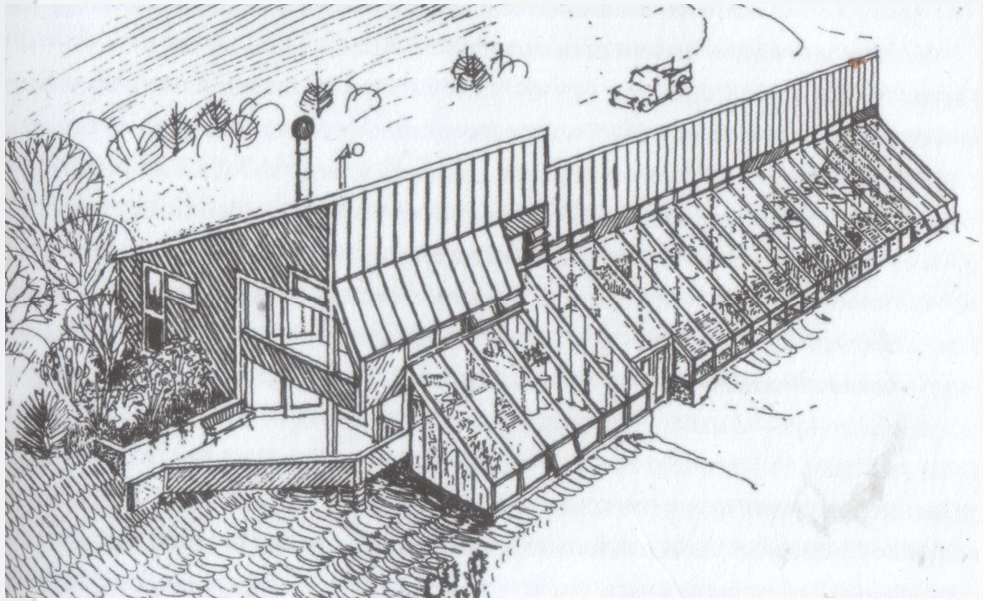


Year Round Solar

Aquaponics Greenhouse

for the Yorklands Green Hub

Paul Neelands, BSc(Hon), MSc

Instrumenting Bioshelter Performance

The PEI Ark 1978

Energy Crisis Days

The Canadian Federal Urban Demonstration Program funded the Ark, a model bioshelter, built as an example of Canada's future sustainable housing. The author measured 64 variables in the Ark systems, including aquaponics, to rate actual performance against design expectations. https://peiark.com/

Ontario's Greenhouse Industry: Environmental Impacts

Leamington, Ontario

North America's largest greenhouse industry: 2,900 acres of indoor agriculture

- $11 billion of exports of tomatoes, cucumbers and bell peppers to the US

Typical Leamington Greenhouses

Double-layered polycarbonate, gas-heated for year-round food production

Greenhouse Gas Emissions

Leamington Greenhouse Industry

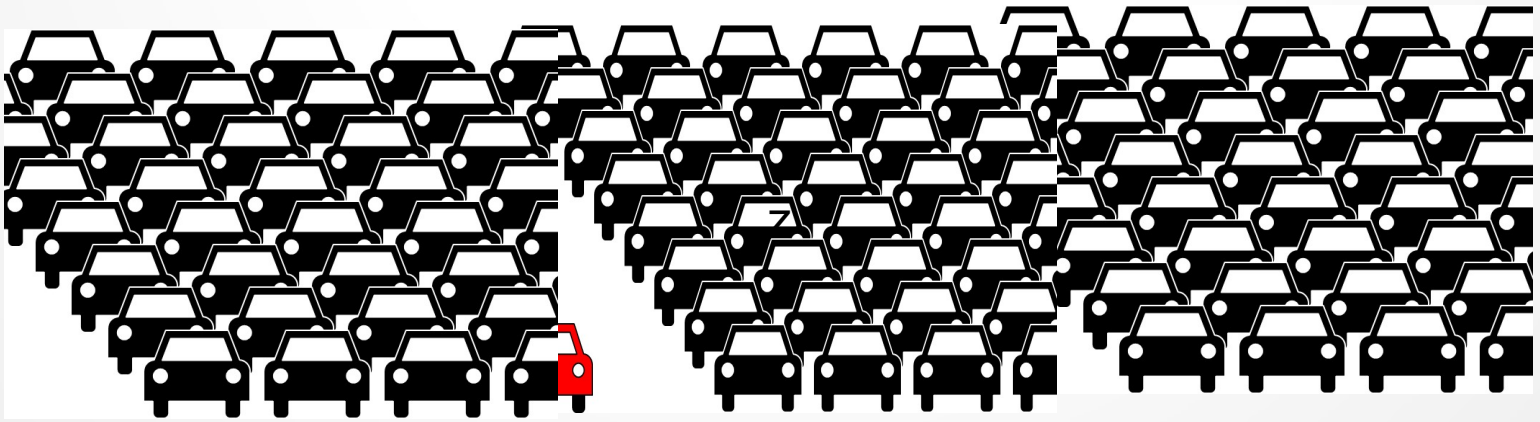
Heating and Carbon Dioxide (CO2) Emissions

$137 million/year of natural gas consumed

1,777,411,600 kg. CO2 emission/year

To put that in perspective, a typical car gives off 4,600 kg. of CO2 per year. Leamington GHGs are the equivalent of

- **386,393** cars.



Water Pollution

Waterway Nutrient Loadings (Pollution)

Leamington-Kingsville

Parameter	Average concentration	Standard	Times Over Reg. Limit
Nitrate	90.3 mg/L	3.0 mg/L	30
Phosphorus	33.6 mg/L	0.03 mg/L	1120
Potassium	180 mg/L	- mg/L	180
Copper	300 µg/L	5.0 µg/L	60

Fig. 4 - *Waste Nutrient Loadings to Surface Waters*

Environmental Issues

Today's commercial greenhouses:

- Consume large quantities of natural gas
- Produce substantial greenhouse gas emissions
- Consume water replacing spent fertilized water in hydroponic systems
- Pollute local waterways disposing of chemical hydroponic water waste

Greenhouse Solutions

YORKLANDS GREEN HUB

Innovating, educating and collaborating
to open green doors to the future.

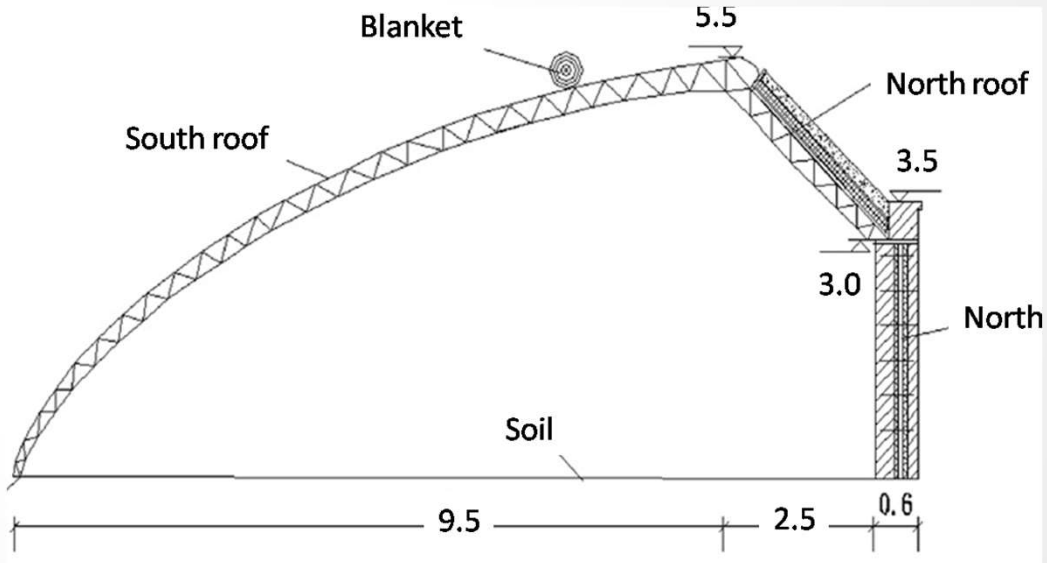
Why a solar aquaponics greenhouse for YGH?

- Local food, community involvement
- Energy conservation
- Water conservation, pollution reduction
- Fulfill UN Sustainable Development Goals, Guelph Circular Economy and Guelph/Wellington Food Future - innovation

Solar Greenhouse Models

Chinese Solar Greenhouses Reduce Artificial Heating

- South-facing, solar heated
- Insulated for heat retention
- Little or no supplementary heating required
- 4 generations of design since the 1980s



Chinese Solar Greenhouse Interior

Chinese Solar Greenhouses

Large-Scale Indoor Agriculture in China

5.7 million acres or 2.3 million hectares under cultivation

https://www.hortidaily.com/article/6017327/caas-a-closer-look-at-the-efficiency-of-china-s-immense-greenhouse-industry/

China: Solar Farm + Solar Greenhouses

July 2017 - A general view of greenhouses equipped with solar panels in Zhenghe County, southeast China's Fujian Province. A photovoltaic agriculture model benefits farmers as the local government makes efforts to develop a solar panel integrated greenhouse system that also serves as tourist attraction and electricity provider. (Xinhua/Lin Shanchuan)

Invermere Community Greenhouse

Groundswell Network Society and David Thompson High School, Invermere, BC
Solar heated, renewables powered greenhouse

Invermere Community Greenhouse

Invermere community – local population 3,300

- Partnership between Groundswell Network Society and David Thompson high school teachers to create a gardening project
- School board license to build on David Thompson secondary school property - Groundswell owns and operates 3,000 sq. ft. greenhouse
- Wide community consultation, 35 funders, 300 volunteers to build
- Living demonstration, community education hub
- Food for Chef's Training Program at David Thompson and school caf.
- Organic, wholesome, local food
- Renewable energy, seasonal heat storage
- Recycling of water
- Employment, skill development, meaningful work
- 3-year performance analysis of all aspects of building and programs
- **https://groundswellnetwork.ca/community-greenhouse/**

Hydroponic Agriculture

Soil-less cultivation typical of

Ontario greenhouse food production

Hydroponic Agriculture

Soil-less cultivation

- Most greenhouses in Leamington grow food hydroponically (in water with liquid fertilizer)
- The hydroponic solution (growth medium) must be changed and discharged periodically
- Hydroponic discharge contributes to pollution in local waterways and Lake Erie

Hydroponic Agriculture

Hydroponic Greenhouse Food Production: Four Problems to Solve

- Energy consumption
- Greenhouse gas emissions
- Water consumption
- Water pollution

What is Aquaponics?

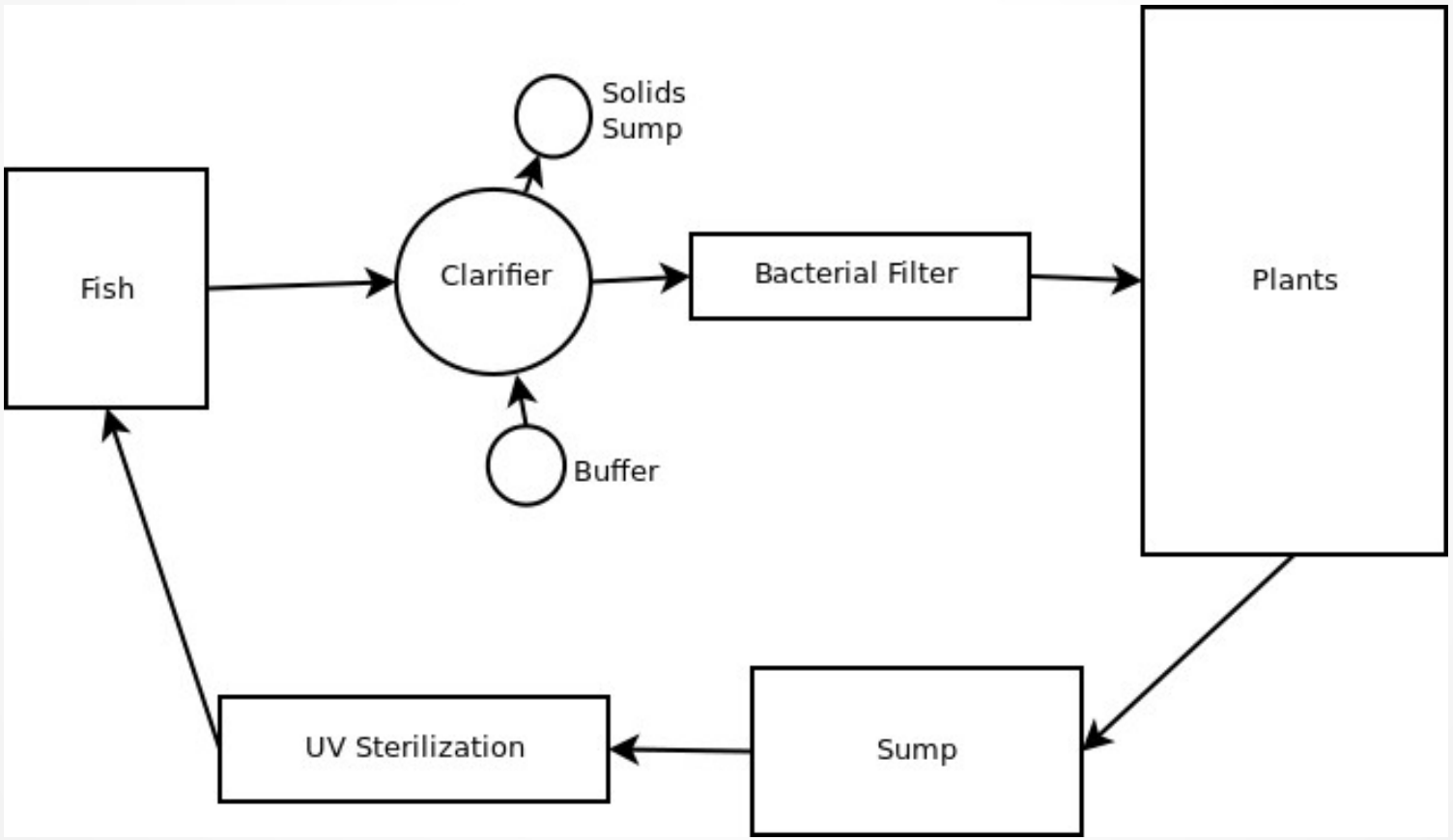
The combination of hydroponics (the soil-less growing of plants in water) and aquaculture (raising fish)

- Closed-loop ecosystem
- Fish raised in tanks
- Bacteria convert fish ammonia waste to nitrate fertilizer, pumped to plant beds
- Fish-waste fertilizer feeds plants
- Water is cleansed by plants, re-circulated to fish
- Very low water consumption and waste

What is Aquaponics?

Aquaponics

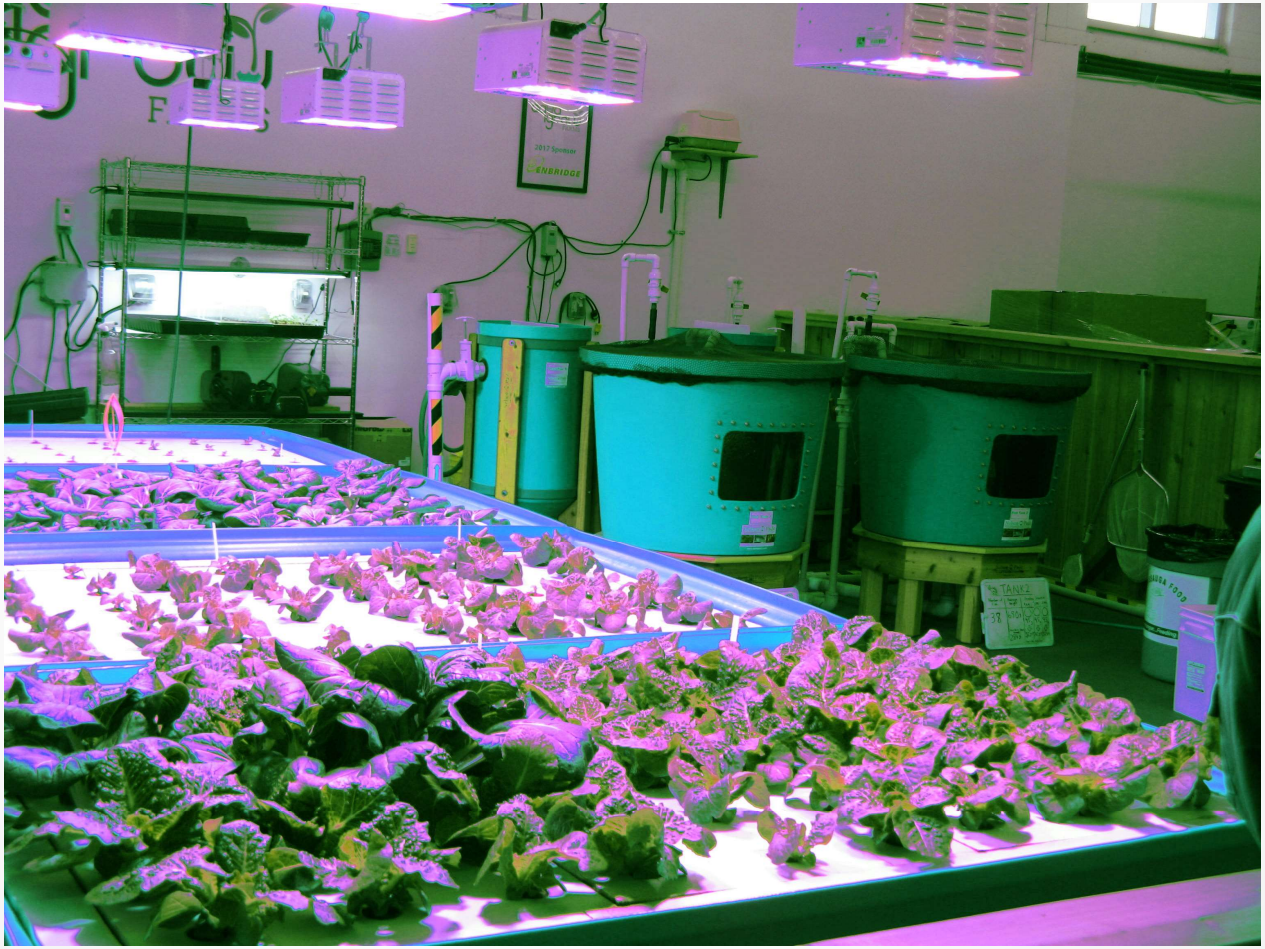
Closed-loop Water Flow



What is Aquaponics?

Mississauga Food Bank Aquaponics System

Tilapia (fish), lettuce and bok choy



Solar Energy Performance Simulation

Solar Energy Simulation for Greenhouse Performance Design

- Energy calculations (solar heat gain, heat losses, energy flows, ventilation, air leaks) on which the solar aquaponics greenhouse design is based were made using real temperature data for one year in Ontario (MOE)
- 3 locations (Windsor, Mt. Forest, Thunder Bay)
- Hourly readings of temperature, wind, solar energy insolation
- Real weather data provided the basis for simulating the performance of a series of greenhouse designs using the US Dept. of Energy ***EnergyPlus*** energy simulator, during the development of this final design proposal (several hundred simulation runs)

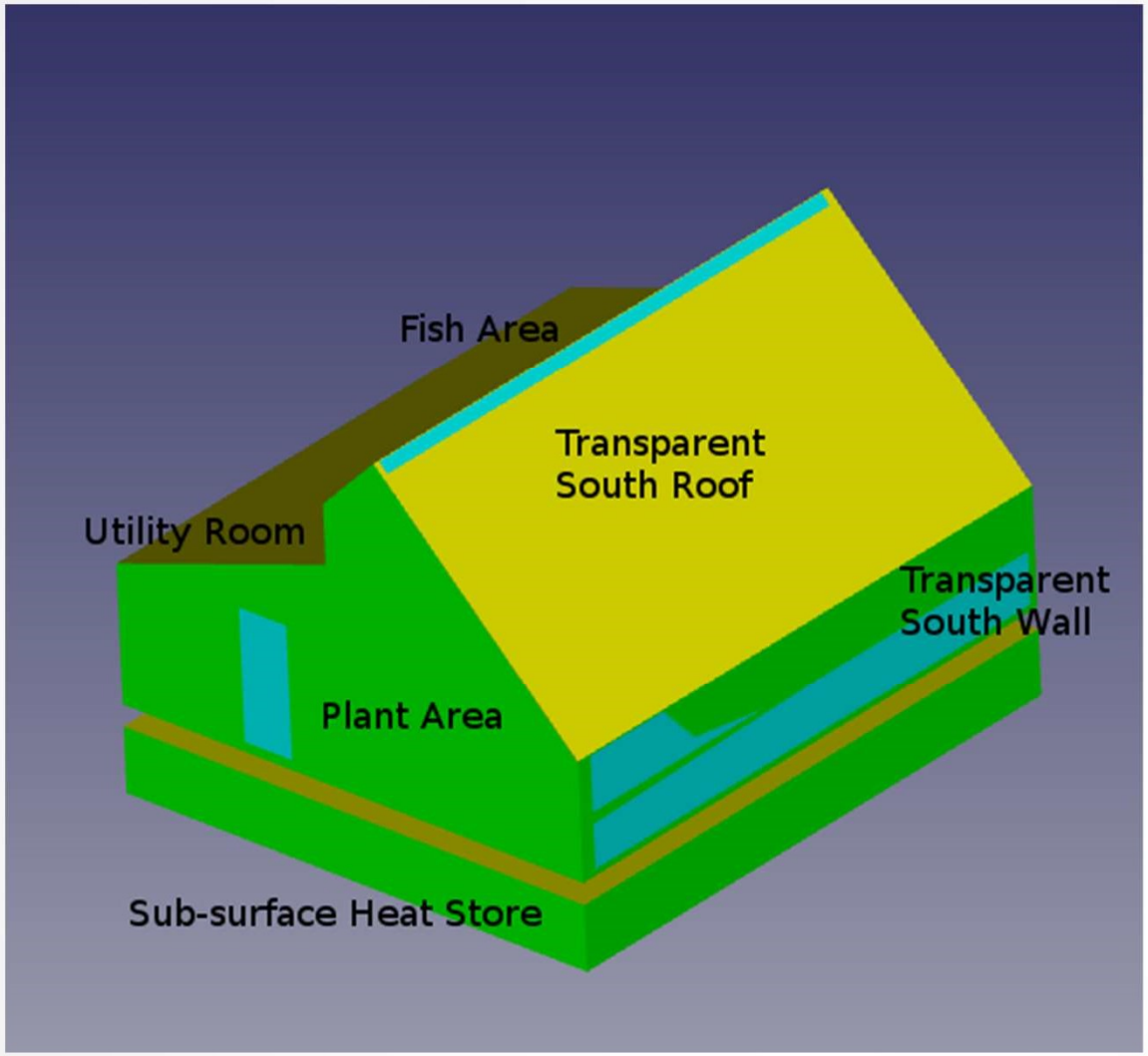
Solar Energy Performance Simulation

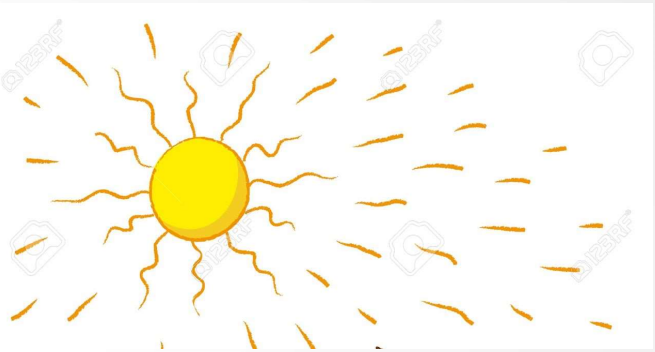
Solar Energy Simulation

Heat-retaining Design and Materials Choices Resulting from the Simulation Process

- Greenhouse: Overall 26’ x 30’ (7.92 x 9.15m)
- Plant space 14’ x 30’ (4.27 x 9.16m), fish room 12 x 20’ (3.66 x 6.1m), processing room 10’ x 12’ (3.05 x 3.66m)
  - Triple-glazed polycarbonate south wall & roof
  - Heavy (R44, Cdn. RSI 7.7) insulation in north, east and west walls, and roof
  - 1 metre-deep rip-rap rock heat store beneath the greenhouse floor (RSI 3.5 insulation)
  - 33 heat-retaining water barrels along central dividing wall

Solar Aquaponics Greenhouse





SOUTH

Proposed design 26 x 30’

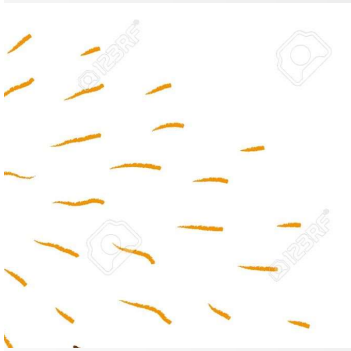
Solar Aquaponics Greenhouse

Triple-wall Polycarbonate

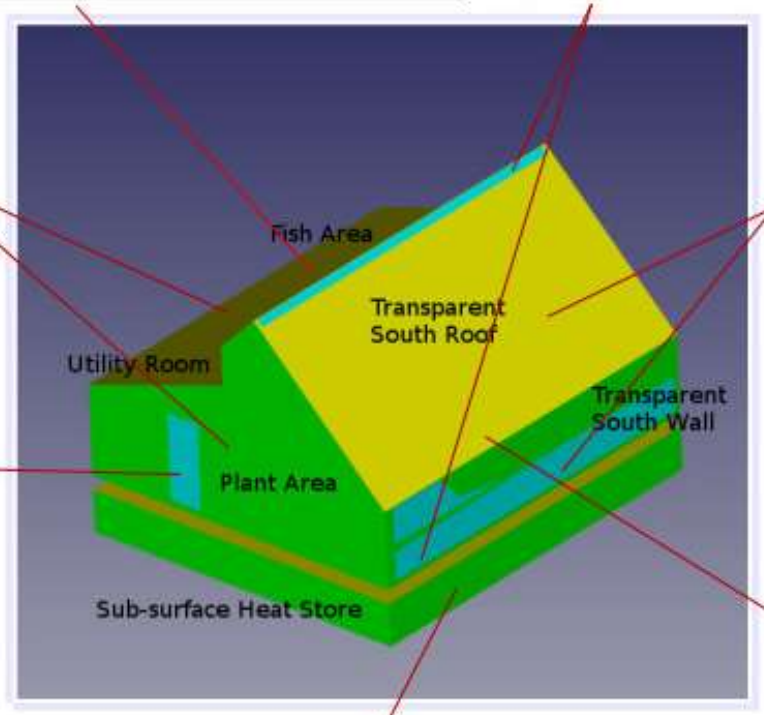
Solar Aquaponics Greenhouse Features

Fish (tilapia or perch) are raised in tanks at the rear of the greenhouse, away from the sunlight to minimize temperature shifts. The water from the fish tanks is circulated through the plant beds at the front of the greenhouse to fertilize them organically.

Vents in the transparent south wall and at the top back of the roof are thermostatically controlled to open and release hot air as needed on summer days.



Side and rear walls and the back portion of the roof are thickly insulated to retain heat.



The south facing transparent roof and vertical south wall are triple-glazed for heat retention.

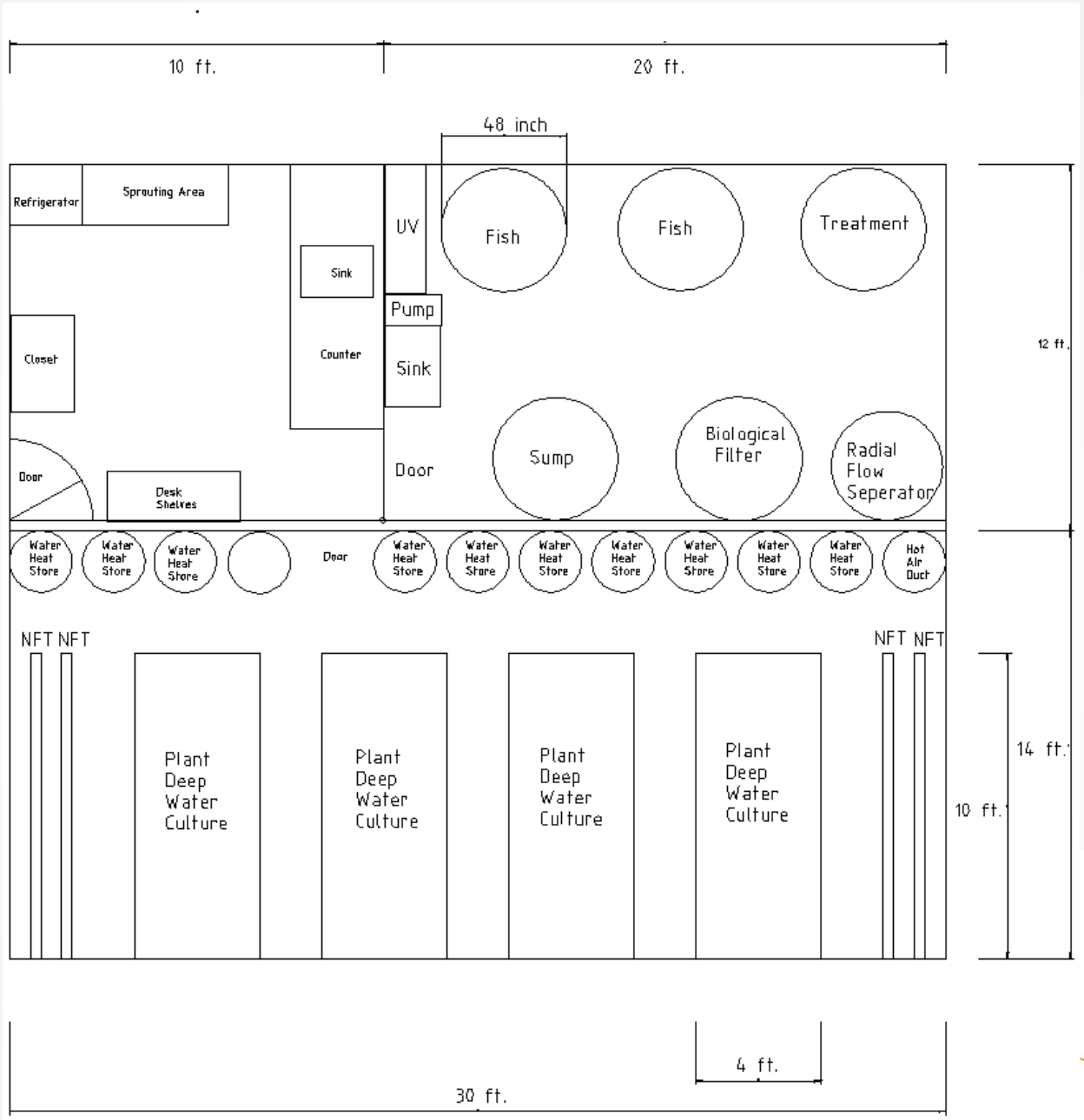
The greenhouse includes a utility room at the rear for the processing of fish and the washing and packaging of greens for sale.

The plant-growing area occupies the front of the greenhouse beneath the glazed roof, and is separated from the fish area by a dividing wall and 36 heat-retaining water barrels.

The foundation is insulated concrete filled with one metre of rip-rap rock beneath the entire green-house floor. A fan blows sun-warmed daytime air down from the greenhouse peak through the rocks to heat them, and pulls warm air up from the heated rock store at night to maintain a stable interior temperature range.

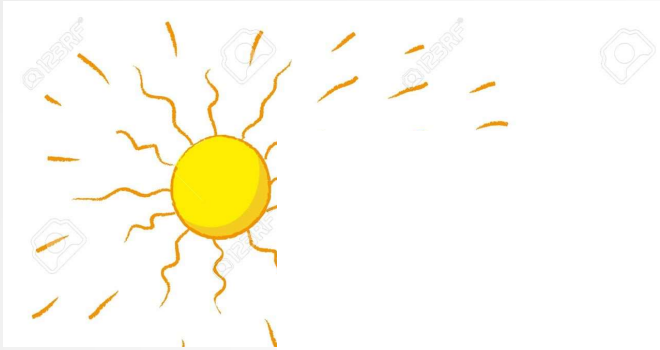
Solar Aquaponics Greenhouse

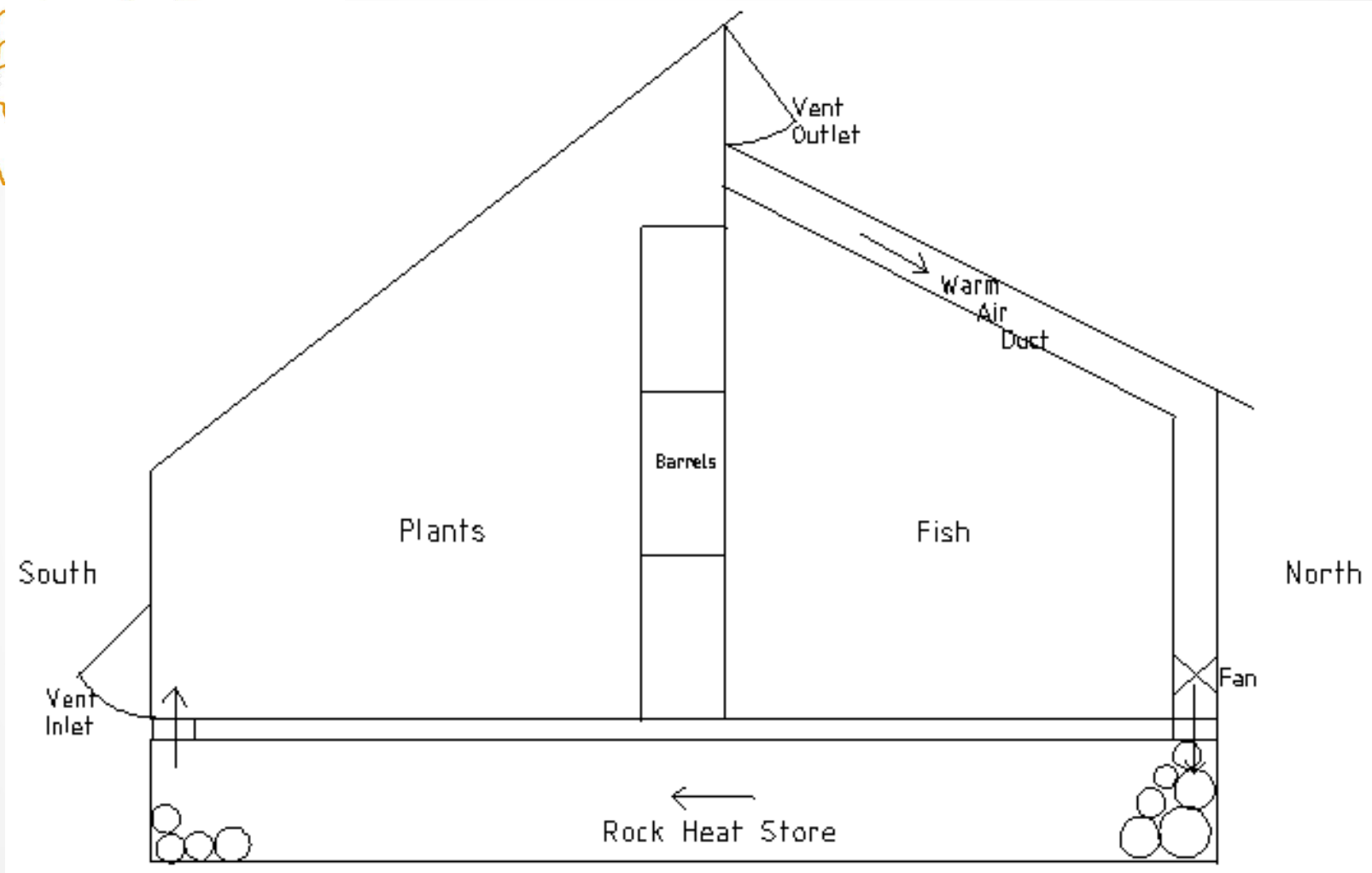
Floor Plan
26 x 30’



Solar Aquaponics Greenhouse

Heating & Cooling





Solar Aquaponics Greenhouse

Heating and Cooling – Passive and Active Systems

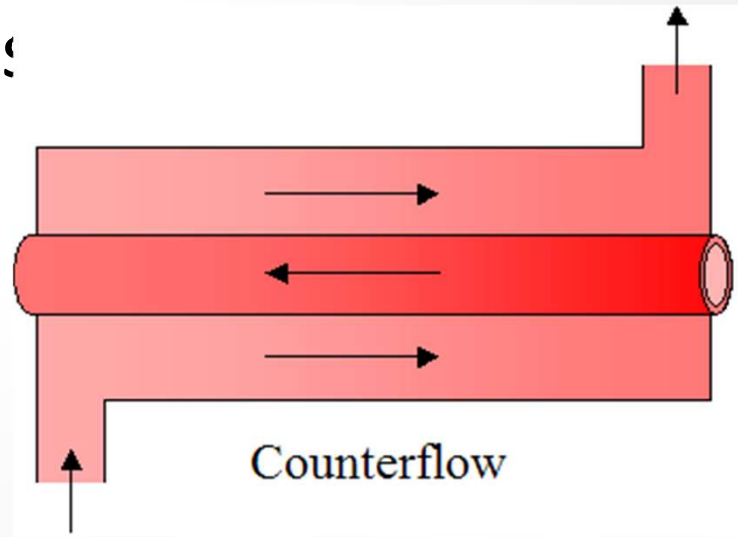
- Passive system - heat store in 33 water barrels along central dividing wall
- Active system - rock heat store beneath floor with fan to circulate warm air from greenhouse peak down to rock store in the daytime, reversing at night to pump warm air up from the rock store to the greenhouse
- Vents at the front bottom and roof peak open and close to regulate air temperature during hot weather

Solar Aquaponics Greenhouse

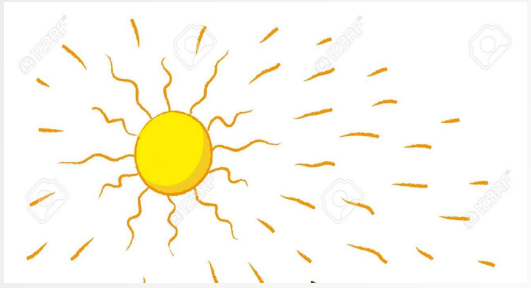
Ventilation: Counterflow Heat Exchanger

Control humidity, provide fresh air, prevent heat loss

- Provides continuous air exchange between inside and outside of greenhouse (1 complete air exchange every 8 minutes)
- Transfers heat from warm exhaus cooler air to conserve heat
- Removes humid air
- Keeps indoor CO2 level up
- 90% efficient operation (2 fans)



Performance Modeling

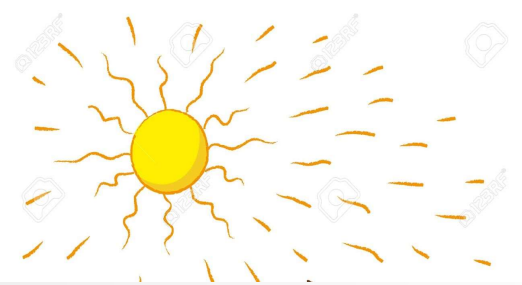


Solar Aquaponics Greenhouse

Solar Heat Retention

- Three Ontario locations (1. Mount Forest, 2. Windsor, and 3. Thunder Bay)
- Temp. graphs: exterior (ambient/blue) vs. interior (pink) greenhouse temperatures over a year
- Mount Forest is closest to Guelph
- Windsor is closest to Leamington
- Thunder Bay is of interest in modeling solar greenhouse performance in a northern location

Performance Modeling



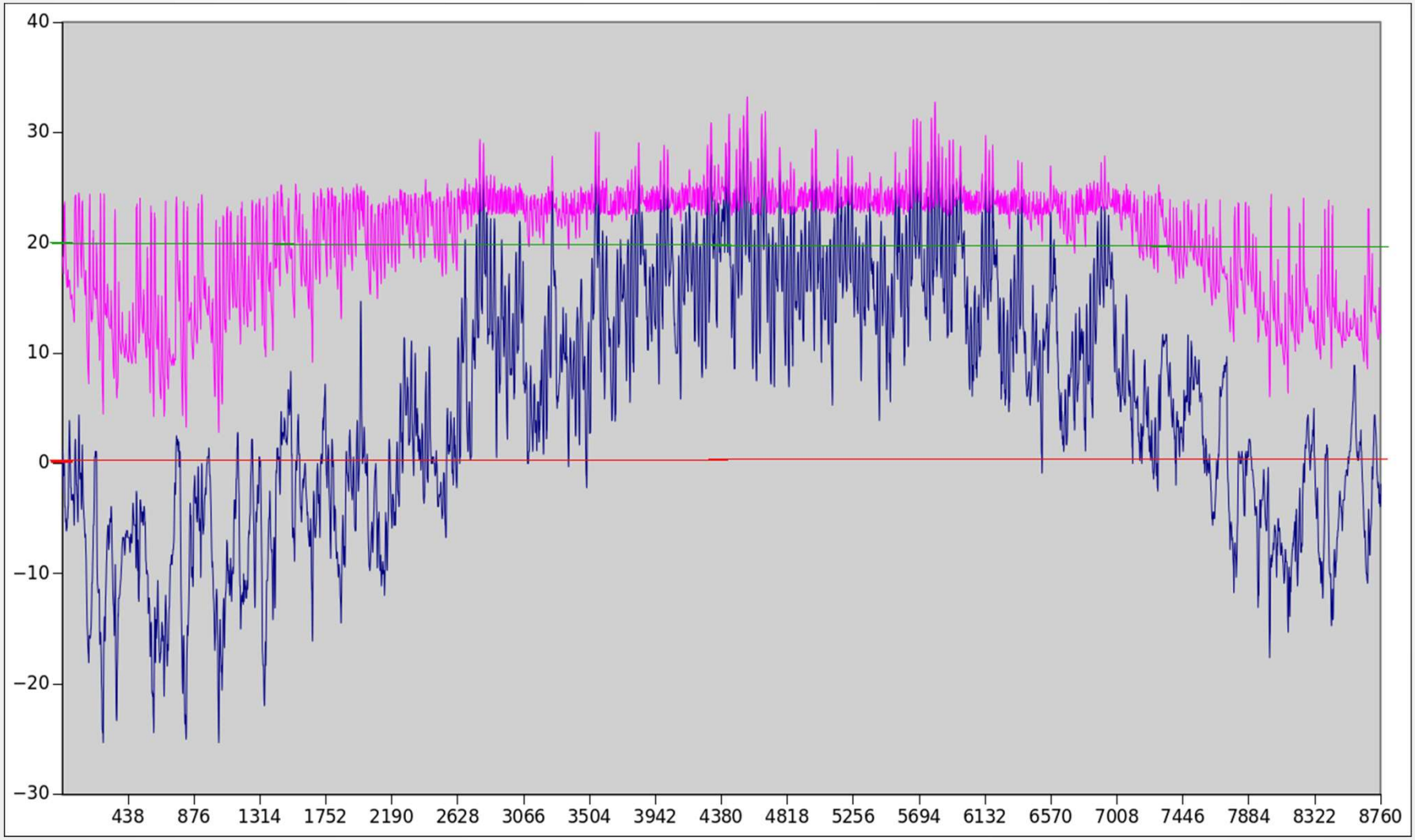
Solar Aquaponics Greenhouse

Solar Heat Retention

- A - Temp. graphs with solar heat only
- B - Temp. graphs with added supplementary gas heat for coldest days
- C – Temp. graphs for fish tanks (in blue) – using supplementary heat when needed

Mount Forest - Solar Heat Only

1A) ambient (outdoor/blue) temperature vs. **solar-only** heated interior (pink)

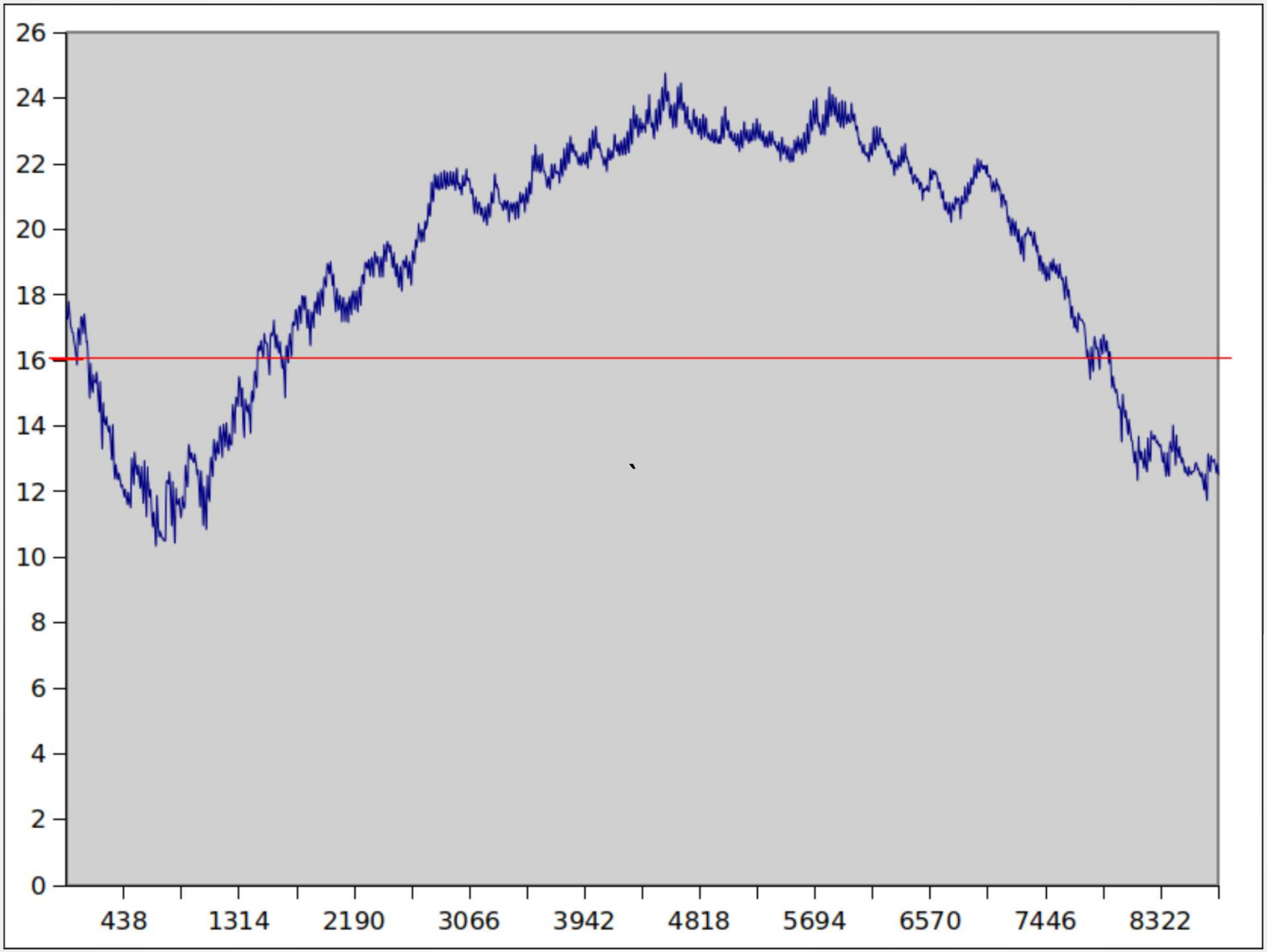


Mount Forest - Solar Heat Only

In this model, plant area temperatures go down to 5.8° C

- Minimum temperature for sensitive plant survival is 4° C.
- Minimum temperature for active plant growth is 13° C – optimum plant growth at 20 ° C

Mount Forest Fish Temp. Solar Only

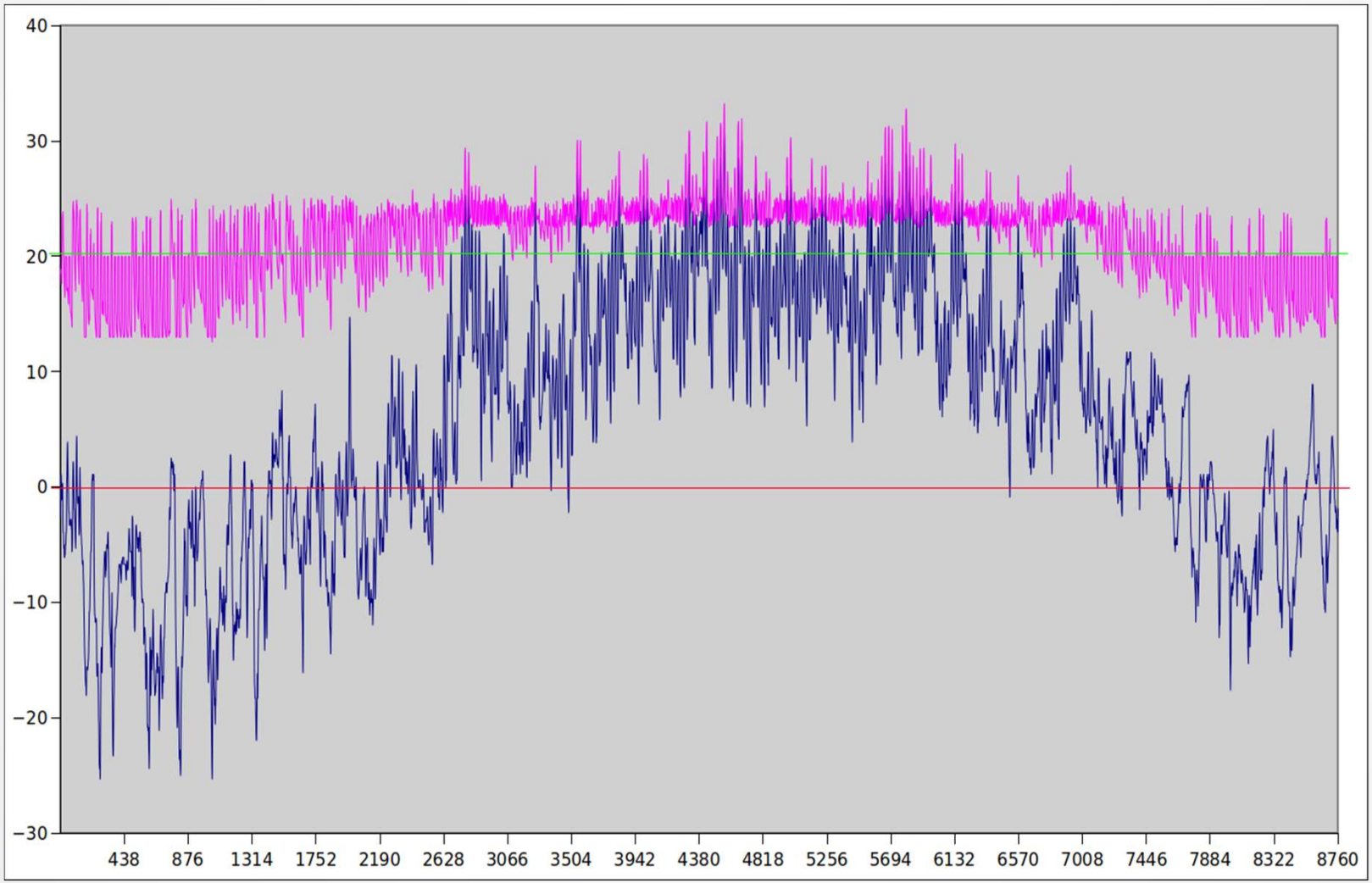


Mount Forest - Fish Tank Temp.

- Temperature range 10°C - 24°C
- The minimum temperature that tilapia tolerates is 16° C. Growth range 18°C - 32°C
- Yellow perch growth range 16°C -24°C
- Striped bass growth range 16°C - 32°C
- Trout growth range 4.4°C – 18.3°C

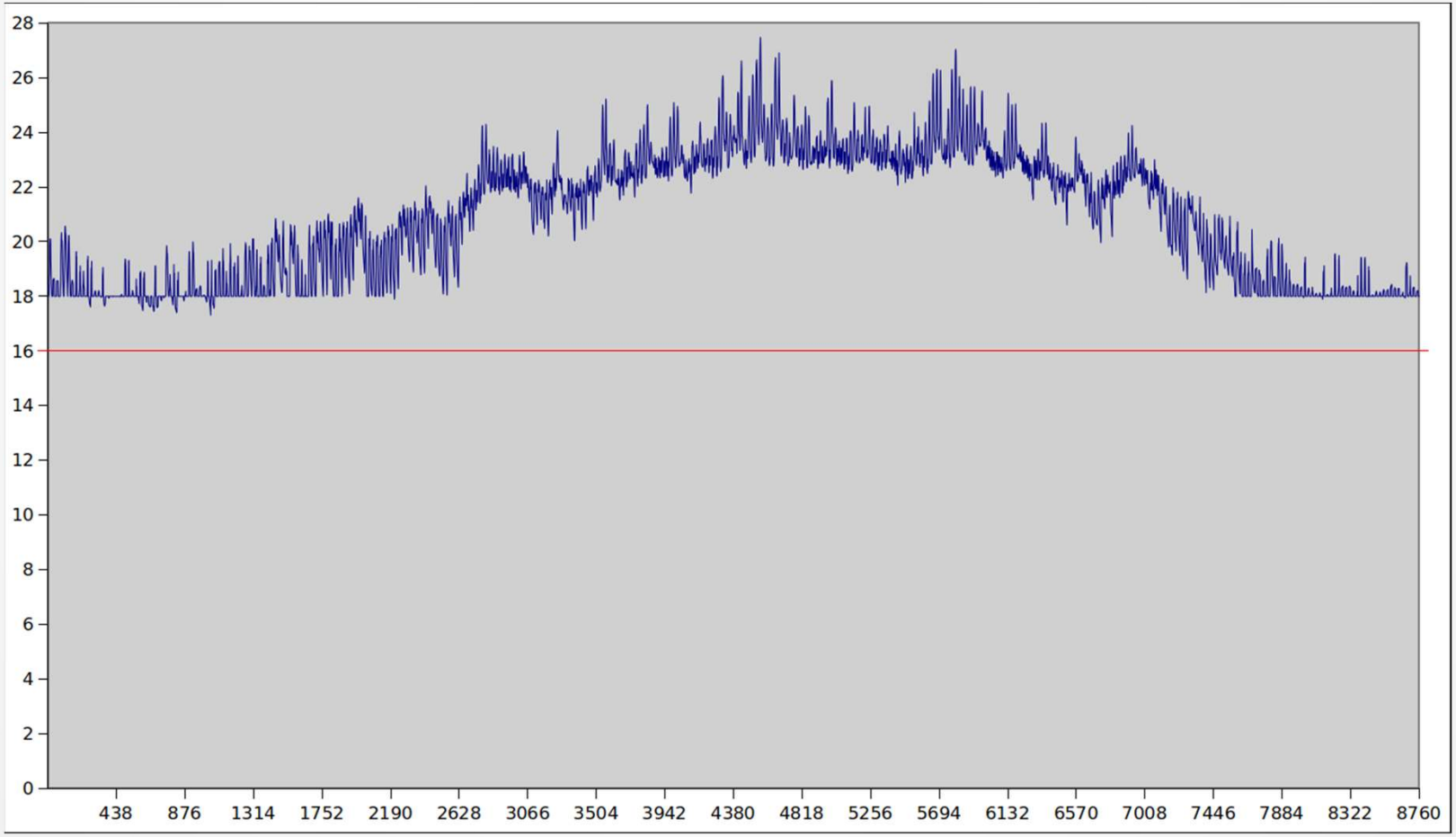
Mount Forest - Solar + Gas Heat

1B) Ambient (outdoor/blue) temperature vs. interior **solar heat supplemented with natural gas** (pink): min 16C°/night, min 20 C°/day



Mount Forest – Fish, Solar + Gas

1C) Fish tank temperatures, **supplemented with natural gas**



Mount Forest

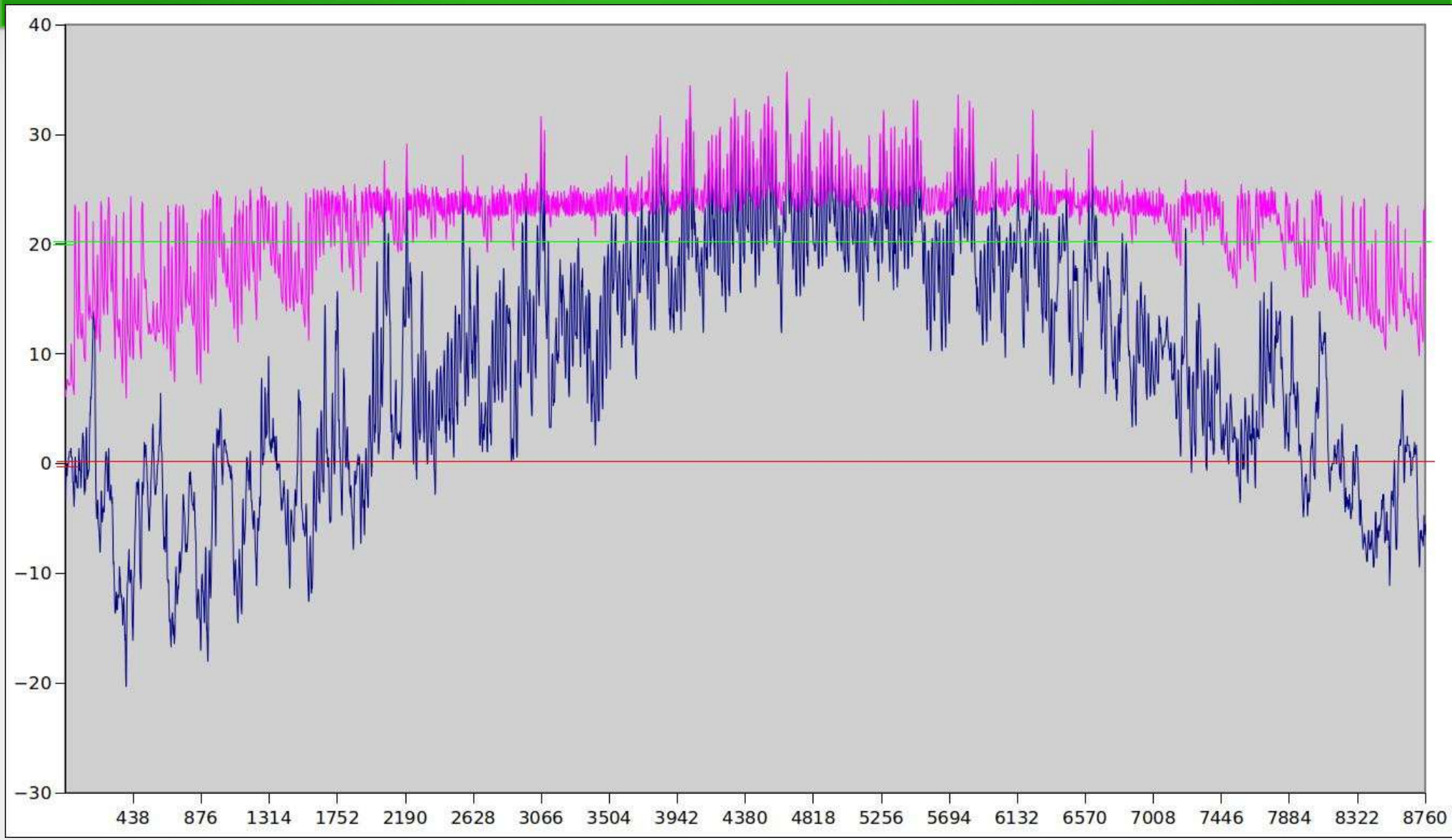
Annual Supplementary Heat Required for Mount Forest

- Natural gas – 353 cu. Metres - $70.63
- Electricity for fans – 1,460 KwH - $175.25

Total cost: $245.88

Greenhouse gas emissions: 690 kg. CO_2
(15% of one car)

Windsor – Solar Heat Only



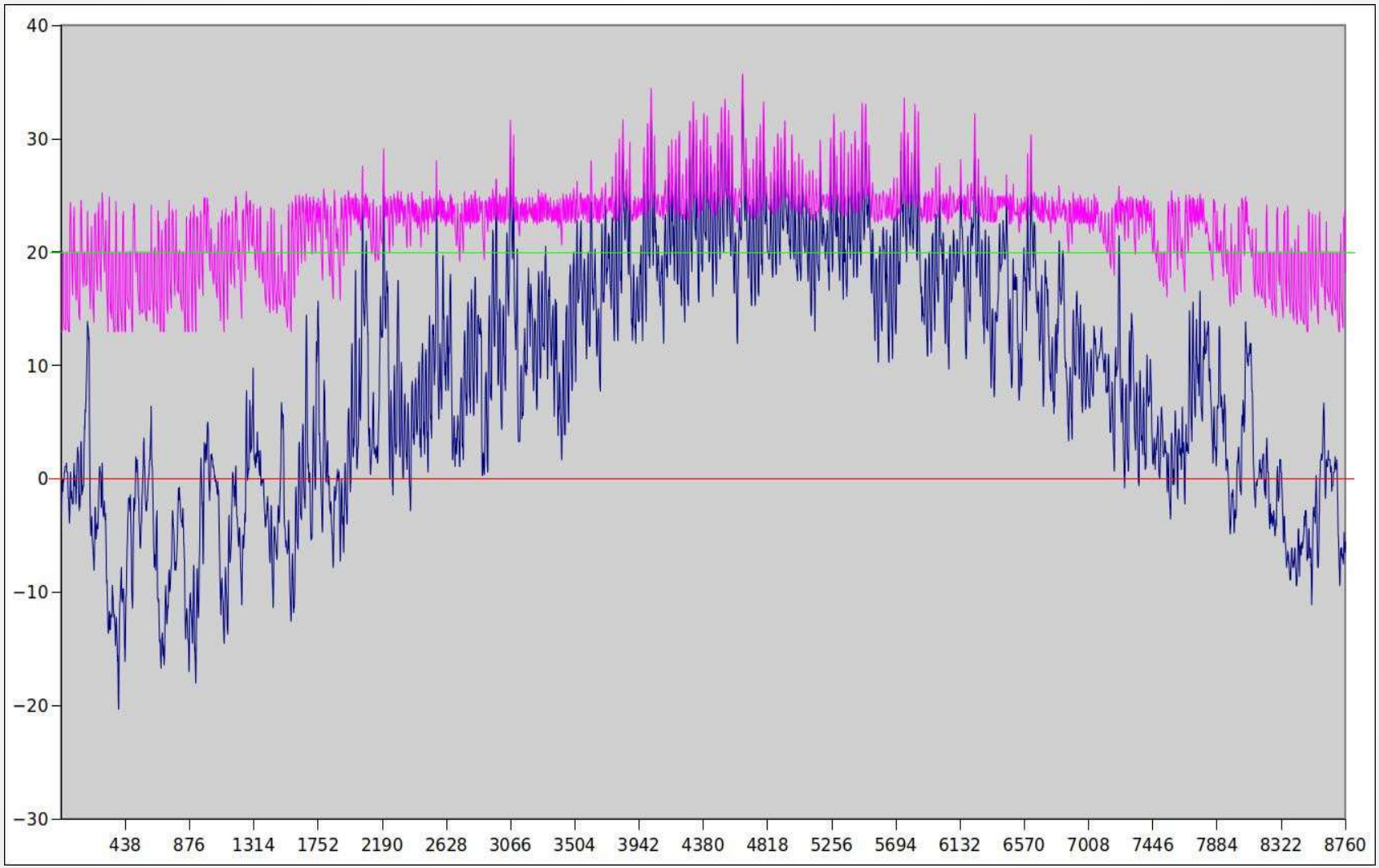
Windsor – Solar Heat Only

2A) In this model, plant area temperatures go down to 6.0° C

- Minimum temperature for sensitive plan survival is 4° C.
- Minimum temperature for active plant growth is 13° C – optimum plant growth at 20 ° C
- The minimum temperature that tilapia tolerates is 16° C.

Windsor – Solar + Gas Heat

2B) Ambient (outdoor/blue) temperature vs. interior **solar heat supplemented with natural gas** (pink): min. 16C/night, 20C/day



Windsor

Annual Supplementary Heat Required

- Natural gas – 188 cu. metres - $37.70
- Electricity for fans – 1,460 KwH - $175.25
- Total cost: $212.95
- Greenhouse gas emissions: 367.6 kg. CO2 (8% of a car)
- **Note**: Gas heating in the commercial greenhouse business is costed **per hectare.** The average annual cost of heating per hectare in Leamington is $95,063.
- The solar greenhouse would cost $5,204 **per hectare** for supplementary gas heating, or 5.5% of the energy cost of a standard commercial greenhouse - or 11 cars.

Windsor

Solar Greenhouse Carbon Emissions Windsor vs. Commercial Greenhouse

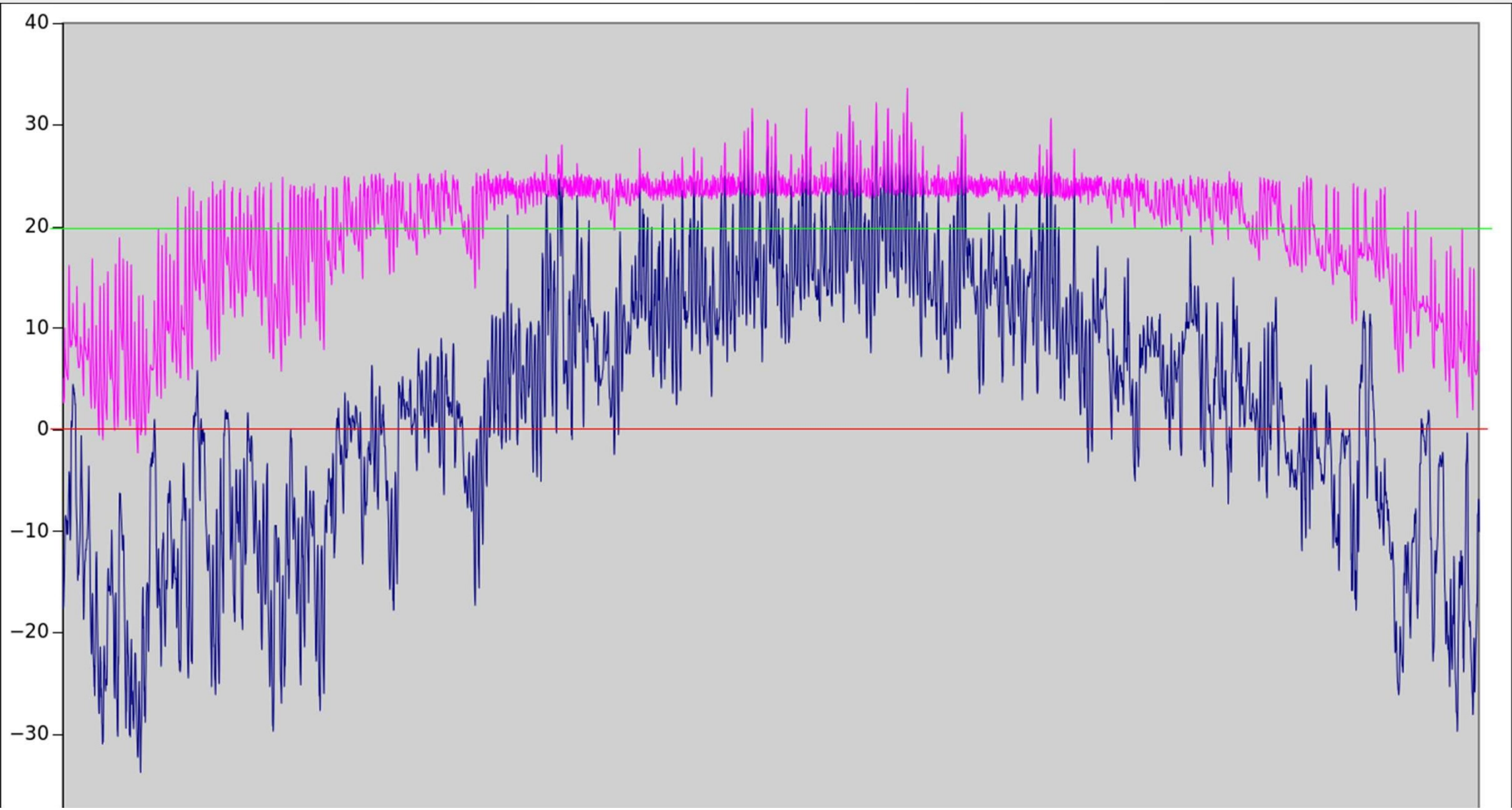
- 50,747 Kg CO_2 **per hectare** or 11 cars vs.

- 1,231,065 Kg CO_2 per hectare for a standard commercial greenhouse or 267 cars

4.1% of the CO_2 emitted per year of a standard greenhouse

Thunder Bay – Solar Heat Only

3A) Ambient (outdoor/blue) temperature vs. **solar-only** heated interior (pink): below 4C and some freezing in winter



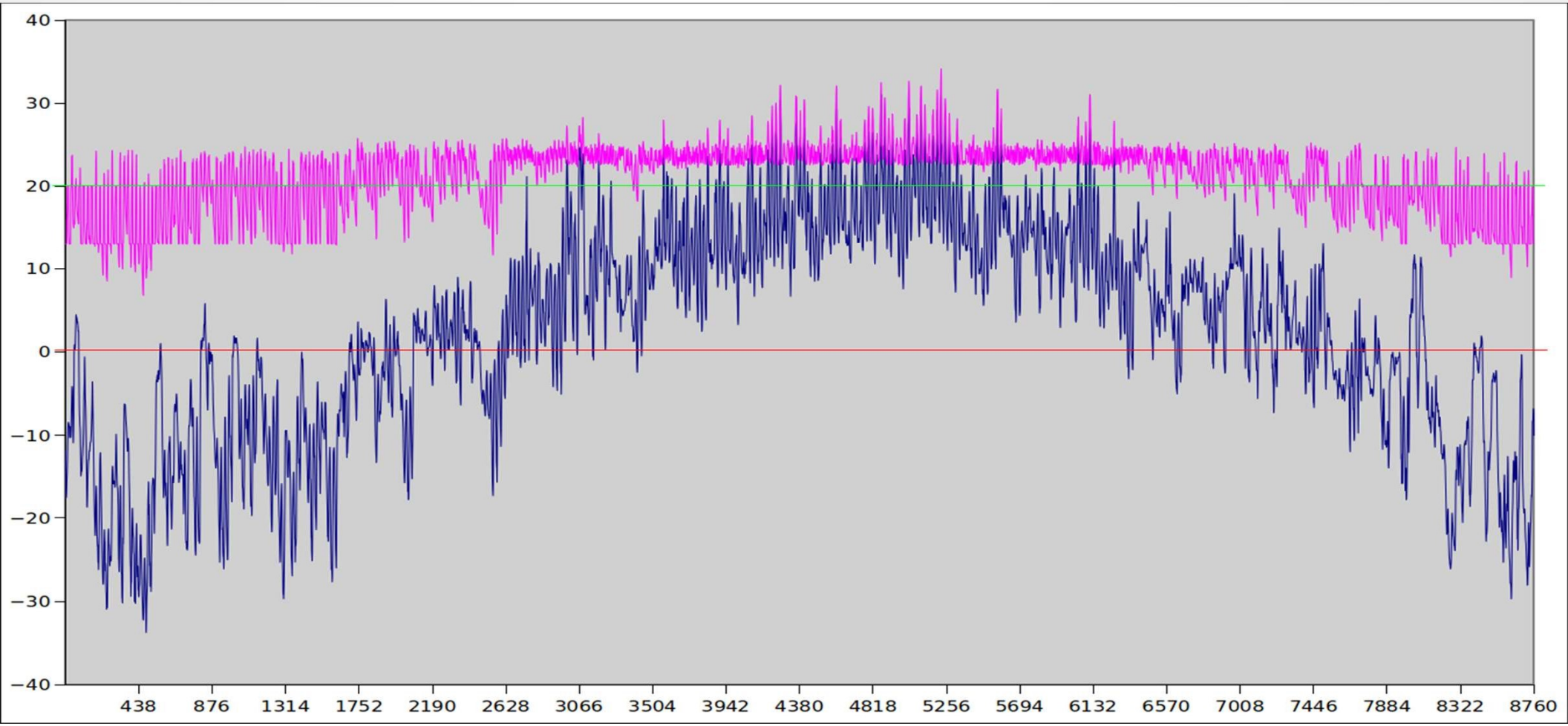
Thunder Bay – Solar Heat Only

3A) In this model, plant area temperatures go down to -5.7° C

- Minimum temperature for sensitive plan survival is 4° C.
- Minimum temperature for active plant growth is 13° C – optimum plant growth at 20 ° C
- The minimum temperature that tilapia tolerates is 16° C.

Thunder Bay - Solar + Gas Heat

3B) Ambient (outdoor/blue) temperature vs. interior **solar heat supplemented with natural gas** (pink): min 16C/night, 20C/day

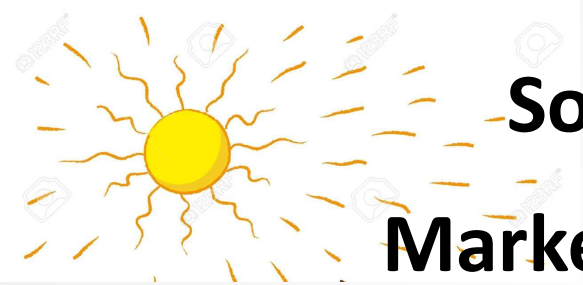


Thunder Bay

Annual Supplementary Heat Required for Thunder Bay

- Natural gas – 618 cu. Metres - $123.61
- Electricity for fans – 1,460 KwH - $175.25
- Total cost: $298.86
- Greenhouse gas emissions: 1,205 kg. C[illegible] [illegible]6% of one car)

Potential Produce Yields



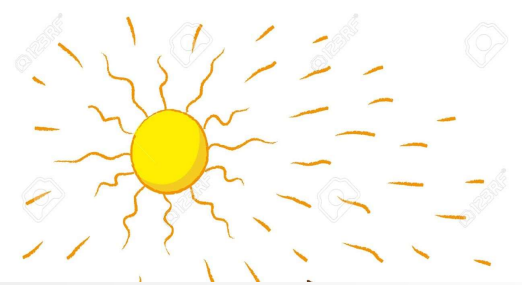
Solar Aquaponics Greenhouse

Market Value Potential Annual Yields

- 111 heads lettuce/week @ $2.50 $14,430
- 4.5 kilos tomatoes/week @ 3.77/kg $ 882
- 526 tilapia @$5.00 $ 2,630

- Total Gross: $17,942

Pest Management



Solar Aquaponics Greenhouse

Pest Management

- Insect pests may develop in an aquaponics system
- Fish are very sensitive to pesticides
- Using predatory insects and/or parasites (Integrated Pest Management) to control plant pests is a first line of defense
- If more aggressive (chemical) pest control is required, growers should follow guidelines from the Organic Materials Review Institute

Pest Management

Solar Aquaponics Greenhouse Pest Management

Fig. 15 - Integrated (Biological) Pest Management Species

Pest	Predators	Parasites
Whitefly	Green lacewing, Delphastus catalinae Lady bug	Encarsia formosa
Mite	Amblyseius californicus, Phytoseiulus persimilis	
Peach Aphid	Green lacewings, Lady bugs	*Aphidius matricariae*
Mealybug	Cryptolaemus montrouzieri Lady bug, Green Lacewing	

YGH + City of Guelph – Smart Cities Challenge

YGH is one of the partners in Guelph's submission to the Smart Cities Challenge Initiative "Circular Food Economy," a national competition with a $10 million prize to the winning city

Their submission is "*Our Food Future* Guelph-Wellington: Canada's First Food-smart Community" - partnerships and food systems that solve local food problems that are globally relevant

- Vision: a global food system that values planet, health, equity and dignity for everyone
- Through collaboration, big data, local expertise and innovative technology… and creating Canada' first circular food economy, achieve 3 goals by 2025
  - Increase access to affordable nutritious food by 2050
  - 50 new circular business and collaboration opportunities
  - 50% increase in economic revenue by reducing and re-imagining food waste
- Create a food-secure ecosystem that benefits People, Prosperity, Planet

UN Sustainable Development Goals

- SDG 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture.
- SDG 7: Affordable and clean energy. Ensure access to affordable, reliable, sustainable and modern energy for all.
- SDG 8: Promote inclusive and sustainable economic growth, employment and decent work for all.

UN Sustainable Development Goals

- SDG 9: Build resilient infrastructure, promote sustainable industrialization and foster innovation.
- SDG 13: Climate action: take urgent action to combat climate change and its impacts

Costs

Solar Aquaponics Greenhouse

Estimated Cost to Build (exclusive of labour)

• Building materials	$21,626
• Aquaponics system components	$18,765
• Hardware, wiring, appliances, backup systems, etc.	$12,282
• Taxes	$ 7,900
TOTAL:	$60,575

Opportunities

Solar Aquaponics Greenhouse – Learning Opportunities

This design is a first iteration of a plan for an energy-efficient greenhouse. From this stage, the project offers multi-disciplinary opportunities for community participation in:

- Final architectural drawings
- Community funding
- Building the greenhouse – community participation
- Instrumentation and monitoring of heat performance of the building
- Fish-raising
- Choices/growing of plant crops/destinations
- Partnering with local community and institutions for use of food produced
- Papers on overall performance of building and programs for others to emulate

Scaling Up

China has demonstrated enormous strides in investment and development of solar greenhouse agriculture with minimal fossil fuel heating, in northern parts of the country

- The costs of fossil fuels in Canada are likely to rise
- Carbon taxes will affect greenhouse growers
- Opportunities for investment in passive and active solar construction for the greenhouse industry in Canada are worth researching and pursuing
- Part of the calculated return on investment should include paybacks from avoided natural gas heating and applicable carbon tax disincentives at time of projects

Contact

Paul Neelands

paulnee@xplornet.com

11373 Fith Line Nassagaweya

RR 22

Rockwood, Ont.

N0B 2K0