Future Exploration Greenhouse Design of the EDEN ISS Project

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The Future Exploration Greenhouse (FEG) is the heart of the international EDEN ISS project, which aims to investigate and validate techniques for plant cultivation in future bio-regenerative life support systems. The EDEN ISS project partners designed and built the Mobile Test Facility (MTF), which consists of two modified 20 foot shipping containers. The FEG is integrated into one of these containers. It has a shelf-like plant cultivation system with up to four levels for growing plants and it has a cultivation area of roughly 12.5 m². The FEG is designed to accommodate different plant species ranging from leafy greens (e.g. lettuce, spinach) to tall growing plants (e.g. tomato, cucumber). The plants grow in customized trays which hold the plants in position and contain the plants' roots. The trays can be connected to one of the two nutrient solution supply lines, each line providing a different nutrient mix. All plants grow in the same atmosphere and water-cooled LED lamps provide the light energy for photosynthesis. The FEG design has evolved from early designs in 2014 over the preliminary design by the end of 2015 to the final design which is described in this paper. Following assembly, integration and testing, the complete MTF will be shipped in October 2017 to Antarctica, where it will arrive in December 2017 and undergo a 12 month space analogue mission.

Nomenclature

AMS	=	Atmosphere Management Subsystem
AWI	=	Alfred-Wegener-Institute for Polar and Marine Research
CDH	=	Command and Data Handling Subsystem
DLR	=	German Aerospace Center
EC	=	Electrical conductivity
FEG	=	Future Exploration Greenhouse
HPP	=	High-pressure pump
MTF	=	Mobile Test Facility
NDS	=	Nutrient Delivery System
NFT	=	Nutrient Film Technique
NM III	=	Neumayer III
RH	=	Relative humidity

I. Introduction

The international EDEN ISS project started in March 2015 with the purpose to further develop plant cultivation technologies and operations in space. Fourteen partners from eight countries in Europe, Canada and the US joined forces to build a space analogue greenhouse to validate plant cultivation technologies during a twelve month analogue mission at the German Neumayer III (NM III) research station in Antarctica[1]. Early design concepts for an analogue space greenhouse in Antarctica from the project leading organization, the German Aerospace Center (DLR), date back several years before project inception[2]. In September 2015 a concurrent engineering study was performed in order to generate a preliminary design of the Mobile Test Facility (MTF), the facility that houses the greenhouse and all of its subsystems[3]. As preparation for the design study, early trade-offs and top-level design drivers for Antarctic greenhouses were identified[4]. The designs of past and current Antarctic greenhouses[5] were also taken into account in the design of the MTF. A plant selection methodology was developed and employed in order to select the plant species to be grown during the twelve month analogue test campaign[6].

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The preliminary design of the MTF has been further improved by the project consortium over the course of 2016. In spring and summer 2016 the manufacturing of the MTF outer structure, the greenhouse subsystems and the platform on which the MTF will be located in Antarctica was completed. In January 2017, the platform was subsequently deployed and constructed around 400 meters away from the Neumayer III. The MTF outer structure, the two customized containers, was delivered to the DLR site in Bremen in October 2016 for the integration of the different subsystems and components. The first installed components were the power distribution system including a large portion of the harnessing and the shelf-like structure of the plant cultivation system inside the Future Exploration Greenhouse (FEG). At the end of October 2016, the nutrient delivery system (NDS) and the control and data handling system (CDH) were delivered and integrated into the MTF. At the beginning of December 2016, the plant growth LEDs were installed and then tested during the first week of January 2017. At the end of the same month, the thermal control system and a computer rack were assembled and mounted in the Service Section. In February 2017 the Atmosphere Management System (AMS) and in March 2017 the ISS rack-like plant cultivation system and the work desk were installed.

A several months long MTF testing program was commenced at the end of March 2017. This testing program involved tests of individual MTF components and subsystems as well as longer term testing in which several growth cycles with actual plants are performed. The EDEN ISS project schedule foresees the delivery of the MTF containers for shipping to Antarctica in October 2017 and the arrival in Antarctica by mid-December 2017.

This paper describes the final design of the FEG which makes up 50% of the volume of MTF. The design is explained in detail using technical drawings and photographs of the actual hardware installed in the MTF as of March 2017.

Figure 1. Illustrative impression of the MTF on its platform (Right image, Credit: LIQUIFER Systems Group). The MTF at DLR Bremen in January 2017 with the integration tent on the right side (Right image).

II. Mobile Test Facility Design Overview

The EDEN ISS MTF consists of two customized 20 foot high-cube shipping containers. The two container approach was necessary, because the logistic chain from Germany to the Neumayer III research station is based on that format.

The Service Section Container consists of the Cold Porch, a form of air lock between the outside environment and the working area, and the Service Section which houses the bulk of all of the greenhouse subsystems and also provides a work desk with an integrated sink and storage space. An ISS rack-like plant production facility[7] is also located in the Service Section. The Service Section has a large window in the north wall from which one can observe Neumayer III from a distance, see Figure 2. The design of the Service Section Container is described in detail in another publication[8].

The second container houses the FEG which is separated from the Service Section by a wall and a sealed door. The FEG is the main plant cultivation room of the MTF. The design of the FEG is described in detail in the following sections of this paper.

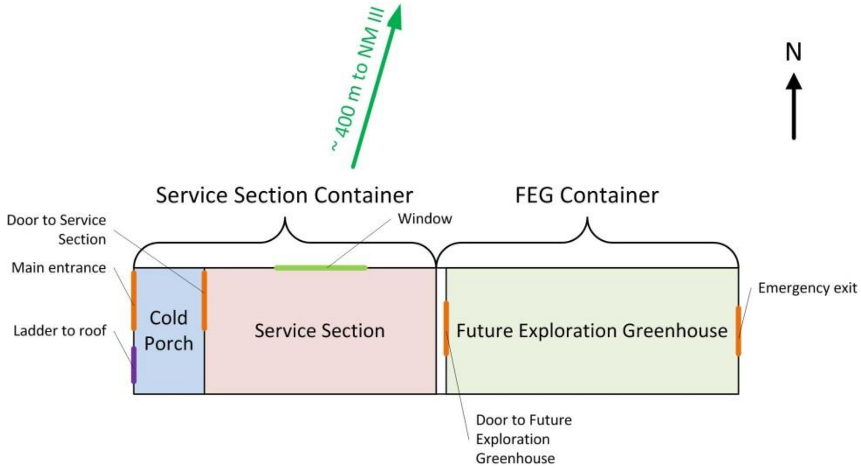

Figure 2. Overview of the EDEN ISS MTF main elements.

III. Future Exploration Greenhouse Design

A. Structural Design

The FEG is installed in a customized 20 foot high-cube shipping container. The container includes rock wool insulation (~80 mm) and wood plates (10 mm) attached to the inner walls. The inner side of the walls and the ceiling are covered with white high pressure laminate plates to provide a smooth and clean surface. Furthermore the plates installed in the FEG are fire retardant and have a special top layer which greatly reduces microbial growth. The floor of the container is also insulated (~120 mm polyurethane foam). A stainless steel basin is installed on top of the original wood panel floor. The basin is 100 mm high and covers the complete floor of the FEG. This design decision is made in order to avoid potential spill water running into the container wall construction. The basin collects all leakage water of the FEG and from there it can be pumped to the wastewater tank.

The internal space of the FEG is 2150 mm wide, 2550 mm high and 5700 mm long. This provides an internal volume of roughly 32 m^3. Figure 3 shows cross-sections of the FEG with its main components and dimensions.

Another special design choice for this project is the sub floor space. A raised floor made of anodized steel bars is installed inside the basin of the FEG. The space between the container floor (basin) and the corridor floor, is 300 mm high and allows for pumps, water and cooling fluid pipes to be placed below the lowest cultivation surface. The corridor floor is covered with metal grids to allow free air movement into the sub floor space.

The project team decided to build the FEG in a center aisle fixed shelves design (corridor centered, shelves on each side). Other approaches, such as, the side aisle fixed shelves and designs with movable racks and shelves[9] were studied but found to be inconvenient for the EDEN ISS FEG. The side aisle approach would lead to cultivation racks being approximately 1150 mm deep. This is rather deep to allow for easy human access of the complete shelf. Movable shelves and racks were neglected, because it was assumed that their transport to Antarctica would be rather complicated. Furthermore the project engineers wanted to reduce the amount of moving parts. The final design has a corridor of 1000 mm width. Although this could be considered somewhat large a corridor, the project team sees the corridor also as working space and, moreover, some of the plant canopies may extend slightly into the corridor. Nevertheless a wider corridor means less cultivation area, but the project team decided that since the FEG is still a research facility it is better to have more free space so that two or three operators can work at the same time inside the FEG, rather than focusing exclusively on maximizing cultivation area per unit volume. The wide corridor also increases safety of the operators in Antarctica, because there is more free space to move.

The actual plant cultivation rack structure is mounted on top of the raised floor framework and is 2250 mm high. The shelves are 575 mm deep on either side of the corridor. There are four racks per side, see Figure 3. The racks on the north wall of the FEG are named left side, as seen from the Service Section, and those on the south wall are named right side. The racks have different arrangement of levels. The FEG has racks with one, two and four levels to allow the volume optimized cultivation of different plant species. The rack structure is based on an aluminum profile system. The profiles have a cross-section of 30x30 mm. These profiles are used to mount all other subsystem components (e.g. lamps, pipes, pumps) inside the FEG.

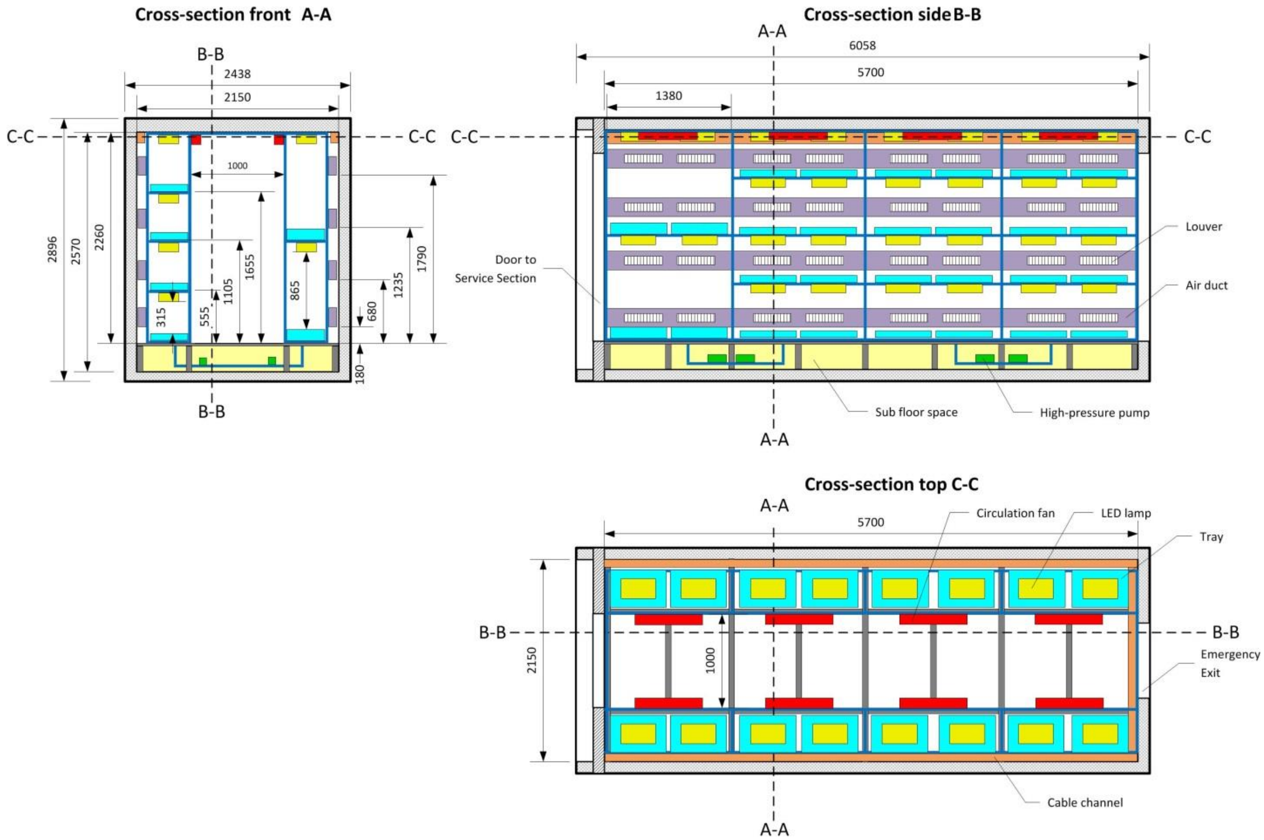

Figure 3. FEG main components and dimensions in millimeter (mm).

B. Atmosphere Management System

The Future Exploration Greenhouse environmental conditions are managed primarily by the Atmosphere Management System (AMS). Excluding the interactions between the Service Section and FEG environments as a result of crew entering and exiting, the FEG environment is a closed system.

Fresh air, relatively cold, dry and rich in CO_2 is provided to the plants. The gas exchanges between the environment and the crops, as well as the thermal loads which act on the air, result in a deviation of the climatic conditions from the desired set points. The hot, humid and O_2 rich air is transported from the FEG to the AMS unit in the Service Section where it undergoes a number of treatment steps, such as dehumidification and filtration, to once again obtain the desired environmental parameters. Following these treatment steps, the treated air is transported into the FEG and injected into the plant canopy. Figure 4 illustrates the positions of the air inlets and outlets.

As mentioned, the FEG is designed to maximize crop cultivation area within the available volume by using a vertical stacking of grow levels. The number of levels ranges from one, for tall growing crops such as cucumber, to four for smaller crops, such as lettuce. A consequence of this approach is that supply of fresh air from beneath the plants, in order to take advantage of the natural buoyancy tendencies of air, becomes more problematic, as the lower plant canopies would inhibit air flow to the crops on the upper levels. Furthermore, in such an approach the environmental parameters of the fresh air supply would differ significantly between the vertical levels.

On account of these issues, it was decided to position eight horizontal air supply ducts at the sides of the racks; four on both the left and right side of the FEG. The four levels of ducting correspond to the maximum number of cultivation levels, enabling the supply of fresh air directly at each plant cultivation tray.

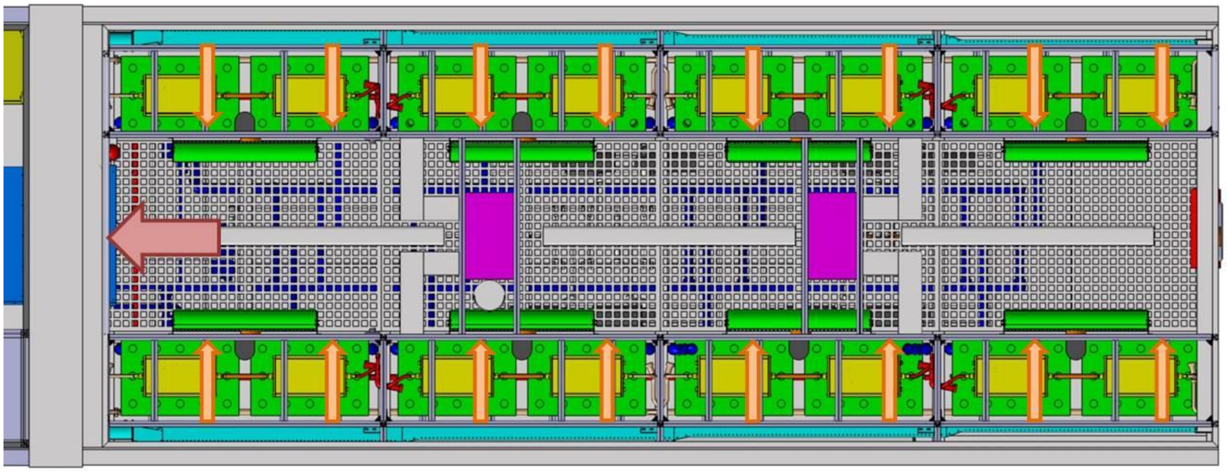

Figure 4. Top-view of the FEG with arrows indicating the air flow.

A detailed design of these horizontal ducts can be seen in Figure 5. The nominal air flow through the FEG is 1400 m³/h, which corresponds to roughly 44 volume exchanges per hour. To ensure equal mass flow distribution for each of the plant cultivation trays, flow control valves are used to balance the air flow across the air supply ducts in the FEG. Ports are incorporated in the duct design, to allow for flow rate measurements which can validate the flow control valve settings. The supply ducts themselves are tapered, reducing in width along the length of the duct, to obtain a better mass flow distribution within the duct itself. For ease of manufacturing, the tapering is done in discrete steps, even though a continuous tapering would result in further improvement in balancing the flow distribution.

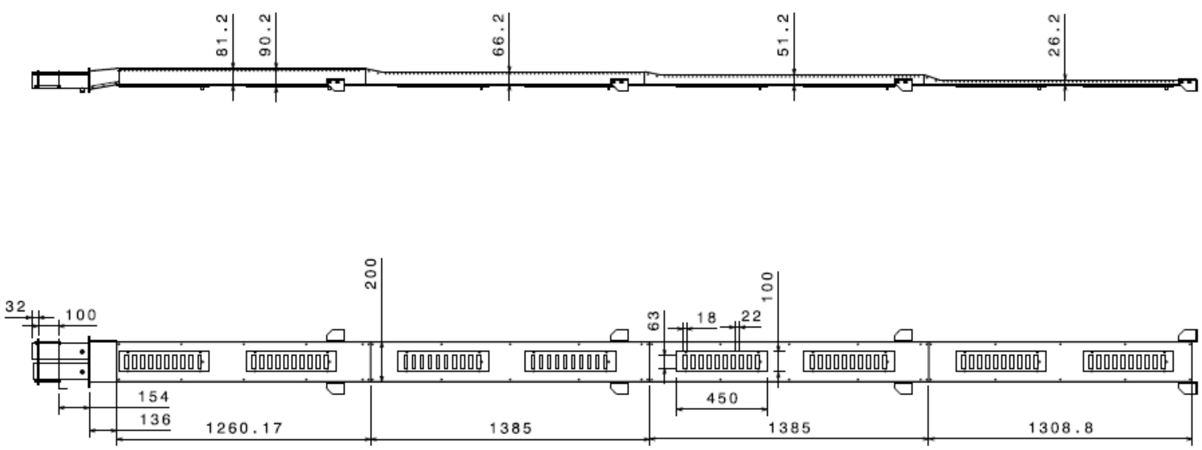

Figure 5. Air supply ducts along the long side of the FEG.

Each supply duct contains eight louvers, which can be adjusted to further balance the mass distribution per plant tray. A photo of one of these louvers can be seen in Figure 6. The size of the louver openings was selected to allow for a velocity of the fresh air onto the plant canopy of approximately 0.4 m/s.

Note the holes at the top of the duct in the CAD image. These holes, present on the top and bottom along the length of the duct were incorporated to promote air flow along the walls of the FEG, in an effort to reduce the risk of condensation occurring at these locations.

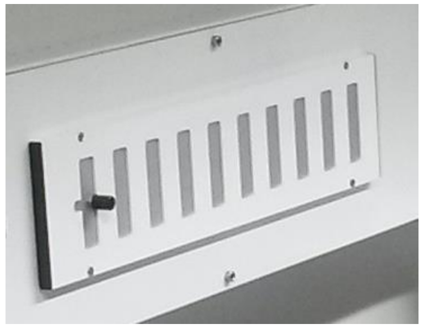

Figure 6. Louver integrated in the air supply duct.

The design of the horizontal ducts was validated using computational fluid dynamics simulations. These simulations demonstrated that the air flow distribution across the horizontal ducts was balanced within acceptable margins. The flow rate through each of the eight ducts is expected to be 175 m^3 per hour. Furthermore, the flow distribution within one duct across the eight louvers met the requirements (maximum difference in flow rate 10-20%). Each of the eight louvers per horizontal duct is expected to provide 16-20 m^3 per hour fresh air to the plants.

Further simulations of the FEG environment were carried out to determine the behavior of the environmental conditions over time. A point of concern was the stratification indicated by the initial simulations. For this reason, the design of the FEG evolved to include eight tangential fans which would induce additional air circulation and create a more homogeneous environment.

Other points to note in these simulation results are the hot spots surrounding the trays. These are caused by heating of the trays as a result of incident radiation (at the top of the trays) and waste heat from the LED panels at the bottom of the trays. Also note the stratification in the sub-floor area, and the limited interaction between the sub-floor and above floor areas. A number of changes were implemented in the floor design to facilitate the air movement between these regions, but further simulations to investigate the impact of these changes have not been carried out.

C. Illumination and thermal system

The plant cultivation racks inside the FEG are outfitted with water-cooled LED lamps. In total there are 42 lamps, two per level, as shown in Figure 7. The rack R3 is assigned for cucumber plants. The LED lamps in this rack have two positions, a lower position for the early stages of the growth cycle and a higher position for the later stage. The lamps can moved between the two positions in order to provide optimal illumination at all times of the growth cycle.

The LED lamps themselves were developed specifically for the EDEN ISS project by Heliospectra (Göteborg, Sweden). The lamps are based upon the LX-601 Heliospectra panels with the original air cooled heat exchange replaced by a water-cooled setup in order to reduce the height of the lamp and to remove excess heat without heating the greenhouse atmosphere. Each lamp has LEDs in four different wavelengths (red: 630 nm, blue: 450 nm, far-red: 735 nm, white: 5700 K) which can be controlled independently in 0.1% increments from 0-100% output. Furthermore, illumination schedules can be individually programmed for each lamp. Consequently the FEG operator has a high degree of freedom in controlling the illumination inside the FEG. For the EDEN ISS project, lamps can provide up to 300 µmol/(m^2*s) for small growing plants (racks L2-L4) and 600 µmol/(m^2*s) (racks L1, R1-R4) for tall growing plants, taking into account the employed LED to plant growth tray heights. All of the LED panels used for EDEN ISS are constructed identically, save for differing power supplies within the panels used for the small growing and tall growing plants. The LEDs also include a thermal runaway cut-off switch, which will shut the LED off should its temperature rise above 50 °C.

In January 2017 a system test of the illumination system (without thermal cooling lines operational) was performed. The different wavelengths were tested individually and combined. No error occurred. Figure 8 shows photos taken during the illumination system test.

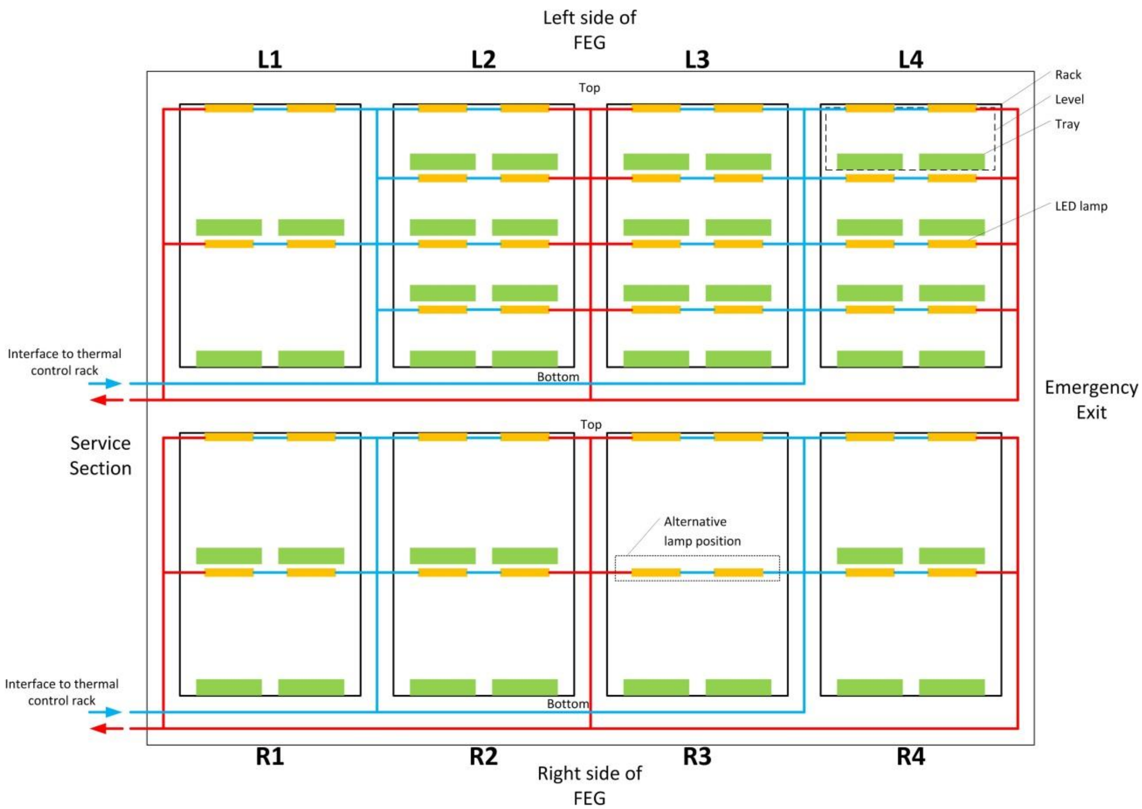

Figure 7. Illumination system including cooling pipes inside the FEG. Feed lines (cool)shown in blue, return lines (warm)pipes shown in red.

Figure 8. FEG LED test in January 2017. Different wavelengths are turned on at 50% intensity. From left to right: Blue, red, blue and red, white. Photo taken from the Service Section looking into the FEG.

D. Nutrient Delivery System

The majority of the nutrient delivery system (NDS) components (e.g. mixing tanks, sensors) are placed in the Service Section. However, the NDS also extends into the FEG which is described here. The EDEN ISS NDS consists of two separate solution loops, each with its own set of feed and drainage pipes in the subfloor of the FEG. Three-way valves in the subfloor are used to define which nutrient solution is fed to the different racks. One high-pressure pump (HPP) is able to supply all plant cultivation trays (see next subchapter for details) in one rack, see Figure 9.

The setup with two tanks and their own distribution piping provides the possibility to have two separate nutrient solutions with different nutrient compositions, EC and pH value. Two nutrient solutions with the same nutrient composition but with different EC values are foreseen for the planned Antarctic field campaign. The solution with the lower EC is considered for leafy greens and herbs, while the solution with the higher EC will be fed to the tall growing plants like cucumber and tomato.

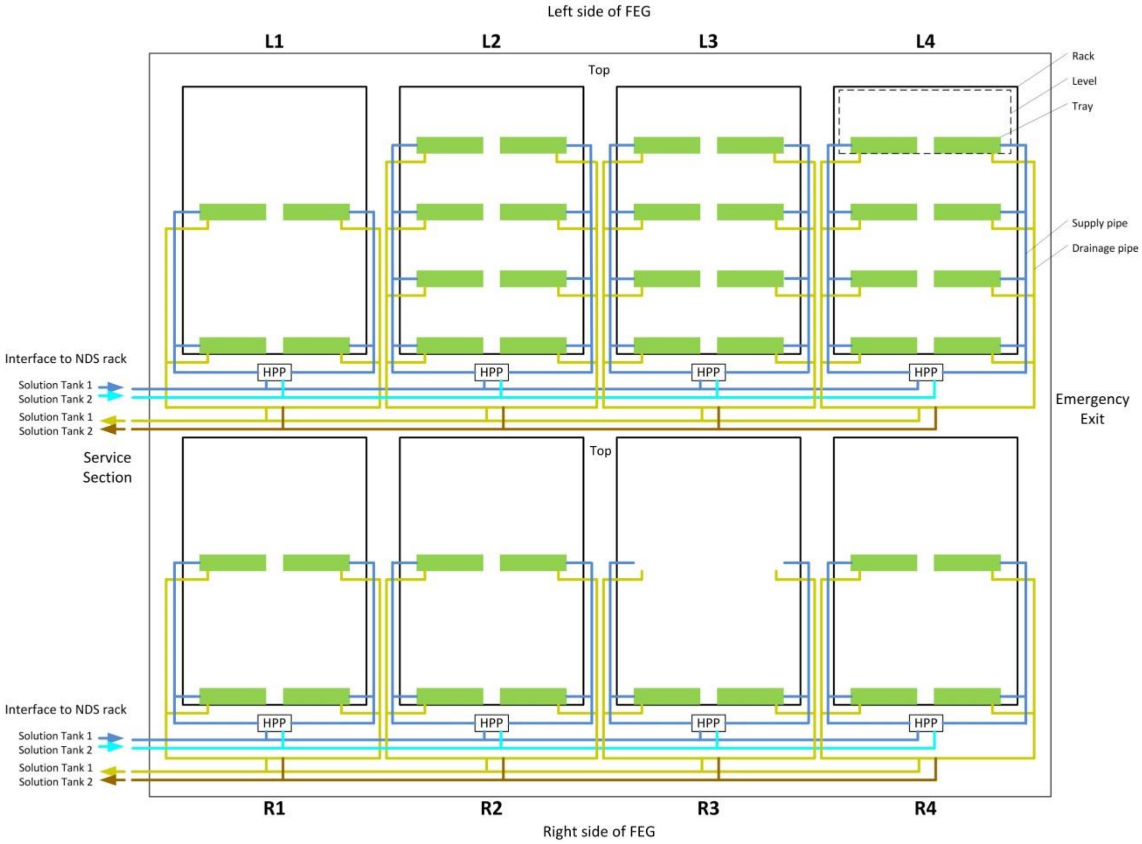

Figure 9. Overview of the NDS components in the FEG.

E. Plant tray design

The Protocol on Environmental Protection to the Antarctic Treaty[10] significantly constrains the import of non-native soils and the utilization of local soils to grow plants in Antarctica. This, like the drive to reduce waste generation in Antarctica, as well as the requirements of space missions to reduce launch mass, imply that currently operating Antarctic greenhouse facilities are based upon hydroponic nutrient delivery systems. The EDEN ISS plant growth trays incorporate nutrient solution delivery tubing and a drain configuration to provide a combination aeroponic/nutrient-film-technique (NFT) nutrient delivery system. This 'combination' aeroponics/NFT configuration is a result of the relatively short plant growth tray height to maximize packing. In this case, once crops reach a certain maturity their roots will rest on the bottom of the tray where the misted nutrient solution (aeroponics) run off will flow past them as it drains (NFT). Misters are of the 0.5 mm diameter variety, which are small enough to provide a fine mist but large enough to reduce the occurrence of emitter blockages.

The overall plant growth tray concept is to employ standard commercial off the shelf Euroboxes. This permits a standard form factor, the ability to use accessories specifically made for these standard tray sizes and the use of food grade plastic containers all for reasonably low cost. The 60 cm x 40 cm Eurobox size was selected for reasons of operator handling and modified with the tubing, bulkhead, misters and drain depicted in Figure 10. The trays are outfitted with quick connect tubing to allow for easy and fast removal without shutting down the nutrient and water supply for the entire rack.

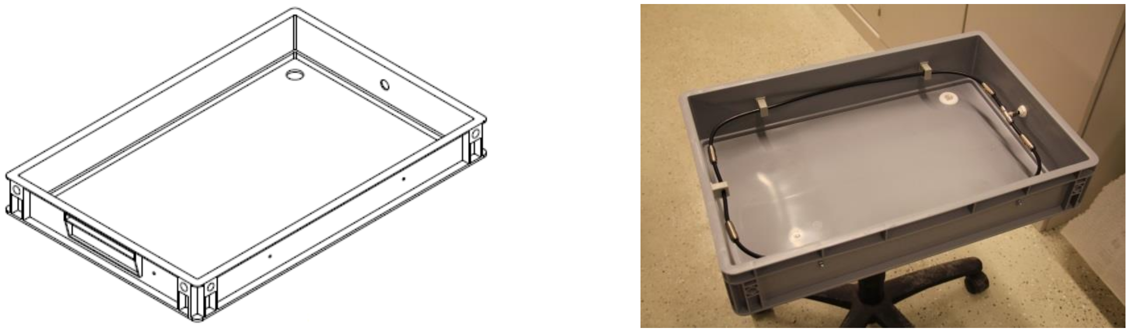

Figure 10. EDEN ISS plant growth tray showing the internal high pressure tubing, misters and drain configuration. Tall crop plant growth tray with four misters configuration shown.

The Eurobox trays were acquired in two different heights. A 7.5 cm deep box is employed for the growth of the short crops (e.g., lettuce, herbs) while a 12 cm deep tray is employed for the growth of the taller crops (e.g., tomatoes, cucumber). The short trays were modified to include two misters placed in opposite corners of the tray while the taller trays were modified to include four misters, with a pair of misters installed on each of their shorter sides (Figure 10). Dark gray trays were chosen so as to reduce the amount of stay LED light reaching the inside of the box. The lids of the trays are modified with different hole patterns and spacing dependent on the crop in question. Selected hole patterns for several of the crops selected for EDEN ISS are displayed in Figure 11.

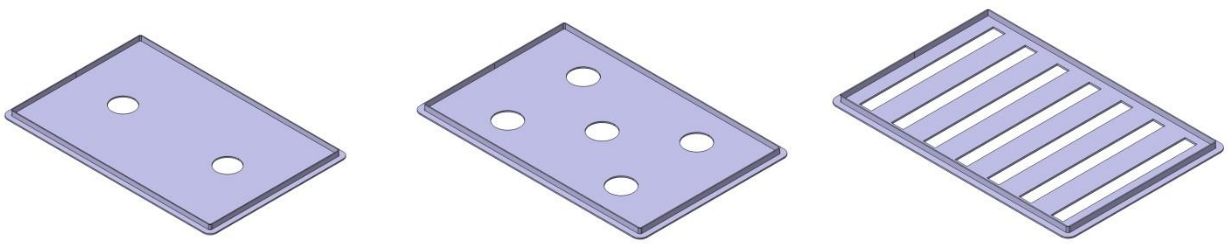

Figure 11. Plant growth tray lids with hole configurations of select EDEN ISS crops (Left to right: tomato, lettuce, rucola).

Although one main benefit of the aeroponics/NFT nutrient delivery system is that it allows the FEG to avoid the use of large amounts of growth substrate and thus reduces waste production over the long duration operational phase, small rock wool plugs will still be used to support the plant within the growth tray lids.

F. Data Handling System and Observation

As only one operator will handle the operation of the FEG, there is a need for objective assessment of plant welfare and performance, through automatic detection and remote expert assessment of information.

One of the key points of the performance monitoring of the FEG is the plant health monitoring, and most of all the early detection of plant disease and the subsequent activation of corrective actions. For that reason, a plant monitoring system is foreseen with the objective of collecting information suitable for analysis by a knowledge system (either local or remote) to assess and advise prophylactic measures to the local operator.

For that purpose, several cameras are taking images of the plants once a day, or as required, which are delivered to the remote mission operation center in Bremen, for local/remote analysis. Image analysis software will pre-screen the images and select images that may require further human analysis. In case of need the cameras are also controllable over the internet to get access from remote side.

There are 21 fixed top view cameras implemented in the plant health monitoring system, which take pictures of two growth trays and in case of the nursery even each individual tray. In addition to those cameras there are also 8 fixed side cameras looking from one side to the other. The lay-out of the cameras is given in Figure 12.

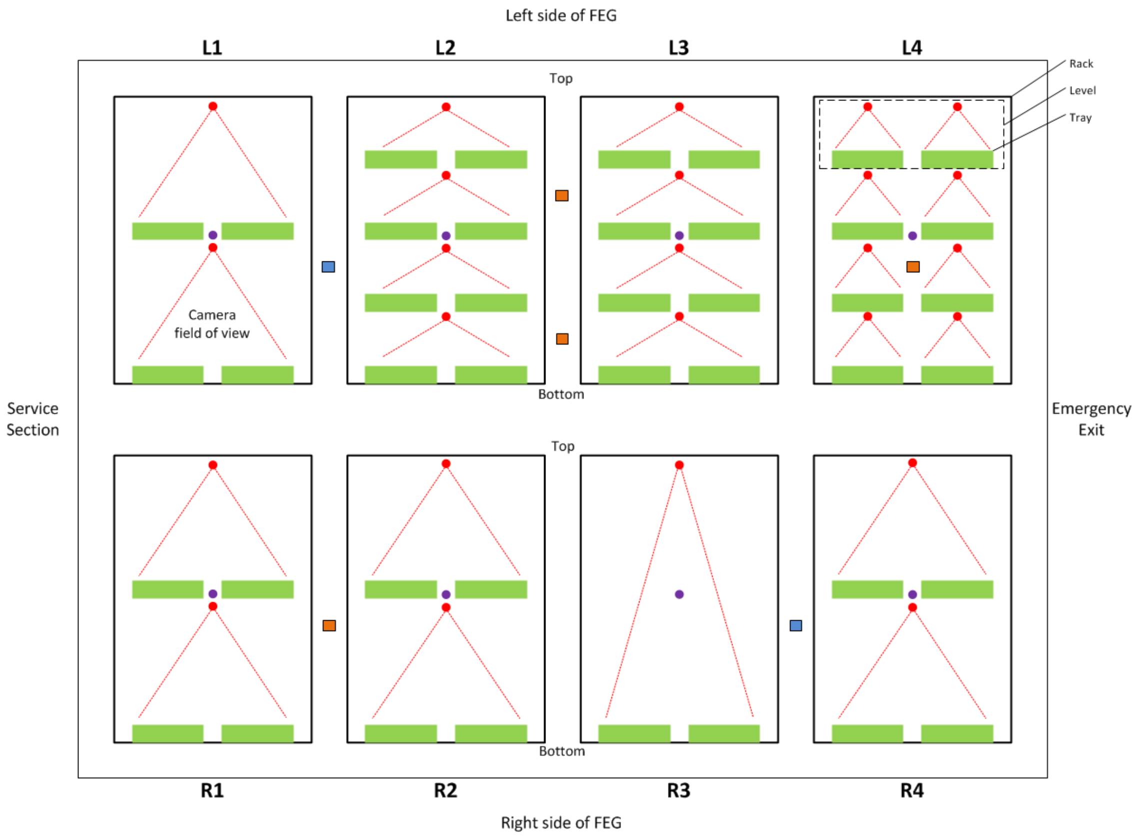

Figure 12. Overview of the lay-out of the sensors and cameras: the red circles represent the top view plant cameras and the purple circles the side view plant cameras; the blue squares the combined placement of air temperature, relative humidity and CO_2 concentration sensors; the orange squares only of temperature and relative humidity.

A number of sensors for air properties will be installed in the FEG and connected to the CDHS for maintaining proper environmental conditions for the plants: temperature; relative humidity and CO_2 concentration, placed in Argus Titan Omni Sensor aspirated boxes (see left side of Figure 13). The boxes also carry a sensor for Photosynthetically Active Radiation. In addition to those two boxes four EE071 temperature and relative humidity sensors from E+E Elektronik are placed at various locations in the FEG (see right side of Figure 13). The location of the sensors is given in Figure 12.

Figure 13. Left: The Argus Titan Omni aspirated box; Right: Temperature and relative humidity sensor EE071

G. Plants

In total 15 different plan species have been selected for the analogue test campaign. While the project team would like to test a number of additional species, the limited space of the FEG and the defined campaign duration made a selection necessary. All selected plants follow the pick-and-eat approach, which means that all harvested edible biomass of the plants can be eaten directly without any further processing (except washing and cutting). The selected plant species also have in common that their shelf lifetime, the time from harvesting until rotting, is relatively short and therefore they cannot be stored for a long period of time in the fresh state after harvest.

With tomato, pepper and cucumber three tall growing crops have been selected. Furthermore three different types of lettuce (Outrageous, Crispy green and Rocket), spinach, radish, red mustard and a number of herbs (basil, parsley, chives, coriander and mint) will be grown. The project team also decided to try out the cultivation of strawberry plants. Strawberries have unique advantages as they are one of the few relatively small crop species which produce sweet fruits. However, the cultivation of strawberries is challenging, but initial growth trials at the Wageningen University and Research (WUR), one of the EDEN ISS project partners, indicate that the plants thrive under the conditions in the FEG.

Figure 14 shows the initial plant allocation in the different racks and levels of the FEG, although the plant setup might develop over the course of the analogue campaign.

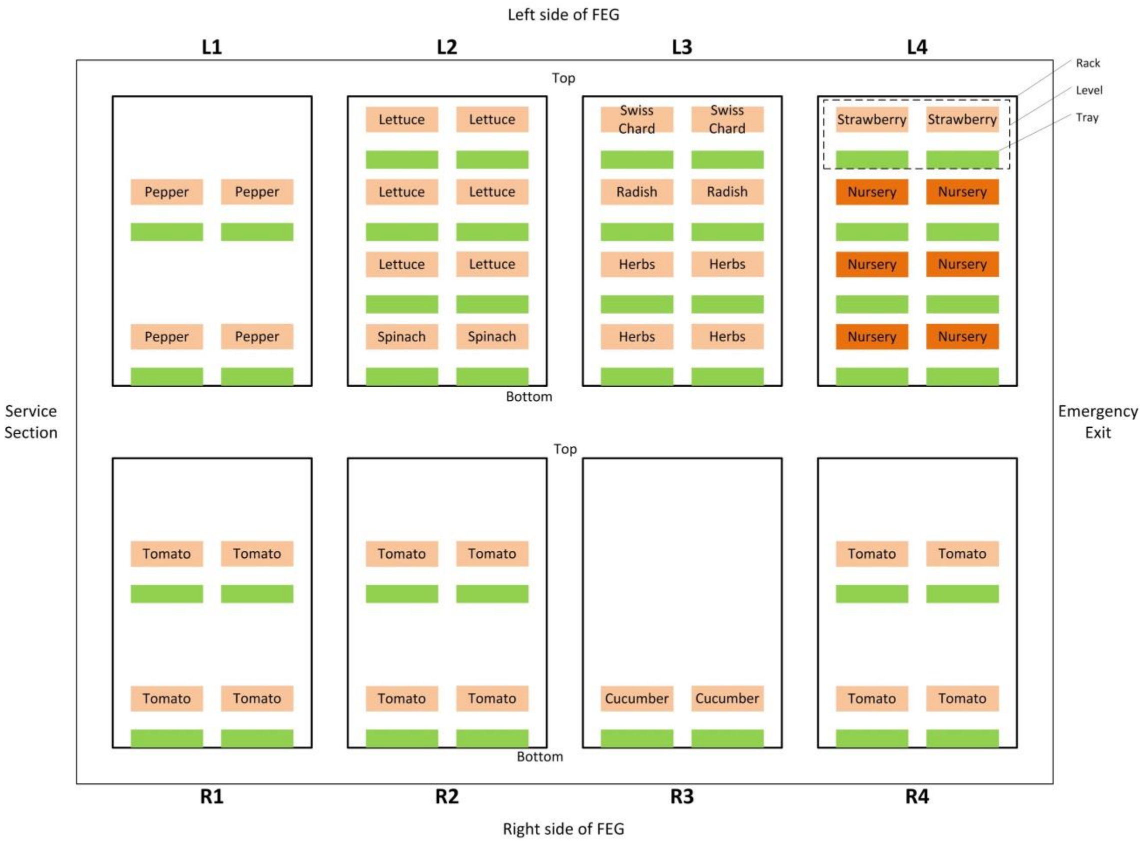

Figure 14. Final plant allocation to the cultivation racks of the FEG.

IV. Operational Characteristics

The hardware installed in the FEG has a wide range of operational settings, which allows the operator to adjust the environmental parameters to the desired level. Table 1 gives a summary of the main operational characteristics. All plants are grown in the same environment, because dividing the FEG into separately controlled closed chambers would have increased the amount of subsystem components (e.g. AMS) to a degree were two 20ft shipping containers would not have provided enough space. Consequently, the nominal environmental settings are a compromise between the primary target plants and not optimized to a specific crop species. The air velocity for each level can be adjusted to some degree individually by controlling the opening of the nearest louvers in the air supply duct. The settings of each lamp and therefore for each tray can be adjusted individually. However, since the trays and the levels are not separated from the neighboring ones, there is always some stray light from adjacent lamps. The nutrient delivery system supplies two different nutrient solutions to the FEG and for each rack the operator can decide which solution is supplied. The FEG is built to be operated by a single trained full-time operator. However it is envisioned that other crew members help during critical stages of the mission (e.g. harvest).

Table 1. Summary of FEG operational characteristics

Subsystem	Parameter	Nominal operational values	Unit
Overall FEG			
	Cultivation area per level	~0.6	m^2
	Total cultivation area	~12.5	m^2
	Floor area	12.26	m^2
	Total internal volume	31.50	m^3
Atmosphere Management System			
	Oxygen concentration	21*	%
	Carbon dioxide	750	ppm
	Pressure	101*	kPa
	Air temperature, light cycle	21	°C
	Air temperature, dark cycle	19	°C
	Relative humidity, light cycle	75	%
	Relative humidity, dark cycle	85	%
Illumination System			
	Photosynthetic Photon Flux	300/600**	$\mu mol/(m^2*s)$
	Photoperiod	17	h/d
Nutrient Delivery System			
	pH	5.8	-
	EC	2.5/3.5**	mS/cm
	Number of trays	42	-
	Tray dimension	600x400	mm
	Root zone height	70/115**	mm
	Shoot zone height	315/865/1990***	mm
	Irrigation method	aeroponic/NFT	-

* values defined by average external conditions

** first value for short growing plants (e.g. lettuce, herbs), second value for tall growing plants (e.g. tomato, cucumber)

***different heights for racks with four/two/one level

V. Summary and next steps

The FEG design has been elaborated over the last three years. The final configuration of subsystems and components inside the FEG has been described and design choices have been explained. The FEG with its roughly 12.5 m² of cultivation area, its flexibility and selected plants will advance the knowledge of bio-regenerative life support systems. The planned Antarctic space analogue campaign will generate valuable data for future research in the field of plant cultivation in space. EDEN ISS will also validate key technologies and operation procedures with the MTF and its heart the FEG.

With all the major subsystems and components installed, the assembly and integration phase of the EDEN ISS project was completed at the end of March 2017. Between April and mid-September 2017 an overall system test of the complete facility at the DLR Institute of Space Systems in Bremen will be conducted to verify the functionality of the integrated system. During the testing phase, not only will the systems be tested, but multiple growth cycles of all selected crops will also be performed. This will allow adjustments to be made to the final growth conditions, should they be required. In mid-September 2017 the project staff will shut down the MTF and begin with the preparations for shipment to Antarctica. The preparations include the cleaning of the entire MTF, the disassembly of all externally mounted equipment, the removal of all sensitive equipment from the MTF and its packaging in transport cases, as well as the packaging of all the campaign supplies. In October 2017 a ship departs from the German port of Hamburg in North Germany for its journey to Cape Town in South Africa. There the MTF will be transferred onto a South African Antarctic supply vessel for the last leg of the tour to Antarctica where it will arrive around mid–December 2017.

At the same time, an assembly crew consisting of four project staff members will arrive at the Neumayer III station by plane. The assembly crew together with workers from the station operator, the Alfred-Wegener-Institute for Polar and Marine Research (AWI), will lift the two MTF containers onto their platform. Once on the platform, the two containers will be joined together again. All the equipment that has been dissembled for transport will be brought back into the facility and re-installed. Initial system tests will be conducted to ensure that the equipment is working properly. A small remote operations work place will be set up inside the Neumayer III and a data connection will be established between the MTF, the Neumayer III and the main operations center at DLR Bremen.

From the end of February 2018 the MTF will be operated by a single on-site operator, a staff member of DLR Bremen, with the occasional assistance of the other nine overwintering crew member from AWI.

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