	Classroom	Classroom(age 9 plus)	50	635	0.12	32	10	394	100.0	394	512
3	Corridor	Corridor	0	1181	0.06	0	0	71	100.0	71	92
3	Demo Kitchen	Classroom/Kitchen	-	947	0.12	37	10	484	100.0	484	629
3	Classroom	Classroom(age 9 plus)	50	605	0.12	30	10	375	100.0	375	488
3	Classroom	Classroom(age 9 plus)	50	610	0.12	31	10	378	100.0	378	492
3	University Incubator Office	Office	7	654	0.06	5	5	62	100.0	62	81
									V_{ot}	1764	2293
Fourth Floor											
4	Staff Area	Break Room	25	337	0.06	8	5	62	100.0	62	81
4	Corridor	Corridor	0	1350	0.06	0	0	81	100.0	81	105
4	Director	Office	-	358	0.06	1	5	26	100.0	26	34
4	Meeting	Conference Room	-	409	0.06	15	5	100	100.0	100	129
4	Office Area	Office	-	799	0.06	7	5	83	100.0	83	108
4	Reception Area	Reception Area	30	328	0.06	10	5	69	100.0	69	90
4	Copy	Copy, Printing Room	4	122	0.06	0	5	10	100.0	10	13
									V_{ot}	431	560
									ΣV_{ot}	7118	9254

Exhaust Schedule

Floor	Zone Name	Classification	Area [ft²]	V_{exh} [CFM/ft²]	Number of Units	Exhaust Rate [per Unit]	Minimum Exhaust Rate [CFM]	Design Exhaust Rate [CFM]
B	Women's Showers/Lockers	Locker Room	331	2	-	-	662	700
B	Men's Showers/Lockers	Locker Room	331	2	-	-	662	700
1	Women	Toilet Room	165	-	2	75	150	200
1	Men	Toilet Room	165	-	2	75	150	200
2	Women	Toilet Room	166	-	4	75	300	300
2	Men	Toilet Room	166	-	3	75	225	300
3	Women	Toilet Room	166	-	4	75	300	300
3	Men	Toilet Room	166	-	3	75	225	300
3	Demo Kitchen	Kitchen	250	0.7	-	-	175	200
4	Women	Toilet Room	166	-	2	75	150	200
4	Men	Toilet Room	166	-	2	75	150	200
4	Copy	Copy Room	130	0.5	-	-	65	70
							Total:	**3670**

Demand controlled ventilation is designed for all spaces. Amount of outdoor airflow is based off a midband CO_2 of 800 ppm. The amount of outdoor airflow is proportional to the CO_2 concentration in each space.

ASHRAE 62.1 Ventilation for Acceptable Indoor Air Quality Rate Procedure

V_{bz}= Breathing zone outdoor airflow

A_z = Zone floor area

P_z = Zone population

R_p = Outdoor airflow rate per person

R_a = Outdoor airflow rate per unit area

E_z = Zone Air Distribution Effectiveness

$$V_{bz} = R_p P_z + R_a A_z$$

$$V_{oz} = V_{bz}/E_z$$

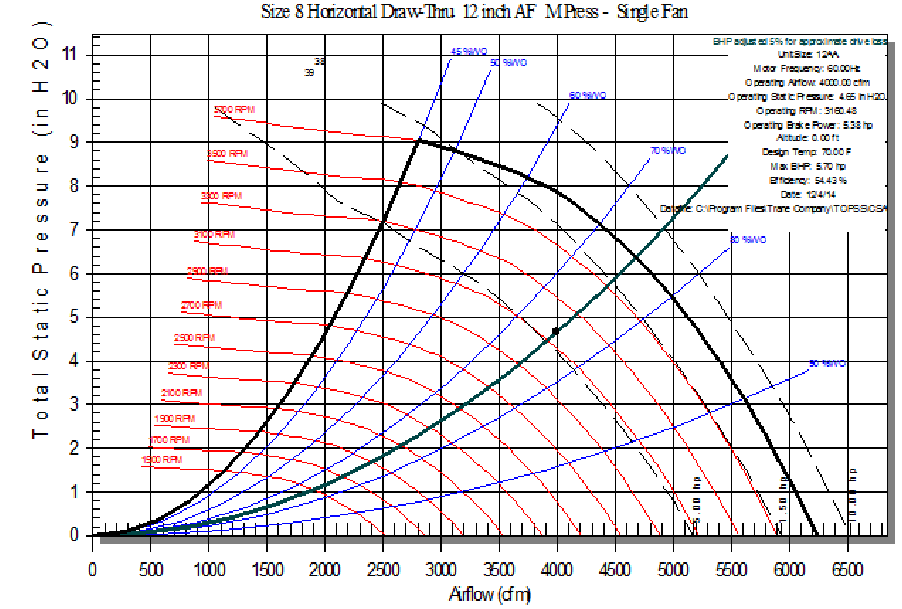
$$V_{ot} = \Sigma V_{oz}$$

APPENDIX R – PUMP AND FAN CALCULATIONS

Waterside Pressure Drop Calculation												
Pipe	Type of Run	Length [ft]	Velocity [ft/s]	Flow Rate [GPM]	Diameter [in]	Area [in^2]	Reynold's Number	Frictional Factor, f	Kinematic Viscosity, υ [ft^2/s]	Roughness,ε [in]	Fitting Loss Coefficient, K	Pressure Drop [ft H2O]
Chilled Water Pump 1												
CHWS	Elbow	-	5.00	150	3.5	9.62	8.77E+04	0.032789	1.66E-05	1.80E-03	0.9	0.350
CHWS	Straight	12	7.52	115	2.5	4.91	9.41E+04	0.036316	1.66E-05	1.80E-03	-	1.835
CHWS	Balancing Valve	-	7.52	115	2.5	4.91	9.41E+04	0.036316	1.66E-05	1.80E-03	3.6	3.159
CHWS	Elbow	-	7.52	115	2.5	4.91	9.41E+04	0.036316	1.66E-05	1.80E-03	0.9	0.790
CHWS	Balancing Valve	-	7.52	115	2.5	4.91	9.41E+04	0.036316	1.66E-05	1.80E-03	3.6	3.159
CHWS	Straight	6	7.52	115	2.5	4.91	9.41E+04	0.036316	1.66E-05	1.80E-03	-	0.918
CHWS	Elbow	-	7.52	115	2.5	4.91	9.41E+04	0.036316	1.66E-05	1.80E-03	0.9	0.790
CHWS	Straight	27	7.52	115	2.5	4.91	9.41E+04	0.036316	1.66E-05	1.80E-03	-	4.129
CHWS	Elbow	-	7.52	115	2.5	4.91	9.41E+04	0.036316	1.66E-05	1.80E-03	0.9	0.790
CHWS	Straight	11	11.80	65	1.5	1.77	8.87E+04	0.043149	1.66E-05	1.80E-03	-	8.212
CHWS	Elbow	-	11.80	65	1.5	1.77	8.87E+04	0.043149	1.66E-05	1.80E-03	0.9	1.947
CHWS	Straight	16	4.25	65	2.5	4.91	5.32E+04	0.036474	1.66E-05	1.80E-03	-	0.785
CHWR	Elbow	-	3.27	32	2	3.14	3.27E+04	0.039338	1.66E-05	1.80E-03	0.9	0.381
CHWR	Straight	48	3.27	32	2	3.14	3.27E+04	0.039338	1.66E-05	1.80E-03	-	1.879
											Total:	**36.919**

AHU-1 - Supply Fan sec [8]-1

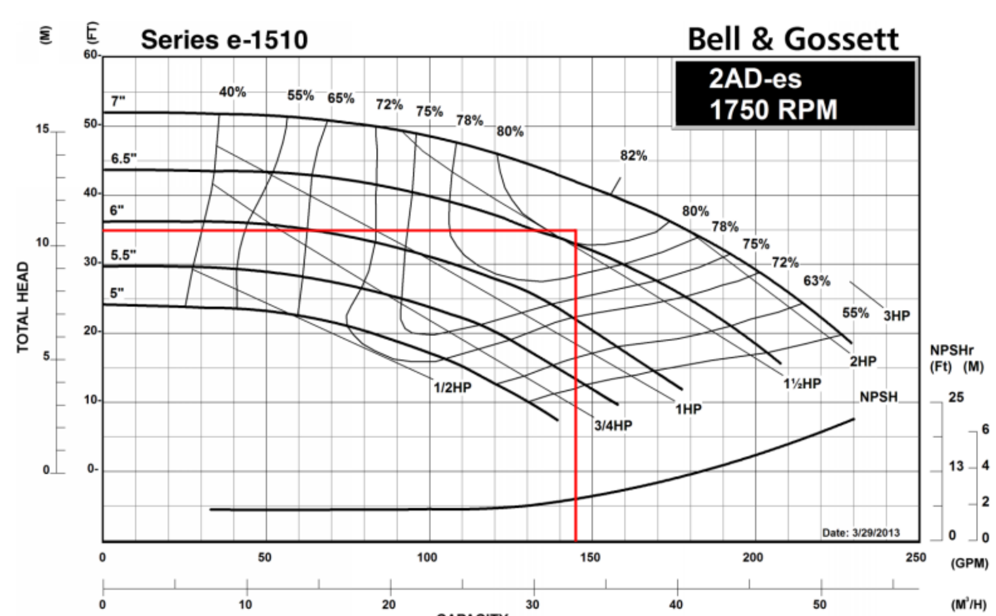
Size 8 Horizontal Draw-Thru 12 inch AF M.Press - Single Fan

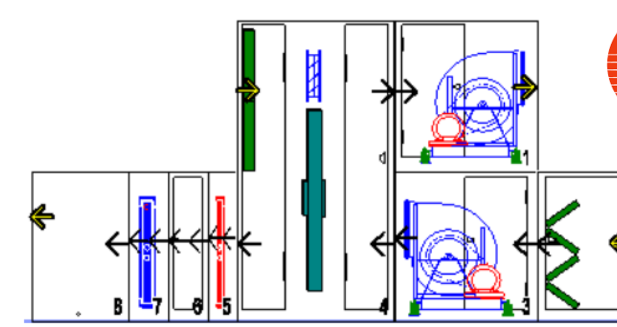


AHU-1 - Supply Fan sec [8]-1

Size 8 Horizontal Draw-Thru 12 inch AF M.Press

	63Hz	125Hz	250Hz	500Hz	1 kHz	2 kHz	4 kHz	8 kHz
Casing	80	82	71	78	72	57	46	39
Supply Front	87	87	86	92	87	82	77	72
Outdoor	79	82	76	81	76	75	68	54





All pumps were sized by calculating pressure losses and volumetric flow rates produced.

A 12 ton outdoor air handling unit supply and exhaust fan were sized based off of total static pressure loss through the system

APPENDIX S – FIRE SUPPRESSION & LIFE SAFETY PLAN

The Mechanical Team focused on ways to ensure a safe working and learning environment for the Vertical Farm by providing a fire suppression system in the event of a fire. One fire pump will serve the entire Vertical Farm. The required flow rate and pressure needed to serve the sprinkler system were determined in order to size the pump.

Fire Pump Sizing				
Type	Required Flow Rate [GPM]	Total Pressure Required [psi]	Available Pressure [psi]	Required Fire Pump Pressure [psi]
Fire Pump-1	750	144	30	114

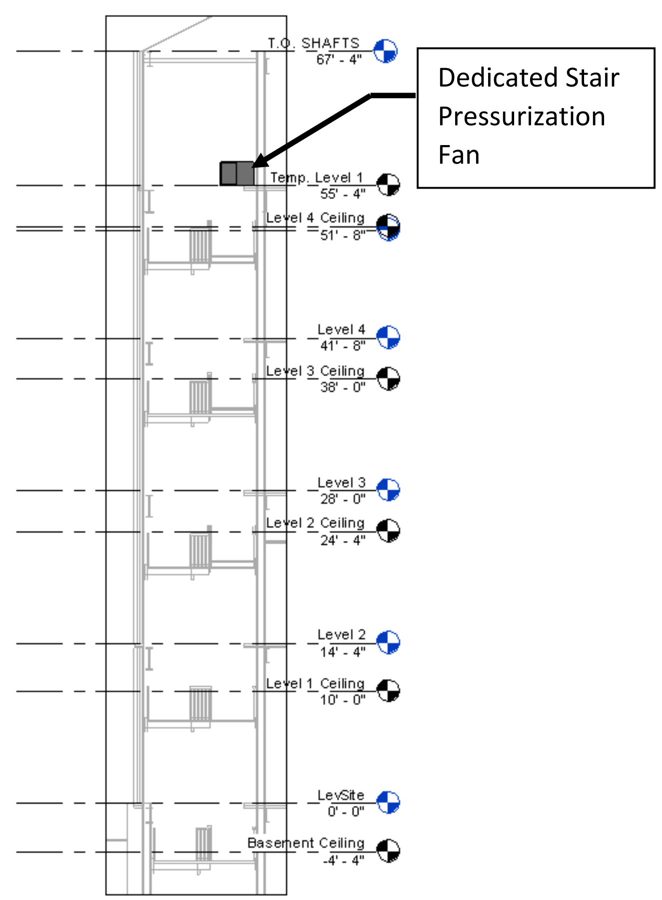
Pressure Required	
Top Floor Required Pressure [psi]	100
Head [psi]	23.8
Pipe Loss [psi]	10
Equipment Loss [psi]	10
Total Required Pressure [psi]	143.8

Life Safety Plan:

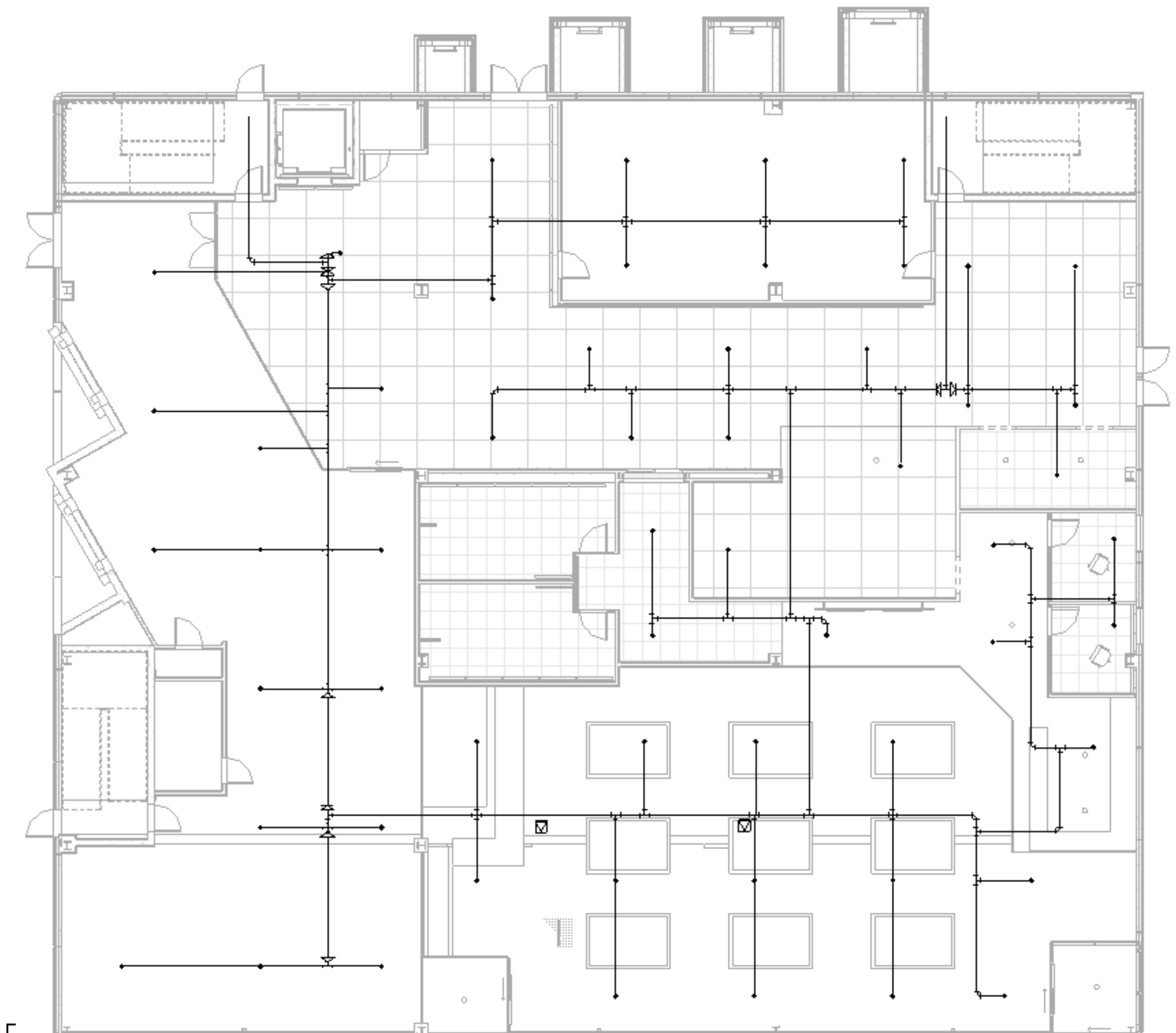
In the case of a fire alarm evacuation, the elevator will no longer be accessible and stairwells will be the main areas of refuge. HVAC fire/smoke dampers are activated inside of the ducts that pass through fire-resistance rated walls to prevent the spread of smoke and fire.

Stairwell Pressurization: A dedicated stair pressurization fan is used to supply air to the stairwells to prevent smoke from entering when the stairwell access doors open. The figure to the right displays a section of the stairwell with a supply duct providing air to each floor.

Greenhouse Fire Prevention: A 1-hour fire-rated wall separates the greenhouse spaces from the rest of the building.



Stairwell Pressurization: Section of dedicated stair pressurization fan



First Floor Sprinkler Layout: First floor plan displaying the sprinkler spacing. Two standpipes serve each floor of the Vertical Farm. One standpipe (500 GPM) is located in the northeast stairwell and one standpipe (250 GPM) is located in the northwest stairwell.

Sprinkler Spacing Requirements: Based on NFPA 13

Occupancy: Light/Ordinary Hazard

- Maximum 15 feet spacing between sprinkler heads, each head covering 130 square feet.
- Maximum distance from sprinkler head to wall is 7'-6"
- Minimum distance from ceiling to sprinkler head is 1", maximum distance from ceiling is 12"

APPENDIX T – INDOOR AIR QUALITY & ACOUSTICS

Air Quality – An air quality test was performed for both cities of Milwaukee and Miami to determine the amount of pollutants in the air. All outdoor air is used to condition each space, so it is important to analyze the quality of air used to condition. Pollutants found in the air were analyzed to determine the excess cancer risk (r_e). The excess cancer lifetime risk is the probability of developing cancer following exposure. Aggregate risk estimates cancer risks for an exposed population.

Average Ambient Concentrations (PPB)					
Pollutant	**Milwaukee**	**Miami**	**PEL (PPM)**	**Molecular Weight**	**Unit Risk Factor ($m^3/\mu g$)**
Benzene	18	18	10	78.1	2.65E-05
Carbon Tetrachloride	3	3	2	153.8	9.44E-05
Chloroform	10	10	2	119.4	1.12E-04
Formaldehyde	20	20	3	30	1.60E-05
Perchloroethylene	5	5	25	166	3.93E-06
Styrene	5	5	50	104.2	2.43E-06
Population ($P_{k,j}$)	600,000	420,000			

Average Ambient Concentrations for various pollutants in both Milwaukee and Miami. Unit risk factor associated with each pollutant.

Pollutant	Milwaukee				Miami				Unit Risk Factor ($m^3/\mu g$)
	Concentration [$\mu g/m^3$]	Excess Lifetime Risk (r_e)	$P_{k,j}$*$C_{k,j}$	Aggregate Risk (Aj)	C_j	Excess Lifetime Risk (r_e)	$P_{k,j}$*$C_{k,j}$	Aggregate Risk (A_j)	
Benzene	57.38	1.52E-03	3.44E+07	912	57.38	1.52E-03	24099428.57	639	2.65E-05
Carbon Tetrachloride	18.83	1.78E-03	1.13E+07	1067	18.83	1.78E-03	7909714.286	747	9.44E-05
Chloroform	48.73	5.46E-03	2.92E+07	3275	48.73	5.46E-03	20468571.43	2292	1.12E-04
Formaldehyde	24.49	3.92E-04	1.47E+07	235	24.49	3.92E-04	10285714.29	165	1.60E-05
Perchloroethylene	33.88	1.33E-04	2.03E+07	80	33.88	1.33E-04	14228571.43	56	3.93E-06
Styrene	21.27	5.17E-05	1.28E+07	31	21.27	5.17E-05	8931428.571	22	2.43E-06
Total		**9.33E-03**				9.33E-03			

Excess Lifetime and Aggregate Risk associated for both Milwaukee and Miami climates

Classroom Acoustics Study- The classrooms located on the third floor were acoustically analyzed to determine if vinyl floor tiling was appropriate to reach the desired reverberation time. The desired reverberation time for the classrooms is 0.6 seconds for mid to high frequencies. All partitions are constructed out of gypsum board on studs and the east outer wall is constructed out of CMU. Acoustic ceiling tile helps reduce the reverberation time significantly making it unnecessary to change the floor to a more absorbent material.

Surface Description	Surface Area, S [ft²]	Material Description	Sound Absorption Coefficient, α						S *α (sabins)					
			Frequency (Hz)						Frequency (Hz)					
			125	250	500	1000	2000	4000	125	250	500	1000	2000	4000
West Wall	143	Gypsum Board on Studs	0.29	0.1	0.05	0.04	0.07	0.09	41.47	14.30	7.15	5.72	10.01	12.87
East Wall-Windows	225	Glass: Window	0.35	0.25	0.18	0.12	0.07	0.04	78.75	56.25	40.50	27.00	15.75	9.00
East Wall-CMU	82	Concrete Block-Painted	0.1	0.05	0.06	0.07	0.09	0.08	8.20	4.10	4.92	5.74	7.38	6.56
North Wall	908	Gypsum Board on Studs	0.29	0.1	0.05	0.04	0.07	0.09	263.32	90.80	45.40	36.32	63.56	81.72
South Wall	908	Gypsum Board on Studs	0.29	0.1	0.05	0.04	0.07	0.09	263.32	90.80	45.40	36.32	63.56	81.72
Ceiling	635	Acoustic Ceiling Tile	0.7	0.66	0.72	0.92	0.88	0.75	444.50	419.10	457.20	584.20	558.80	476.25
Floor	635	Vinyl Tile on Raised Floor	0.02	0.03	0.03	0.03	0.03	0.02	12.70	19.05	19.05	19.05	19.05	12.70
								ΣSα=	1112.26	694.40	619.62	714.35	738.11	680.82
								Avg. α =	0.33	0.21	0.18	0.21	0.22	0.20
								Air absorption constant for 20°C and 40% RH,	0	0	1.83E-04	3.26E-04	7.86E-04	2.56E-03
							Sabine Reverb Time: *(s)*	*RT* =	0.40	0.64	0.71	0.61	0.58	0.58
							Norris-Eyring Reverb Time: *(s)*	*RT* =	0.33	0.57	0.64	0.55	0.52	0.52
								Target RT(s)	0.8	0.7	0.6	0.6	0.6	0.6
								Calculated *RT* (s)	0.33	0.57	0.71	0.55	0.52	0.52