Abstract -- In this paper, we present a method of producing tomatoes for profit in an isolated Arctic community using only renewable energy sources. A modified rockwool drip hydroponics system was employed, which uses electrodialysis to reclaim effluent nutrient solution. The facility proposed is a modified A-frame greenhouse with highly insulated exterior walls and a slanted roof made of transparent polycarbonate. The facility operates on passive solar radiation that is supplemented by wind power from a 10 kW turbine. A heat exchanging ventilation system is implemented to reduce the amount of heat lost in the winter. A control system is included to partially automate operation and to allow for remote system control and monitoring through the Internet.

Index Terms -- Arctic, Greenhouse, Hydroponics, Wind Turbine.

I. INTRODUCTION

ARVIAT, Nunavut is an isolated hamlet on the coast of Hudson Bay. It is difficult for the 2000 inhabitants to find reasonably priced produce due to limited accessibility and harsh weather conditions that do not favor traditional agricultural practices. Off grid renewable power and water recycling are required due to the low power grid capacity and limited fresh water supply in Arviat. The operation must be completely self-contained and compatible with the northern climate. Currently non-profit greenhouses operate during the summer in similar northern communities [1]. However, our facility will produce crops for profit. Commercial, fully automated and self-contained greenhouses have been implemented successfully but in very different climatic regions [2]. The design proposed is unique because it aims to operate all year round in the Arctic in a manner that is both environmentally and economically sound. Thermodynamic testing, energy analysis, and cost analysis were performed to illustrate the feasibility of the design solution. The main focal point of the greenhouse design is the optimization of energy efficiency. The milestone for this project is a three-dimensional model of the facility simulated in AutoDesk Architectural and Viz 2007©.

II. CONCEPTUAL DESIGN METHODOLOGY

A. Overall design

The facility is triangularly shaped and oriented to maximize solar radiation through the slanted transparent roof. The facility houses 80 heirloom tomato plants through all three stages of their life cycle. This variant of tomato was chosen because of its frost tolerance, high nutritional value, and exceptional flavor [3]. The plants are grown in a rockwool hydroponics system that reclaims water using an electrodialysis filter. The facility is ventilated using a heat exchanger to minimize winter heat loss. Power requirements beyond what are supplied by passive solar heating is provided by a single wind turbine. The system is semi-autonomous but will require trained staff for harvesting, equipment maintenance, and limited amounts off-site monitoring.

III. DETAILED DESIGN

A. Structure & Insulation

The design has a floor area of 12.5 m x 5 m. The building is a modified A-frame design with the side profile given below. The building is orientated design at a 60° angle north of west to optimize incident light and minimize snow drifting at the northern entrance. The structure is raised on steel piles to limit damage to underlying permafrost. The roof of the structure is made of translucent, triple-pane polycarbonate to allow light transmittance while acting as a good thermal barrier. The walls and floor are insulated using 15 cm of polyurethane foam and a 10 cm air gap. The internal walls of the structure are covered in a layer of a reflective barrier made of aluminum composite to stop heat absorption. It rests on top of a layer of vapor barrier which prevent moisture damage to the structure.

Figure 1: Side profile of facility.

B. Hydroponics & Water Recycling

A three-stage rockwool hydroponics system is best for growing vine plants such as tomatoes [4]. On average, rockwool hydroponics facilities produce 30 times the amount of tomatoes as compared to conventional soil greenhouses [4]. Stage 1 of the production is designed to meet the needs of the tomato plants in the early stages of their growth. When the first leaves emerge, the plants are transplanted to stage two. The approximate duration of stage one is 7 days. When the tomato plants outgrow the cubes in stage two, the plants are transported to the rockwool slabs of stage 3. The length of the slabs allows us to grow roughly 4 - 5 tomato plants per slab. When
natural lighting becomes insufficient, additional light is provided using three 1 kW high pressure sodium lights placed 3.75 m above the facility's floor.

In order to reduce water usage, the nutrients that are not absorbed by the plant will be removed from the water stream so that the ion free water can be recycled. The nutrients are removed based on charge using 42 pairs of electrodi lysis cells with an estimated power consumption of 5 W. The water stream entering the electrodi lysis unit is continuously titrated down to a pH of 3 to prevent calcification.

A two tank gravity fed system is used to ensure even dispersion of nutrient to the main pipeline. The mainline diverges into separate lines that feed each tomato plant. The nutrient solution passes through the plant roots, the rockwool cubes/slabs, and into a return line that takes the solution back to the control system for filtering and re-di lution.

C. Ventilation

The heat exchanger used is a counter-current shell in a tube design that provides 0.75 air exchanges per hour. The hot inside air is expelled through a 0.9 m diameter outer shell. Nine pipes of 0.1 m diameter run inside the outer shell and bring outside air into the facility. The total surface contact area between the cold and hot air streams is 9 m². The heat exchanger's efficiency is estimated at 40 percent when outside temperatures are below zero. During the summer months the two fans that drive air exchange can both be set to drive air out of the facility to help remove excess heat and humidity.

D. Control System

The system contains water sensors and controls for: electrical conductivity, pH, flow rate and temperature. The system also contains air sensors and controls for: humidity, CO₂ levels, light levels and temperature. All control devices can be adjusted and logged through a central computer and sensory output. Using a satellite Internet connection the system can be adjusted and monitored by centralized off-site technicians.

E. Wind Power

The facility is off-grid and wind powered. Wind power was chosen due to the high mean wind speeds of 7 m/s in Arviat and the lack of viable alternatives. Power requirements are met by a southeast facing 10 kW Bergey Excel turbine that is mounted on a 24 m lattice style tip-up tower [5][6]. The turbine can exceed the facility's total power requirements by 25 percent. The excess power is used to charge a string of batteries of 36 kWh total capacity with a nominal voltage output of 120 V.

IV. DISCUSSION

This design proves that a facility like this is feasible; however it is still too costly due to its high power requirements. Heat loss through ventilation was the biggest factor in determining heating requirements. It is suggested that future designs use a heat exchanger that is more efficient like the one proposed by D. Rousse et al. [7]. Lighting also proved to be a large power cost; we propose that tests be performed to determine how much light is actually needed for satisfactory plant growth. The proposed idea of using remote monitoring of the facility by centralized technicians is beneficial because it will allow operators to globally service multiple operations simultaneously. Some on site staff is still required because fully automated systems will still require daily monitoring of the ion concentration in the nutrients. To improve on economic feasibility, future designs should attempt to service more than one community whenever possible. In addition, we propose to sell any excess power to the local power grid.

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REFERENCES