TABLETOP BIOSPHERE EXPERIMENT

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ABSTRACT

This purpose of this project is to design and construct a closed ecological system in which plant life and possible insect life may be self-sustained. The main goal, however, is to demonstrate the creation of oxygen gas by utilizing the plant Arabidopsis Thaliana. The biosphere is self-sustaining, contains one uniform environment. This paper discusses the construction of a tabletop experimental design and measuring devices used to quantify the oxygen levels and other environmental variables, such as relative humidity, temperature and light intensity. The system is completely enclosed from its beginning to its conclusion. This paper will report on our initial findings and the underlying scientific principles of creating a biosphere. It is a contribution for research in providing oxygen needed for survival of future outposts in space. A successful biosphere has been created. Although much has been learned through research and experimentation for this enclosed ecological system, there is still much to discover and alter. A complete analysis of the results of the experiment have not yet been conducted due to the length of time necessary for plant growth and taking a reliable series of data. However, the research accumulated thus far is an important first step.

I. INTRODUCTION

From the time of its discovery, Mars has been a topic of major interest to mankind. Following the Moon, the Red Planet has attracted more spacecraft than any other object in the solar system, despite the tremendous challenge of visiting and observing it. Therefore major challenges are visitation, exploration and colonization.

Mars has an average temperature of –60 °C and the atmosphere contains 95 percent CO₂, indicating that direct habitation is almost impossible. Therefore, other means of colonizing Mars are being explored, such as the establishment of permanent bases on it – and the creation of an artificial biosphere necessary for human life.

Biospheres are meant to be life-sustaining and self-sufficient. This means they have to be capable of recycling food, water and air, like the natural biosphere “Earth”. A biosphere is sealed from its onset from all external influences except energy transfers in form of light or heat. Over
the past fifty years efforts were being made to build and observe biospheres. These biosphere experiments range from simple designs to complex experimental set-ups. Simple designs include simple live-forms as shrimps and consists of one ecosystem, e.g. Beachworld\textsuperscript{3}. More complex systems like Bios-3, the Laboratory Biosphere, and NASA’s BioHome contain complex flora and fauna to gain a more realistic image of the natural biosphere. One of the most successful so far has been Biosphere 2 located in Arizona. However, it has encountered major challenges in air recycling as far as the depletion of oxygen and overall increase in toxic gases.

The objective of the project is to build and observe a tabletop (scaled) biosphere to observe the increase in oxygen content. To accomplish this task, oxygen, humidity, temperature, and light intensity will be measured. The results produced by this experiment may advance the desire of man to eventually inhabit Mars.

II. ENVIRONMENTAL MEASUREMENTS AND EXPERIMENTAL DESIGN

This section of the paper discusses the measurements taken to observe the aerial conditions of the Tabletop Biosphere Experiment over time. Following the explanation of the measurements, the design of the experiment set-up and devices needed to observe it are described.

A. Environmental Measurements

Temperature, relative humidity, light intensity and oxygen content are measured in order to observe the biosphere’s aerial environment. As Kim and Portis\textsuperscript{14} show, temperature plays an important role for the rate of photosynthesis. Since the temperature is not actively controlled, measuring the temperature is an important variable from which to draw conclusions in the creation of oxygen. “Relative humidity indicates the ‘relative’ fraction of water vapor in a volume of air to how much water vapor that air would contain at saturation at the same temperature and pressure.”\textsuperscript{15} Eamus and Shanahan\textsuperscript{16} showed in their study that humidity has an impact on the rate of photosynthesis. Since the Tabletop Biosphere has no environmental regulation regarding the humidity level, the measurement of relative humidity is also essential for the observation of oxygen creation. Light is the energy resource for the photosynthesis. The light spectrum and its intensity is kept constant in the experimental biosphere. Nevertheless, a measurement is taken to show differences between the night and day phases.

B. Experimental Design

The experimental design of the Tabletop Biosphere is relatively simple. The size of the closed ecological system was the first decision made. As mentioned in the literature review, different sizes are documented for experimental closed ecological systems. Differences existed also between water-based and soil-based biospheres. When considering the size of the closed ecological system the following points need to be taken into account. The size of the closed ecological system has tremendous influence on its leakage rate. The difficulty of sealing off a system completely from gas and liquid exchange is positively correlated with the size of the
system. Therefore, it can be concluded that the smaller the system the easier and more likely it is to completely seal the system. The objective of our closed ecological system is to observe the change in oxygen content of the enclosed air. This aerial environmental characteristic is "quantified with instruments that provide numbers. With these numbers we can compare the environment under investigation with a predetermined standard and then seek improvement … We can also evaluate changes in environment over time."

For the experimental assessment of oxygen creation through plant growth, measuring the oxygen content, light intensity, relative humidity and temperature were essential data to consider. These measurements are taken at certain points. Therefore, it is punctual data which represents only the conditions of the environment around that specific measuring point. Consequently, the larger the observation area, the more reading points need to be installed. Furthermore, the objective of our closed ecological system was narrowly chosen, mainly focusing on oxygen level observation. Creating a larger biospheric model would raise its system complexity. Due to the objectives, resources and experimental restraints, this biosphere observation experiment is the size of a tabletop.

After determining the size of the biosphere, the next step was choosing the material for the construction of the biosphere. As mentioned above, a biosphere differs from a greenhouse through complete elimination of matter exchange. Hence, the boundary to the environment should prevent matter exchange yet admit energy transfer in terms of light and thermal energy. Glass possesses these characteristics: low permeability to gases and air, and high permeability for light energy and thermal radiation. These characteristics allow the control of temperature and light intensity from the outside of the biosphere. For the size of a tabletop biosphere a terrarium provided the ideal size and volume. The experimental biosphere has a length of 23.5 in., a width of 11.75 in., and a height of 15.75 in., enclosing a volume of 18.75 gallons. The terrarium is joined together with silicon rubber, which has a relatively low permeability for oxygen and other gases.

In an airtight, rigid, closed system pressure differences occur and need to be taken into account in its construction. There are three reasons for these pressure differences.

"As temperature rises and falls, expansion and contraction of the contained gases tend to explode or implode the enclosure. Variations of internal humidity are actually variations of the amount of gas contained (water vapor) and likewise contribute to pressure fluctuations. Thirdly, variations in external barometric pressure create positive and negative differential pressures between the inside and outside."\(^{18}\)

Due to the relatively small size of the Tabletop Biosphere in comparison to Biosphere 2 and the airflow within the Tabletop Biosphere, the humidity does not contribute drastically to pressure differences. An increase or decrease in pressure inside the Tabletop Biosphere would result in structural instability and higher leakage rate. In order to prevent these adverse implications, the Tabletop Biosphere is connected with two gas bags called "lungs" via vinyl tubing. A similar method of pressure balance was used in Biosphere 2 and the Laboratory Biosphere. The gas bags
(Qubit systems, G122) made from heat-sealed, gas-impermeable, nylon polyethylene laminate, when fully inflated have a volume of 30 liters each, which amounts roughly to about 100% of the fixed volume of the chamber. The initial inflation of the lungs is roughly 100% of the maximum volume in one lung and 0% of the second lung to balance the positive and negative pressure differences. The initial setup of the lungs was chosen in that matter, to determine the complete amount of air enclosed. When temperature within the **Tabletop Biosphere** rises and the air volume expands, excess volume flows through the vinyl tubing into the lungs and expands them. As the temperature decreases, the opposite result occurs. A three way valve with a syringe attached will be placed between one of the lungs and the lid of the enclosed box. This three way valve (depicted below) has a knob that will block one passage while allowing free air flow to the other two.

The sensors for the data collection are combined with two data loggers, which are placed inside and outside of the **Tabletop Biosphere** to record the data and show changes in data levels over time. It also gives potential relations between the variables. Due to the relatively small size of the **Tabletop Biosphere**, data collection takes place at a specific measuring point located at the center of the **Tabletop Biosphere**. To allow the HOBO device to take measurements at the same level as the plants, a large rock was added to the “stone” section of the **Tabletop Biosphere**. On top of the rock a piece of acrylic attached with silicon provided a stable position for the HOBO device. The other measuring point, which logs the outside temperature and oxygen level is placed outside of the **Tabletop Biosphere**, mounted to the outside wall of the **Tabletop Biosphere**. The internal data logger device as seen in Fig. 1 (HOBO U12 Temp/RH/Light/External Data Logger, MicroDAQ.com) “is a four-channel data logger that provides temperature, relative humidity, relative indoor light level measurements and accepts one external input. . . . [it] offers 12 bit resolution, high accuracy, 64k memory and direct USB connectivity.”

A further description of the data logger with its specifications is given in the Appendix. The data logger has an internal power supply with a battery life expectancy of a year. Having the sensors combined into one unit holds the danger of lower systems reliability in case of a malfunction of the data logger. In contrast to the reliability aspect, the data logger unit combines recording and measurement in an inexpensive and simple way. It does not hold the danger of incompatibility between the sensors and logging device. Furthermore, the one-unit solution provides the possibility of perfect synchronization of measuring the different variables. The oxygen sensor (SO-B0-250, Electrovac), which is enclosed into the biosphere, is connected via cable, which runs through the lid to the driver and analysis unit (EDAB-M1, Electrovac) outside of the biosphere. It measures in a range of 0.1% - 25.0% the oxygen content and returns a signal back to the analysis unit, which converts the signal into an linearized output signal between 0 V–2.5 V DC. The analysis unit connects the outside data logger via a 2.5 mm stereo cable, which in turn records and stores the oxygen content. In order to record and store the data for outside temperature and the oxygen content, the data logger contains memory for 7,943 data points. A schematic drawing of the device connection is given in the Appendix B.

In the natural world light is generated by the sun. It is the essential resource for the photosynthesis process to take place. Specific light characteristics play an important role for the photosynthesis rate. The **Tabletop Biosphere** is illuminated with a 125 Watt compact fluorescent grow light, held by a hydrofarm light fixture (ACF Greenhouses) with a length of 19 in. and a width of 13 in, as seen in Fig. 2. “The 6400 k bulb is a full spectrum bulb which promotes
overall plant growth. …Fluorescent grow lights also have better color rendering properties incandescent…and produce much less heat.” The light fixture is mounted about 2 inches above the top of the biosphere, leaving an opening for heat deflection.

In order to construct and create the initial conditions of the Tabletop Biosphere additional equipment was essential. In order to reach a low leakage rate, the biosphere is closed with an acrylic lid of thickness of about 0.5 in. Acrylic is also known as Polymethylmethacrylate and features a low permeability to gases. In Appendix C is a schematic view of the lid shown. There it can be seen that a cable gasket, containing a rubber sealing ring is manufactured into the lid and sealed off with Teflon tape. Through the cable gasket an aluminium pipe is run surrounded by the inside sealing ring. This cable gasket functions as the connection of the Tabletop Biosphere inside with the outside environment. The cable from the analyze unit to the oxygen sensor, the cable from the PC to the data logger, and the power supply for the fan is run through the aluminium pipe. By filling the 2.5 in. long steel pipe with silicon, an airtight sealing was achieved. Furthermore, Fig. 9 in Appendix C contains an z-shaped aluminium frame, mounted to the inside surface of the lid. On the left side the frame contains a crescent cut-out, for the fastening of the fan. On the lower platform of the frame a 9/16 in. hole was drilled to support the oxygen sensor, pointing downwards. In the upper corner of the lid two wholes where drilled to be fitted with tube connectors for the connecting the lungs with the inside of the biosphere. The gap between biosphere and acrylic lid is sealed with the specialized sealant (Qubitac sealant, Qubit systems), which is gas impermeable, “adheres well to glass, rubber and plastic components of gas analysis systems without bonding to them permanently… [does not] …produce or consume CO₂, O₂, H₂, C₂H₂, or other biologically important gases.” The biosphere is tightly sealed off so that no natural air movements occur. In Biosphere 2 and the Laboratory Biosphere, air handlers were installed to solve this problem. Since the Tabletop Biosphere is relatively small in comparison to the other experimental designs, the Tabletop Biosphere is equipped with a PC fan. This fan is mounted to the aluminum frame to the acrylic lid and powered by an external source, circulating the air and prevent the plans from over heating. In order to set-up the initial conditions with an increased CO₂ content, CO₂ is inserted via a syringe. “A closed and confined grow room does not supply optimum 400-600ppm levels of CO₂. By adding CO₂ to your grow room your plant's growth should increase by up to 30%.” This ensures optimal conditions for the photosynthesis to take place. The syringe was connected via the three way valve between the lungs and the biosphere. It, has an approximate volume of 30 milliliters, and was filled with CO₂ to added to the closed system. The Tabletop Biosphere will be monitored by an outside web cam, which is connected to a PC. The unsealed Tabletop Biosphere is seen in Fig. 3.

III. FLORA, FAUNA AND INTERNAL SET-UP

This section deals with the internal environment and set-up. It explains the reason for the proposed design, describes the plants and life forms include in the Tabletop Biosphere Experiment.

A. Internal Environment
The internal environment of this closed life system must be fashioned to accomplish the goal of the overall project, which is to show an increase of oxygen percentage in the internal atmosphere. To accomplish this goal, two main aspects of the life inside must be controlled. One is to maximize the process of photosynthesis, and the other is to minimize the process of aerobic respiration. To accomplish the first goal, optimal photosynthetic conditions must be provided to the plants.

Optimal photosynthetic conditions are the aspects of the atmosphere and the soil that will allow plants to perform photosynthesis at the fastest rate possible. The formula of photosynthesis is a complex series of reactions involving conformational changes in several protein complexes and can be diagramed as Fig. 4, called the z-scheme. However complex this reaction seems it can be summarized in Eq. (1),

\[ \text{O}_2 + \text{CO}_2 \rightleftharpoons \text{O}_2 \text{COG}lucose \]

(1)

From this summarization it is clear what the three major aspects of optimal photosynthetic conditions are; water availability, carbon dioxide availability, and irradiation from a powerful light source.

The optimal light source in nature is the sun, which gives off the entire spectrum of visible light. Through the use of the various pigments present in the plants, they can only utilize the red (far right of Fig.5) and the blue spectra (far left of Fig. 5). The absorption of these spectra of light leaves only the green spectra to be reflected, giving the plants their green color. In order to provide these spectra to the plants a special fluorescent grow light with reflector was attached to the terrarium. This light provides the appropriate wavelengths to make up the absorption spectra of the plant. The light is connected to a timer set up to allow twelve hours of light and twelve hours of dark simulating the cycle of day and night.

Another factor in creating optimal photosynthetic conditions is the availability of water in the atmosphere. Oxygen molecules generated from photosynthesis come from water and not carbon dioxide. This means that for best results the air should be saturated with water vapor, and accomplishing this is relatively simple. By sealing the Tabletop Biosphere and providing an excessive amount of water, the humidity will rise to 100% naturally by the vapor pressure properties of water. A definite amount of water was added to the closed system totaling in approximately 2700 ml. This water was added just prior to the sealing process, and was immediately absorbed into the soil and the air. The evidence of the water joining the internal atmosphere in the form of vapor was shown by an increase in humidity within minutes.

The last condition that affects the rate of photosynthesis is the concentration of carbon dioxide in the atmosphere. In the photosynthetic reaction, reduction of carbon dioxide to glucose is the final step. This anabolic pathway is the driving force of photosynthesis and is the recipient of all the energy built up during the photosynthesis process. To help ensure the presence of enough carbon dioxide, a tank containing the aforementioned gas will be connected to the terrarium. The use of the tank will allow the creation of an atmosphere with concentrations of carbon dioxide far higher that those in nature, but will not continue to add carbon dioxide after that. With these conditions in place, photosynthesis should proceed at an optimal rate, however in order to have
an overall increase in oxygen aerobic respiration must be controlled as well. In the past biosphere projects, the major problem was consistently oxygen concentrations and this also poses a potential problem to this project as well. The majority of oxygen consumed is put into the process of aerobic respiration, a metabolic process that provides energy for the cells. This means that the more organisms that are present in the closed life system, the faster the consumption of oxygen.

Controlling this aspect of life within the biosphere is relatively easy. Although the absence of aerobic organisms would although maximum increase of atmospheric oxygen, this should not be the goal. Many bacteria that live in soil would not only be very difficult to remove completely, but have unique metabolic pathways that may include the processing of nutrients that would otherwise be unavailable to the plants. These bacteria are needed for healthy plant growth and should be the only aerobic organisms present in the terrarium.

Once the two metabolic processes have been controlled properly, a few other conditions must be maintained to protect the health of the plants. Two such conditions considered: the release of heat from the plant and prevention of decomposing in the roots. Without proper release of heat from the plant, the plant body can heat up by one hundred degrees per minute. When the temperature of the plant body becomes too high, the internal processes of the plant cells, including photosynthesis, shut down; resulting in the eventual death of the plant. The three ways in which a plant releases heat, are transpiration, convection from the wind, and radiation from the leaf surface. The first two of these would be almost nonexistent within the enclosure, being as there is no wind in the enclosed structure and the humidity would be at 100%. To compensate for this, a small fan will be placed inside the biosphere. This fan will be powered by a small solar panel and will circulate the air and in turn cooling the plants.

The rotting of roots is the result of soil saturated with water, and no place for the water to go. To hinder this, the area of the biosphere was divided into two separate sections by a piece of acrylic and connected by small holes cut at the bottom. The bottom of both areas was lined with rocks averaging half an inch in diameter and weighing approximately six kilograms. The area containing the plants (Fig. 6), which measures 11.5 in x 15 in., was lined with four inches of common potting soil from a gardening store totaling 2851.26 g in mass. The remainder of the total area contains only rocks and will act as a reservoir for the excess water. The rocks on both sides of the acrylic barrier will allow the water to drain from the soil to the reservoir. To ensure that drainage occurs in the direction of the empty side, small wedges were placed under the side opposite of the reservoir creating a slope that will complete the cycle of water in the closed system.

B. Arabidopsis Thaliana

After the terrarium was established the next step was to select the flora and fauna to be transplanted into the biosphere. The flora (plant life) would be solely represented by the plant Arabidopsis thaliana. Commonly called mouse-ear cress, this plant is a member of the family Brassicaceae (mustard family) and is found in forty-two out of fifty states. In addition, Arabidopsis thaliana has a rapid life cycle, which is shown in Tab. 1 below; going from germination to production of mature seeds in only six weeks. It has also been shown that
Arabidopsis has no trouble growing in restricted spaces. For these reasons *Arabidopsis* has been made a model plant for cellular and genetic research in plants. The rate at which this plant assimilates CO\(_2\) and produces O\(_2\) was calculated by Raymon A. Donahue, Mary E. Poulson and Gerald E. Edwards to be 30.2 micromoles per squared meter of plant surface per second in full light.\(^{28}\) This rate is slightly higher than that of most plants, making *Arabidopsis* a model organism for this experiment as well.

C. Fauna

The fauna (animal life) is to be kept at a minimum to reduce the assimilation of oxygen. However, some animals can be beneficial or even essential to healthy plant growth. To aid in the production of nutrients from the soil to the plants, the addition of common earth worms was proposed. However, the presence of worms has the potential to have both positive and negative effects on this project. The beneficial aspect of the earth worms is that they digest organic material in the soil leaving a natural fertilizer that provides essential nutrients to the plants. This is not a large necessity for the experiment, considering the amount of nutrients that will already be present in the potting soil. In addition to this the process, the worms will assimilate large amounts of oxygen, making the presence of worms detrimental to the overall goal of the project. With the exception of the bacteria that will be present in the soil at the time of planting, there will be no other organisms present in the terrarium. By putting these controls on the flora and fauna within the biosphere, the maximum net production of oxygen will be provided. Prior to the sealing of the *Tabletop Biosphere* the plants inside were allowed to grow for several weeks. Due to this open set up several flies began to take up residence with in the terrarium. These flies, if allowed to stay inside, would be detrimental to the overall goal of the project. To decrease to population of the flies a piece of fly tape was placed on the glass inside the *Tabletop Biosphere*.

IV. FINAL CLOSURE PROCEDURE AND OBSERVATION CHARACTERISTICS

A. Final closing procedure

The description of the final closing procedure shall help everyone to reproduce the closure of the biosphere. It an attempt to describe the closing procedure of the *Tabletop Biosphere* as thorough as possible. The closing procedure is separated into Pre-closing test phase, Closing phase, and Post-closing phase.

1. Pre-closing test phase

   - Testing of internal HOBO by connecting HOBO via USB to the PC according to HOBO manual
   - Testing of external HOBO by connecting HOBO via RS232 to PC and test run according to HOBO manual
   - Testing of the oxygen sensor
     - Connecting the oxygen sensor according to the user manual, given in Appendix D
     - Connecting of the power supply to the analyzation unit
     - Diode on analyzation unit lights up for about 5 seconds
• Heating of oxygen sensor starts, indicated by flashing diode
• Heating finished, when LED on analyzation unit is lit up constantly
• Connecting of analyzation unit via gray 2.5 mm stereo cable to external HOBO
• Test run of HOBO device for a testing period of at least 10 min including change of oxygen content on oxygen sensor results in output voltage change measured by the external HOBO
  • Test run of the fan with external power supply
  • Camera test run

2. Closing phase

  • Flatten of Qubit Sealant by compressing to a thickness of about 1 mm
  • Equal distribution and application of Sealant around the rim of the Tabletop Biosphere without any air pockets
  • Connection of oxygen sensor to outgoing cable
  • Connection of USB cable to internal HOBO device
  • Water addition to the Tabletop Biosphere, if experiment requires it
  • Sealing off the Tabletop Biosphere by closing lid application of equal pressure on the edges of the lid
  • Application of additional Sealant closing the gap between lid and edge of the top of the Tabletop Biosphere
  • Inflation of one lung up to maximum volume
  • Connection of the lung via tubing and tube connectors on top of the lid
  • Application of Sealant on the gap between the tube connector and tubing
  • Opening valve so that tubing to the filled lung is closed
  • Connection of syringe to the valve and injection of CO₂
  • Turning of valve, so that tubing to syringe is closed, and lung and biosphere can exchange air
  • Setting up power supply to analysation unit, check starting procedure of analyzation unit
  • Setting up HOBO devices with analysation unit, PC and camera to measure variables
  • Setting interval to measure data according to HOBO manual
  • Start data collection

3. Post closing phase

  • Readout HOBO devices and check expected data after first measures are take by HOBO devices and camera
  • Resume HOBO devices and camera for data collection
  • Check proper function of HOBO devices and camera in self set intervals

B. Observation characteristics

In this section of the paper the observation characteristics are described. This includes the interval for taking measurements, the duration of the planned experiment as well as the final results. Table 2 shows specifications of the experiment. The output data has resulted in five time
series. The temperatures (inside and outside) are measured in Fahrenheit, relative humidity in percent, light intensity in lumen per square foot and the oxygen content in percent.

C. Observation Results

The main objective of the Tabletop Biosphere was to observe the oxygen content. Overall the oxygen content decreased significantly over the observation period. The initial conditions amounted to an oxygen content of 20.56 percent oxygen. This number decreased over the observation period to 7.47 percent. The run of the curve of the oxygen content shows constant decrease in oxygen from the beginning up to the 66th day of the observation period with a minimum of 6.98 percent. After the 66th day a slightly increase in oxygen is observable. Fig. 7 shows the progression of the oxygen content over time. On day 70 a sudden drop in the oxygen level to 0.15 percent is noticeable. This abrupt decline is due to a power outage, which resulted in an malfunction of the oxygen sensor. Considering the progression of the oxygen content during a day/night phase, in the majority of cases the oxygen content increases during the beginning of the night phases slightly but declines during the light phase.

Regarding the progression of the inside and outside temperature, it is noticeable that the inside temperature curves follows the run of the outside temperature curve. This is not surprising because the experimentation set-up does not influence the temperature of the Tabletop Biosphere. On average the temperature difference between the daily outside and the inside temperature average amounts to 5.25 degrees Fahrenheit. Further observation data is shown in Tab. 3; Fig. 10 in Appendix D shows the progression of the average daily temperatures. The temperature progress during a single observation day consists of an temperature increase during the lighting period and a temperature decrease during dark periods.

Once the Tabletop Biosphere was completely sealed off, the relative humidity increased. The progression shows an initial rise of the relative humidity from 82.78 percent to a first high of 92.21 percent. For a period of about 56 days the relative humidity averaged daily around 92 percent. During this period two exceptions are recorded, where the daily average of the relative humidity rose to peaked at 94 to 95 percent. After day 61 the relative humidity rose above 92.5 percent. The progression of the relative humidity is shown in Fig. 11 in Appendix D. Considering the relative humidity between light and dark phases, its is noticeable that the relative humidity at dark phases is on average 2.1 percent point above the light phases. During a dark phase the relative humidity increases with a logarithmic progression and during light phases the relative humidity decreases with a logarithmic run.

The lighting conditions were set that the Tabletop Biosphere has a light and dark time of 12 hours. During the light phases the average light intensity amount to 831.38 lum/sqft and during dark times an average of 7.32 lum/sqft was measured. During the observation period an exception of the regular set-up was measured on day 23 and 24. During this time light illuminated for 24 hours due to a malfunction of the light timer.

The optical observation of the plant conditions show a decline in plant life. In the initial conditions the plants developed seeds and senescence took place. Some new plants were developing and growing, however mold started to grow on death and shriveled plant material.
The grown seeds did not seem to fall off the plant to be seized with mold. On the contrary small new plant growth could be observed, where seeds touched the moist walls of the Tabletop Biosphere. Small roots started to sprout and to grow towards the ground, thus it did not result into further plant development.

V. CONCLUSION

Through a collaboration of efforts, a successful biosphere has been created. Although much has been learned through research and experimentation for this enclosed ecological system, there is still much to discover and alter. The results of the experiment have not yet been analyzed thoroughly due to the length of time necessary for plant growth and taking a reliable series of data. The previous given observations constitute a first insight about the progression of the experiment. Nevertheless, a decline in oxygen content could be measured. A first analysis of the data shows that plant deterioration increased in this warm and humid environment. What causes the plant deterioration is speculative. A possible explanation could be the advanced stage of the plants life in the initial set-up or the warm, humid environment. However, a slight increase in oxygen content is noticeable at the end of the observation period. The observation of the oxygen content in the air also indicates that during the beginning of the dark phases the oxygen content increases. This proves that oxygen is created by the plants. However, the research accumulated thus far is an important first step in the long journey towards its completion. For further research some recommendations for extension and improvement can be derived. First, it is essential that more research be done from a biological perspective in the area of the size of the terrarium. An increase in the overall volume would allow for more diverse forms of life to be grown within the biosphere. It is possible that one or more species of plants, as well as smaller animal life forms such as insects could be included. Secondly, from an design standpoint further research could be done in the areas of water drainage and circulation as well as in the monitoring of CO₂. Regarding the aerial environment, a cooling system could be designed to regulate the internal temperature and thus the humidity. Through a cooling system, a “real” climate could be create through the control of the humidity.
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FIGURES AND TABLES

Figure 1. Hobo U12 Temp/ RH/ Light/ External Data Logger

Figure 2. Hydrofarm light fixture with 6400 k bulb

Figure 3. Unsealed Tabletop Biosphere Experiment without instrumentation
Figure 4. Photosynthesis I and II
Source: Institute of Chemistry, Faculty of Science, The Hebrew University of Jerusalem, “Photosynthesis - an Ideal Natural Biochemical Process Driven Photochemically,” Fig.1, 20 March 2005 http://chem.ch.huji.ac.il/~eugeniik/photo_enzymes1.htm

Figure 5. Absorption spectra for Arabidopsis
http://webexhibits.org/causesofcolor/7.html
Figure 6. Planting area with stone bed

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<thead>
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<th>Stage of Cycle</th>
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<tr>
<td>1</td>
<td>Germination</td>
</tr>
<tr>
<td>2</td>
<td>Emergence of hypocotyls and cotyledons</td>
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<tr>
<td>3</td>
<td>Root development</td>
</tr>
<tr>
<td>7</td>
<td>Leaf growth</td>
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<tr>
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<td>Formation of leaf rosette</td>
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<td>23</td>
<td>First floral bud</td>
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<td>30</td>
<td>Inflorescence</td>
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<tr>
<td>40</td>
<td>Formation of fruit</td>
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<td>Seed development and senescence</td>
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Table 1. Arabidopsis Life Cycle

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Table 2. Observation Specifications
Figure 7. Progression of oxygen content over the observation period

Table 3. Observation Data - Inside and Outside Temperatures

<table>
<thead>
<tr>
<th></th>
<th>Inside Temperature (°F)</th>
<th>Outside Temperature (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. daily average</td>
<td>84.47</td>
<td>79.24</td>
</tr>
<tr>
<td>Min. daily average</td>
<td>74.45</td>
<td>69.45</td>
</tr>
<tr>
<td>Average Temperature</td>
<td>79.69</td>
<td>74.44</td>
</tr>
<tr>
<td>Highest</td>
<td>89.73</td>
<td>82.24</td>
</tr>
<tr>
<td>Lowest</td>
<td>68.69</td>
<td>66.28</td>
</tr>
</tbody>
</table>
APPENDIX

A. Contact information for companies of instrumentation and materials

**ACF Greenhouses**
380 Greenhouse Drive
Buffalo Junction, VA 24529
phone: 888-888-9050
fax: 434-374-2055
Website: www.littlegreenhouse.com

**Grow–light.com**
Web Network Billing LLP
Website: www.grow-light.com

**electrovac GesmbH**
Aufeldgass 37-39
A-3400 Klosterneuburg/Austria
phone: +43/2243/450-0
fax: +43/2243/450-319
Web site: www.electrovac.com

**Qubit Systems Inc.**
4000 Bath Road, 2nd Floor
Kingston, Ontario, Canada K7M 4Y4
phone: 888-262-2219
fax: 613-384-9118
Website: www.qubitsystems.com

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B. Schematic view of the cable device connection

![Schematic diagram](image)

**Figure 8. Schematic experiment set-up**
Source: own illustration
C. Schematic view of the lid with cable gasket

Figure 9. Lid including cable gasket, aluminum frame and lung drillings

Source: own illustration
D. Observation Progressions

**Figure 10. Progression of daily average inside and outside temperatures**
Source: own illustration

**Figure 11. Average daily relative humidity**
Source: own illustration