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8. Figure 10: Map of Milwaukee area courtesy of Bing Maps
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10. Figure SD 1: Well-X-Trol pressurized tank courtesy of Amtrol
11. Figure SD 3: Raft aquaponics image courtesy of aquaponics.com
12. Figure SD 7: BM-55/88 courtesy of Viessmann
13. Figure SD 17: Water Source Heat Pumps courtesy of Daikin
14. Drawing D2: Equipment Images Courtesy of Viessmann Group, Bell and Gossett, Haase Tanks, Hydroflex Systems, Maxim Heat Recovery Silencers, Clever and Brooks, Moyno
15. Drawing D1: Image Courtesy of Marley

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GREENHOUSE WATER USAGE

With traditional farming techniques, up to 50% of water can be lost.[20] By using a recirculating aquaponic growing system coupled with both rainwater and groundwater harvesting, the greenhouse water demand is completely self-sufficient.

The following calculations reflect values for Milwaukee. All sumps are sized such that the system may remain in operation for a full day in the event that the system requires maintenance

Table SD 1: Greenhouse Water Use Analysis

Roof ID	Area	Avg Monthly Rainfall		Avg Rain Collection			Water Demand			Size of Rain Collection			Groundwater Pumped to GH	
							Aquaponics	Fan & Pad	Total	Volume	Height	Diameter		
	SF	in.	ft	ft^3	gal/month	gal/day	gal/day	gal/day	gal/day	ft^3	ft	ft	gal/day	gpm
2	1754	2.69	0.22	393.19	2941.05	98.03	132	16	148	20	3	2.91	49.97	0.03
3	1753.8	2.69	0.22	393.14	2940.71	98.02	132	16	148	20	3	2.91	49.98	0.03
4	2918.79	2.69	0.22	654.30	4894.13	163.14	132	16	148	20	3	2.91	-15.14	-0.01
5	2842.75	2.69	0.22	637.25	4766.63	158.89	132	56	188	30	3	3.57	29.11	0.02

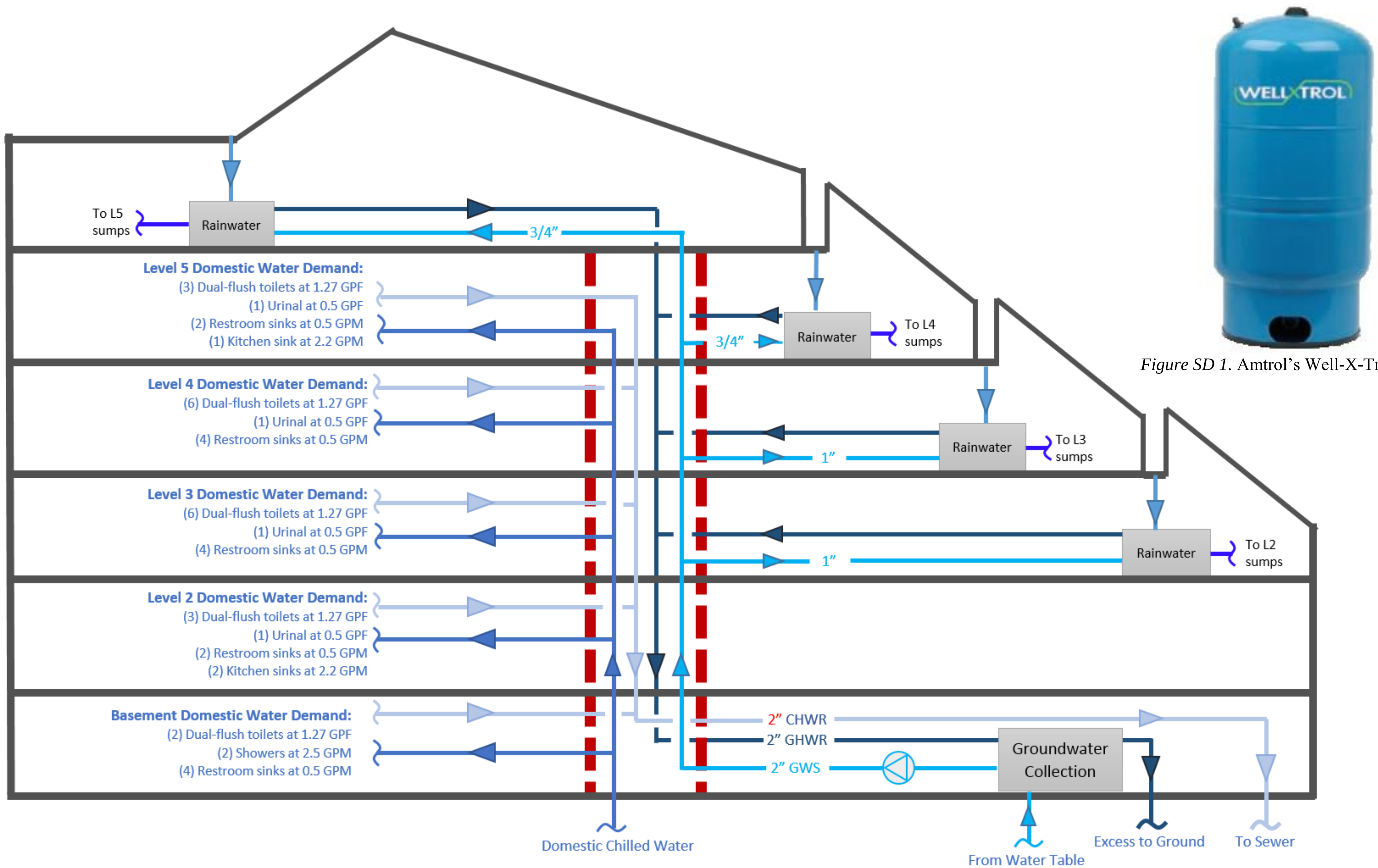

Figure SD 1. Amtrol's Well-X-Trol

Greenhouse Water Demand Sequence

Rainwater enters the greenhouse through the troughs located in between roofs of the individual greenhouses, where it is cleaned via biofilters. The water is then collected into a rainwater harvesting tank.

The water in the rainwater harvesting tank is delivered to the sumps of both the aquaponic and evaporative pad sumps. These sumps are pre-pressurized, acting much like a piston-cylinder to ensure that there is always the required supply of water in a system.

When the volume of water within these sumps decrease, the diaphragm within the sump tank "deflates," causing the sump to automatically restore the diaphragm to equilibrium by drawing water from the rainwater harvesting tank. Figure SD 1, on left, is an example of Amtrol's Well-X-Trol tank which uses this technology.

A float valve in the rainwater harvesting tank indicates if there is insufficient water in the system via a float inside the tank. When the water levels fall to insufficient levels, water will be pumped to the rainwater harvesting tank from the groundwater collection tank. Conversely, a pipe at the top of the rainwater storage tank will allow excess water to flow into the groundwater collection tank when water levels are too high, such as in the event of a rainstorm.

The groundwater collection system draws water from the water table to act as a well for the site, effectively becoming a new water supply. Because the groundwater collection system is connected to the rainwater harvesting tank, any excess water in the groundwater collection tank can be sent back into the ground.

FAN & PAD EVAPORATIVE COOLING CALCULATIONS

Milwaukee Fan & Pad Evaporative Cooling Calculations

Table SD 2: Weather Characteristics of Milwaukee Evaporative Cooling

System Characteristics	
Saturation Effectiveness	0.8
Maximum Indoor Air Temperature [°F]	80
Face Velocity [fpm]	250
Corrugated Cellulose Thickness [in]	4

Table SD 3: System Characteristics of Milwaukee Evaporative Cooling

Location-Based Criteria: Milwaukee	
Average Solar Radiation [BTU/h*ft^2]	138
Design Day DB Temp. [°F]	86.18
Design Day WB Temp. [°F]	72.32
Temp. Leaving Evaporative Cooler [°F]	76

Table SD 4: System Sizes for Milwaukee Evaporative Cooling

Growing Space Level	Growing Space Area	Cooling Air Volume	Face Area of Evaporative Cooling
	SF	CFM	SF
2	2750	47438	190
3	1920	33120	133
4	1665	28722	115
5	4625	79782	320

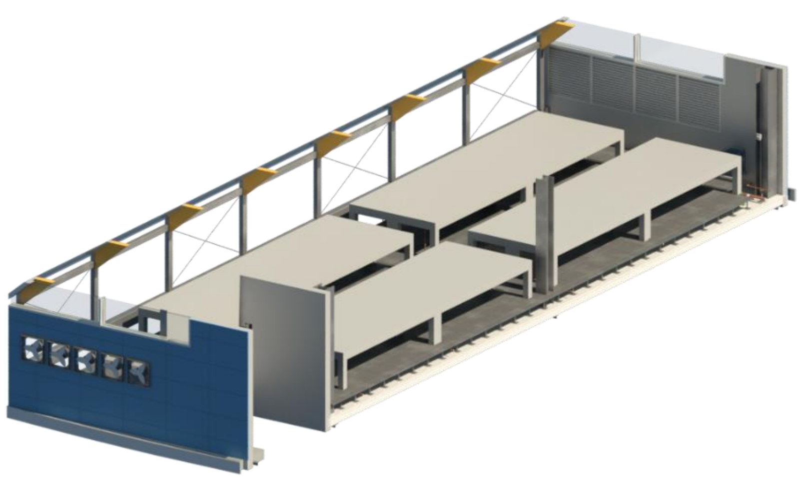

Figure SD 2. The greenhouse spaces in the Growing Power Vertical Farm feature evaporative fan and pad cooling on the East and West walls.

Miami Fan & Pad Evaporative Cooling Calculations

Table SD 5: Weather Characteristics of Miami Evaporative Cooling

System Characteristics	
Saturation Effectiveness	0.8
Maximum Indoor Air Temperature [°F]	82
Face Velocity [fpm]	250
Corrugated Cellulose Thickness [in]	4

Table SD 6: System Characteristics of Miami Evaporative Cooling

Location-Based Criteria: Miami	
Average Solar Radiation [BTU/h*ft^2]	153
Design Day DB Temp. [°F]	90.32
Design Day WB Temp. [°F]	77.36
Temp Leaving Evaporative Cooler [°F]	80

Table SD 7: System Sizes for Miami Evaporative Cooling

Growing Space Level	Area	Cooling Air Volume	Face Area of Evaporative Cooling
	SF	CFM	SF
2	2750	105188	421
3	1920	73440	294
4	1665	63687	255
5	4625	176907	708

Table SD 8: Sizes for Evaporative Cooling Sump Tank

Evaporative Cooling Sump		
Volume	**Diameter**	**Height**
gallons	**ft**	**ft**
16	1.25	2.66
16	1.25	2.66
16	1.25	2.66
56	2	2

Governing Equations

Calculations based off of 2011 ASHRAE Handbook- HVAC Applications, Chapter 52.13, Evaporative Cooling- Other Applications, Cooling Greenhouses section.

$$T_{ec} = T_{DB} - [\varepsilon * (T_{DB} - T_{WB})]$$

$$Q_{cooling} = \frac{0.5 * Greenhouse\ Area * I_{rad,solar}}{T_{max,GH} - T_{ec}}$$

$$A_{ec} = \frac{Q_{cooling}}{face\ velocity}$$

T_{ec} = temperature leaving the evaporative cooler [°F]

T_{DB} = design dry bulb temperature of the site [°F]

T_{WB} = design wet bulb temperature of the site [°F]

$Q_{cooling}$ = cooling air volume [cfm]

$I_{rad,solar}$ = average solar radiation of the site [BTU/h*ft^2]

$T_{max,GH}$ = maximum indoor air temperature of the greenhouse [°F]

A_{ec} = face area of the evaporative cooling pads [sf]

A comparison of the sizes of the fan and pad evaporative cooling systems in Milwaukee and Miami shows that a considerably greater air volume and face area are needed in the Miami site to deliver similar space conditions in the greenhouse. This indicates that a future design of a vertical farm in the Miami site, and similarly hot and humid climates should strongly consider a heavier reliance on the naturally ventilated roof for cooling.

The required fan and pad sizes were calculated using the equations given in Chapter 52.13 of the 2011 ASHRAE Handbook – HVAC Applications, giving the length of pad required. According to Bucklin, et. al., evaporative cooling sumps should be sized to hold 1 to 1.25 gallons per linear foot of pad in order to hold all water that drains to the sump when the system stops.[16] Therefore the evaporative cooling sumps were sized at 1 gallon per linear foot of evaporative pad.

AQUAPONIC SYSTEM PROCESS

1. Aquaculture Raceway. Water enters the aquaculture raceway, home to tilapia. A raceway, as opposed to a circular tank, makes sediment removal much simpler by directing flow towards the sediment collection tank.

2. Sediment Collection. Any unwanted fish waste is sent into the sediment collection tank such that it cannot reach the plants in the grow beds.

3. Pumps. The pumps serving the aquaponic system are located beneath the grated floor system to avoid any potential tripping hazards.

4. Grow Beds. Lettuce is grown in a raft bed system, in which a floating bed holds the lettuce in place.(11) Aquaponic water flows beneath the raft, during which the roots of lettuce absorb nutrients provided by the aquaculture.

5. Aquaponic Sump. Water leaves the grow beds and is sent to the aquaponic sump, which is an atmospheric tank which serves as the indicator of insufficient water levels in the system. The tank's diaphragm will indicate when water levels are low and pull water from the rainwater collection tank. The sump also maintains the aquaponic water temperature at a minimum of 72 °F by absorbing waste heat rejected from the CHP plant.

6. Rainwater Collection. As rain enters the greenhouse space through roof troughs, it is piped into the rainwater collection tank in each greenhouse. From the rainwater collection tank, makeup water is delivered to both the aquaponic sump and evaporative cooling sump.

7. Evaporative Cooling Sump. The evaporative cooling sump collects water from the rainwater collection tank such that the pads of the fan and pad system remain moist throughout its operation.

8. Groundwater Collection Tank. Any deficiency in water circulation of the greenhouse is mitigated by the groundwater collection tank. Conversely, any extra water in the rainwater collection tank is sent back to groundwater collection for later use.

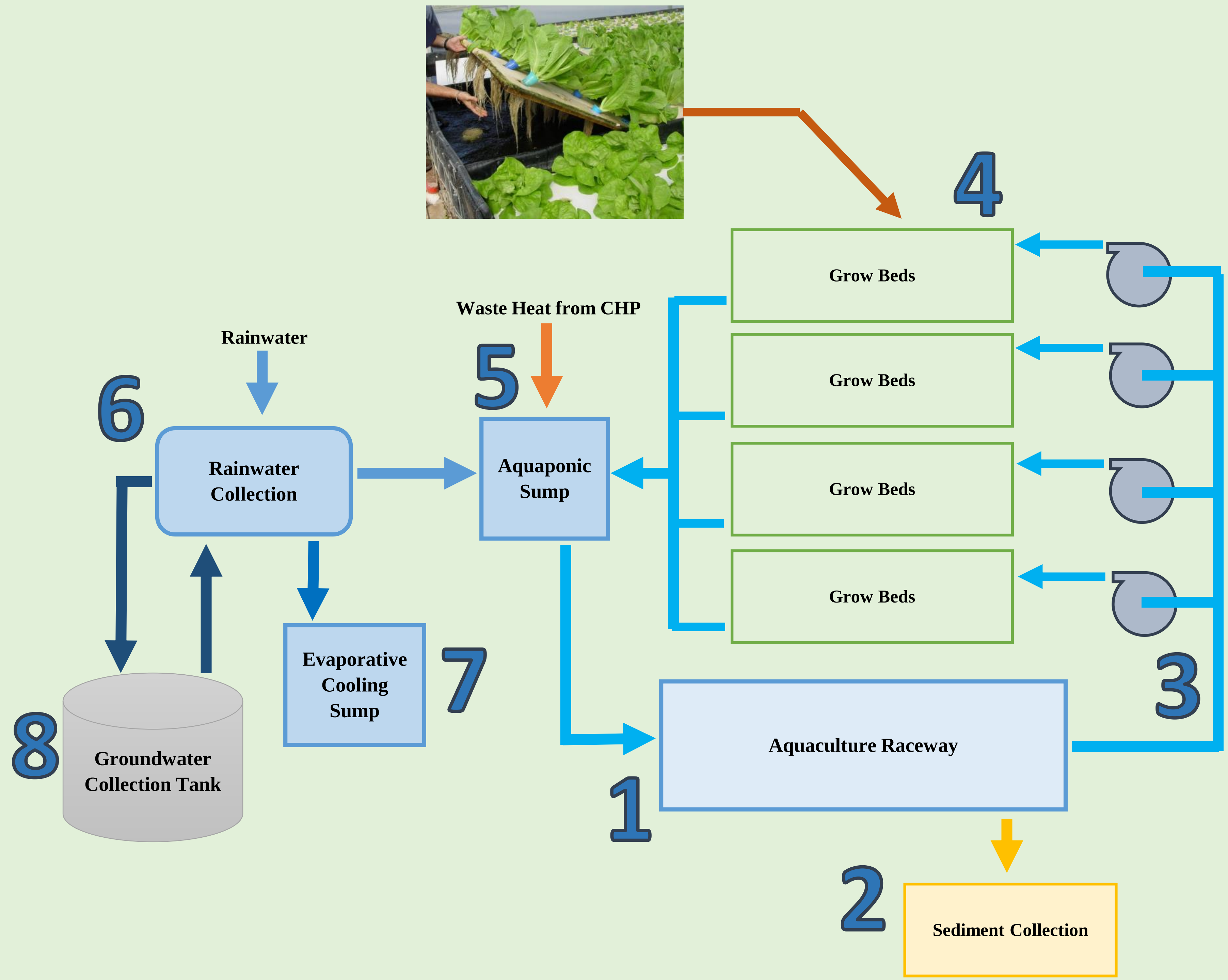

Figure SD 3. The Growing Power Vertical Farm facility comprises of a complex network of aquaculture, plants, and water sources within its greenhouses. Photo of raft grow bed courtesy of aquaponics.com.

AQUAPONIC SYSTEM SIZING

The flow rate through the growing beds was determined using the Aquaponic Media Bed Sizing Model (Ver. 2.0) by Lennard.[21] The model bases its calculations off of the findings in the University of the Virgin Islands aquaponics facility researched by Rakocy.[23] The model asks for inputs on the aquaculture side of the system, including fish tank volume, fish culture density, daily feed rate, and feed protein to output the size of the grow bed. Due to a limiting factor of square footage in the greenhouses, the aquaponic system in the Growing Power Vertical Farm was sized first by determining the appropriate size of grow beds and using the Lennard model in reverse to find an appropriate aquaculture tank size.

An aquaponics system loses about 2% of its water due to evaporation and transpiration per day.[20] Therefore the aquaponic sump tank on each greenhouse level was sized to hold 2% of the aquaculture raceway volume.

Table SD 9: Sizes for Grow Beds, Aquaculture Raceway, and Sump Tank included in the Aquaponic Growing System at Growing Power Vertical Farm

Growing Place Level	Growing Beds			Aquaculture Raceway		Pumps			Sump
	Quantity	Area	Flow Rate	Volume	Flow Rate	Total Flow Rate	Flow Rate per Pump	Quantity per Floor	Volume
		SF	gal/hr	gallons	gal/hr	gal/hr	gal/hr		gallons
2	16	832	1545	6604	2201	3746	1000	4	140
3	16	832	1545	6604	2201	3746	1000	4	140
4	8	416	772.5	3302	1101	1873	1000	2	70
5	36	1872	3462	14794	4931	8393	1000	9	300

Pump Flow Rate Calculations

The Aquaponic Media Bed Sizing Model (Ver. 2.0) by Lennard determined the flow rate through the growing beds. Using the same model, the volume of the aquaculture raceway was determined. Because the water in aquaculture tanks are typically turned over every three hours[23], the total flow rate through the aquaponic system is found by the following equation:

$$GPM_{system} = GPM_{grow\ beds} + \frac{V_{raceway}}{3}$$

Using this equation, the pumps were sized such that each pump can serve one set of four (4) grow beds at 1000 GPH.

GREENHOUSE ENVELOPE OPTIMIZATION

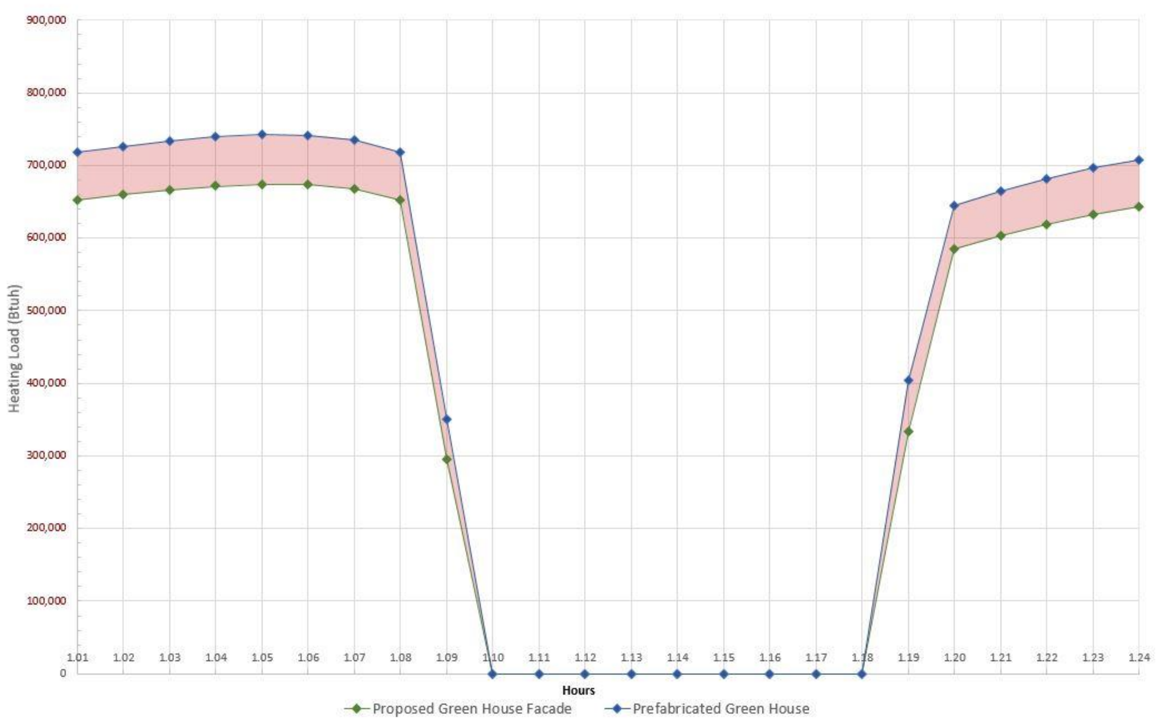

Figure SD 4. Typical greenhouse heating loads for January. The heating load is reduced compared to the prefabricated greenhouse by optimizing the glazing to mass wall ratio.

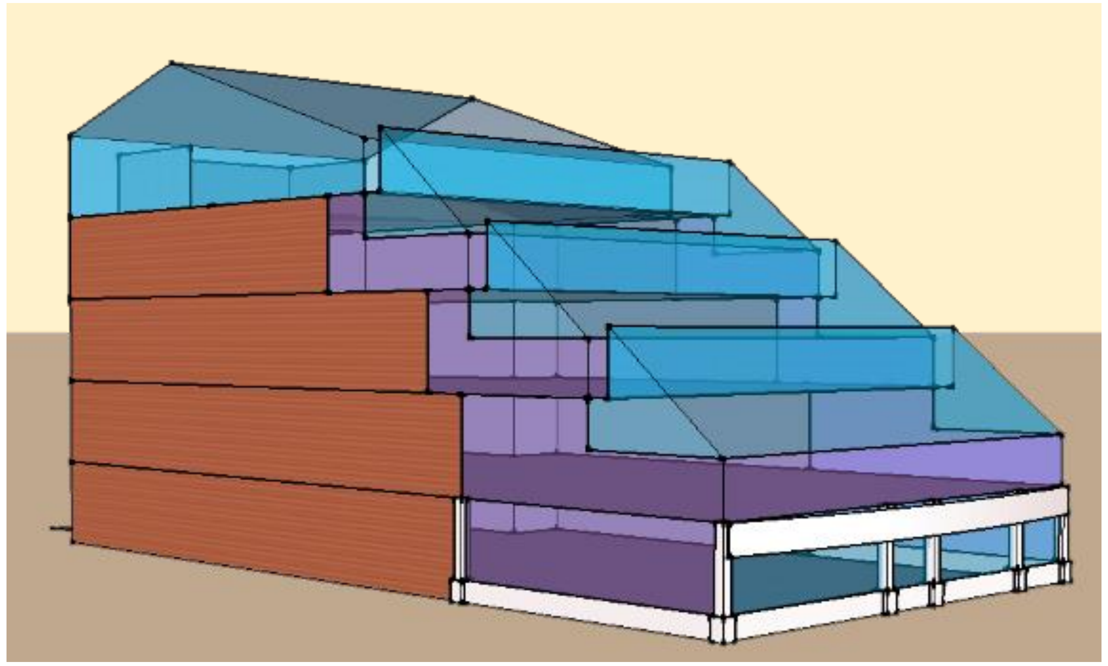

Figure SD 5. The areas highlighted in purple indicate the areas of the greenhouse where glazing could be replaced by thermal mass walls.

After the lighting/electrical design partners realized the glazing area needed in each greenhouse to optimize plant growth, the mechanical partners used this opportunity to replace glazing with mass walls to increase the thermal performance of the greenhouses. Choosing to analyze and optimize the greenhouse system rather than specifying a prefabricated system allowed the design team achieve this thermal benefit.

ANAEROBIC DIGESTION FACILITY

Table SD 10: Parameters Considered for Sizing the Two Phase Anaerobic Digestion System.

Two Phase Anaerobic Digestion Parameters											
		780 Kg Dry Waste/m3	*18.74% VS*		*750m3/tVS*	*65% CH4 / 35% CO2*		*1 Kbtu / m3 CH4*	*Currently Held Constant*	
Food Waste		Waste Volume	Volitale Solids	Vs Concentration	Biogas yeild	Methane Yield	Methane Yield	Energy Content	Organic Loading Rate	Tank Volume
Kg	lb	m3	Kg	Kg/m3	m3	m3	ft3	KBtu	Kg/m3/Day	m3
10	22.04	0.013	1.874	146	1.406	0.91	32.26	32	3.0	0.62
20	44.08	0.026	3.748	146	2.811	1.83	64.52	65	3.0	1.25
30	66.12	0.038	5.622	146	4.217	2.74	96.79	97	3.0	1.87
40	88.16	0.051	7.496	146	5.622	3.65	129.05	129	3.0	2.50
50	110.2	0.064	9.37	146	7.028	4.57	161.31	161	3.0	3.12
1700	3747	2.179	318.58	146	238.935	155.31	5484.54	5485	3.0	106.19
1710	3769	2.192	320.454	146	240.341	156.22	5516.80	5517	3.0	106.82
1720	3791	2.205	322.328	146	241.746	157.13	5549.06	5549	3.0	107.44
1730	3813	2.218	324.202	146	243.152	158.05	5581.32	5581	3.0	108.07
1740	3835	2.231	326.076	146	244.557	158.96	5613.59	5614	3.0	108.69
1750	3857	2.244	327.95	146	245.963	159.88	5645.85	5646	3.0	109.32
1760	3879	2.256	329.824	146	247.368	160.79	5678.11	5678	3.0	109.94
1770	3901	2.269	331.698	146	248.774	161.70	5710.37	5710	3.0	110.57

Design Justification

The anaerobic system sizing was based on an assumed organic loading rate of 3 kg/m^3/Day. The assumption was based on the average found organic loading rate of typical food waste performed at the Clarkson University anaerobic digestion campus study.(29)

The decision to install two phase anaerobic digestion system was made due to the assumed fluctuation in loading rate that might be expected at the Growing Power vertical farm. The two phase system will allow for a more stable process and require less maintenance.(29)

The anaerobic facility was confined to the basement to be sensitive to site constraints that might exist in different locations. Maintaining the system within the footprint of the building allows Growing Power to explore more urban sites than the current Milwaukee location.

Table SD 11: Energy Potential Calculation

Energy Potential BY Two Phase Anaerobic Digestion		
Energy Potential = EA - (EB+EC)	4,299	kBtu
EA = Mp * LHV,Methane	5,469	kBtu
EB = Q * Cp * (Ti-To)	49	kBtu
EC = k*A*(Ti-To)*(3600*24)	1,121	kBtu
(EB+EC)/24=Anaerobic Heat Demand/hr	**49**	**MBH**

Energy Potential Parameters			
Methane Potential	Mp	5581	ft^3
Low Heating Value	LHV	980	Btu/ft^3
Waste Mass Flow	Q	3800	lbm/day
Avg. Specific Heat of Waste	Cp	1	Btu/lbm-^{o}F
Digester Temerature	Ti	85	^{o}F
Ambient Temperature	To	72	^{o}F
Thermal Conductivity	k	1.703	Btu/SF-hr-^{o}F
Surface Area	A	2110	SF

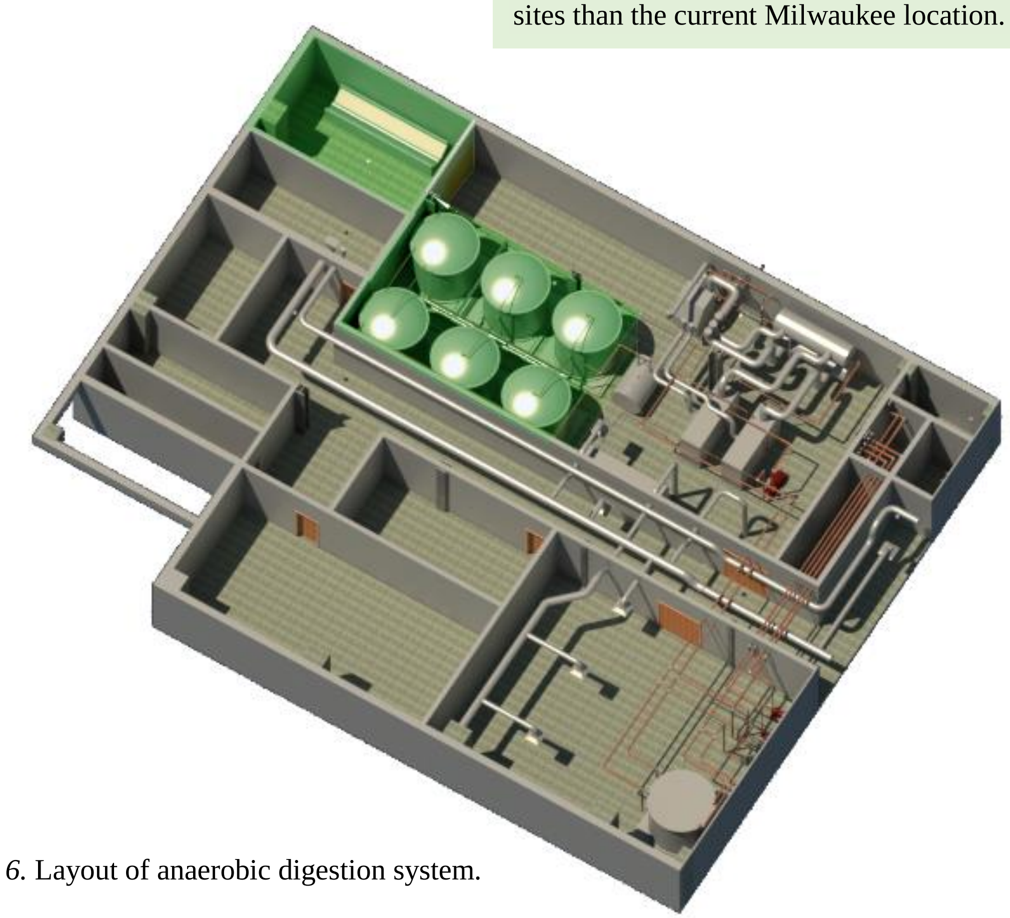

Figure SD 6. Layout of anaerobic digestion system.

Anaerobic Tank Volume Calculations (Curry, 2012)

$$Volume(m^3) = \frac{Flow\ Rate\left(\frac{m^3}{Day}\right) * Volitile\ Solids\ Concentration\ \left(\frac{kg}{m^3}\right)}{Organic\ Loading\ Rate\ \left(\frac{kg}{m^3}/Day\right)}$$

- Volatile Solids Concentration assumed to be 18.74% VS/Unit Waste Based on typical food waste composition.(28)
- Waste volume based on the Density and typical dryness of food waste.(26)
- D = 780 kg Dry Waste/m^3

$Density\left(\frac{kg}{m^3}\right) = 1 - e^{\left(\frac{-0.3}{b-0.1}\right)}$, where b = Dryness %

COMBINED HEAT AND POWER (CHP) FACILITY

The CHP facility was sized by studying the simulated thermal and electrical loads from Trane TRACE 700. The thermal to electric ratio of the site was matched with an internal combustion engine with a similar ratio. Understanding that the thermal to electric ratio would not be constant throughout the year, the duration curve and primary energy utilization factors to the right were used to design a CHP facility that could out perform a separate heat and power facility for the majority of the year.

Table SD 12 shows a study that was performed to better understand how the CHP facility would perform throughout the year. By looking at the table it can be seen that larger thermal stresses in the winter require that the system be equipped with a supplemental boiler to meet peak thermal load, but at yearly average weather conditions the CHP facility can handle the building demand on its own.

Viessmann BM-55/88	
(2) 55 kW IC Engines	λ=1.30
Electric Power (kW)	110
Heating Power (kW)	176
Gas Consumption (kW)	330
Electric Efficiency (%)	33
Heating Efficiency (%)	53
Overall Efficiency (%)	87

CHP Equations

$$\lambda_{Site} = \frac{Q_D}{w_{e^-}}$$

$$\lambda_{CHP} = \eta_{HRU}\left(\frac{1}{\eta_{CHP}} - 1\right)$$

$$PEUF_{SHP} = \frac{\eta_B * \eta_{GTD}(1 + \lambda_{site})}{\eta_B + \eta_{GTD} * \lambda_{site}}$$

$$PEUF_{CHP} = \eta_{CHP}(1 + \lambda_{site})$$

Figure SD 7. BM-55/88 courtesy of Viessmann

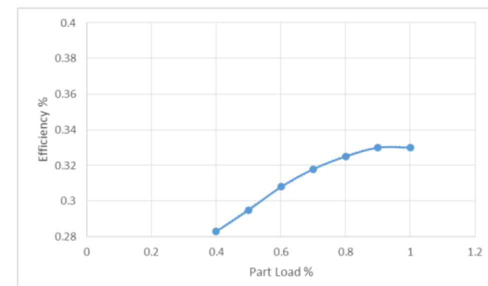

Figure SD 8. BM-55/88 Part Load Efficiencies.

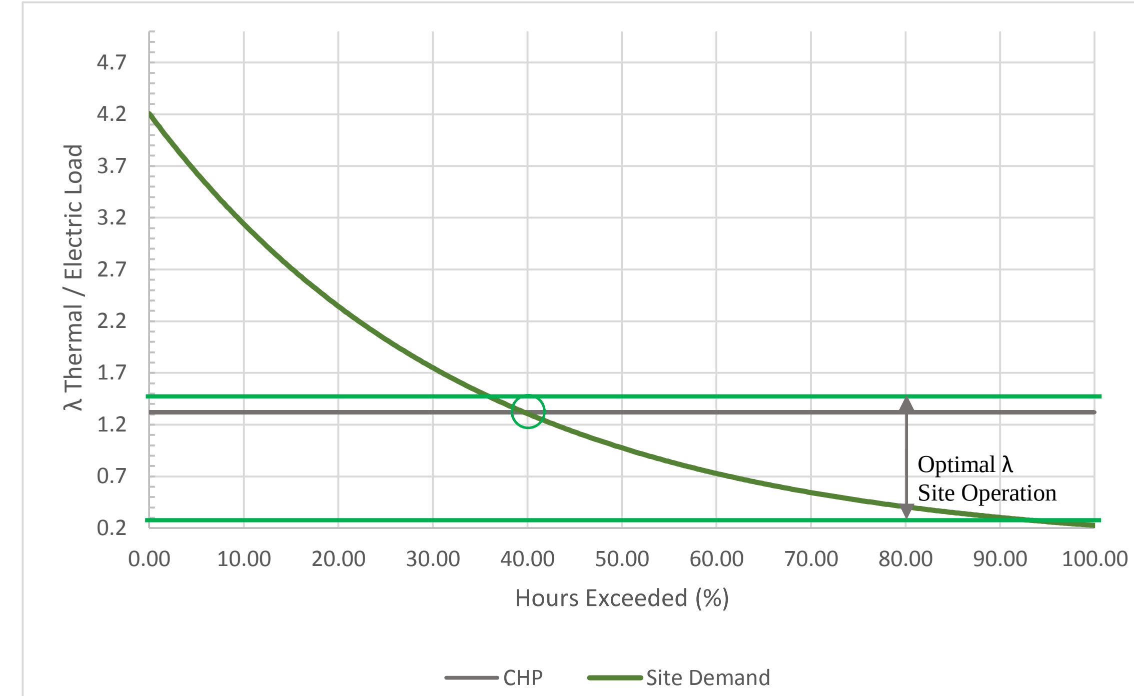

Figure SD 9. Thermal to Electric ratio duration curve. The thermal to electric ratio of the CHP system was plotted against the building λ demand. The data suggests the 40% of year the facility has a larger λ than can be provided by the system.

Table SD 12: CHP Operation Simulation at Typical Seasonal Days.

	Heat Demand (kW)							Electric Demand (kW)						Year Avg. Operation		
Hours	Yearly Average	Summer	Heat Δ	Fuel Cons.	Winter	Heat Δ	Fuel Cons.	Yearly Average	Summer	Electric Δ	Winter	Electric Δ	Lambda	Heat Δ	Electric Δ	Fuel Cons.
1	50	14	21	100	86	28	330	36	30	0	43	67	1.40	0	11	144
2	55	14	21	100	97	17	330	37	30	0	46	64	1.50	0	15	158
3	61	15	20	100	110	5	330	38	30	0	48	62	1.58	23	39	240
4	66	15	20	100	121	6	330	40	30	0	51	59	1.67	18	37	240
5	71	15	20	100	130	16	330	41	30	0	54	56	1.73	13	36	240
6	74	15	20	100	137	22	330	42	30	0	57	53	1.75	10	35	240
7	75	15	7	64	139	25	330	37	24	0	52	58	2.04	9	40	240
8	200	57	27	240	315	201	330	70	59	18	83	27	2.85	86	40	330
9	132	52	32	240	204	89	330	73	71	6	80	30	1.80	18	37	330
10	140	60	46	304	208	94	330	87	96	0	87	23	1.60	26	23	330
11	125	52	58	320	190	76	330	90	102	0	85	25	1.40	11	20	330
12	116	46	53	286	180	66	330	84	90	0	83	27	1.39	2	26	330
13	113	41	58	286	179	64	330	82	90	0	80	30	1.38	1	28	330
14	108	36	73	314	174	60	330	88	99	0	84	26	1.23	6	22	330
15	106	33	78	320	172	57	330	91	102	0	87	23	1.16	8	19	330
16	106	32	73	303	173	58	330	86	95	0	84	26	1.23	8	24	330
17	79	24	70	273	129	15	330	75	84	0	72	38	1.06	5	2	240
18	83	25	67	265	134	20	330	74	81	0	72	38	1.13	0	3	240
19	89	27	63	260	144	30	330	73	79	0	74	36	1.22	5	4	212
20	96	28	55	240	157	42	330	69	71	6	72	38	1.40	0	21	278
21	99	29	32	176	162	48	330	58	55	0	67	43	1.69	0	35	285
22	27	15	28	125	42	72	330	41	40	0	45	65	0.65	57	36	240
23	37	14	21	103	61	53	330	35	31	0	40	70	1.07	47	42	240
24	45	14	21	103	75	40	330	36	31	0	42	68	1.25	39	41	240
Sum	*2151*	*690*	*985*	*4822*	*3520*	*774*	*7920*	*1481*	*1478*	*30*	*1587*	*1053*		*96*	*636*	*6447*
Average	*90*	*29*	*41*		*147*	*32*		*62*	*62*	*1*	*66*	*44*	*1.47*			
Max	*200*	*60*	*78*		*315*	*72*		*91*	*102*	*18*	*87*	*70*	*2.85*			
Yearly Peaks	*565*							*125*					*5.94*			

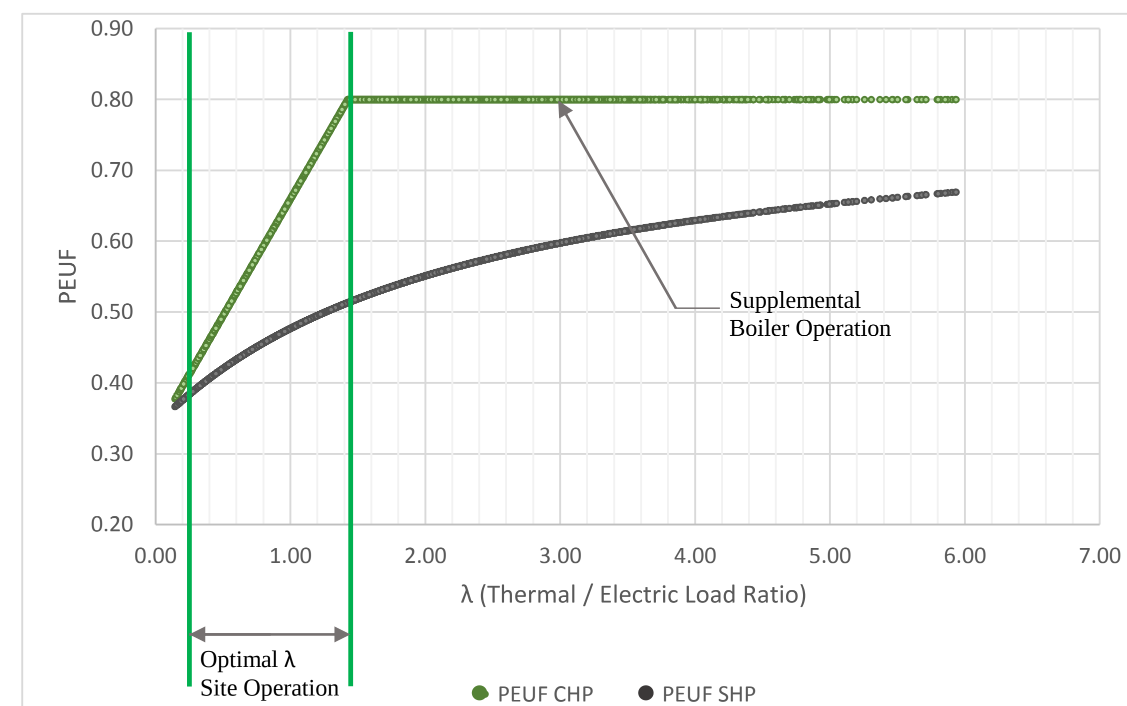

Figure SD 10. Comparison of CHP and SHP Primary Energy Utilization Factor at variable λ. The data shows that the PEUF of the Growing Power CHP facility outperforms typical SHP facilities. It also shows that a supplemental boiler will need to be included in the system for days that generate large cold stresses, increasing λ beyond the optimal site operation.

EMISSIONS STUDY

Table SD 13: EPA Calculator for Emissions Reductions and Environmental and Energy Benefits for Landfill Gas Energy Projects. Courtesy of the EPA and Landfill Methane Outreach Program.[37]

For direct-use projects, enter landfill gas utilized by project: **0.0086** million standard cubic feet per day (mmscfd)

Emission Reductions and Environmental and Energy Benefits for Landfill Gas Energy Projects						
Direct Equivalent Emissions Reduced		**Avoided Equivalent Emissions Reduced**		**Total Equivalent Emissions Reduced**		
[Reduction of methane emitted directly from the landfill]		[Offset of carbon dioxide from avoiding the use of fossil fuels]		[Total = Direct + Avoided]		
$MMTCO_2E$/yr million metric tons of carbon dioxide equivalents per year	**tons CH_4/yr** tons of methane per year	**$MMTCO_2E$/yr** million metric tons of carbon dioxide equivalents per year	**tons CO_2/yr** tons of carbon dioxide per year	**$MMTCO_2E$/yr** million metric tons of carbon dioxide equivalents per year	**tons CH_4/yr** tons of methane per year	**tons CO_2/yr** tons of carbon dioxide per year
0.0008	33	0.0001	82	0.0008	33	82
Equivalent to any one of the following annual benefits:		**Equivalent to any one of the following annual benefits:**		**Equivalent to any one of the following annual benefits:**		
Environmental Benefits		Environmental Benefits		Environmental Benefits		
• Carbon sequestered by __ acres of U.S. forests in one year:	616	• Carbon sequestered by __ acres of U.S. forests in one year:	61	• Carbon sequestered by __ acres of U.S. forests in one year:		677
• CO2 emissions from __ barrels of oil consumed:	1,748	• CO2 emissions from __ barrels of oil consumed:	173	• CO2 emissions from __ barrels of oil consumed:		1,921
• CO2 emissions from __ gallons of gasoline consumed:	84,584	• CO2 emissions from __ gallons of gasoline consumed:	8,351	• CO2 emissions from __ gallons of gasoline consumed:		92,936
Energy Benefits (based on project size entered):						
• Heating __ homes:	21					

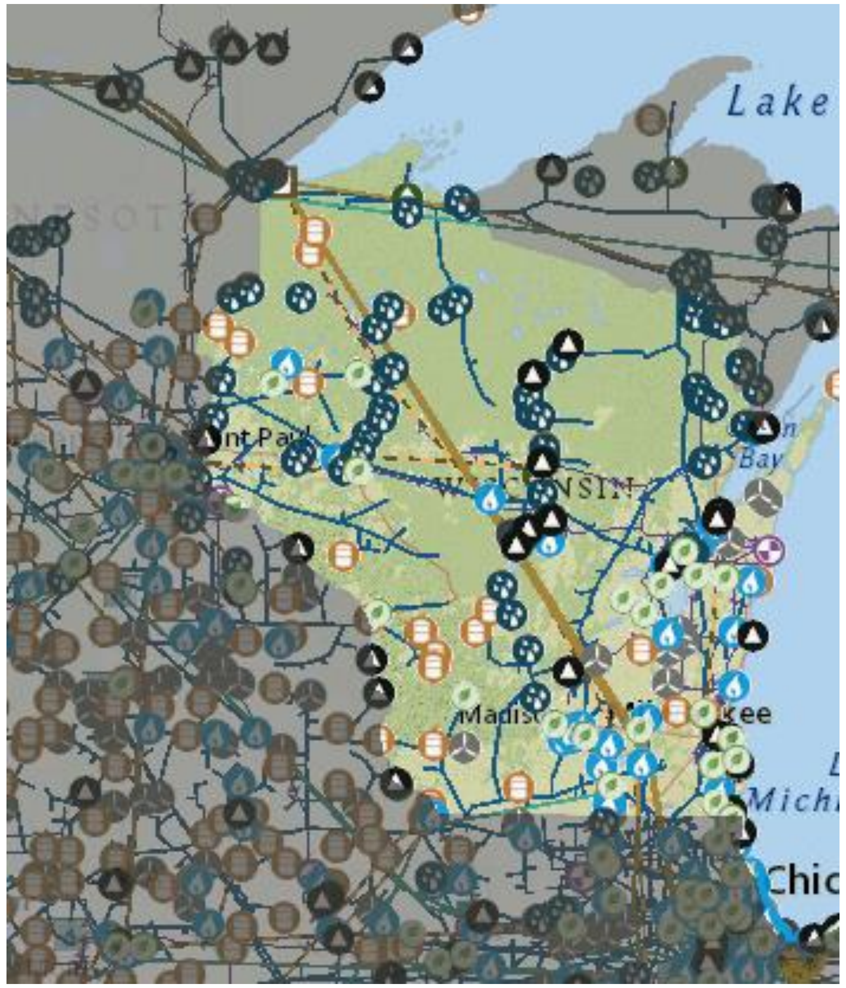

Figure SD 11. Power plant locations throughout Wisconsin. In 2013 coal power plants counted for 62% of Wisconsin's total power generation.[35]

Table SD 14: CO_2 Reduction of the CHP Facility versus a Standard Separate Heat and Power Facility.[36]

Emissions Characteristics of CHP Facility				
				Totals
CF / Year	724153.00	0.12037	lb CO_2/CF CH^4	87166.29661
kWh/Year	540763.46	1.18	lb CO_2/kWh	638100.8828
CO^2 Emissions Reduction (lb CO_2)				550934.5862
Emissions Savings Compared to Separate Heat and Power				***86%***

Social Considerations for Growing Power's Combined Heat and Power Facility

Alongside the feasibility study for the CHP and anaerobic digestion facility for Growing Power, the emissions reduction realized by the facility was documented. On top of the possible economic and efficiency benefits of the CHP facility, reduced emissions provides a benefit to the entire community and helps Growing Power establish themselves as a community leader.

ECONOMIC ANALYSIS

Economic Considerations for Growing Power's Combined Heat and Power Facility

An economic study was performed on the Growing Power Milwaukee's CHP and anaerobic digestion facility to determine the payback on the system. When considering if CHP and on site fuel generation is feasible at future locations, it is the hope of the TBD design team that the same feasibility, economic, and social factors will be considered.

The economic analysis shows that the CHP and anaerobic facility installed in Milwaukee had a reasonable payback period of 3 years if the local Wisconsin incentives were perused. The longer payback of 6 years without incentives should still be weighed against all the social benefits the CHP facility creates by lowering community CO_2 emissions.

Table SD 16: NPV Calculations from 0 to 10 Years

Net Present Value Calculations				
3.00%	Discount Rate (%)			
4.50%	Assumed Escalation Rate of Electricity			
	Offset Total	Offset Electricity	No incentive	Incentive
0	$ (780,600.00)		$ (780,600.00)	$ (390,300.00)
1	$ 127,362.32	$ 50,280.52	($656,947.26)	($266,647.26)
2	$ 129,624.94	$ 52,543.15	($534,763.32)	($144,463.32)
3	$ 131,989.38	$ 54,907.59	($413,974.34)	($23,674.34)
4	$ 134,460.23	$ 57,378.43	($294,508.17)	$95,791.83
5	$ 137,042.25	$ 59,960.46	($176,294.32)	$214,005.68
6	$ 139,740.47	$ 62,658.68	($59,263.87)	$331,036.13
7	$ 142,560.12	$ 65,478.32	$56,650.55	$446,950.55
8	$ 145,506.64	$ 68,424.84	$171,514.83	$561,814.83
9	$ 148,585.76	$ 71,503.96	$285,393.44	$675,693.44
10	$ 151,803.44	$ 74,721.64	$398,349.46	$788,649.46

Table SD 15: Capital Cost for CHP and Anaerobic Digestion Facilities

Capital Cost For CHP facility[32]			Capital Cost For Anaerobic Digestion (AD)[31]		
Growing Power CHP Capacity	**110**	**kW**	**Growing Power AD Capacity**	**696**	**tons/yr**
Average Capacity	100	kW	Capital Cost	600	($/ton)
Gen Set Package	1,400	($/kW)			
Heat Recovery	250	($/kW)			
Interconnect/Electrical	250	($/kW)			
Exhaust Gas Treatment	--	($/kW)			
Thermal Storage	400	($/kW)			
Total Equipment	2,300	($/kW)			
Labor/Material	500	($/kW)			
Total Process Capital	2,800	($/kW)			
Construction Management	125	($/kW)			
Engineering Fees	250	($/kW)			
Project Contingency	95	($/kW)			
Project Financing	30	($/kW)			
Total Plant Cost	3,300	($/kW)			
Total Operation and Maintenance Cost	0.024	($/kWh)	Total Operation and Maintenance Cost	34	($/Ton)
Energy Offset	127,362.32	($/year)	Tipping Fees	40	($/Ton)
Growing Power CHP Capital Cost	$363,000.00		Growing Power AD Capital Cost	$ 417,600.00	
Total Facility Capital Cost	**$780,600.00**				

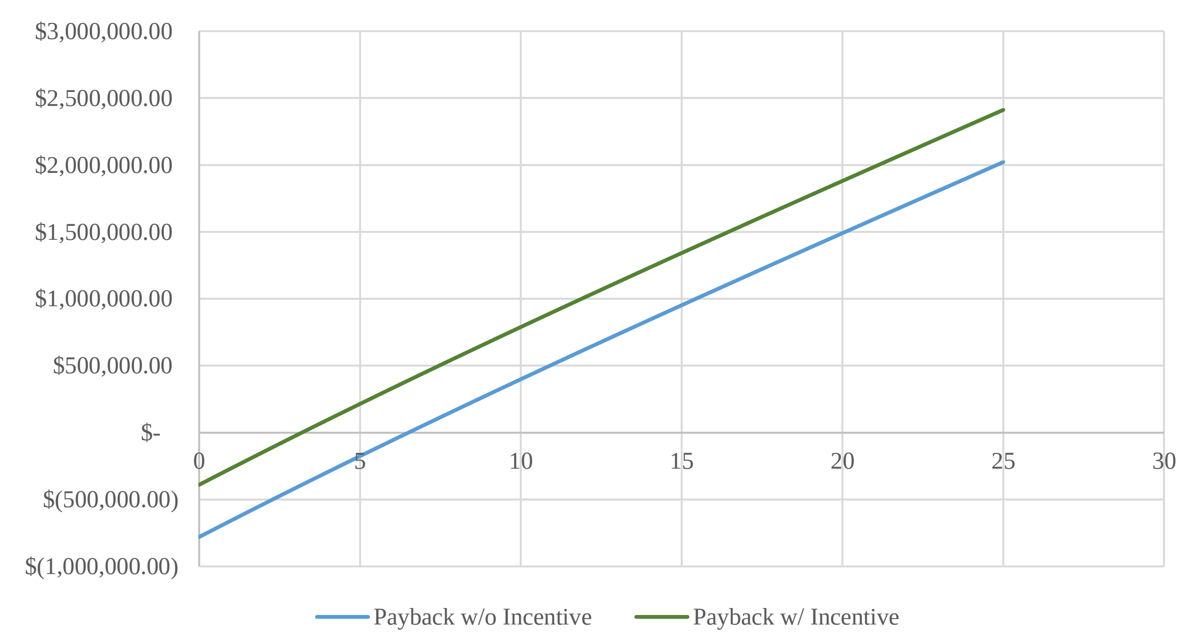

Figure SD 12. Net Present Value calculation of the CHP and anaerobic digestion facility at Growing Power Vertical Farm Facility in Milwaukee.

OVERALL MECHANICAL SYSTEM SCHEMATIC

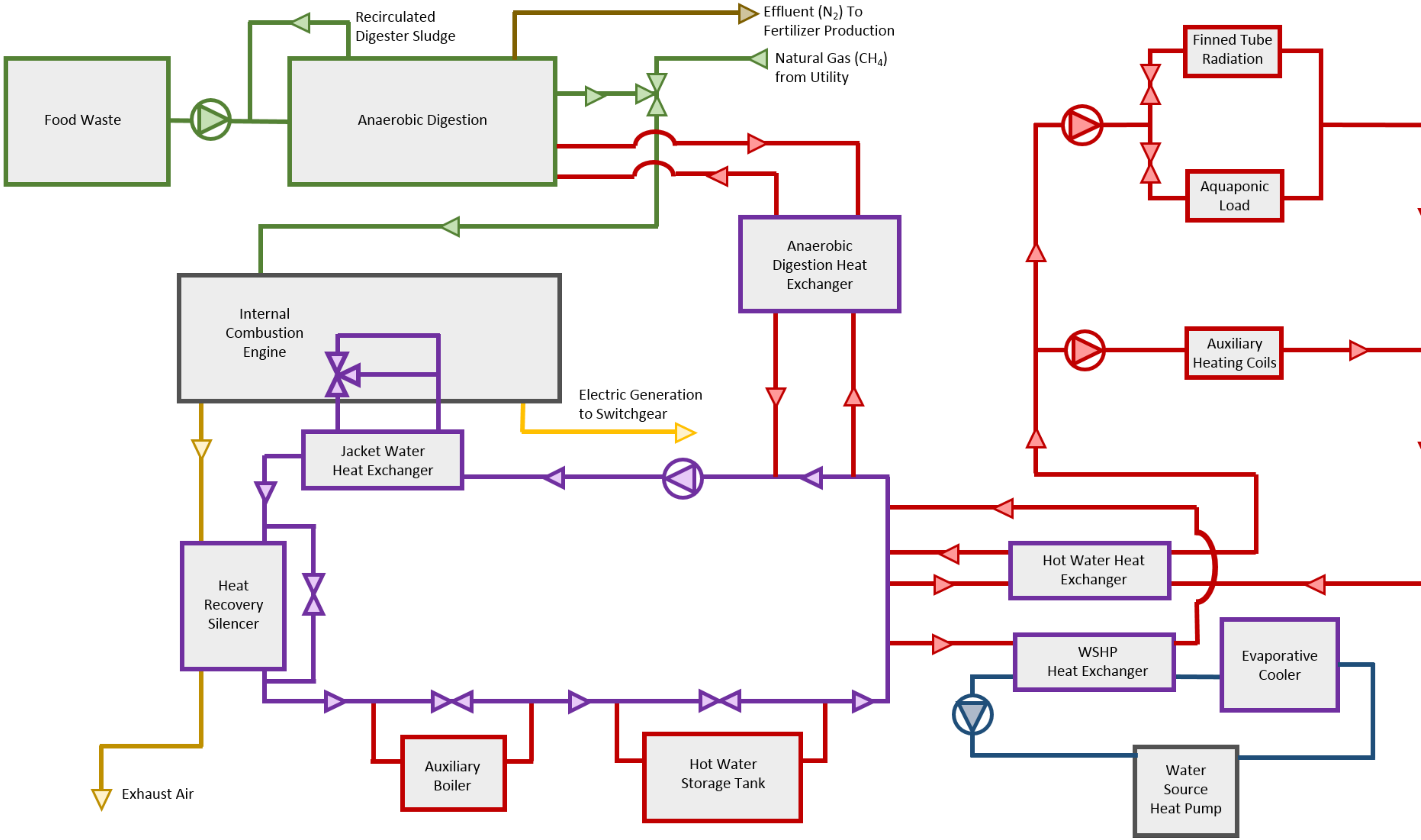

Figure SD 13. The overall mechanical system schematic demonstrates how the combined heat and power facility interacts with the building loads and anaerobic digestion. The heat recovered from the internal combustion engines is redirected to the main building and greenhouse loads. A hot water storage tank is used to meet heating loads that are out of phase with building electric loads, while an auxiliary boiler is used to meet design day heating loads. The anaerobic digestion facility feeds the internal combustion engine until additional natural gas is needed from the utility.

SOYBEAN OIL BIODIESEL PRODUCTION: AN ALTERNATIVE FOR FUTURE GROWING POWER VERTICAL FARM SITES

Soybean Oil Biodiesel Production Process:

1. Soybean Oil Press. Pre-cleaned soybeans enter the soybean oil press where they are compressed into soybean oil, after which soybean oil is dripped into a holding tank. Also resulting from the press is a soybean mash held in the meal mixing bin for later use.

2. Transesterification. Soybean oil reacts in a biodiesel processor in which it is turned into biodiesel through transesterification. Transesterification involves soybean oil reacting with ethanol and sodium hydroxide to create crude biodiesel.

3. Membrane Biodiesel Purification. The resulting crude biodiesel from transesterification is used to feed the biodiesel generator for the combined heat and power plant. The membrane system of biodiesel purification is a simple filter system in which components of the biodiesel are separated by particle size and shape.[40] The purification of crude biodiesel results in a recovery of glycerin that is sent to the meal mixing bin.

4. Meal Mixing. The main coproduct of transesterification is glycerin, which is used produce fish feed in the meal mixing bin. Using both the crude glycerin from transesterification and the recovered glycerin from membrane biodiesel purification, meal mixing combines the glycerin and soybean mash to create a fish feed for the aquaponic system.

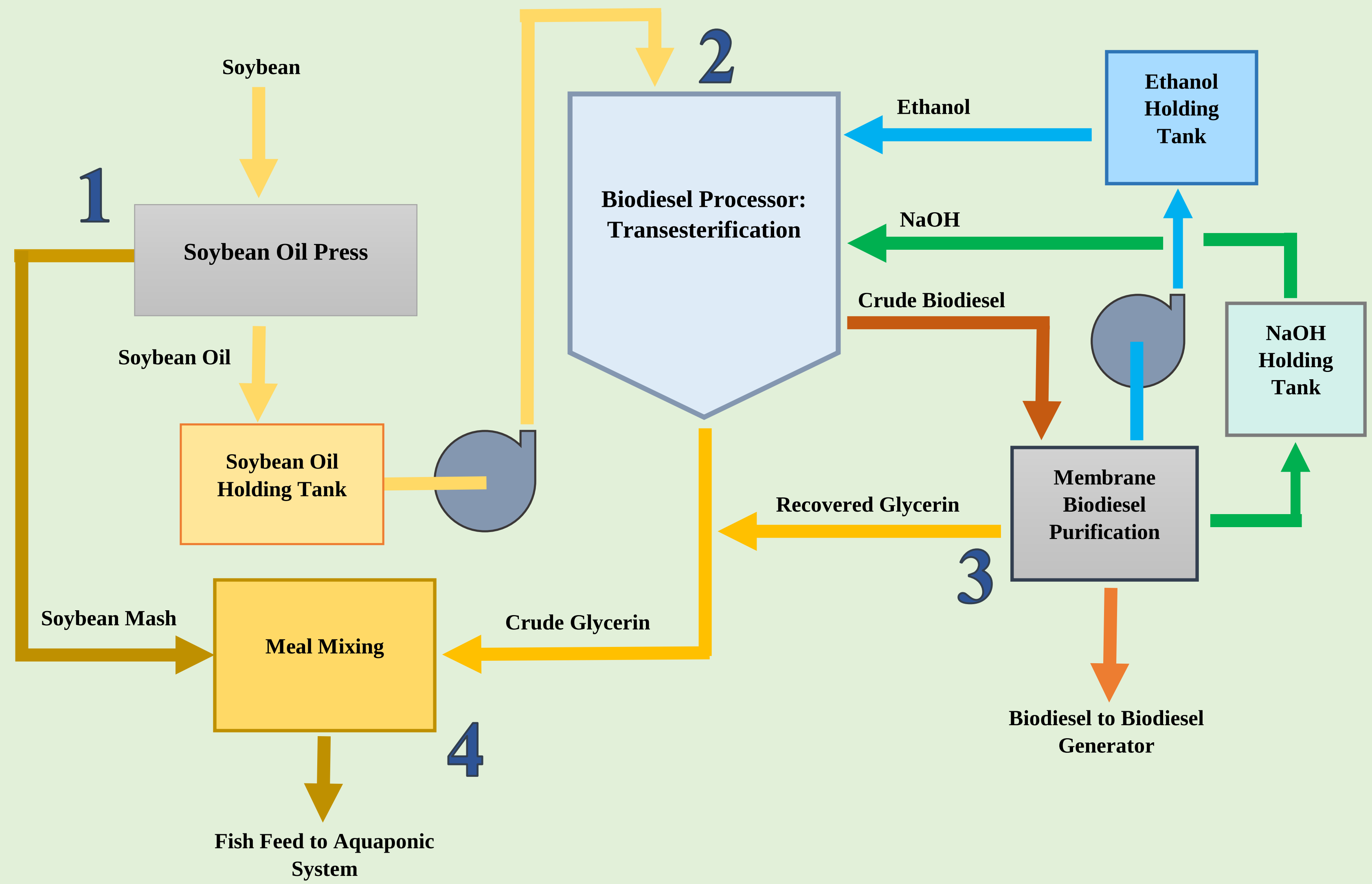

Figure SD 14. A typical soybean oil biodiesel production plant consists of mechanically pressing beans to oil then producing biodiesel through transesterification. A valuable coproduct of this process is the ability to produce fish feed to be used in the aquaponic growing system.

SIZING FOR A SOYBEAN OIL BIODIESEL PROCESS

The following steps were taken to select equipment and size the required components of soybean oil biodiesel production.

1. Size the biodiesel generator for thermal demand of the building.
2. Use the generator data to determine the fuel input of biodiesel required to operate the generator.
3. Select a biodiesel processor that will produce biodiesel at a rate greater than or equal to the fuel input required in 2.
4. Use the biodiesel processor data to determine a soybean oil input volumetric flow rate required for the processor.
5. Select a soybean oil pressing unit that will produce the necessary volumetric flow rate of soybean oil as specified in 4.
6. Use the data from the soybean press to determine the amount of soybeans needed daily.

SOYBEAN OIL BIODIESEL PRODUCTION ENVIRONMENTAL BENEFITS

49.5% less greenhouse gas emissions than a gas generator

90% less pesticides used in production than corn grain ethanol

Table SD 17: Comparison of Soybean Biodiesel to Other Fuels*

	Pesticides	Fertilizer		GHG
	Application /NEB	Nitrogen	Phosphorus	Emissions /NEB
		Application/NEB		
Fuel Type	[g/MJ]	[g/MJ]	[g/MJ]	[g/MJ]
Methane	0	0	0	96.9
Diesel	0	0	0	82.3
Soybean Biodiesel	0.01	0.1	0.2	49
Corn Grain Ethanol	0.1	7	2.6	84.9

*Data Courtesy of Hill et. al, 2006

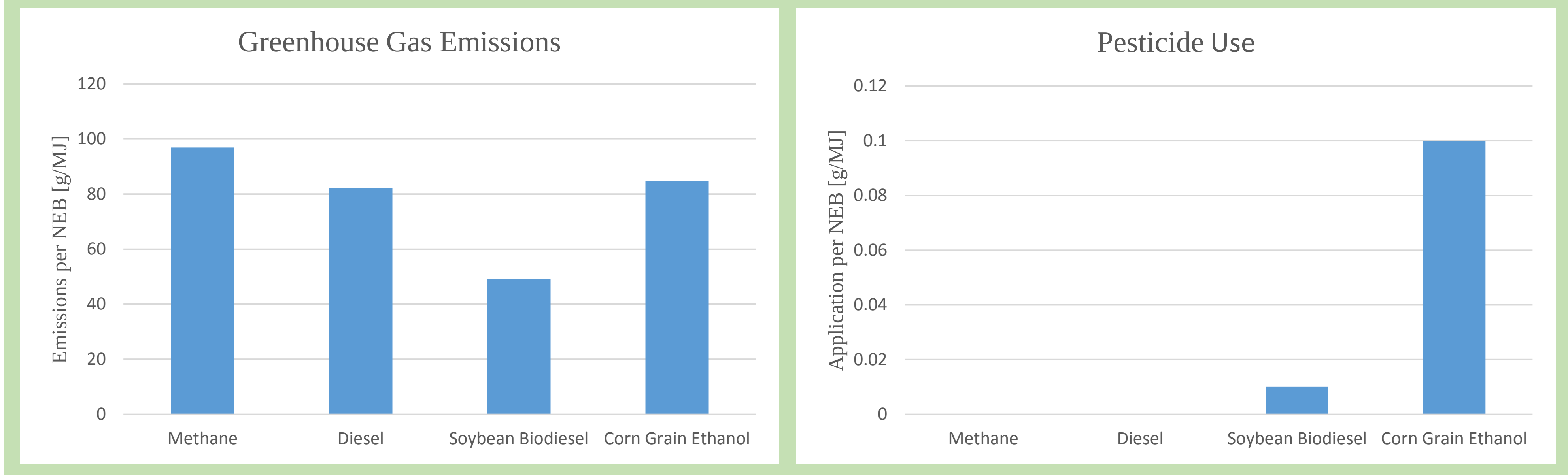

Figure SD 15. Soybean oil biodiesel produces almost half of the GHG emissions of other comparable fuels, and requires 10% of the pesticide used in corn production for ethanol.

Net Energy Balance (NEB) is the energy content of a biofuel relative to the fossil fuel energy input to create the particular biofuel.[42] Thus finding greenhouse gas emissions and pesticide use per NEB becomes a relatable measure of the particular output of a biofuel per fossil fuel input. The left graph of Figure SD 15 shows that soybean oil biodiesel emits a drastically lower amount of greenhouse gases compared to its other fuel counterparts. Compared to corn grain ethanol, which is increasingly used for generator biofuel purposes, soybeans require a tenth of the pesticides used for corn production as shown in the graph on the right of Figure SD 15.

Table SD 18: Average Soybean Production in Wisconsin by County courtesy of AgWeb.[38]

County	Average Soybean Production	Area of Soybean Production	Average Soybean Production per County
	bushels/acre	acres	bushels
Manitowoc	58.4	32	1868.8
Fond du Lac	52	200	10400
Jefferson	59	55	3245
Columbia	50	120	6000
Sauk	10	100	1000
Dane	56.1	647	36296.7
Waupaca	42	500	21000
Crawford	54	50	2700
Oconto	14	60	840
Taylor	41	25	1025
Buffalo	51.05	88	4492.4
Dunn	47	236	11092
Polk	37.5	153	5737.5

Total Bushels of Soybean Produced in Wisconsin in 2014: 105,697.4

Supply and Demand of Soybean Oil Biodiesel Production

It must be recognized that soybean oil biodiesel production is only viable with a strong supply of soybeans within a reasonable radius of the future site. Figure 16, on right, is the 2014 AgWeb Soybean Harvest Map [38] which shows the average bushels of soybean produced in each county of Wisconsin per acre of land allotted to soybean production.

Variables that make soybean oil biodiesel production a strong candidate for fuel used in combined heat and power for a future Growing Power location are soybean availability as well as cost of soybean in the area.

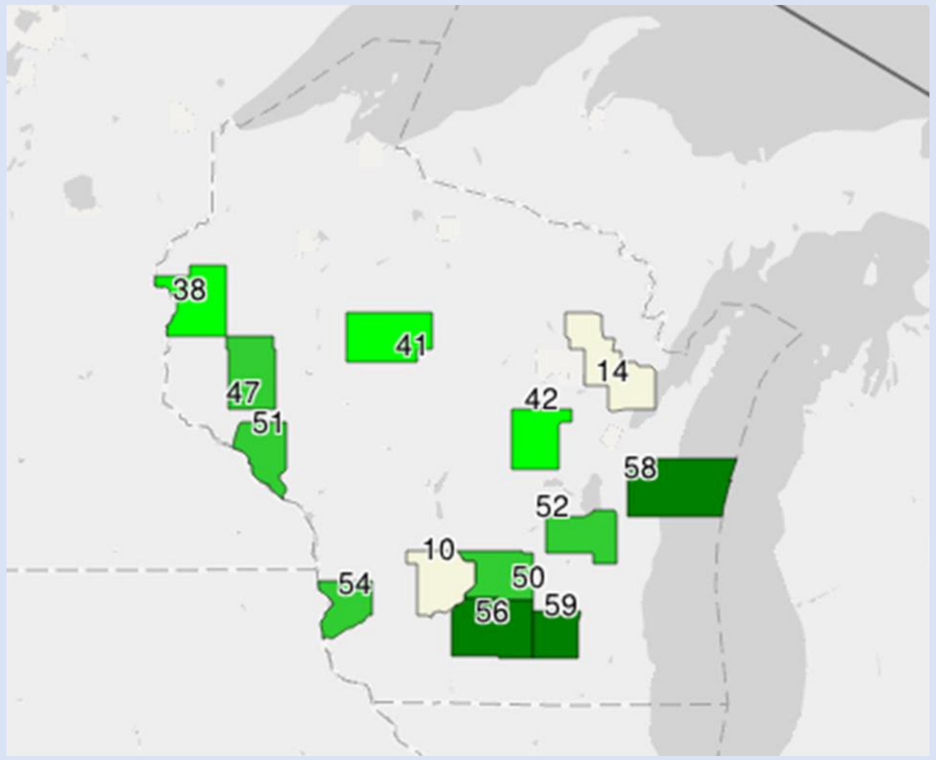

Figure SD 16. Soybean Harvest Map shows the availability of soybeans in Wisconsin.

WATER SOURCE HEAT PUMPS AND DEDICATED OUTDOOR AIR SYSTEM

The water source heat pumps in the Growing Power Vertical Farm were selected to meet the cooling coil capacity output from Trane Trace for each zone. From these capacities it was determined that these WSHP units would sufficiently provide optimal cooling, heating, and airflow within each zone.(D1) The DOAS units provide the minimum outdoor air required by ASHRAE 62.1.

Table SD 19: Summary of DOAS Units in Building

Unit ID	Levels Served	OA Intake CFM	Exhaust to Outside CFM
DOAS-1	Basement, L1, L2	5220	2020
DOAS-2	L3, L4	2460	980

Figure SD 17. Water source heat pumps, such as the units above manufactured by Daikin, are used in the Growing Power Vertical Farm Facility.[13]

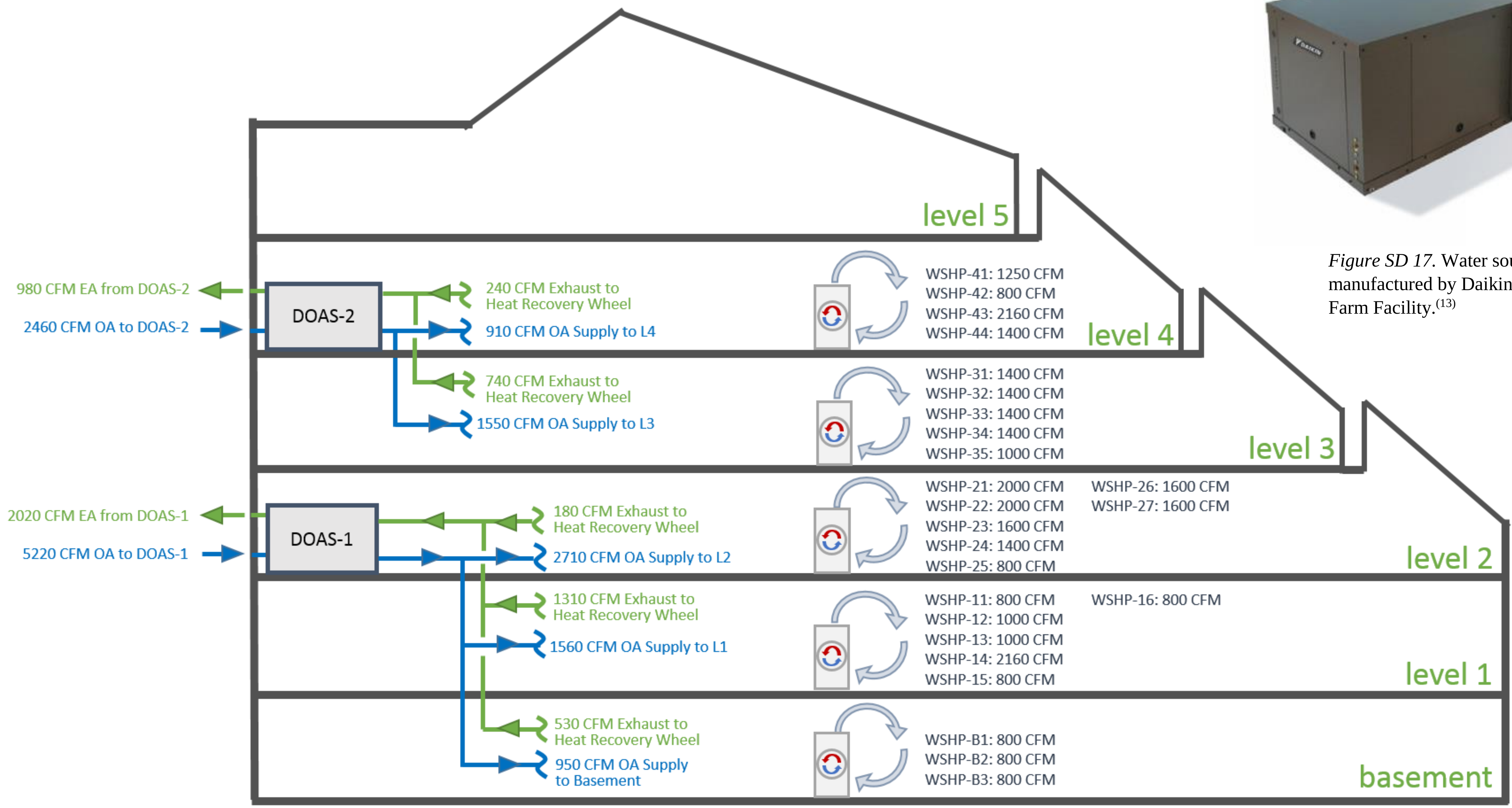

Figure SD 18. Water source heat pumps and dedicated outdoor air units provide heating and cooling, as well as ventilation, respectively.

OCCUPANT COMFORT ANALYSIS

GATHERING SPACE ACOUSTICAL QUALITY ANALYSIS

A reverberation time (RT) calculation was performed to analyze the sound quality of the gathering space. Comparing values of the ideal RT values for a speech auditorium with the calculated values within the gathering space determined that the space would be well suited to hold educational lectures and presentations for the public. It is important to note that an STC calculation is to be performed to specify a partition around the WSHP units in the gathering space such that the noise criterion level is below 25 as specified in the 2009 ASHRAE Fundamentals Chapter 48.3.(4)

Table SD 20: Calculations for Gathering Space Reverberation Time

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
North Wall	613	gypsum wall board	0.29	0.10	0.05	0.04	0.07	0.09	177.75	61.29	30.65	24.52	42.91	55.16
East Window	40	glass window	0.35	0.25	0.18	0.12	0.07	0.04	14.00	10.00	7.20	4.80	2.80	1.60
East Walls	724	gypsum wall board	0.29	0.10	0.05	0.04	0.07	0.09	210.07	72.44	36.22	28.98	50.71	65.19
South Wall	225	gypsum wall board	0.29	0.10	0.05	0.04	0.07	0.09	65.25	22.50	11.25	9.00	15.75	20.25
West Windows	240	glass window	0.35	0.25	0.18	0.12	0.07	0.04	84.00	60.00	43.20	28.80	16.80	9.60
West Walls	360	gypsum wall board	0.29	0.10	0.05	0.04	0.07	0.09	104.40	36.00	18.00	14.40	25.20	32.40
Ceiling, ACT	951	acoustic ceiling tile	0.40	0.50	0.95	1.00	1.00	1.00	380.40	475.50	903.45	946.25	946.25	946.25
Ceiling, Gypsum Panels	2853	gypsum board panels	0.12	0.11	0.05	0.06	0.04	0.05	328.10	313.83	142.65	156.92	116.97	139.80
Floor	3804	smooth concrete	0.01	0.01	0.01	0.02	0.02	0.02	38.04	38.04	38.04	76.08	76.08	76.08
Seats, Occupied	1381	lightly upholstered, occupied	0.51	0.64	0.75	0.80	0.82	0.83	704.44	884.00	1035.94	1105.00	1132.63	1146.44
West Bench vertical	95	gypsum wall board	0.29	0.10	0.05	0.04	0.07	0.09	69.60	24.00	12.00	9.60	16.80	21.60
West Bench horizontal	119	wood	0.10	0.10	0.09	0.08	0.08	0.08	95.10	95.10	85.59	76.08	76.08	76.08
								ΣSα=	2271.15	2092.7	2364.18	2480.41	2518.97	2590.45

	125	250	500	1000	2000	4000
Avg. α =	0.20	0.18	0.21	0.22	0.22	0.23
Air Absorption constant for 20°C and 40% RH, *m*	0.00	0.00	0.00	0.00	0.00	0.00
Sabine Reverberation Time [s]=	0.85	0.92	0.80	0.76	0.73	0.73
Norris-Eyring Reverberation Time [s]=	0.76	0.83	0.72	0.68	0.65	0.65
Calculated RT [s]	**0.85**	**0.92**	**0.72**	**0.68**	**0.65**	**0.65**
Ideal RT [s]	**0.897**	**0.7935**	**0.69**	**0.69**	**0.69**	**0.69**

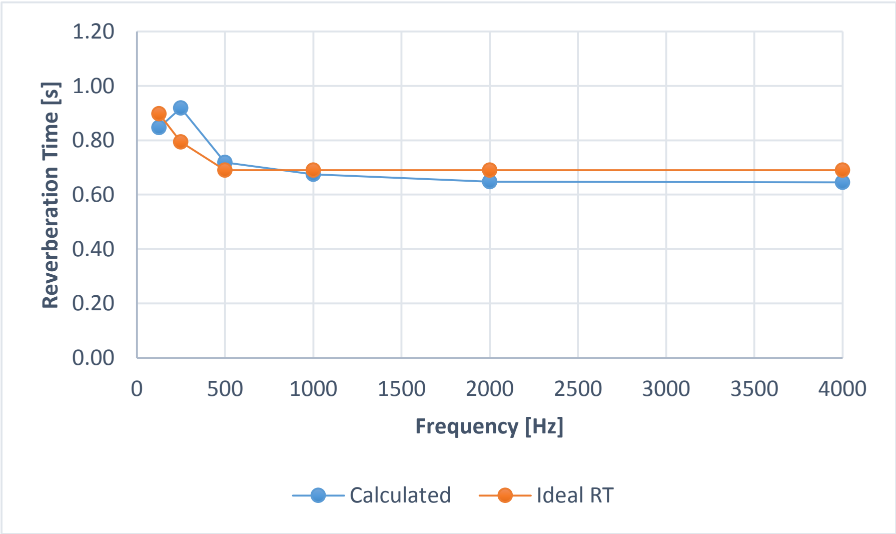

Figure SD 19. Comparison of calculated reverberation time and ideal reverberation time for a speech auditorium