

Resource and

Production Model for the

South Pole Food Growth Chamber

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ABSTRACT

NASA scientists have previously researched biomass production units for the purpose of bioregenerative life support systems (BLSS). The University of Arizona, Controlled Environment Agriculture Center (UA-CEAC) in cooperation with Sadler Machine Company (SMC) designed, constructed and assisted real-time operations of the South Pole Food Growth Chamber (SPFGC). The SPFGC is a semi-automated, hydroponic, multiple salad crop production chamber located within the U.S. National Science Foundation New Amundsen-Scott South Pole Station. Fresh vegetables are grown for the Station crew during the annual eight-month period of isolation in one of the most extreme and remote environments on Earth. An empirical mathematical model was developed from data monitored onsite and remotely by Internet and telecommunications during the winter of 2006. The SPFGC model was based on a mass balance, whereby all carbon dioxide and water were monitored within the system and biomass generated by the crops was recorded. Edible production yields within the 21.90 m² SPFGC Plant Production Room averaged 2.8 kg day⁻¹ (\pm 1.0 kg day⁻¹) with 12 kW of installed high intensity discharge lighting and a 17-hour photoperiod. Other operational resources were monitored including labor, energy, and plant nutrients. The data generated from the remote and isolated location of the SPFGC includes information for future BLSS applications.

INTRODUCTION

The Amundsen-Scott South Pole Station (Station) is a permanently manned U.S. research facility in Antarctica (latitude -90° S). The U.S. National Science Foundation (NSF) Office of Polar Programs supports science and

research the year around at the South Pole utilizing ski-equipped C-130 cargo aircraft to supply fuel, cargo, food and all operational and maintenance needs of the Station during the four month austral summer. The remaining months of the year the Station is isolated, without the possibility of re-supply due to the extreme cold climate conditions (+13.6 °C / -82.8 °C record high/low winter mean temp. -65 °C). Stored food comprised all of the diet of the crew. Fresh vegetable produce cannot be stored and was therefore grown on site within the South Pole Food Growth Chamber (SPFGC), an enclosed plant growth facility located inside the Station.

The SPFGC was designed, constructed and tested, at the University of Arizona, Controlled Environment Agriculture Center (UA-CEAC) in cooperation with Sadler Machine Company (SMC), Tempe, Arizona, and shipped and re-constructed at the South Pole by Raytheon Polar Services Company (RPSC), Denver, Colorado. Both the Station and the SPFGC are operated by RPSC. The project was funded by the National Science Foundation Directorate for Education and Human Resources for the Office of Polar Programs (NSF/OPP). Since initial operation that began July 2004, lettuce, herbs, tomato, pepper, cucumber, cantaloupe, edible flowers, and strawberries have been grown. In addition to providing fresh vegetables the SPFGC provides an intensely lighted, with warm light quality, and relatively humid space for members of the isolated crew (typically 50-60 people). Those who choose to utilize it may volunteer to help with plant care, crop harvest or housekeeping. A small 9.2 m² (2.35 m X 3.91 m) sitting area (the Environmental Room), which is adjacent to, but separated from the Plant Production Room by a clear glass wall, can be enjoyed by anyone for rest and relaxation during their free time. An

independent, non-automated hobby hydroponic system was located in this room for station personnel to learn about hydroponics, however, plant production and resource consumption from this system was not included in the Resource and Production Model for the SPFGC (Figure 1).

OBJECTIVES

The Resource and Production Model was developed to predict the amount of resources (CO_2 , water, nutrients and energy) needed, and to determine the amount of fresh vegetables produced by the system for a given production period, assuming the crop management practices, environmental conditions, and resulting crop responses (described below) were similar to those of 2006 operations of the SPFGC. The Resource and Production Model was subsequently used to estimate the capacity for air revitalization (CO_2 - Oxygen), and number of people that could be supported by the SPFGC design if used within an advanced life support (ALS) system.

MATERIALS AND METHODS

SPFGC (SOUTH POLE FOOD GROWTH CHAMBER)

Complete detail of the design, operation, crop production and resource utilization of the SPFGC were described by Patterson, et al, 2008. Only the relevant information about the SPFGC for understanding the Resource and Production Model was included in this publication. The SPFGC was housed within the climate controlled South Pole Station which was maintained at approximately 16 °C and 10% relative humidity. Atmospheric pressure during 2006 averaged 67.9 kPa and ranged from 70.2 to 65.5 kPa. Crop cultivation occurred within the 54.7 m³ (5.60 m X 3.91 m X 2.50 m) Plant Production Room, one part of the SPFGC, which also included a Utility Room and an Environmental Room. The plant production area was 21.9 m² (5.60 m X 3.91 m). Artificial lighting and all electrical components were powered by diesel-fired engine generators.

Table 1 includes the list of environmental conditions maintained in the Plant Production Room by the climate control system. There was only one aerial environment zone in the Plant Production Room, with the same set-points for all crops, therefore providing less than optimal environmental conditions for every crop within this polyculture food growth chamber. The climate control system automatically maintained elevated atmospheric carbon dioxide concentration, air temperature and relative humidity, as well as hydroponic nutrient quality and quantity.

Twelve, water-cooled 1000-watt high-pressure sodium (HPS) lamps provided a minimum average of 425 $\mu\text{mol m}^{-2} \text{s}^{-1}$ ($\pm 7.8 \mu\text{mol m}^{-2} \text{s}^{-1}$) at the plant canopy for the 17-hour photoperiod within the Plant Production Room. The lamp technology was designed by SMC, and utilized General Electric LU1000/TD bulbs, surrounded by a glass water jacket for cooling (Giacomelli, et al, 2003).

During the 17-hour photoperiod the average air temperature maintained was 23.6 °C (± 0.9 °C), and 19.3 °C (± 0.1 °C) during the 7-hour dark-period. The average relative humidity maintained was 59.6 % ($\pm 4.1\%$). The air in the SPFGC cycled between the room and HVAC for conditioning at 1.5 m³ s⁻¹, or 1.7 chamber volume air changes per minute. Water vapor was extracted from the air by condensation coils, heating was provided by hot coils, and carbon dioxide was added from compressed gas cylinders. Carbon dioxide was automatically injected into the Plant Production Room whenever the concentration dropped below 1000 ppm during the photoperiod. During the dark period none was injected. However, the average 24-hour CO_2 concentration in the Plant Production Room was measured and calculated to be 1334 ppm (± 463 ppm) during the 8-month production period. Note that the Plant Production Room was a working food production facility; therefore it was opened for people to access the crops, providing atmospheric losses, as well as, supplementation with human respired carbon dioxide.

HYDROPONIC CROP PRODUCTION SYSTEM

Crops were grown within a recirculating hydroponic system without root zone substrate, except for a 25 mm germination/transplant seedling cube. Electrical conductivity (EC) and pH were automatically maintained at an average of 2.4 mS cm⁻¹, (± 0.15 mS cm⁻¹) and 6.0 (± 0.2), respectively for all crops. Primary chemicals to create the nutrient solution are listed in Table 2. Dissolved oxygen in the nutrient solution was not measured, but oxygenation was provided by air introduced through bubblers (0.01 m³ min⁻¹) directly in the nutrient solution storage.

A multitude of small leafy green crops and tall fruiting crops were grown to provide continuous production and full production space and volume utilization. Leafy greens, primarily lettuce, were harvested and immediately replanted, while the fruiting crops were planted once, and cultured for continuous harvest.

RESOURCE AND PRODUCTION MODEL FOR THE SPFGC PLANT PRODUCTION ROOM

The Model was based on the four physical components of the SPFGC that require resource inputs, and that establish a simple closed environment system for air revitalization and food production:

Climate Controlled Plant Production Room The climate controlled Plant Production Room is a semi-closed space, where the atmosphere was treated by the bioprocessors located within (plants and people (or CO_2 tank) (Figure 2).

HVAC system The air handlers (blowers) of the HVAC system recycled the internal atmosphere of the Plant Production Room and processed it with cooling coils to de-humidify, and heating coils to re-heat, to maintain air moisture content (RH) and temperature.

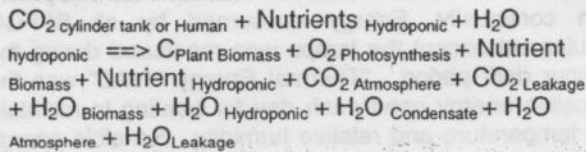
Hydroponic Nutrient Solution System The nutrient system, included the hydroponic nutrient

solution and storage reservoirs, nutrient distribution pump, nutrient aeration pump, and nutrient concentrate injectors. The nutrient concentrate injectors maintained the pre-determined proportion and concentration of nutrients provided to the plants. The nutrient solution concentration was measured as total electrical conductivity within the hydroponic solution. Plant transpiration water vapor was returned to the nutrient storage tank, after condensation by the HVAC system, to complete the hydrological cycle of the system.

Bioprocessors The bioprocessors are the plants and crew (in this example, one person).

The mass balance components of the SPFGC Resource and Production Model are listed in Equation 1. The general photosynthesis equation accounted for carbon of the plant tissues ($C_{\text{Plant Biomass}}$) and the atmospheric oxygen ($O_2_{\text{Photosynthesis}}$). The source of carbon dioxide was the high pressure cylinder tank for the SPFGC, but would be from human respiration within a life support system ($CO_2_{\text{cylinder tank or Human}}$).

Equation 1. Total Resource and Production Model Mass Balance



The nutrients were the dry salts containing the macro and micro elements provided by the hydroponic fertilizer ($Nutrients_{\text{Hydroponic}}$). These were dissolved within the liquid water of the hydroponic system ($H_2O_{\text{hydroponic}}$) at the appropriate concentrations and then distributed to the root system of the plants. The nutrient biomass term ($Nutrient_{\text{Biomass}}$) included the macro and micro elements within the plant tissues, while H_2O_{Biomass} term was liquid water within plant tissues. The water condensed from the atmosphere during dehumidification was $H_2O_{\text{Condensate}}$, water vapor in the atmosphere was $H_2O_{\text{Atmosphere}}$, and water vapor lost from the system was H_2O_{Leakage} . Carbon dioxide in the atmosphere was $CO_2_{\text{Atmosphere}}$, and carbon dioxide lost from the system was CO_2_{Leakage} . Leakage rate of the Plant Production Room was measured as 0.0015 volume air changes per hour, and was assumed negligible for this analysis.

The model was based on the SPFGC Plant Production Room systems operations. The water not incorporated as plant tissue was recycled as nutrient solution within the hydroponic system, and the water transpired by the plants was condensed on the cooling coils and measured, but was not re-incorporated into the hydroponic nutrient solution. Water accumulated in plant tissues was determined as a percentage of the wet weight of the harvested crops. Carbon dioxide production was assumed from human respiration rather than from a compressed gas cylinder. There was a one

to one molecular relationship assumed between the oxygen generated and the carbon dioxide consumed by the plants (Wheeler, 2003).

The model was developed in Excel spreadsheet format such that materials consumption, energy required, biomass production, and oxygen production, could be estimated based on the size of the Plant Production Room. The model predictions are linearly proportional to the amount of resources that were needed and the amount of fresh vegetables produced by the system, assuming the crop management practices, environmental conditions, and resulting crop responses were similar to those of 2006 operations of the SPFGC Plant Production Room.

Figure 2 is a schematic of air revitalization of oxygen and carbon dioxide via plant photosynthesis and plant/human respiration, as well as, water cycling via plant transpiration, and physical processes of evaporation and condensation within a simple life support system containing plants and one human as bioprocessors. It was determined from the SPFGC Resource and Production Model that 0.18 kg day^{-1} of dry nutrient salt within a Plant Production Room of 57.2 m^3 would provide 0.835 kg of oxygen per day, which is the amount of oxygen required to support a person for one day (Hanford, 2006). The model was then provided inputs of 0.18 kg day^{-1} with a plant production room of 57.2 m^3 and the resulting consumption of resources and production of plant biomass were calculated in terms of specific units of daily mass and energy per unit area and unit volume of the Plant Production Room.

RESULTS AND DISCUSSION

Material Consumption, Energy Consumption, and Oxygen Production

The results from the model were based on a mass balance, whereby the primary sources and sinks of carbon, oxygen and hydrogen were accounted for within the system. The model focused on the cycle of the compounds of gaseous oxygen (O_2) and carbon dioxide (CO_2), and both gaseous and liquid water (H_2O). All the other chemical elements needed for system operation of biomass production were assumed to be provided by the hydroponic system in the form of plant fertilizer salts, and to be used only once. These elements (N, Ca, K, P, S, Mg, Cl, Cu, Fe, Mo, Zn, Mn) were added to the system in the compound forms of calcium nitrate ($CaNO_3$), monopotassium phosphate (KH_2PO_4), Magnesium Sulfate ($MgSO_4$), molybdenum trioxide (MoO_3), potassium hydroxide (KOH) and Aquagrow 16-12-16 all purpose hydroponic salt (Table 2). The assumption was that the proper amounts and proportions of nutrient elements were continually maintained within the hydroponic nutrient solution by the automated computer control system.

Table 3 includes the measured CO_2 inputs and the calculated CO_2 and carbon biomass outputs of the Plant Production Room. The CO_2 gas injected into the room

was measured (difference of full and depleted CO₂ bottle mass) over time. In addition, the chamber was occupied by 2 people approximately 14% of the time for harvest and plant care activities and the additional carbon dioxide input from the workers was calculated from Hanford, 2006. The carbon plant mass was the amount of carbon sequestered by plants (assumed 90% of daily harvest mass was water, and 90% of the dry mass was assumed to be carbon). Oxygen produced was calculated using the general photosynthesis equation (1:1, CO₂:O₂) based on the amount of CO₂ injected each day. Note that the Total CO₂ mass balance (CO₂ inputs vs. carbon sequestration and oxygen production) in Table 3 differ by 0.17 kg or 11% given the stated assumptions. Table 4 contains the model results for the support of one person's air revitalization for one day. "Total Plant Production" was the total edible and non-edible biomass harvested each day, and included a combination of lettuce, cucumber, herbs, cantaloupe, tomatoes, edible flowers, peppers and other greens that had been grown in the Plant Production Room. "Non-Edible Biomass Production" was the non-edible plant mass, such as roots and leaf trimmings, obtained during harvest each day. "Edible Biomass Production" was the amount of edible biomass harvested each day. Lettuce accounted for 45.8 % by weight of fresh edible harvest, cucumber accounted for 40%, and the remaining was proportioned as 5.4% herbs, 3.7% tomatoes, 3.5% cantaloupe, 1.3 % peppers, and 0.1% edible flowers and other greens. Note that the area required for the immature stages of the plants which were not ready for harvest, was accounted for, such that a continuous and periodic harvest management regime was practiced. The area for seedlings and young plants required that on average approximately 1/3 of the crop area was unharvested in each crop cycle. Finally, "Human Food Caloric Value" was the estimated calories for all edible harvest each day.

The "Plant CO₂ Uptake" was the carbon dioxide consumed by plants each day (Table 4). The mass of CO₂ consumed per unit time was determined by the weight change of the CO₂ cylinder. One cylinder lasted approximately 30 days. Plant Production Room leakage rate was assumed negligible. "Plant Net Oxygen Production" was the net production of oxygen (photosynthesis minus respiration) each day. This prediction assumed a 1:1 molar relationship (1.38:1.40 mass relationship) of CO₂ consumed to oxygen produced.

"Hydroponic Nutrient Chemicals" (Table 4) represented the dry hydroponic salts used each day. Hydroponic nutrient chemical consumption was calculated by multiplying the nutrient injection intervals (recorded by the computer control system) by the respective nutrient injection rate and the respective concentration of hydroponic stock solution available for the Plant Production Room hydroponic systems. Periodic draining and refilling of the nutrient storage tanks were excluded from these calculations.

"Condensation from Atmosphere" was the water condensed from the chamber atmosphere each day and was an estimate of plant transpiration (Table 4). Daily plant transpiration water was estimated by subtracting 90% of the total daily plant biomass (6.0 kg) from the daily fresh water injected (34.9 kg ± 9.4 kg.) into the hydroponic systems. "Plant Tissue Water" was estimated as 90% of the fresh weight of the plant. "Total System Water" was the total liquid water mass needed to operate the Plant Production Room. It corresponded to the hydroponic nutrient reservoir in Figure 2 (1526 kg, or 67 kg m⁻², or 27 kg m⁻³), distilled water (90 kg) for the lamp cooling technology, and the concentrated hydroponic stock solutions (Total 330 kg) (Table 2).

"Electrical Energy Lamps" was the electrical energy needed each day for powering the HPS Lamps (Table 4). Power consumption (excluding lamps) was constant during both the light and dark periods. Energy consumed by the lamps was calculated from the difference of light and dark period power consumption. "Electrical Energy All Other" was the electrical energy used each day for pumps, blowers, actuators and computer for automating control of the Plant Production Room. This equipment ran continually. Energy consumed by all SPFGC equipment except the lamps was measured during the 7-hour dark period. "Thermal Energy HVAC" was the sensible energy used each day for heating to maintain air temperature and relative humidity. Sensible energy was approximated by measuring the air mass flow rate (with a mechanical anemometer) and the temperature differential across the Plant Production Room HVAC heat exchangers during the photoperiod and the dark period (Table 1). The combined heat demand was approximated with the results of the sensible energy equation for the two periods.

The energy predictions were based on the measurement of electrical energy powering the HPS lamps, pumps, sensors, computer, and HVAC blowers, which required 293 kWh day⁻¹, with the 17-hour photoperiod. The lighting technology provided the photosynthetic energy and was the largest electrical demand and the largest source of heat gain into the Plant Production Room. The lamps require a nominal 12 kW of electrical power, 37 % of which became PAR lighting, 42% became heat imparted to the lamp coolant and 18% became ballast heat (Giacomelli et al, 2003). The ballasts are located outside the Plant Production Room, and thus did not contribute to the heating of the room. The heat was extracted from the chamber by the cold glycol heat exchange coils used in controlling Plant Production Room air temperature and relative humidity. Thermal Energy calculations included melt-water used from ice at -40 °C to working temperatures (5°C (40°F) to 47°C (117°F)). Cold coil energy requirements were not measured, as there was essentially no energy cost for cooling the inside cold coil glycol heat exchanger via the heat exchanger located outside of the Station within the Antarctic environment. "Volumetric Air Exchanges" was

the number of times the air volume of the Plant Production Room was cycled within the HVAC system each day. This was 2448 times per day.

"Labor" was the estimated number of hours each day required to maintain the crops and the systems. The labor duties were divided into three categories, daily, weekly and monthly, and recorded as hours per day. Daily duties included: checking the computer controller and current data, checking the concentrated nutrient stock tanks of the hydroponic systems, comparing computer controlled EC and pH measurements with manual EC and pH measurements of the hydroponic nutrient solution, watering seedlings, maintenance of plants in production (pruning, pollinating), and updating the operations log, for a total of 1.6 hr day^{-1} . Weekly duties included: harvesting, transplanting, seeding, cleaning trays, completing the Safety Inspection Report and the Situation Report, for a total of 1.5 hr day^{-1} . Monthly duties included: draining and refilling nutrient storage tanks, filling and preparing concentrated stock nutrient solutions, and calibrating the manual EC / pH sensors (0.2 hr day^{-1}). Therefore, 3.3 hours per day was the required time for operations to maintain the crop production within the Plant Production Room of the SPFGC. However, the time required for repair and maintenance of hardware and systems was not measured, nor included in this accounting.

The daily pan evaporation of the Plant Production Room was determined by measuring by water level decrease in a water filled graduated cylinder, and was $0.007 \text{ kg day}^{-1}$, or $3.0 \times 10^{-4} \text{ kg m}^{-2}$, or $1.2 \times 10^{-4} \text{ kg m}^{-3}$.

Lettuce and cucumber comprised the majority of the edible harvest mass produced within the Plant Production Room. With the specific environmental conditions and management practices maintained within the Plant Production Room, an average of 6.0 kg day^{-1} ($\pm 2.1 \text{ kg}$) of biomass was harvested. An average of 2.8 kg day^{-1} (± 1.0) was edible biomass providing a harvest index of 47%.

CONCLUSION

A production and resource model was developed for support of the operation of a hydroponic plant biomass growth room, which estimated the food production, energy, nutrient and labor requirements, and air revitalization capacity of the facility. For every 0.18 kg of dry nutrient salt used, 1.1 kilograms of CO_2 was sequestered, 0.836 kilograms of oxygen was produced, and 31 kg of water was cycled. Therefore, approximately 62 kg of nutrient salts was predicted to produce sufficient crops to accommodate the oxygen requirements for one human for one year using a 57.2 m^3 Plant Production Room, and resulting in a contribution of 516 Calories (2.1 MJ) to the daily diet.

The uniqueness of the SPFGC Plant Production Room was that its remote location, its importance to those

living and working at the South Pole, and the infrastructure support provided through the US-NSF, the agency that supports all operations at the South Pole. Furthermore, the SPFGC represented a polyculture of crops, each forced to grow within compromised environmental conditions, that were able to provide yields equivalent to $47 \text{ kg m}^{-2} \text{ year}^{-1}$.

Biological-based life support techniques can potentially reduce the amount of material re-supply required from earth to stations on other planets by recycling materials needed in life support. The SPFGC began to demonstrate the challenges involved for such an undertaking. However, the purpose of the SPFGC was to produce fresh vegetable biomass on Earth for the isolated winter crew at the South Pole. It was not designed for closed experiments involving humans. Therefore the data and results of the model offer conservative empirical information, such that comparisons to other future designs may be completed.

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DEFINITIONS

PAR – photosynthetically active radiation

EC – electrical conductivity

HVAC – heating ventilation and air-conditioning

RPSC – Raytheon Polar Services Company

NSF/OPP - National Science Foundation / Office of Polar Programs

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ADDITIONAL SOURCES

1. For more information on the SPFGC visit <http://ag.arizona.edu/ceac/SPFGC/>
2. For more information on the Amundsen-Scott South Pole Station visit <http://www.usap.gov>

APPENDIX

Figure 1. View of the Plant Production Room from the Environmental Room separated by glass wall with access doors, showing the two wall mounted small crop growing systems for lettuce and greens (left and right), and the floor mounted tall crop growing system for tomato, pepper, cucumber (center).

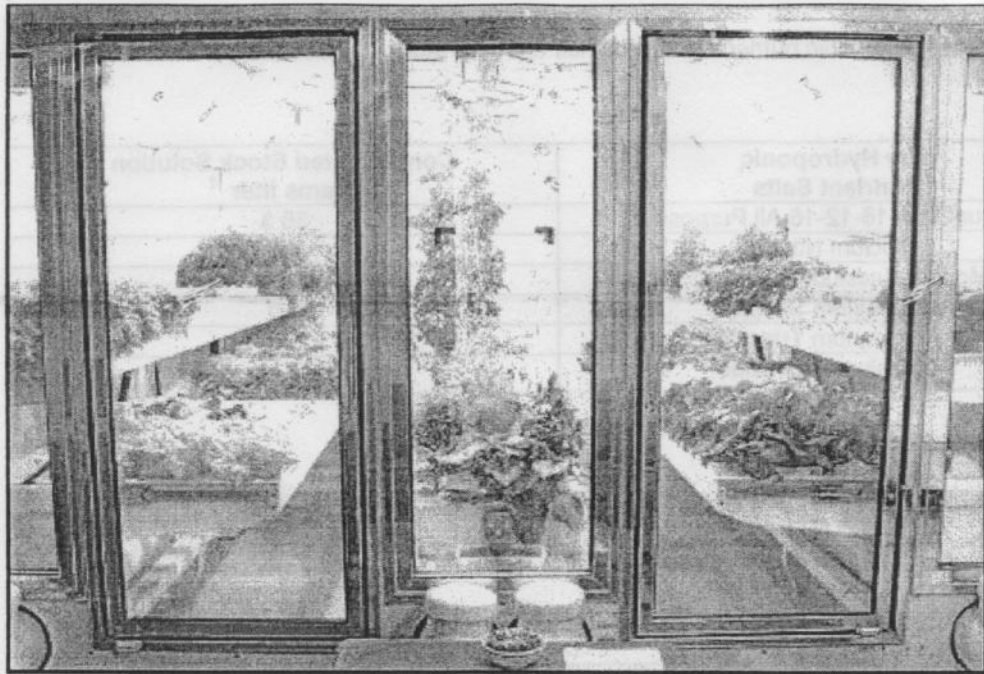


Table 1. Environmental conditions automatically maintained in the Plant Production Room by the climate control system.

SPFGC Environment Conditions	
Photoperiod (hrs day ⁻¹)	17
Average PPF (1 m below Lamps) ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	425
Hydroponic Nutrient pH	6
Hydroponic Nutrient EC (mS cm^{-1})	2.4
Photoperiod Temperature (°C)	23.6
Dark period Temperature (°C)	19.3
Photoperiod Relative Humidity (%)	59
Dark period Relative Humidity (%)	59
Average Pressure (kPa)	68
CO ₂ Concentration (ppm)	1334

where:

"Photoperiod" was the number of hours per day the lamps were in operation; "Average PPF" was the average photosynthetic photon flux at the plant canopy (~1 m below lamps); "Hydroponic Nutrient pH" was the pH of the hydroponic nutrient solution, "Hydroponic Nutrient EC" was the electrical conductivity; "Photoperiod Temperature" was

the air temperature of the SPFGC when the lamps were in operation; "Dark period Temperature" was the air temperature of the SPFGC when the lights were not in operation; "Photoperiod Relative Humidity" was the air relative humidity during the photoperiod; "Dark period Relative Humidity" was the relative humidity when the lights were not in operation; "Average Pressure" was the atmospheric pressure in the SPFGC; "CO₂ Concentration" was the average atmospheric carbon dioxide concentration in the SPFGC.

Table 2. List of the dry hydroponic nutrient salts and their aqueous stock injection concentrations.

Dry Hydroponic Nutrient Salts	Concentrated Stock Solution grams liter ⁻¹
AquaGrow 16-12-16 All Purpose	38.3
Calcium Nitrate	5.7
Mono Potassium Phosphate	4.0
Magnesium Sulfate	8.0
Molybdenum Trioxide	0.002
Potassium Hydroxide	12

Figure 2. Schematic of air revitalization of oxygen and carbon dioxide via plant photosynthesis and plant/human respiration, as well as water cycling via plant transpiration, and physical processes of evaporation and condensation within a simple life support system containing a number of plants and one human as bioprocessors.

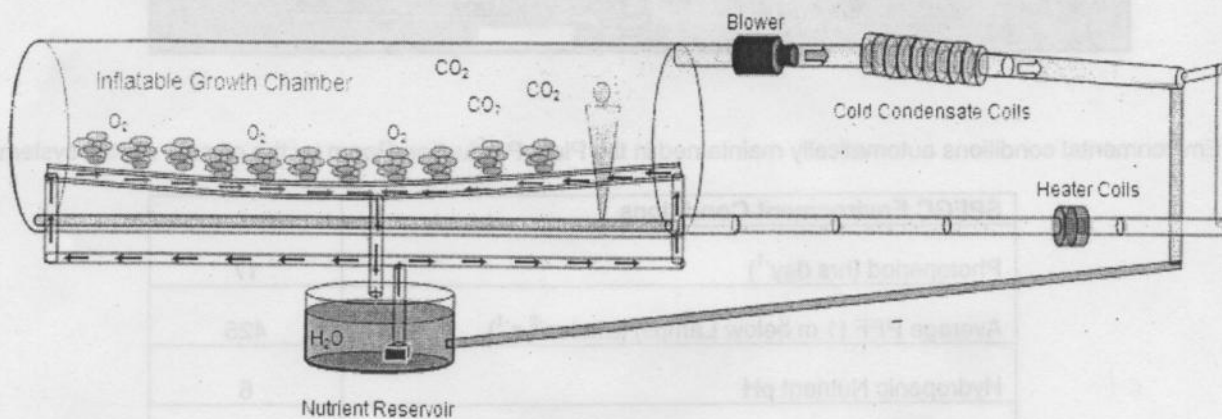


Table 3. Daily carbon dioxide input vs. carbon sequestration and oxygen production of the SPFGC used in the model calculations.

Daily CO ₂ Inputs	kg	Daily Carbon sequestration and O ₂ production	kg
CO ₂ Bottled	1.1	CO ₂ Leak	Negligible
Additional Human introduced CO ₂ due to harvesting in the SPFGC	0.28	C Plant Mass 90% Dry bio mass	0.54
Additional Human introduced CO ₂ due to repair or occupancy not related to harvesting in SPFGC not calculated	Not calculated	O ₂ from General Photosynthesis Formula (1:1 molar ratio = 1.38 kg CO ₂ : 1.4 kg O ₂ = 1.01)	1.01
Total mass	1.38		1.55

Table 4. SPFGC Resource and Production Model predictions of resource consumption and biomass production m^{-2} and m^{-3} for the minimum volume ($57.2 m^3$) and minimum dry hydroponic nutrient ($0.18 kg day^{-1}$) for one day of air revitalization for one person ($0.835 kg O_2 day^{-1}$) (note production and consumption per m^2 and m^3 (specific units) are included)

	Predictions per $57.2 m^3$ volume	Predictions Specific units m^{-2}	Predictions Specific units m^{-3}
Total Biomass Production ($kg day^{-1}$)	6.3	0.27	0.11
Edible Biomass Production ($kg day^{-1}$)	2.9	0.13	0.05
Non-Edible Biomass Production ($kg day^{-1}$)	3.3	0.15	0.06
Human Food Caloric Value ($Cal day^{-1}$)	516	22.5	9.0
Plant CO_2 Uptake ($kg day^{-1}$)	1.1	0.1	0.02
Plant Net Oxygen Production ($kg O_2 day^{-1}$)	0.836	0.04	0.01
Hydroponic Nutrient Chemicals ($kg day^{-1}$)	0.18	0.01	0.003
Condensation from Atmosphere ($kg H_2O day^{-1}$)	31	1.3	0.5
Plant Tissue Water ($kg day^{-1}$)	6	0.2	0.1
Electrical Energy Lamps ($kWh day^{-1}$)	216	9.5	3.8
Electrical Energy All Other ($kWh day^{-1}$)	77	3.4	1.4
Thermal Energy HVAC ($kWh day^{-1}$)	49	2.1	0.9
Volumetric Air Exchanges (day^{-1})	2448	2448	2448
Labor ($hr day^{-1}$)	3.4	0.2	0.1

where:

"Total Plant Production" is the total edible and non-edible biomass harvested each day.

"Edible Biomass Production" is the edible biomass harvested each day.

"Non-Edible Biomass Production" is the non-edible plant mass harvested each day.

"Human Food Caloric Value" is the estimated calories for all edible harvest each day.

"Plant CO_2 Uptake" is the carbon dioxide consumed by plants each day.

"Plant Net Oxygen Production" is the net production of oxygen (photosynthesis minus respiration) each day.

"Hydroponic Nutrient Chemicals" is the dry hydroponic salts used each day.

"Condensation from Atmosphere" is the water condensed from the chamber atmosphere each day and estimates plant transpiration.

"Plant Tissue Water" is the water contributing to the fresh weight of the plant.

"Electrical Energy Lamps" is the electrical energy needed each day for powering the HPS Lamps.

"Electrical Energy All Other" is the electrical energy used each day for pumps, blowers, actuators and computer for automating control of the BLSS.

"Thermal Energy HVAC" is the energy used each day for heating to maintain air temperature and relative humidity.

"Volumetric Air Exchanges" is the number of times the air volume of the Plant Production Room was cycled within the HVAC system each day.

"Labor" is the number of hours each day needed to maintain the crops and the systems.