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Introduction to Lunar Greenhouse

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ABSTRACT

A lunar greenhouse is a controlled environment designed to facilitate plant growth on the Moon. Given the Moon's harsh conditions, including extreme temperature fluctuations, high levels of radiation, and a lack of atmosphere, creating a suitable environment for plant growth is a significant challenge. However, the concept of lunar greenhouses has gained attention due to its potential benefits for future lunar exploration and colonization efforts. The construction of planetary outposts and habitats on the Moon and Mars will promote additional solar system exploration. To reduce resupply needs and increase system resilience, the crews that run, live in, and work in these artificial structures will rely on bio-regenerative closed-loop technologies and concepts, such as algae reactors and higher plant chambers. A big part of closing the oxygen, carbon dioxide, and water supply loops will be played by greenhouse modules, which will also help the crew by delivering fresh food. Only tiny greenhouse systems will be installed in early mission scenarios, while the habitat is still being built up, serving as a backup food strategy. A small number of crops with a high-water content, such as lettuce, cucumber, and tomatoes, will be grown in order to supplement the crew's pre-packaged meals and improve their diet.

Keywords: Lunar greenhouse, bio regenerative life support system, Key features.

INTRODUCTION

A lunar rock considered as a potential substrate for a plant growing. A greenhouse will be a reality that is now being planned, either within or outside the home. It appears to be viable and economical to employ local resources for plant growth from the outset of an in-situ Moon exploration. This endeavour would require tight coordination with the bioregenerative life support system. The biotechnological method for extracting certain elements from regolith for the production of food and fuel can be combined with a method for processing regolith to create fertile protosoil. A lunar greenhouse represents a pioneering concept at the forefront of space exploration, aiming to overcome the Moon's inhospitable environment and enable sustainable plant growth. In the face of the Moon's extreme temperature fluctuations, high radiation levels, and lack of atmosphere, the lunar greenhouse emerges as a potential solution to support future lunar missions and colonization efforts. By recreating controlled environments that mimic Earth's conditions, these innovative structures hold the promise of providing essential resources for astronauts, conducting crucial research, and paving the way for extended human presence beyond our planet.

A viable requirement for providing an enhanced life support system for humans while residing in a permanently manned lunar station is the ability to cultivate plants in greenhouses. For astronauts residing on lunar bases, plants will supply clean water, oxygen, and food that is fresh. The idea of first-generation plants growing in a lunar base anticipates them to play a key role in establishing an adequate protosoil needed for purposefully cultivating second-generation plants (wheat, rice, etc.) at a cheap cost. Within a cycle of regenerative life support, the leftovers from first-generation plants might be composted and converted by microorganisms into a substrate resembling soil. It would be practicable to employ a local resource, such as lunar regolith, for plant growth in lunar greenhouses to lower the cost of early expeditions to the Moon.The NASA Artemis programme [1] that brought people back to the Moon has increased scientific interest in the lunar environment and its effects on terrestrial life [2,3].Questions regarding the effects of the lunar environment on biology and biological systems have taken a large place on the lunar exploration agenda, as the return to the Moon is seen as a dedicated, longer-term commitment to lunar exploration. The inclusion of plants in lunar dwellings [4–8] and exploration situations [9–10] has long been contemplated.

The modified Energy Cascade Model (MEC)

The "Energy Cascade" crop model built for the wheat crop utilising data from the literature [13] and utilised for ALS system research by Jones and [12] is where the MEC model [11] got its start. Due in part to the model's simplicity, it had been demonstrated in a number of applications [14]. In order to predict the growth of various crops while taking into account the pertinent controllable factors in advanced life support system (ALS) plant growth facilities, such as radiation, temperature, humidity, pressure, and CO2 partial pressure, the model needed to be expanded. Soybean, white potato, lettuce, peanut, rice, sweet potato, dry bean, and tomato were also added to the list of foods for which the MEC model was constructed. In order to forecast plant transpiration and oxygen production, it was later enhanced utilising information from the literature and descriptive models.

Prototype Plant Growth System

In lunar regolith with low bioavailability, pioneer plants should be able to thrive under specific conditions. They must be disease-resistant and unaffected by light, low gravity, etc. The primary function of the first plants is to create an acceptable level of soil fertility required for intentionally growing second-generation plants (such as wheat, rice, soybean, etc.) that will have given lunar explorers new sources of vitamins, organogenic elements, and oxygen. Within a loop of regenerative life support system (RLSS), first-generation plant leftovers might be composted and converted into a substrate resembling soil [15, 16].

General Design of Greenhouse Module

The concept comprises of a stiff core module with four inflated growth petals, two corridors for connecting to lunar base buildings, four deployable light concentrators to provide a hybrid natural and artificial illumination system (ILS), and emergency radiators (not visible in the diagram below). The structure is supposed to have a sintered regolith cover around it to protect it from radiation and micrometeoroids as well as to make the greenhouse's temperature control easier.

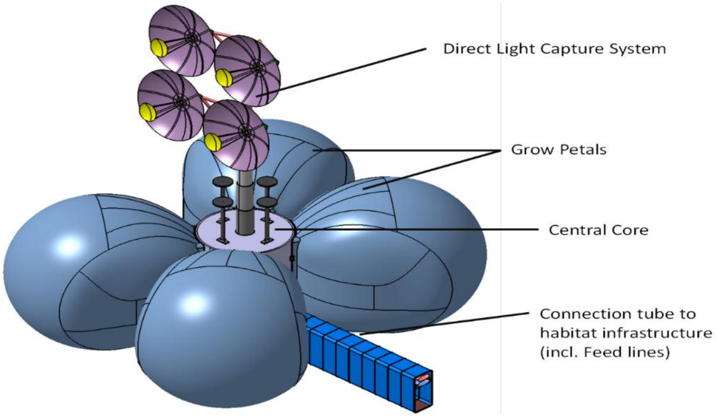
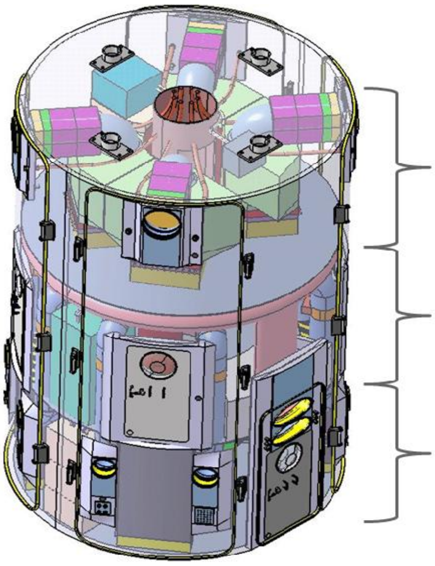


Fig. 1 Main Elements of Greenhouse Module System

In order to create compartmentalised development regions with environmental conditions that are best suited for a particular crop, the inflated petals are connected to the core via airlocks. Similar measures can be taken to block any negative GHM events from negatively affecting the habitat and vice versa at the links between the core module and the habitat (lunar base structures).

Central Core

Three levels can be arranged inside the central core. All connections between the rigid core and the petals, including those for cooling fluid, irrigation water, power lines, light cables, and air, as well as the habitat link corridors, can be sealed off using specialised seals or vacuum-proof valves, or (in the case of the bigger air tubes) with shutters.



Upper Level:
- General Air Management System (incl. fans, filters, water recovery units, sensors, etc.)
- Gas storage (nitrogen, oxygen, carbon dioxide)
- Air output ring for the breathing mode towards the habitat

Middle Level:
- Pre-and Post-Processing System
- Access to the petals
- Working desks
- Command and Data Handling System

Lower Level:
- Nutrient Delivery System and storage tanks
- Thermal and Power Control Systems
- Access to the habitat infrastructure incl. feed lines for consumables

Fig. 2 The three levels of the inner rigid core of the GHM system.

Upper Level

Four separate Air Management Systems (AMS) (including fans, filters, water recovery units, sensors, etc.) are integrated on the upper level of the central core. Each AMS is linked to a single growth petal by ducting, enabling air exchange with the environment or recirculation within the petals. To refresh the air inside the core, there is also a relatively straightforward AMS unit installed here. On this level, the atmospheric pressurisation system is also anticipated, together with the required connections to the AMS (including gas buffer storage and compressor unit). Last but not least, the interaction with the direct light collection system and the fibre optics that travel through into the petals is located on the upper level.

Middle Level

The Preand Post-Processing System (PPPS) for the crops, the Command and Data Handling System (CDHS), and multiple workstations are all located on the middle level of the central core. Additionally, at this level, the astronauts can access the petals. Each petal exists independently of the others. You can use emergency airlocks to isolate each petal from the hard core. The airlock doors are lowered to the lower level in the nominal operation mode. The configuration design of the lower level has taken into account the storage envelopes for the petal airlock doors. In the event of an emergency (such as a sudden decompression), special mechanisms under the stored airlock doors will help the astronauts quickly close the airlock doors.

Lower Level

Two distinct pressurised corridors connect to the habitat infrastructure on the lower level, which serves as the main entry point and connection point to the habitat for safety and redundancy purposes. The Nutrient Delivery System (NDS), which includes storage tanks, the Thermal Control System (TCS), and the Power Control and Distribution System (PCDS), are all located in the lowest level of the rigid core. A tubing system with several valves and shutters for the air exchange with the habitat, as well as interface panels for the interchange of resources between the core and the inflated petals, are also housed in the lower level.

Petal Design

The petals serve as growth cavities. Within the central stiff core, they are linked to the numerous controlled environment agriculture (CEA) subsystems. Throughout the life of the mission, each petal of the design is devoted to a specific growing environment, suitable for one or two crop species. The four petals of the GHM idea are identically arranged. A centre corridor runs through each petal, with growth channels piled vertically on either side. To allow for crew circulation, the middle corridor's width was planned to be 1.20 metres, with guiderails have been put in place on either side of the lift platform that accesses the higher cultivation floors. To the right and left of the service area, the air conditioning, and the corridor close to the entrance pipework and other ductwork. The remaining petals are on either side of the corridor is used for plant cultivation. a portable each petal's opening features an airlock dividing the environment from the petal environment inside of the core.

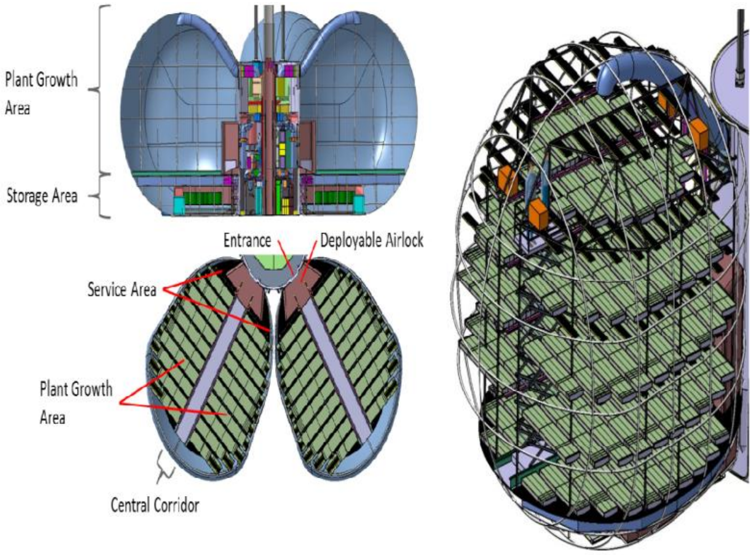


Fig. 3. Left Top: Side view of the GHM in its final version; Left Bottom: Top view of two petals in their final version, right: Petal configuration

Lunar Greenhouse Prototype (LGH)

This greenhouse is inflatable and collapsible, equipped with a hydroponics system and grow lights. The walls are transparent to allow sunlight to shine on the plants. The LGH is surprisingly easy to build because it deploys autonomously, meaning it is deployed and constructed by computers instead of astronauts. We have learned a lot from this lunar greenhouse, even if it is uncertain whether it will ever be used in space. In this greenhouse, scientists experimented with multicropping systems in 2015. Growing two or more crops in the same growing area is known as multicropping. Although it has never been done in space, multicropping can increase yields in conventional agriculture, thus the results of these tests could guide future space gardening decisions. The LGH serves as a space greenhouse in addition to serving as a useful, commercially viable controlled environment greenhouse for use on Earth. The LGH is a useful study tool for figuring out how to grow plants on Earth and elsewhere, even if it is never utilised on the Moon or Mars.

Fig. 4. Lunar Greenhouse Prototype

Bio Generative Life Support System

This greenhouse is a bioregenerative life support system (BLSS) since it produces food while recycling waste materials, specifically CO2 and nutrient waste. Five key features are offered by BLS systems: 1) Rejuvenation of the atmosphere, 2) Recycling of Water, 3) Production of Food, 4) Recycling of Organic Waste, and 5) Production of Power.

Fig. 5. Bio Generative Life Support System

The cropping mechanism enables filling the chamber both horizontally and vertically, hence maximising the canopy area that can be produced. For the latter, tall plants are allowed to grow on the outer walls while shorter plants are planted on the interior rows of the cable system. A hydroponic crop production system based on the substrate-free Nutrient Film Technique (NFT) that uses growing envelopes strung via cable from each end of the LGH unit along the longitudinal section is known as a "Cable-Culture system," in which crops are cultivated.The nutritional solution is poured into the system at the end of the suspended envelopes, where it flows to the system's centre drain and is forced back into the reservoir. The latter makes it possible to continuously irrigate plant roots. A hydroponic nutrient system with two independent systems that may dispense different nutrient formulations is used by LGH. The latter are given aeration and autonomous pH and electrical conductivity monitoring.

Microorganisms as aids to increase the bioavailability of rocks. Except for organogenic ones, almost all of the elements required for growth are present in rocks, but they are not readily available to plants. It would be advantageous to use local lunar material as a substrate for planting seeds or seedlings as well as a supply of vital nutrients for growing plants, but its accessibility needs to be increased. In order to free vital components for plants, a RACM of microorganisms could be used. Decontamination procedures on the Moon are not envisaged due to absence conditions for a life, under the Committee on Space Research's (COSPAR) planetary protection policy.Without microorganisms, a plant's intrinsic immunity is inhibited [17]. Microorganisms are crucial partners for plants. Without microorganisms, the plant has a lower probability of surviving stressful situations and fending off biotic and abiotic stresses [18, 19].

Rhizobacteria that promote plant growth offer defence against soil-borne plant diseases through antagonistic processes [20]. Aerial parts of the plant may develop systemic resistance as a result of plant-associated bacteria colonising the root surface [21, 22].Any microorganisms have the potential to minimise the accumulation of some heavy metals, as is known [23, 24]. We suggest priming a plant-candidate with beneficial microbes to prevent suppression of plant immunity, to stimulate plant development, and to give plants a bio-factory for substrate leaching and releasing essential elements for plant growth [25–27] in order to support the growth of plants under hostile stressful conditions.

In-situ Soil Forming the concept of composting garbage from a manned station with lunar particles [28]. For the purpose of intentionally developing plants, microorganisms are creating a protosoil by composting crop leftovers analysed [29–32].

Key Features of Lunar Greenhouse

1. Protection from the Environment

Lunar greenhouses would need to shield plants from the Moon's extreme conditions. This involves insulating the greenhouse to regulate temperature and protect against radiation. Some proposals suggest burying the greenhouse partially underground to provide additional shielding.

2. Lighting

Since the Moon has long periods of darkness (about two weeks of night followed by two weeks of day), a reliable lighting system is essential for plant growth. This could involve using solar panels to generate electricity, which in turn powers efficient LED lighting systems to mimic sunlight.

3. Air and Water

Plants require air (primarily oxygen and carbon dioxide) and water for photosynthesis. On the Moon, these resources would likely need to be artificially supplied, possibly through advanced life support systems or recycling processes.

4. Nutrient Supply

Plants also require nutrients for healthy growth. Hydroponic or aeroponic systems, which deliver nutrients directly to plant roots without soil, might be ideal for a lunar greenhouse due to the absence of lunar soil and the controlled environment they provide.

5. Regolith Utilization

Lunar regolith, the layer of loose material covering the Moon's surface, could potentially be used to provide a medium for plant growth if it's properly processed and supplemented with necessary nutrients.

6. Automation and Monitoring

Lunar greenhouses would likely rely heavily on automation for tasks such as planting, watering, and maintaining environmental conditions. Sensors and monitoring systems would be crucial to ensure the health of the plants.

7. Research and Experimentation

Lunar greenhouses could serve as valuable research platforms for studying how plants grow in reduced gravity and how different plant species adapt to lunar conditions. This knowledge could be applied to future long-duration space missions and even sustainable agriculture on Earth.

CONCLUSION

In conclusion, the concept of a lunar greenhouse represents a remarkable fusion of scientific exploration, technological innovation, and human determination. As humanity looks towards the Moon and beyond, the challenges of creating sustainable environments for life become ever more pressing. The lunar greenhouse, with its intricate balance of shielding against radiation, controlled atmosphere, and artificial illumination, stands as a beacon of our capacity to adapt and thrive in even the most inhospitable environments.The lunar greenhouse is more than just a structure; it is a testament to human resilience and ambition. It symbolizes our relentless pursuit of knowledge, our desire to expand our horizons, and our commitment to ensuring the survival of life in even the most unforgiving environments. As we gaze towards the Moon and the stars beyond, the lunar greenhouse stands as a pioneering step towards a future where humanity flourishes amidst the stars.

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