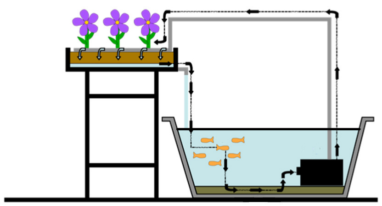
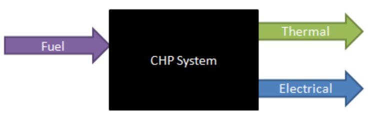
Collaboration for Aquaponics Sustainable Energy
A Low Carbon Emitting Energy Source for Urban Aquaponics Systems
2011-2012

Abstract:

Aquaponics is a new and emerging practice which joins agriculture and aquaculture. Although there are functioning systems in existence, the fact that aquaponics is an up and coming technology has left the optimization of the operation largely overlooked. Additionally, renewed focus on energy efficiency and minimizing carbon emissions makes an engineered energy solution all the more vital. Through the engineering analysis performed by the senior design group, a best practices manual and accompanying design software were developed to help make aquaponics an efficient and more sustainable process. The design software and best practices guide focus on the use of a combined heat and power generator set to provide the energy needs for the system.

Aquaponics and CHP at a Glance:





Design Constraints:

Aquaponics:

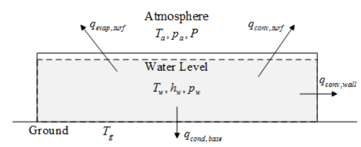
- Maintain tank temperature between 75°F-85°F
- Consider both natural and artificial lighting
- Rearing tank sizes ranging from 1,000-20,000 gallons
- Aquaponic system located in urban setting
- Greenhouse environment between 45-60% relative humidity and 55°F-85°F

Power Production:

- Less CO_2 emissions than average emission factor for hot water and electricity generation in the Milwaukee area
- Meet noise and ventilation standards
- Provide power to aerate, heat, and pump tank water
- Provide power for artificial lighting
- Lowest environmental impact at reasonable cost
- Operate on natural gas
- Continuous operation with exception for maintenance

Thermal Modeling:

A diagram of the modeled system with the considered mechanisms of heat transfer is presented below.



TANK HEAT TRANSFER DIAGRAM

Heat is lost from wall convection, surface convection and surface evaporation. The equations used to model the heat transfer are listed below.

Wall Convection:

$$\dot{q} = \frac{T_2 - T_1}{R_{wall}}$$

Surface Convection:

$$\frac{q_c}{q_e} = 0.004943\left(\frac{T_w - T_a}{p_w - p_a}\right)\frac{P}{14.7}$$

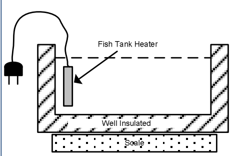
Surface Evaporation:

$$G = (0.491)\frac{(98.7 + 0.43V)}{h_{fg}}(p_w - p_a)$$

An empirical model was used that was developed by Carrier in 1918 based on indoor swimming pools.

Testing Approach:

The greatest uncertainties in the thermal modeling are the predictions of the evaporative and convective losses from the tank surface. An experiment was designed to easily monitor the evaporative and convective losses to determine that uncertainty in the models. This was done by insulating the sides and base of a fish tank with foam sheet insulation. By heating the tank water through a submersible electrical-resistive heater the operating environment of typical aquaponic system was established. A schematic of the tank used for the verification is shown below. Also seen below, are the actual tank and the psychrometric chamber used to simulate certain environmental conditions.



Results:

From the psychrometric testing it was determined that the Carrier evaporation model matched the experimental results. Additionally, the surface convection model showed good agreement with the experimental data.

Software Selection Tool:

A software design/analysis tool was developed that can aid in either the design of new aquaponic systems or the retrofit of existing systems. The user can choose from three different modeling scenarios, as shown below.

Please Choose One:

- (•) New System, Need Power Estimates
- ( ) Existing System, Need Power Estimates
- ( ) Existing System, Known Power Requirements

The scenarios provide flexibility to match differing needs of potential users. If it is a new aquaponic system the software will also provide recommendations for pumping and aeration power requirements, as well as the requierd energy to use supplemental artificial lighting. Power estimates are calculated and returned in both scenarios where the power estimates are unknown, which help the user understand the amount of energy the aquaponic system uses. The model performs an economic analysis of incorporating a combined heat and power system in the design and also quantifies the avoided carbon dioxide emissions. The inputs and outputs of the first modeling scenario are presented below as an example of the programs functionality.

INPUTS

City

City	Milwaukee, Wisconsin
Cost of Electricity	0.11 ($/kWh)
Cost of Natural Gas	0.76 ($/therm)

Environmental

Average local CO2 emission for electricity generation	610 (g/kWh)
Average national CO2 emission for electricity generation	550 (g/kWh)

CHP

Total Purchase and Installation Cost (excluding incentives)	33000 dollars
Total Savings from Incentives	1500 dollars
Total Annual Maintenance Cost	100 dollars
Max Thermal Output Per Unit	12 kW
Max Electrical Output Per Unit	4.7 kW
Generator Efficiency	0.25 out of 1
Heater Efficiency (enter 2 for electric heater)	0.75 out of 1
Number of units	1

Tank

Number of Tanks	1 Tank
Width of Each Tank	4 ft
Length of Each Tank	60 ft
Height of Each Tank	4 ft
Fish Stocking Density	0.5 lb/gal

Plumbing Information

Number of elbows	2
Number of tees	0
Pipe diameter	3 in
Height difference between grow bed and tank	8 ft
Aeration Blower efficiency	0.64 out of 1
Water Pump Efficiency	0.45 out of 1

Artificial Lighting

Grow Area per kW	50 ft^2/kW
Desired Grow Time per Day	18 hr/day

Tank and Weather Information

Input the expected green house conditions and tank water temperature.

	Indoor Ambient Temperature	Water Temperature	Relative Humidity
January	60 F	71.5 F	45 %
February	60 F	71.5 F	45 %
March	60 F	71.5 F	45 %
April	60 F	71.5 F	45 %
May	65 F	71.5 F	45 %
June	70 F	71.5 F	45 %
July	80 F	71.5 F	45 %
August	80 F	71.5 F	45 %
September	75 F	71.5 F	45 %
October	60 F	71.5 F	45 %
November	60 F	71.5 F	45 %
December	60 F	71.5 F	45 %

Estimated temperature Drop over Grow Bed: 0.5 F

OUTPUTS

CHP System Output Totals

Annual Electric:	41172 kWh
Annual Thermal:	105120 kWh
Annual Benefit:	3793 $
Simple Payback:	8.3 Years
Annual CO2 avoided nationally:	17803 kg
Annual CO2 avoided locally:	20273 kg

Grow Bed Sizing Estimates

Grow Bed Area:	2953 ft^2
Grow Bed Depth:	1.0 ft
Flow Rate:	128 GPM

Pumping and Aeration Estimates

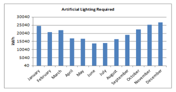
Pumping:	0.677 Hp
Aeration:	1.417 Hp

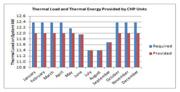
Monthly Artificial Lighting Load Estimates

January	24684	kWh
February	20787	kWh
March	22027	kWh
April	17007	kWh
May	16653	kWh
June	13877	kWh
July	13996	kWh
August	16358	kWh
September	19192	kWh
October	22440	kWh
November	25216	kWh
December	26751	kWh

Thermal Load Estimates and CHP Capabilities

	Provided	Required	Units
January	12.0	12.4	kW
February	12.0	12.4	kW
March	12.0	12.4	kW
April	12.0	12.4	kW
May	12.0	12.2	kW
June	12.0	12.0	kW
July	11.4	11.4	kW
August	11.4	11.4	kW
September	11.7	11.7	kW
October	12.0	12.4	kW
November	12.0	12.4	kW
December	12.0	12.4	kW





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