D 2.5 - Design Report

prepared for

WP 2.3 - Preliminary Facility Design

Version: 1.0

Published: 2015-12-03

Approved by:	Conrad Zeidler	DLR	Work Package Leader
Approved by:	Matthew Bamsey	DLR	Systems Engineer
Approved by:	Daniel Schubert	DLR	Project Manager

List of Authors (continues on next page):

Participant No.	Short name	Author name(s)
1	DLR	P. Zabel, D. Schubert, M. Bamsey, C. Zeidler, V. Vrakking, D. Gyimesi, P. Rettberg, S. Barczyk
2	LSG	B. Davenport, R. Waclavicek
3	CNR	A. Battistelli, F. Nazzaro
4	UoG	M. Stasiak
5	AWI	E. Kohlberg, D. Mengedoht

List of Authors (continued):

Participant No.	Short name	Author name(s)
6	ES	E. Mazzoleni, D. Magnabosco
7	AST	V. Fetter
8	TAS-I	G. Boscheri, E. Guarnieri, I. Locantore
9	AS	G. Bonzano
10	DLO	F. Kempkes, T. Dueck, C. Stanghellini
11	HS	A. Gilley
12	LIT	M. Bennett, P. Downey, T. Larkin
13	TPZ	A. Ceriello, R. Fortezza

Document Change Log:

Version	Date	Author name(s)	Description of Change
0.1	2015-11-24	See author table	Draft
0.2	2015-11-30	M. Bamsey, D. Schubert	Incorporation of partner input to initial draft. C&DH and food quality and safety chapter up-dates. Consistency updates. AMS block diagram addition. Addition of fast-track pathways for ISS section. Common value updates.
1.0	2015-12-03	See author table	Initial release.

Executive summary

This document provides a summary of the results of the two week EDEN ISS concurrent engineering design study conducted from Sep 7-18, 2015. The primary goal of the study was to produce a preliminary design of the EDEN ISS Mobile Test Facility. This preliminary design includes details from all Mobile Test Facility subsystems as well as initial details on a number of scientific and operational themes relevant to the EDEN ISS project. It is important to note, that the design of the Mobile Test Facility will continue to evolve, especially at the subsystem level, but that this document represents a snapshot of the design at the system level, and its status at the completion of the concurrent engineering design study in conjunction with its associated period of post-processing. The design study also generated a number of important supplementary reference documents including subsystem block diagrams and detailed 'subsystem calculators' which detail all subsystem components, quantities, estimated mass, volume and power in addition to a first detailed estimate of project spares and consumables. Although extracts of this information are included directly in the report, the current drafts of these documents should be referenced as separate files.

The EDEN ISS concurrent engineering design study has matured the design of the Mobile Test Facility and its Future Exploration Greenhouse, Service Section (including the ISPR full rack plant growth system demonstrator) and cold porch. The study has proven the feasibility of the EDEN ISS project and demonstrated that the facility will serve as a valuable resource to the Neumayer III Antarctic Station and as a test-bed for testing plant growth technologies and operational techniques for use within future space-based missions.

Table of contents

Acronyms

Acronym	Explanation	Acronym	Explanation
ALARA	As low as reasonably achievable	LOD	Limit of detection
AMS	Air Management System	LUI	Light Use Efficiency
AS	Aero Sekur S.p.A.	MCCS	Major constituents control system
AST	Airbus Defence and Space	MTF	Mobile Test Facility
AWI	Alfred Wegener Institute for Polar and Marine Research	NDS	Nutrient Delivery System
BLSS	Bio-regenerative Life Support Systems	NFT	Nutrient film technique
C&DH	Command and Data Handling	NM-III	Neumayer Station III
CAD	Computer Aided Design	P/L	Payload
CCD	Charge-coupled device	PAR	Photosynthetic Active Radiation
CE	Concurrent engineering	PCA	Principal component analysis
CEA	Controlled Environment Agriculture	PID	Photoionization Detection
CEF	Concurrent Engineering Facility	PSU	Power supply unit
CFD	Computational Fluid Dynamics	QDA	Quality Driving Attributes
CFU	Colony forming units	QMP	Quality Management Plan
CNR	Consiglio Nazionale delle Ricerche	RCD	Residual current device
DLO	Wageningen University & Research	RD	Reference Document
DLR	German Aerospace Center	RH	Relative Humidity
DO	Dissolved oxygen	S/C	Species and cultivars
DoA	Document of Action	S/S	Sub-system
DW	Dry Weight	SMS	Short message service
EC	Electrical Conductivity	SS	Service Section
EDR	European Drawer Rack	SRD	System Requirements Document
EP	Elevated Platform	TAS-I	Thales Alenia Space Italia S.p.A.
ES	EnginSoft S.p.A.	TBC	To Be Confirmed
ESA	European Space Agency	TBD	To Be Determined
ESC	External Storage Container	TCCS	Trace contaminant control system
FEG	Future Exploration Greenhouse	TCP	Transmission Control Protocol
FOV	Field of view	TCS	Thermal control system
H&S	Health and safety	TEC	Thermo-electric cooler
HD	High definition	THC	Temperature and humidity control system
HEPA	High Efficiency Particulate Arrestance	TM/TC	Telemetry/Telecommand
HI	Harvest Index	TPZ	Telespazio S.p.A.
HS	Heliospectra BA	UDP	User Data Protocol
HW	Hardware	UHB	User Home Base
I/O	Input/output	UIP	Utility Interface Panel
IBAF	Institute of Agro-environmental and Forest Biology	UoG	University of Guelph
IF	Interface	UPS	Uninterruptable power supply
ISPR	International Standard Payload Rack	USOC	User Support and Operations Centre
ISS	International Space Station	VOC	Volatile Organic Compound
LAI	Leaf Area Index	VPN	Virtual private network
LED	Light-emitting diode	WP	Work package
LIT	Limerick Institute of Technology	WS	Work station

1 Introduction

The following section reviews key information from the EDEN ISS concurrent engineering (CE) study conducted from Sep 7-18, 2015. This study was conducted within the Concurrent Engineering Facility of the German Aerospace Center's Institute of Space Systems in Bremen. The primary goal of the study was the generation of a preliminary design of the EDEN ISS Mobile Test Facility. This design includes details from all Mobile Test Facility subsystems as well as preliminary details on a number of scientific and operational themes relevant to the EDEN ISS project. Full preparatory details can be found within the EDEN ISS CE study scope document.

1.1 *Mission Objectives*

The overall objectives of the design object, the EDEN ISS Mobile Test Facility are listed in Table 1-1.

Table 1-1: Mission objectives for the EDEN ISS project.

Objective-No.	Objective Description
MI-OJ-0010	Design of a space analogue mobile test facility for a 12+ month mission in Antarctica to provide representative mass flows and proper test environments for plant cultivation technologies as an essential on-ground preparatory activity for future space exploration.
MI-OJ-0020	Integration and test of key elements for plant cultivation in 1) an ISPR-like system (International Standard Payload Rack) for future tests on-board ISS and 2) a Future Exploration Greenhouse (FEG) to prepare for closed-loop bio-regenerative life support systems.
MI-OJ-0030	Adaptation, integration, fine-tuning and demonstration of key technologies and their functionality in respective environments (Laboratory and Antarctica).
MI-OJ-0040	Development and demonstration of operation techniques and processes for higher plant cultivation to achieve reliable and safe production of high-quality food.
MI-OJ-0050	Study of microbial behaviour and countermeasures in plant-based closed ecosystems and their impacts on isolated crews.

1.2 *References*

In addition to the EDEN ISS CE study scope document, participants were also referred to the following EDEN ISS reference document for preparation of the study:

- Document of Action (DoA) (published)
- System Requirements Document (SRD) (published/ Version 1.3)
- Quality Management Plan (QMP) (published/ Version 1.0)
- Plant selection document (not yet published)*

*The first official version (1.0) of the plant selection document was released following the CE study.

1.3 *Study Objectives*

The objectives of the study are listed in Table 1-2 with their respective numbers.

Table 1-2: Global study objectives for the EDEN ISS project.

Objective-No.	Study Objective Description
SO-1	Structure and initial design of the Mobile Test Facility layout (e.g. primary & secondary structure, mechanisms, subsystem accommodation, piping, interfaces towards ISPR system, the Service Section and the FEG) incl. statement of redundant systems/ technologies
SO-2	Design of interface architecture of MTF with Neumayer Station III, with ECC, and with remote user sites
SO-3	System budgets on the subsystem level, mainly power, mass, thermal, link budget, dimensions and equipment lists for each domain
SO-4	Estimate of required supplies/consumables (e.g. CO_2, tools and spare parts)
SO-5	Investigation of human interaction with systems and documentation of process and operational procedures e.g. harvest, maintenance as well as layout of an overall mission plan
SO-6	Definition of the operational, scientific and hardware development goals during the Antarctic test phase (incl. measurements to be conducted)
SO-7	Prepare list of critical questions per domain

1.4 *Study Domains*

The domains of the EDEN ISS CE study are illustrated in Figure 1-1. As these domains differed from the typical satellite design studies conducted within the Concurrent Engineering Facility, the disciplines along with a specific description of their responsibilities were detailed in the EDEN ISS CE study scope document.

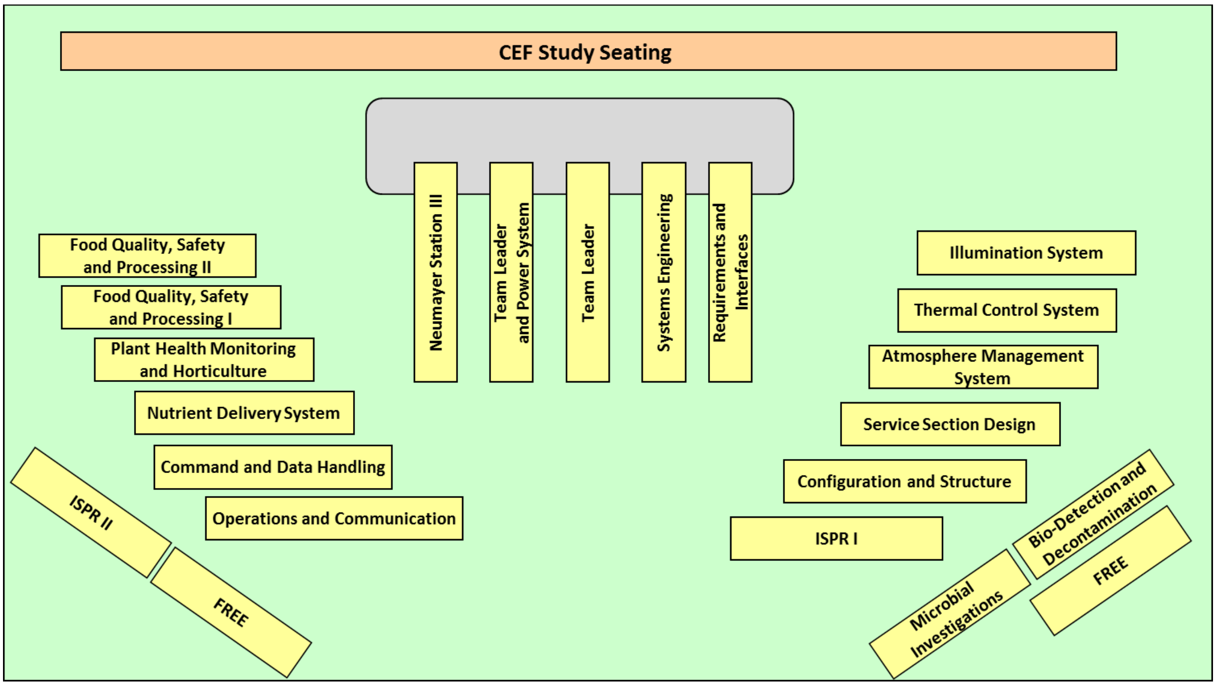


Figure 1-1: EDEN ISS CE study domain distribution.

The EDEN ISS CE study involved participants from all EDEN ISS project partners. The specific study participants and their responsibilities during the study are listed in Table 1-3.

Table 1-3: CE study team.

No.	Discipline/ Domain	Responsible	Contact
1	Team Leader	DLR (Daniel Schubert)	daniel.schubert@dlr.de
2	Co Team Leader	DLR (Paul Zabel)	paul.zabel@dlr.de
3	Systems Engineering	DLR (Matt Bamsey)	matthew.bamsey@dlr.de
4	Nutrient Delivery System	UoG (Mike Stasiak)	mstasiak@ces.uoguelph.ca
5	Illumination System	HS (Anthony Gilley)	anthony.gilley@heliospectra.com
6	Air Management System	AS (Giuseppe Bonzano)	bonzano@sekur.it
7a	Horticulture & Plant Health Monitoring	DLO (Tom Dueck)	tom.dueck@wur.nl
7b	Horticulture & Plant Health Monitoring	DLO (Frank Kempkes)	frank.kempkes@wur.nl
8a	Thermal Control System (& Modeling/Simulation)	ES (Erik Mazzoleni)	e.mazzoleni@enginsoft.it
8b	Thermal Control System (& Modeling/Simulation)	ES (Diana Magnabosco)	d.magnabosco@enginsoft.it
9a	Data Handling & Command	DLR (Conrad Zeidler)	conrad.zeidler@dlr.de
9b	Power Subsystem	DLR (Paul Zabel)	paul.zabel@dlr.de
10a	Operations & Communication	TPZ (Antonio Ceriello)	antonio.ceriello@telespazio.com
10b	Operations & Communication	TPZ (Raimondo Fortezza)	raimondo.fortezza@telespazio.com
11	ISPR I	TAS-I (Giorgio Boscheri)	giorgio.boscheri@thalesaleniaspace.com
12	ISPR II	TAS-I (Christian Lacopini)	christian.iacopini@gmail.com
13	Configuration & Structure	DLR (Vincent Vrakking)	vincent.vrakking@dlr.de
14	Service Section Design	DLR (David Gyimesi)	david.Gyimesi@dlr.de
15	Food Quality/ Safety and Processing I	CNR (Alberto Batestelli)	alberto.battistelli@ibaf.cnr.it
16	Food Quality/ Safety and Processing II	LIT (Peter Downey)	Peter.Downey@lit.ie
17	Bio-detection & Decontamination	ADS (Viktor Fetter)	viktor.Fetter@airbus.com
18a	Neumayer Station III	AWI (Eberhard Kohlberg)	eberhard.kohlberg@awi.de
18b	Neumayer Station III	AWI (Dirk Mengedoht)	dirk.mengedoht@awi.de
19	Systems Requirements & Interfaces	LSG (Bob Davenport)	bob.davenport@liquifer.com
20	Microbial Investigations	DLR-ME (Petra Rettberg)	petra.rettberg@dlr.de
21	Outreach/ Animation Design	LSG (René Waclavicek)	rene.waclavicek@liquifer.com
-	Study Team Support	DLR (Pierre Delmotte)	pierre-alexander.delmotte@dlr.de
-	Study Team Support	DLR (Amin Mohamad)	mohamad.binmohamadhilmi@dlr.de

Figure 1-2 and Figure 1-3 show pictures taken of a number of the EDEN ISS study participants during week 1 and week 2 of the design study.

Figure 1-2: EDEN ISS CE study participants – Week 1.

Figure 1-3: EDEN ISS CE study participants – Week 2.

1.5 *Study Products*

This document, Deliverable D2.5 – Design Report, is a compilation of the EDEN ISS CE study results and is main product of the study. It includes a description of the design of the Mobile Test Facility, the allocation of sections and subsystems, the system budgets (e.g. mass, power) and CAD drawings. Also of relevance, is the stand alone subsystem calculator files that the CE study generated which list estimated masses, volume, power and cost values for subsystem components separated into location within the Mobile Test Facility (an example of which is shown in Figure 1-4).

Nutrient Delivery System

Last Updated: Nov 10, 2015 at 4:00 PM by MS

MOBILE TEST FACILITY

Element/Component	Qty	Spare parts	Mass per element (kg)	Total mass (kg)	Mass comments	Dimensions per element (mm) (L x W x H)	Power per element (W)
Ozone injection venturi	2	0	0.5	1		TBD	0
Ozone check valve	2	2	0.2	0.4		TBD	0
Tubing/piping type 1 - main distribution lines	8	0	0.47	3.8	3/4" SCH40 plastic pipi	varies	0
Tubing/piping type 1 - main return lines	8	0	0.47	3.8	1 1/2" SCH40 plastic pi	varies	0
Tubing - feed lines	40	10	0.16	6.4	1/4" polypropylene	varies	0
Optional NDS cooling system	2		1	2.0			
Subequipment 2 - Sensors							
Flow sensor	2	1	1	2		TBD	2
NDS Tank continuous level sensor	2	0	0.5	1		depends on final tank size	0
Level switch sensor (fresh water tank)	1	0	0.2	0.2		TBD	0
pH sensor	4	2	0.25	1		TBD	0
EC sensor	4	2	0.25	1		TBD	0
DO sensor	4	2	0.5	2		TBD	0
Sensor transmitter	2	1	0.5	1		TBD	0
Arduino Mega	2	1	0.1	0.2		100 x 50 x 20	20
Sensor transmitter box	2	1	0.3	0.6		60 x 220 x 125	0
Sensor plumbing connector - pipe fitting	6	0	0.5	3		TBD	0
Temperature sensor	4	2	0.1	0.4		TBD	0
Ion-selective sensor and associated HW (handheld)	1	0	5	5		TBD	20

Figure 1-4: EDEN ISS CE study example screenshot from a subsystem calculator.

This design report also serves as basis for a number of other upcoming project documents and deliverables:

- Input to update deliverables D2.2 and D2.3 regarding the external and internal interfaces
- Input for CFD simulation report D2.6
- Input for operation modes and test plan report D2.7
- Input for design documents D3.1, D3.5, D3.7, D3.9, D3.11, D3.13

2 Design Overview

The EDEN ISS Mobile Test Facility (MTF) is being designed to provide fresh produce for overwintering crews at the Neumayer III Antarctic station while at the same time to advance the readiness of a number of plant growth technologies (including a full rack plant growth system demonstrator) and operational procedures. The MTF will consist of two 20 foot high cube containers, which will be placed on top of an external platform located approximately 200 m from the Neumayer Station III. The MTF including its elevated platform is graphically depicted in Figure 2-1.

Figure 2-1: Illustrative impression of the EDEN ISS Mobile Test Facility.

The actual MTF can be subdivided into three distinct sections:

- Cold porch: a small room providing storage and a small air buffer to limit the entry of cold air when the main access door of the facility is utilized.
- Service Section: houses the primary control, air management, thermal control, nutrient delivery systems of the MTF as well as the full rack ISPR plant growth demonstrator.
- Future Exploration Greenhouse (FEG): the main plant growth area of the MTF, including multilevel plant growth racks operating in a precisely controlled environment.

The detailed layout and design of the MTF is described in the various chapters of this design report.

2.1 *Common Values*

To ensure that all domain leaders were employing the same baseline values the CE study participants came to a consensus on a number of key assumptions that are summarized in the sections that follow. Several external environmental conditions are summarized in Table 2-1. For detailed external conditions please reference the *EDEN ISS-DLR-WP2.1-Exterior Environmental Conditions* report.

Table 2-1: Neumayer III exterior environmental conditions summary.

Exterior			
Parameter	Value		Note
Temperature	Summer	+5°C	Max
	Winter	-50°C	Min
RH	Nominal	70-95%	Absolute humidity is very low
$ppCO_2$	Nominal	~400 ppm	
Wind speed	Mean	9.1 m/s	Annual mean
	Max	50 m/s	
Light levels	Summer	960 W/m^2	Max
	Winter	0 W/m^2	Min

It should be recalled that these were the input values utilized during the CE study but these and other assumptions may indeed evolve over the project and that the current values can be found with tine EDEN ISS *System Requirements Document* or in the stand alone EDEN ISS common values document. The internal MTF environmental set points and limits within FEG, Service Section and cold porch are illustrated in Table 2-2.

Table 2-2: Internal FEG, Service Section and cold porch environmental set points and limits.

Future Exploration Greenhouse				
Parameter		Value		Note
Day	Temperature	Nominal	22°C	
		Max	30°C	For 1 day with light
			34°C	
		Min	8°C	For 2 days
	RH	Nominal	70±5%	
		Max	96%	For 4 hours
		Min	45%	For 12 hours
	ppCO2	Nominal	600-700 ppm	Target 650 ppm
		Max	1500 ppm	For 24 hours
	ppEthylene	Max	15 ppb	
			100 ppb	For 30 minutes
	Wind speed	Nominal	0.2 m/s	
		Max	5 m/s	For a few hours
Night	Temperature	Nominal	18°C	
		Max	25°C	For 2 days in dark
		All other min and max temperature values same as day		
	RH	Same as day		
	ppCO2	Nominal	400-800 ppm	
	ppEthylene	Same as day		
	Wind speed	Same as day		
Service Section				
Parameter		Value		Note
Day	Temperature	Nominal	21°C	
	RH	Nominal	25-30%	
	Parameter	Value		Note
Night	Temperature	Nominal	18°C	
	RH	Nominal	No control	
Cold Porch				
	Parameter	Value		Note
Day and Night	Temperature	Minimum	5°C	
	RH	Nominal	No control	

A number of other key values and assumptions relevant to the EDEN ISS design team are depicted in Table 2-3. These, like those specific for the illumination system/LEDs shown in Table 2-4 further ensure that the design team utilizes the same baseline values in their analyses. Key values on the LEDs are illustrated due to their significant influence on the overall MTF, in particular on the overall power requirements.

Table 2-3: Other important EDEN ISS key values and assumptions.

Other Important Key Values / Assumptions			
Parameter		Value	Note
Plant growth trays	Total	40	
	Short	22	
	Tall	18	
Tray dimensions	Length	60 cm	
	Wide	40 cm	
	Height	5-12 cm	
Production area		12.3 m^2	Assumes 3 cm extra for each side of tray
Leakage		500%/day	Volume exchanges
NM-III time zone		UTC	
CO_2 abs rate		25 g/hr	Crops at full maturity. Assumes all racks full. During light period.
O_2 production rate		18 g/hr	Molar mass ratio O_2:CO_2. During light period.

The intensity values shown in Table 2-4 represent all the LEDs within the MTF and the total power values assume that all plant growth racks are fully active. The listed intensity values are those provided at the plant canopy. More specifics on the illumination system can be found in the chapter 6.

Table 2-4: Illumination system specific key values and assumptions.

LED Key Values / Assumptions					
Type	Bars	Sets	Intensity (µmol/m^2/s)	Power per set (W)	Total Power (W)
Short	16	8 (each has 2 bars)	300	124	992
Tall	27	9 (each has 3 bars)	600	249	2241
Germination	6	3 (each has 2 bars)	150	62	186
Backlight	3	1 (each has 3 bars)	600	249	249

3 Configuration and Structure

The Mobile Test Facility (MTF) will be constructed using two 20 foot containers, to be connected in-situ in the Antarctic (See Figure 3-1). One of the containers will be utilized as a Future Exploration Greenhouse (FEG), while the other container will house the Service Section and a cold porch.

Figure 3-1: Mobile Test Facility exterior.

Figure 5-2 below gives a top view of the MTF interior, with labels indicating the different sections. The design illustrated in the images in this report represents the state of the MTF at the end of the CE study. The top level design is fixed, barring major complications, and will serve as the basis for subsystem and component level design work during the remainder of the project.

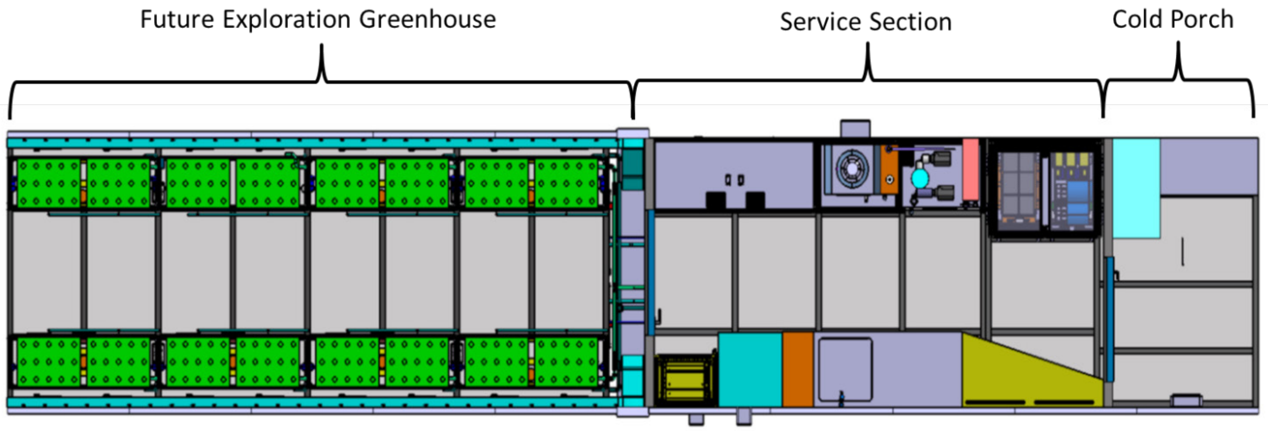


Figure 5-2: Top view of Mobile Test Facility internal configuration.

In this chapter, the configuration of the different subsystems and components in the two containers is presented, along with a discussion of the trades which were considered during the CE study. Additionally, the current internal structural design of the MTF will be shown, along with the relevant calculations as justification. The chapter has been split into four sections, in which the three parts of the MTF will be addressed, respectively: the cold porch, Service Section and FEG. The fourth section details the structural design and related calculations.

3.1 *Cold Porch*

3.1.1 Baseline Design

The cold porch is the entrance area to the MTF and serves to keep the Service Section and FEG protected from the external environmental conditions in the Antarctic. Upon entering, crew will store their gear in a storage cabinet and don protective gear (e.g. lab coats and overshoes) to minimize contamination of the MTF. In addition to the storage cabinet, the cold porch will house safety equipment, a fresh air inlet unit and, in the current design, a cabinet for CO_2 cylinder storage. Underneath the raised floor in the cold porch a fresh water tank and a waste water tank will be installed, which will be accessible to the crew by removing one of the floor panels. To ensure that the temperature within the cold porch remains within acceptable limits, a heater will be installed on the wall of the cold porch to prevent temperatures from dropping too low.

CO_2 cylinder cabinet

During the study the subject of CO_2 storage inside the cold porch was debated in comparison to an outside storage option. After estimation of the gas amount required during the Antarctic mission, it was found that two 13 L cylinders can support the CO_2 demand of the FEG for 54 days. Given that these cylinders weigh 33 kg each, a larger cylinder size would not be feasible from a handling perspective. A smaller cylinder size would require more spare cylinders and a higher exchange rate which was deemed undesirable. The selected cylinder size also provides convenient balance between cylinder exchange cycle and storage space taken up by the cabinet. The cylinders come in a size of 204 mm in diameter and 720 mm in height, based on data from Linde AG (Linde, 2008), which imposes a minimum size requirement on the cabinet. An additional requirement was to select a cabinet equipped with an overpressure valve, or if that is not available, the possibility to equip it with one after the purchase. This safety valve is to be used to vent gas to the outside of the container in case of a leakage. It was also taken into consideration that sufficient space is needed inside the cabinet above the cylinders to accommodate the CO_2 regulator, control valve and pressure gauges. This would take up approximately 150 mm in height.

The currently available gas cylinder cabinets are mainly designed to accommodate 50 L bottles, which makes them excessively large for the purposes of this project. Furthermore, most of these cabinets are equipped with valves for O_2 or argon gases which are incompatible with German standard CO_2 valves. Furthermore, no commercially available cabinet was found with an overpressure valve in its stock configuration. When inquiring about this at a cabinet provider, the following answer was received: "*The cabinet itself does not have a safety overpressure valve. Our supplier stated this valve would be something you would find on your cylinder and not on the cabinet.*" This could be due to the fact that these cabinets are primarily designed for fire protection and not to retain or vent the stored gas.

This leaves no other options than to purchase the most adequately sized cabinet and modifying it to meet the requirements, or to construct a customized cabinet. The second option is likely to be more time consuming and costly, therefore the first option is currently preferred. The selected cabinet is the MG109 gas cylinder cabinet (Grainger, 2015), shown in Figure 5-3, with external dimensions of 609,6 × 457,2 × 1117,6 mm and inside dimension of 502 × 375 × 1022 mm.

Figure 5-3. MG109 CO_2 cylinder cabinet with bottle dividing plate for smaller cylinders.

3.2 *Service Section*

3.2.1 Baseline Design

The Service Section houses the majority of the subsystem components, as well as the ISPR plant cultivation system. Additionally, the Service Section provides working space for the crew and it will have the cable and pipe interfaces to the exterior of the MTF. Figure 3-4 and Figure 3-5 are section views of the Service Section, with labels to indicate the different subsystems and components.

It was decided to place the ISPR as close to the cold porch as possible, since there are no interfaces between the ISPR and the FEG, as opposed to the other subsystems which do interface with the FEG. The AMS was placed directly next to the ISPR to maximize the available space for the air ducts, allowing for a smoother curvature and thus also a more optimal airflow through the ducts. To optimize the volume usage efficiency, the Thermal Control System (TCS) components were placed on either side of the AMS components. The NDS equipment was placed as close to the FEG as possible as it has the largest number of pipes running to and from the second container.

The north-facing side of the Service Section is dedicated to crew activities, with monitors, work benches, tool storage and a sink. Additionally, the computers for command and data handling activities and the power control and distribution cabinet are placed on this side. A large window, ~1600 x 600 mm, is located above the fixed workbench and provides a view of the Neumayer III Station. The workbench nearest the cold porch is wall-mounted and can be folded down against the wall to increase the space available for operating and maintaining the ISPR. Underneath the work benches, the crew will be able to place waste tanks and temporarily store consumables or spare parts.

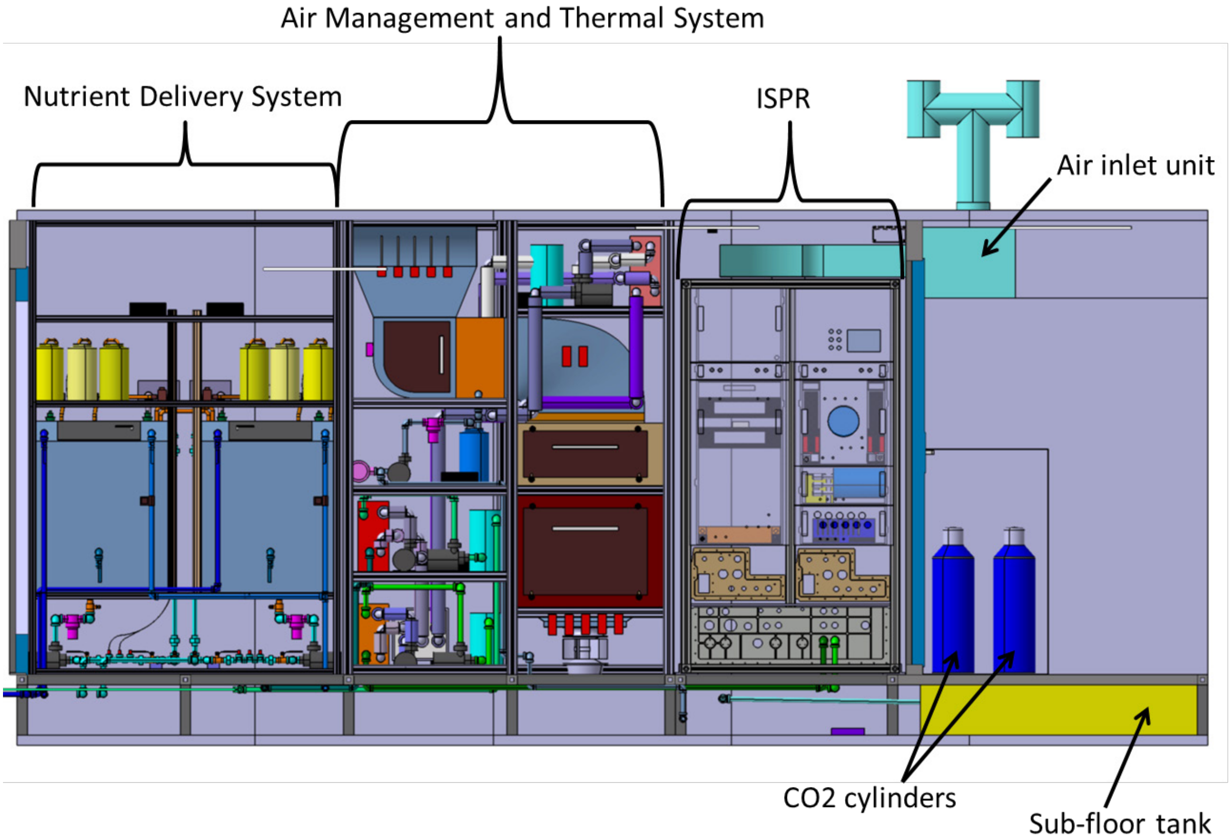


Figure 3-4: Service Section cut view – South side.

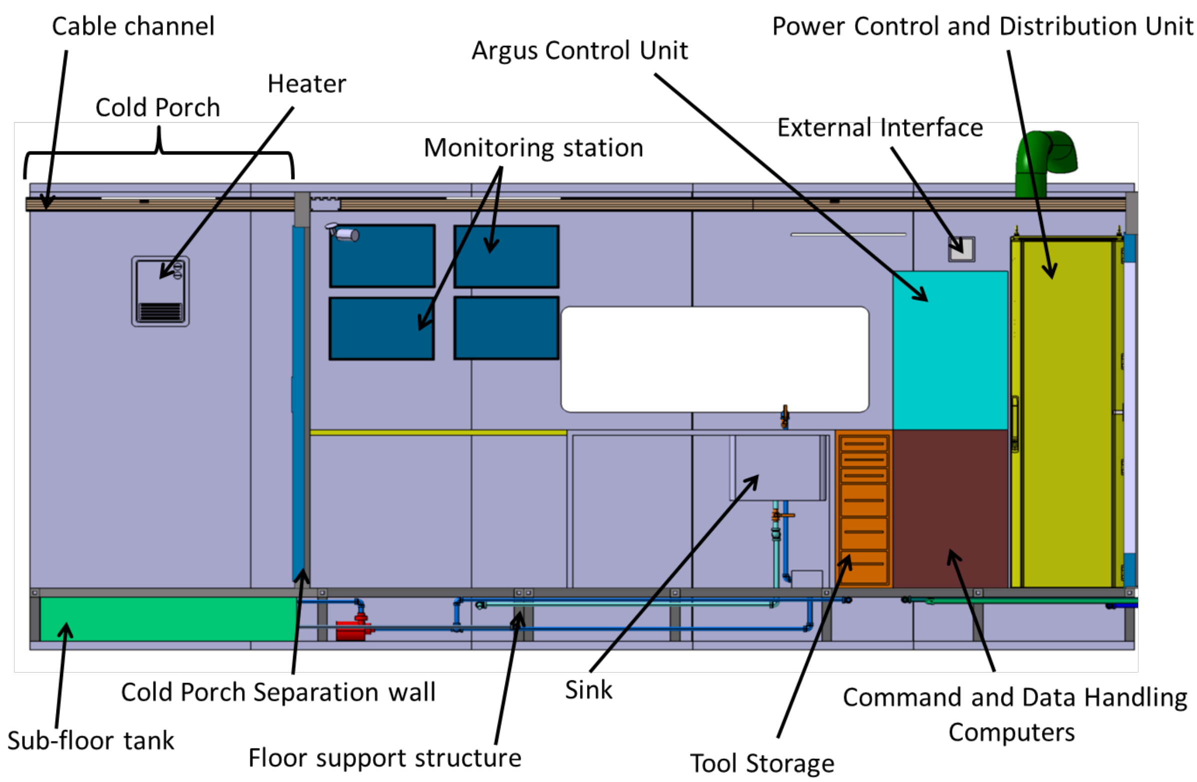


Figure 3-5: Service Section cut view – North side.

As the design matures the component dimensions may vary and result in minor alterations to the overall layout. The different subsystem configurations and related trade-offs will be discussed in the following chapters. In this section a few key aspects, unrelated to specific subsystems, are addressed, such as the doors and separation walls, as well as the external interfaces, among others.

Container doors

The MTF is designed to have four doors: one for the main entrance, one for an emergency exit, a door between the cold porch and Service Section and a door between the Service Section and the FEG. The entrance and emergency exit doors are exposed to the external conditions, furthermore they have to isolate and maintain the internal temperature as long as it is possible. Therefore following the reference found in the NM-III Air Chemistry Observatory documentation (AWI, 2006), a deep freezer door manufacturer, Teledoor was selected as a promising choice for supplying the required doors.

For the entrance, a GT12 1100 × 2000 × 100 mm walking fridge door was selected, having a list price of €1810 [*see Service Section data references folder - Teledoor*]. This has a frame size of 1300 × 2100 × 100 mm which is important from the structural design perspective. For the emergency exit, the same type of door was selected but in a slightly smaller configuration of 1000 × 1900 × 100 mm, having a frame size of 1200 × 2000 × 100 mm and a list price of €1690. The GT12 model can be seen on the left-hand side in Figure 5-6. A door was chosen over a smaller hatch to enhance its overall functionality. For example, during the testing phase of the MTF in Bremen and build-up phase in Antarctica, a full-size door will serve to enhance access to the facility, during these times of high traffic.

The door which separates the cold porch and the Service Section is a simple hinged construction with a rubber seal around its edge. Its main function is to keep the higher temperature of the Service Section from mixing with the lower (e.g. down to 5°C) temperature in the cold porch which requires no specific features. Hence a BT6 was selected in a size of 1000 × 2000 × 80 mm with a frame size of 1200 × 2100 × 80 mm [*see Service Section data references folder - Teledoor*]. This door, shown on the right-hand side in Figure 5-6, has a list price of €1300.

During the CE study the option of having a transparent glass sliding door separating the Service Section and the FEG was addressed. Such a door would allow visitors, without entering the FEG, to enjoy the psychological benefit a greenhouse provides in such a harsh and almost “monochromatic” environment where no plants are growing. The possibility of having a hermetically seal door was also discussed to isolate the FEG environment to the highest level possible.

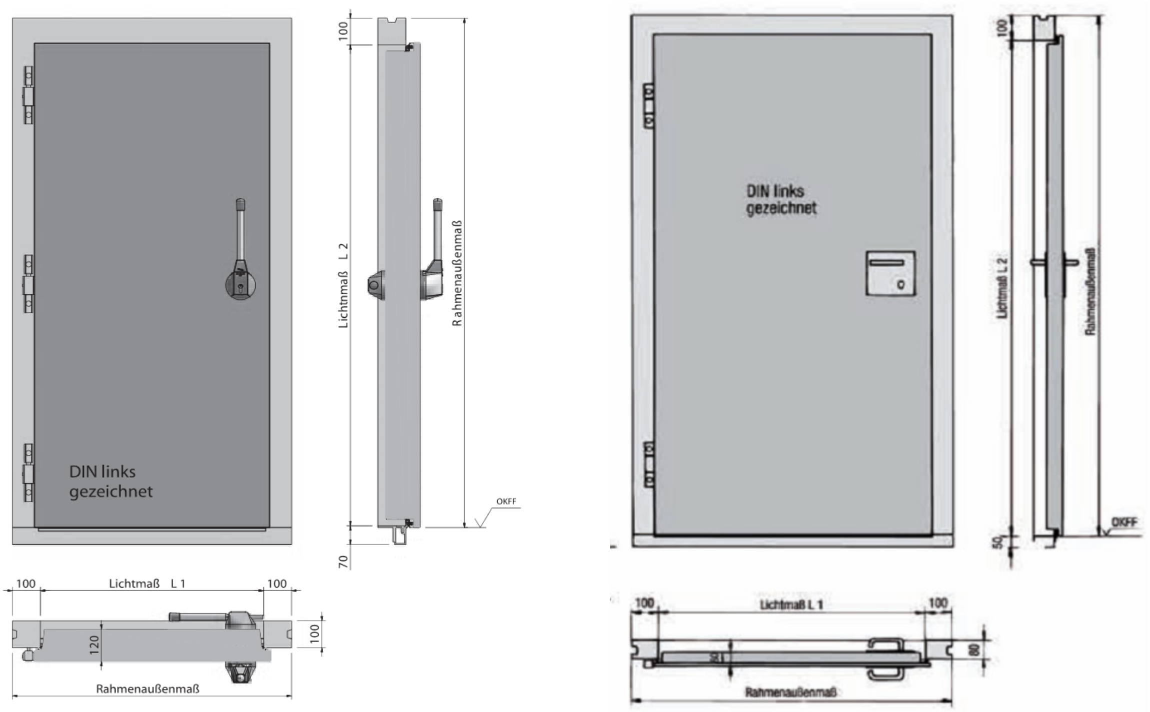


Figure 5-6: GT12 container door (left). BT6 separation wall door (right).

Research into the commercially available options indicated that this option was not feasible on account of the higher costs, as well as the larger envelope required to install and operate a sliding door within the MTF. Dortek and Tanehermetic, both hermetic sliding glass door manufacturers, were contacted and provided an initial quote for the required door [*see Service Section data references folder - DORTEK and Tanehermetic*]. The Dortek MS-5 bi-parting sliding glass door was offered at €9046 while a non-hermetically closing K0/0 HB-SL bi-parting sliding glass door was listed at €8141. Tanehermetic’s TH7 GH 40 hermetic sliding glass door without bi-parting option was offered at €2902. This amount and the fact that the doors would take up more space on each side of the separation wall would rule out this option.

Since the sliding door was deemed infeasible, currently the baseline design for the separation wall between the Service Section and the FEG is to use the same Teledoor BT6 as was selected for the separation wall between the cold porch and Service Section. This is offered in a variety of sizes and means fewer complications when it comes to fitting the frame into its place. The price is also much more affordable and its gas retention capability should be suitable thanks to the rubber seal around the edges of the door frame. The main disadvantage is its hinged construction which mixes much more air upon opening and closing the door.

Container wall interface

In order to accommodate the thermal lines, power and data cables passing through the exterior wall of the container, a water and snow tight, low temperature resistant, insulated interface solution was needed. An overview of the number of interface lines which need to pass through the container wall into and out of the MTF is presented in Table 3-1. During the CE study no decision was made yet regarding the exact method of supply and removal of, respectively, fresh water and waste water. In the case where this would involve fluid lines passing through the container walls an additional, separate, wall interface will be used, similar to those which will be discussed here.

Table 3-1: Cables and pipes to be passed through the container wall interface.

Cable / pipe type	Amount	Diameter Ø (mm)
Thermal pipe	6	30-50
Main power cable	1	25
Flood light (power)	1	9
Door light (power)	2	9
Light surrounding the container (power)	1	9
Camera (power)	2	9
Weather station (power)	1	9
WLAN (power)	1	9
Power sockets	1	9
WLAN (data)	1	12
Weather station (data)	1	12
Cameras (data)	2	12
Safety hardware hard wire to NM-III (data)	1	12
Thermocouples (data)	1	12

Openings on the container wall are to be made on one side below the thermal control unit, on the opposite side, below the power control box and above the data acquisition box. This is to separate cooling, power and data lines and hence three interfaces are required. As mentioned, a fourth interface would be used if necessary to accommodate the fresh water and waste water lines. This fourth interface would be placed on the North-facing side of the cold porch, slightly above the raised floor.

A GK-Packsystem modular marine packing system (GK Marine, 2015) was selected as the most suitable candidate for the opening structure. This system has been proven within the Antarctic environment through use on the Air Chemistry Observatory at NM-III. The GK system consists of a steel or aluminium frame which is welded into place at the point where the cables or pipes need to penetrate through the container wall. The frame is filled with rubber block elements cut to pre-determined sizes. As the cables and pipes are placed through the frame, gaps are filled up by these rubber blocks which are then pressed together with a wedge seal to achieve water and gas tightness (Figure 3-7). The size and shape of the penetration can be selected according to the application and the loading conditions in the wall, as can be seen in Figure 3-8.

Figure 3-7: GK-Packsystem assembly example.

Figure 3-8: GK-Packsystem is used on ships to create water and gas tight connections through walls.

The sizes of the GK frames for the MTF were selected according to the sum of cables which are to be passed through each opening while also accounting for the wedge seal. As a result the following three frames were selected: SPK-2+2×2 (260 × 100 mm) for the thermal pipes and two SPK-2×1 (140 × 135 mm) frames for the data and also for the power lines. The latter one is the minimum size stock option that GK offers. The standard depth of the offered frames is 60 mm, but 100 and 200 mm options are also available. According to GK's brochure, custom frame depths are also offered but will likely not be required as the standard frame can be coated with thermal insulation to meet the requirements of the MTF.

Sump pump

The MTF is designed to have a water-tight insulation cladding beneath the raised floor. This basin or sump will prevent any leakages from seeping in to the insulation material of the containers. Each of the containers will have a separate basin, along with a sump pump to remove the liquid to the waste water reservoir. It is proposed to place two Refco - KAROO drain pan pumps (Figure 3-9) in the basins (Refco, 2015). These pumps have built-in water sensors to trigger the pump activation at a pre-determined water level. This product has a maximum capacity of 12 L/h which should be sufficient to handle any leakages and it can also be operated on 230 V which makes it ideal for the task.

Figure 3-9: Refco - KAROO drain pan pump.

Safety railing

It is expected that the crew operating the MTF will need occasional access to the roof for maintenance of equipment installed there as well as to remove snow and ice build-up. Depending on the frequency of access it might be necessary to have safety railings on the roof of the containers to prevent crew members from falling. In the baseline design the MTF will have a safety railing mounted on the top of the facility to provide a safe environment when working on the roof. A ladder which is to be mounted on the side of the container is also needed. The Air Chemistry Observatory documentation describes a safety railing made of aluminium bars with a 40x40 square cross section of 2 mm thickness, which is currently the baseline assumption for the EDEN ISS project as well. The ladder most probably will be designed with different cross section dimensions to withstand the loads when crew members are climbing it. Taking into account that the length and the width of the container is

12.1 × 2.45 m which needs to be surrounded by the safety railing with at least two horizontal levels and a meter long vertical bar at every meter the calculation yielded a weight of approximately 85 kg using an aluminium density of ρ = 2700 kg/m^3. This result already incorporates a 5 kg margin for miscellaneous equipment such as nuts and bolts. In case the railing material is changed to stainless steel the mass is expected to rise to about 200 kg.

Taking an example cost calculation from Kee Safety railing manufacturer to have an initial budget estimate, it is assumed that the total length of the railing which is 96.1 m would cost €3125.43 [*see Service Section data references folder – Kee Safety*]. This only accounts for the manufacturing, working hours, transportation and mounting costs. The raw material price is constantly changing and is specific to the task and thus not yet included in the cost estimate. It was also determined that 25% cost reduction could be achieved by using a modular rail structure, consisting of pre-fabricated bars (Figure 3-10) and connectors, which only needs to be assembled on site.

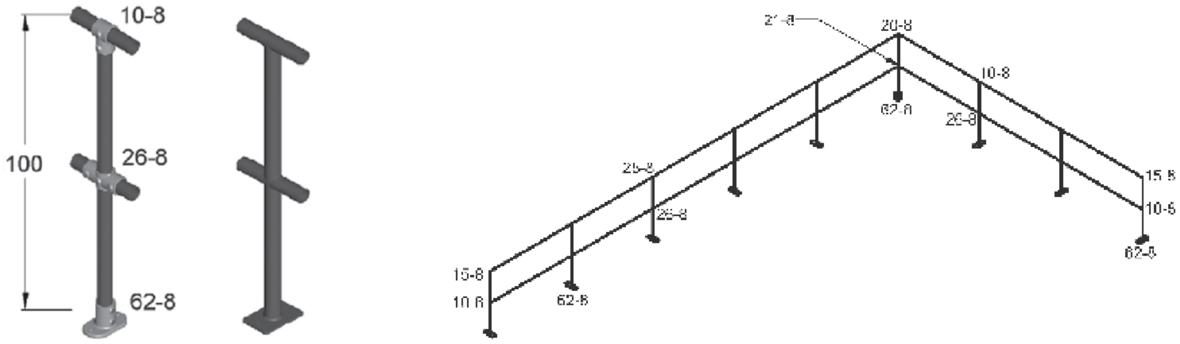


Figure 3-10: Kee Safety modular and welded safety railing examples.

Raised floor

To facilitate the routing of piping, there will be a raised floor within the MTF which will be 30 cm above the bottom insulation cladding. In the cold porch, the sub-floor space will be used to house the fresh water and waste water tanks, while in the Service Section the sub-floor area will be used to accommodate the air duct to the FEG and the fluid lines for the different subsystems, as well as some pumps, filters and other components.

The floor panels will be removable, to allow access to the sub-floor space. The initial design has not yet restricted panel sizes to allow for easy handling by a single crew member. Possible configurations can be found in (Bilco, 2015; BD Index, 2015). Handling experiments, trade-offs and panel selection will be part of further design efforts.

The baseline design for the floor support structure consists of 5 x 5 cm square hollow profiles of predetermined lengths, welded together into a single frame which is built into the container and fixed to the load-bearing structure of the container. The floor support structure is designed such that the subsystem ITEM racks can be directly affixed to the structure. A more detailed description of the structure design is presented in section 6.4.

3.2.2 Options and Trades

Two major design changes were made to the pre-study configuration of the Service Section:

- Prior to the CE study, the NDS cabinet was placed directly next to the AMS, while the Thermal Control System was located closest to the FEG, next to the NDS. Upon consideration of the pros and cons, it was found that it was beneficial to place the NDS closest to the FEG.

- In order to optimize the air flow through the AMS components, the configuration of the subsystem was significantly altered. As a result, the AMS and TCS are combined into one cabinet, as opposed to having separate, smaller, cabinets dedicated to each of the subsystems.

3.2.3 List of Equipment

A full list of structural elements and non-subsystem related equipment can be found in the subsystem calculators. A brief overview of the key values from the subsystem calculators is presented here, in Table 3-2, for the Service Section and cold porch, as well as the related components which are stored in NM-III or one of the external storage containers.

The container is listed as a separate item in the table. It includes the internal insulation and cladding, the raised floor support structure and panels, the separation walls and doors, the window, the Pack-system external interfaces, the external ladder and safety railing as well as additional cut-outs for air in- and outlet. The cost of this complete container is taken to be €40.000,- which was the amount assigned for it within the EDEN ISS proposal.

Table 3-2: Key values of the Service Section and cold porch structural elements and assorted equipment.

	Mass (kg)	Peak power (kW)	Nominal power (W)	Cost (€)
Container	6047,5	0	0	40.000,0
Cold Porch	2,2	0	0	82,5
Service Section	696,1	3,6	221,3	9.383,1
Neumayer III	1,4	0	0	27,5
Spares, consumables, tools	143	0	0	1.378,3
TOTAL	**6890,2**	**3,6**	**221,3**	**50.871,4**

The mass and cost for the Service Section equipment do not yet include the mounting equipment needed to attach the various racks and components to the container frame or the floor support structure.

3.3 *Future Exploration Greenhouse*

3.3.1 Baseline Design

The Future Exploration Greenhouse houses eight multi-level growth racks which will be used to cultivate the crops selected within deliverable D2.4 (plant analysis report) of the EDEN ISS project. In Figure 3-11 a top view of the FEG is presented. As seen in the image, each rack will have two growth trays per level, up to a maximum of eight growth trays per chamber. A total of 40 growth trays can be fitted within the FEG at a time, according to the layout shown in Figure 3-12. In the baseline design, a movable platform will be mounted on rails fixed to the ceiling. A pantographic system attached to this platform will allow for vertical movement of a tray with observation cameras. This system, discussed in more detail in Chapter 13, will allow for automated plant health monitoring of each growth tray within the FEG.

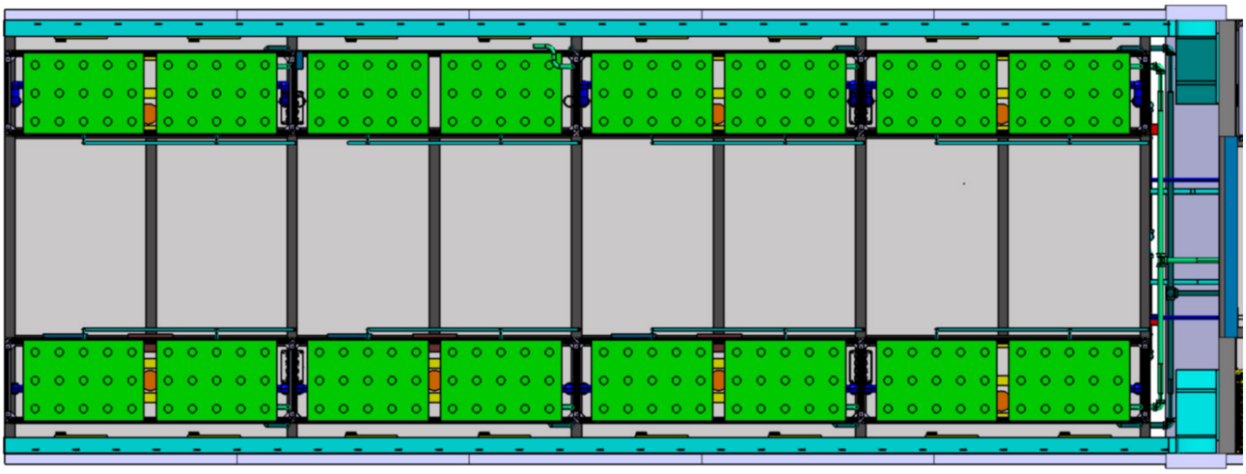


Figure 3-11: Future Exploration Greenhouse – Top view.

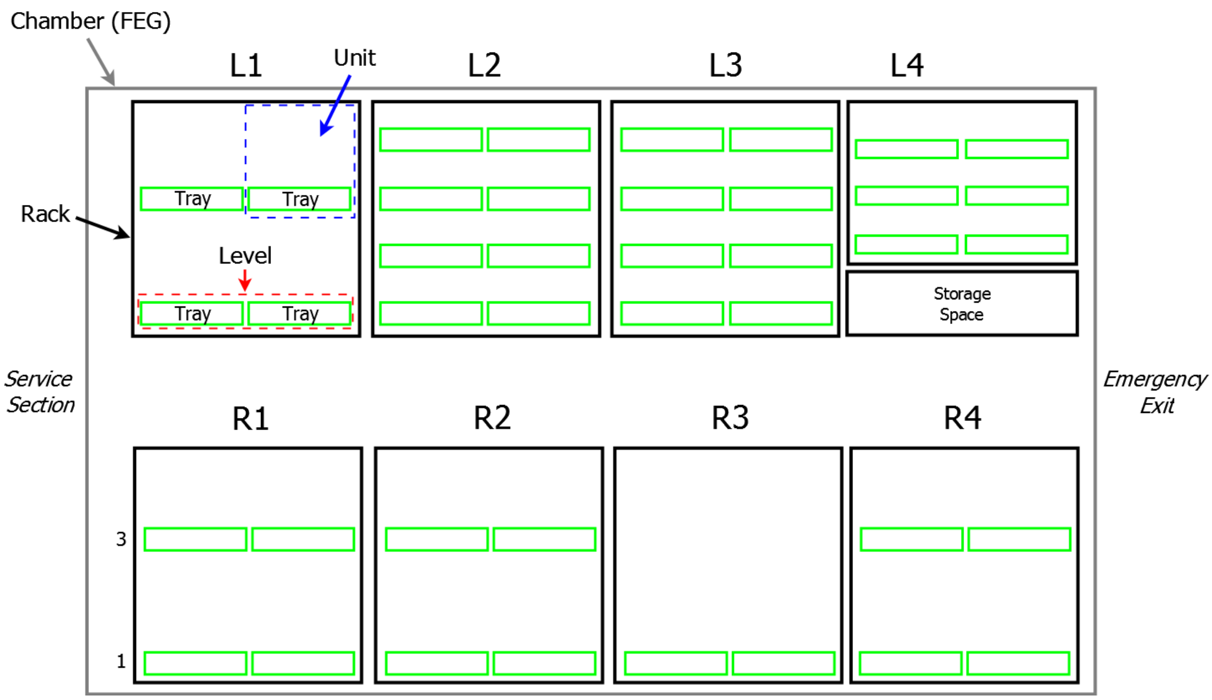


Figure 3-12: Future Exploration Greenhouse – Plant tray configuration including illustration of the relevant definitions of chamber, rack, unit, level and tray.

The baseline design for the plant growth racks within the FEG utilizes ITEM profiles, which are relatively cheap, lightweight and easy to assemble. The left-most image in Figure 3-13 is an illustration of the proposed rack design. Standard 30 x 30 mm ITEM profiles were selected. These profiles were selected because they are big enough to allow for easy manual assembly, while being as lightweight as possible. Calculations done using the worst case load scenario indicate that these profiles provide sufficient load-bearing capability to support the plants and subsystem components, as discussed in section 6.4. For the subsystem racks in the Service Section, 40 x 40 mm ITEM profiles were selected, to withstand the higher loads imposed on the structure.

Panels are used in the NDS, as well as the AMS & TCS, rack to support smaller components. Additionally, the fronts of the racks will be shielded with panels which are coated with acoustic material to reduce noise within the container. Potential acoustic material options were researched (Audimute, 2015), but a final selection still needs to be made.

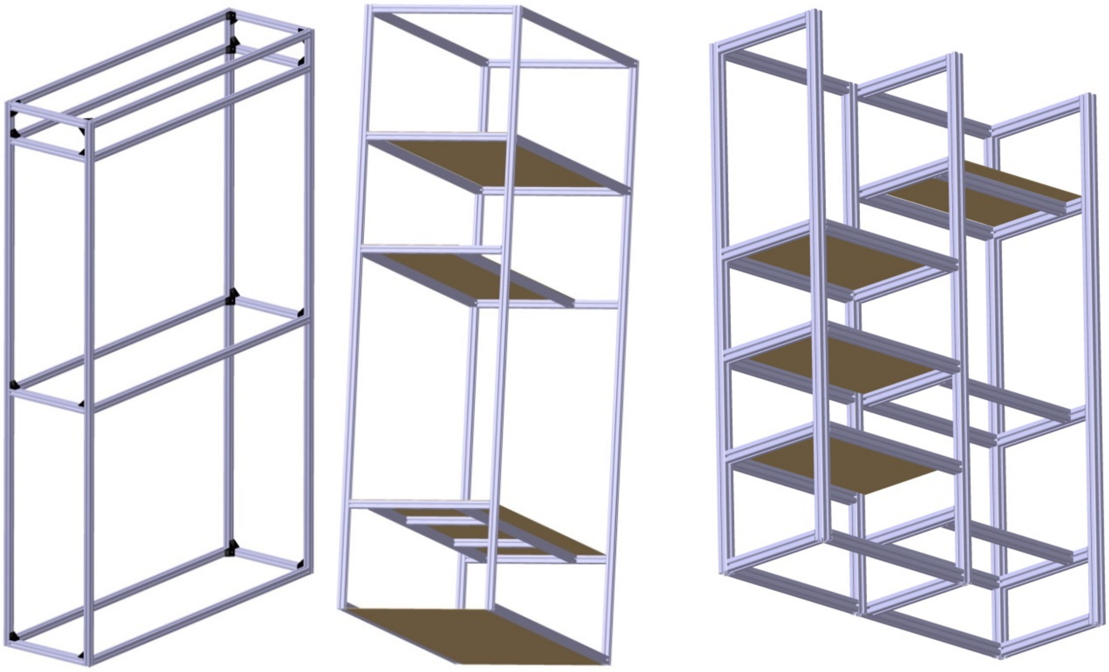


Figure 3-13: FEG rack (left). NDS rack (middle). AMS & TCS rack (right).

Raised floor

Similar to the Service Section and the cold porch, the FEG will also have a raised floor with a structural support frame. The frame serves to transmit the loads from within the FEG to the load-bearing structure of the external container. As in the other sections, 5 x 5 cm square hollow profiles will be used.

3.3.2 Options and Trades

The orientation of the growth trays and consequently the sizing of the growth racks were driven primarily by ergonomic requirements. Following the decision to have the air ducts located behind the growth racks, the pre-study configuration, shown in Figure 3-14, no longer provided sufficient corridor space to comfortably move around or perform maintenance tasks throughout the FEG. Thus, the orientation of the plant trays on the right side of the FEG was altered to increase the corridor size, at the cost of cultivation area.

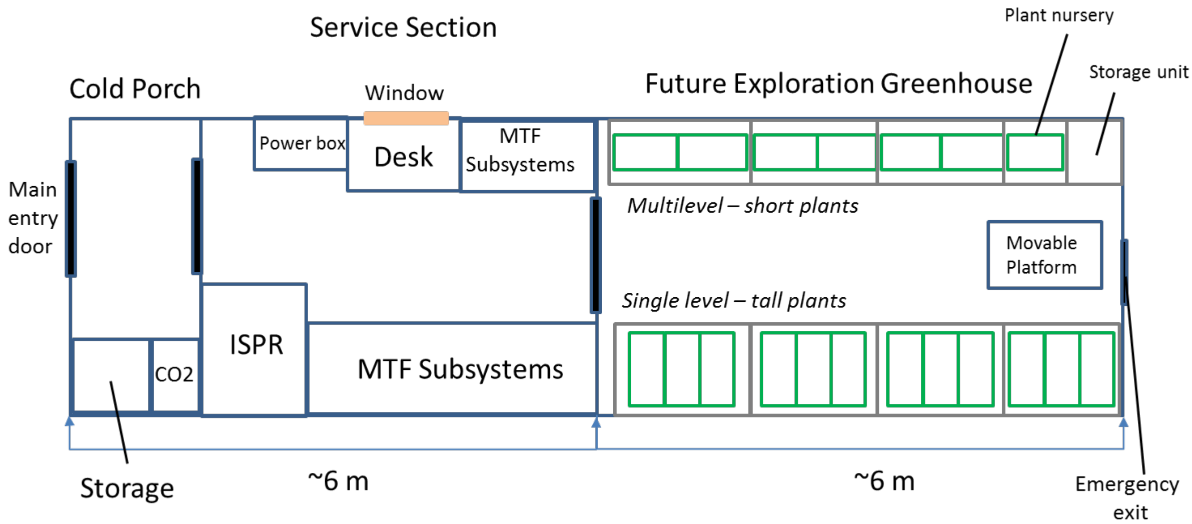


Figure 3-14: Pre-study MTF configuration.

3.3.3 List of Equipment

A full list of structural elements and non-subsystem related equipment can be found in the subsystem calculators. A brief overview of the key values from the subsystem calculators is presented here, in Table 3-3, for the FEG, as well as the related components which are stored in NM-III or one of the external storage containers.

The container is listed as a separate item in the table. It includes the internal insulation and cladding, the raised floor support structure and panels, as well as any cut-outs for air in- and outlet or interfaces which might be required upon further design review. The cost of this complete container is taken to be €40.000,- which was the amount assigned for it within the EDEN ISS proposal.

Table 3-3: Key values of the FEG structural elements and assorted equipment.

	Mass (kg)	Peak power (kW)	Nominal power (kW)	Cost (€)
Container	6288,9	0	0	40.000,0
FEG	262,9	0	0	4.040,5
TOTAL	**6551,8**	**0**	**0**	**44.040,5**

The mass and cost for the FEG equipment do not yet include the mounting equipment needed to attach the various racks and components to the container frame or the floor support structure.

3.4 *Structural Calculations*

The structural calculations discussed in this section can be split into two groups. The first group of calculations relates to the ITEM racks designed to house the AMS, TCS and NDS, as well as the racks used within the FEG. The second group of calculations was used in the design of the floor support structure.

3.4.1 ITEM racks

As mentioned previously, the baseline design incorporates three different ITEM racks, each with different loads imposed on the structure. For the initial sizing of the ITEM profiles a rough static analysis was performed using the estimated loads and a safety factor of 2.

The values used for the worst case load scenario are listed in Table 3-4 for the FEG rack, NDS rack and AMS & TCS rack respectively.

An online load calculator on the ITEM website was used to quickly check whether the selected profiles were capable of withstanding the loads or not. For the vertical ITEM profiles the standard axial loading equations were used to ensure the design was adequate. Further design efforts will include more detailed analysis, incorporating additional load cases, such as shipping and transport, as well as ensuring the connections and panels used in the ITEM racks meet the structural requirements.

Table 3-4: Relevant values for ITEM rack structural design calculations.

	Fx [kN]	Fy1 [kN]	Fy2 [kN]	Lx [m]	Ly [m]
FEG rack	1.3	0.15	0.42	1.38	2.25
NDS rack	1.3	3.1	2.1	1.44	2.25
AMS & TCS rack	1.3	0.6	1.0	0.76	2.25

In the table above, F_x is the horizontal load imposed on a rack, which is taken to be the force which can be exerted by an average human pushing against a vertical strut (NASA, 1999). F_{y1} is the maximum (resultant) vertical load imposed on a horizontal ITEM profile and F_{y2} is the maximum (resultant) vertical load acting on a vertical profile. L_x and L_y are the maximum lengths of the horizontal and vertical profiles respectively. The loads listed in the table above are approximate values as not all equipment masses are known yet. To account for variations which might occur later, a 10% margin was added to the vertical loads, which were estimated based on the masses listed in the subsystem calculators.

3.4.2 Floor support structure

The baseline floor designs are shown in Figure 3-15. To maximize the space available for ducts, pipes and other components, the structures only have vertical struts at the sides of the containers. The horizontal struts were placed to align with the structural elements of the ITEM racks, the ISPR and the separation walls. In the cold porch, the loading is small, compared to the other two sections, and here the struts were placed in order to allow convenient access to the sub-floor tanks and to limit the size of the floor access panels.

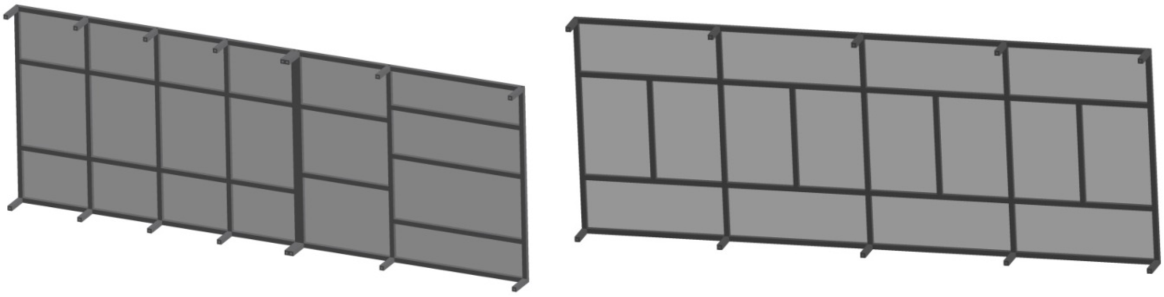


Figure 3-15: Cold porch and Service Section floor design (left). FEG floor design (right).

The maximum loads imposed on the floor support structure are listed in Table 3-5. For the initial sizing a safety factor of 2 is used, as before. The subsystem load bearing elements will be connected directly to the support structure, so the amount of loading on the floor panels is limited.

Table 3-5: Relevant values for floor support structure design calculations.

	Fy1 [kN]	Fy2 [kN]	Lx [m]	Ly [m]
Service Section	19	9.5	2.15	0.25
FEG	12.3	6.2	2.15	0.25

As before, F_{y1} is the max vertical load imposed on a horizontal profile, while F_{y2} is the max vertical load imposed on a vertical profile. Using the equations for maximum stress in a beam, clamped at both ends, subjected to loads at arbitrary points (Engineering Edge, 2015), along with the principle of superposition, the stress in the horizontal profiles was determined. The stress in the vertical profiles was again determined using the standard axial loading equation.

In addition to the loads imposed by the different components, a point load of 8.9 kN was applied as a live load according to Section 4.0 - Live Loads of (ASCE, 2003). This value is significantly higher than will realistically occur, so this assumption should be revisited during the later design stages.

The maximum allowable yield stress and the Young's modulus for steel were taken to be 502 MPa and 180 GPa respectively (The Engineering ToolBox, 2015). As mentioned, the profiles have 50 x 50 mm square cross-sections with an assumed thickness of 4 mm. A density of 8000 kg/m^3 was used to estimate the mass of the floor support structures in the subsystem calculator (see The Engineering ToolBox – Metals and Alloys - Densities). For the raised floor panels, the initial design assumes that aluminium sandwich panels will be used (CEL Components, 2015), with a mass of 2.8 kg/m^2.

4 ISPR

4.1 *Baseline Design*

The ISPR baseline preliminary design, consolidated during the CE study, is presented in the following sub-sections.

4.1.1 Overall Design

In this section the overall ISPR system design is described, including:

- ISPR system concept as precursor of ISS European Drawer Rack EDR II P/L
- Major impacts to ISPR system preliminary design of the CE study
- ISPR system interfaces with Mobile Test Facility (MTF)

The different subsystems are then detailed in the dedicated sub-sections.

4.1.1.a ISPR system concept as precursor of ISS European Drawer Rack EDR II P/L

The main objective of the laboratory and Antarctica ISPR system demonstration is to advance the technology readiness level of the plant growth facility technologies, in view of a near term experiment on the ISS. The facility shall represent an increment with respect to current flight capabilities represented by the NASA Veggie system, mainly in terms of:

- Higher available growth surface (0.5-1,0 m^2 range)
- Longer production cycle possible by complete nutrient solution circulation (and not only watering of substrate with slow release fertilization)
- Robust and reliable safe and high quality food production (while Veggie control capability is limited)

In order to target a feasible ISS exploitation scenario, the system is being designed as an EDR II payload. EDR II is a European rack, capable of hosting up to three experimental inserts (EIs). EDEN ISS ISPR will be modular and capable of operating either:

- as a single EI, ¼ rack, to test critical subsystems (i.e. nutrient delivery system)
- as a single EI, ½ rack, to test a complete system with one growth chamber (of incremental complexity)
- as multiple EIs, ¾ or full rack, with up to three independently controlled growth chambers

Figure 4-1 reports an image of EDR II Engineering Model, EDR II Experimental Inserts available volume and EDEN ISS ISPR system preliminary concept, clearly designed as precursor of ISS European Drawer Rack EDR II plant growth P/L.

The lower section of the rack is dedicated to the interfaces (power, data and cooling water) with the Mobile Test Facility. Above this section are placed the interfaces between the rack and the plant growth facility, exactly as for EDR II EIs interface panels. In the central portion of the system, the following P/L drawers are accommodated (see dedicated sections for more details):

- Power, Command and Data Handling Module
- Nutrient Storage and Distribution Module
- Growth chamber Modules (1 for short plants, 1 for taller plants), including each chamber dedicated air management systems, root modules and crop shoot-zone volumes
- Illumination Modules (one for each growth chamber)

In the top portion of the rack, a panel for manual monitoring and control of some of the rack key functional parameters will be housed, together with a storage drawer.

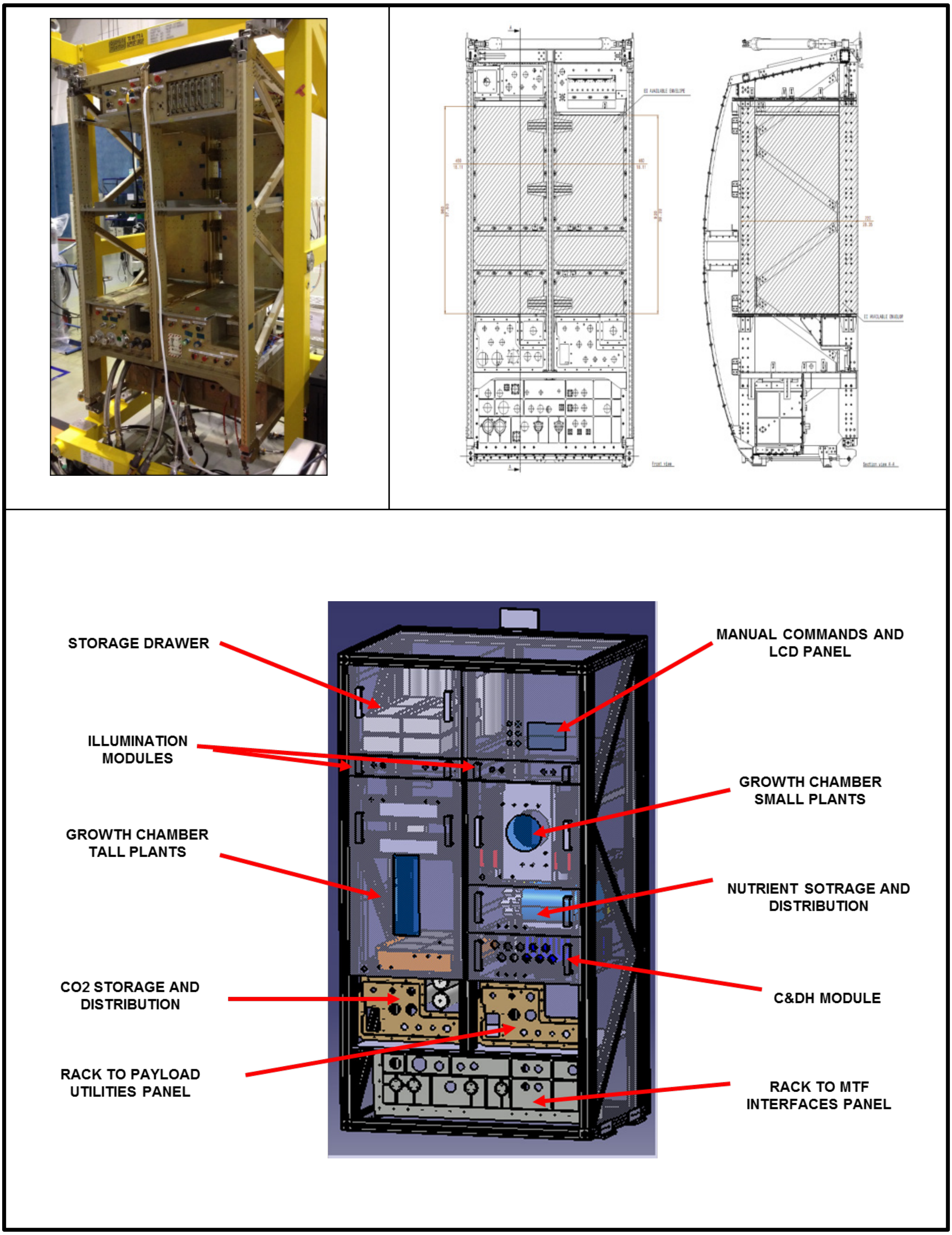


Figure 4-1: EDR II Engineering Model (top left); EDR II Experimental Inserts available volume (top right); EDEN ISS ISPR system concept as precursor of ISS European Drawer Rack EDR II P/L.

4.1.1.b Major impacts to ISPR system preliminary design of the CE study

During the CE study, a further iteration of the preliminary facility designed showed in Figure 4-1 was performed. The results are the following modifications (see also figure below):

- Added storage 130 L rack consumables volume in the top left section of the ISPR
- Implementation of windows (with shutter for visual inspection of the crops without interruption of the growth chamber functionality
- Implemented safety closure system (the drawer cannot open if the system is active)
- Implemented lateral (left side if looking at window) access to the drawer for easier maintenance operations

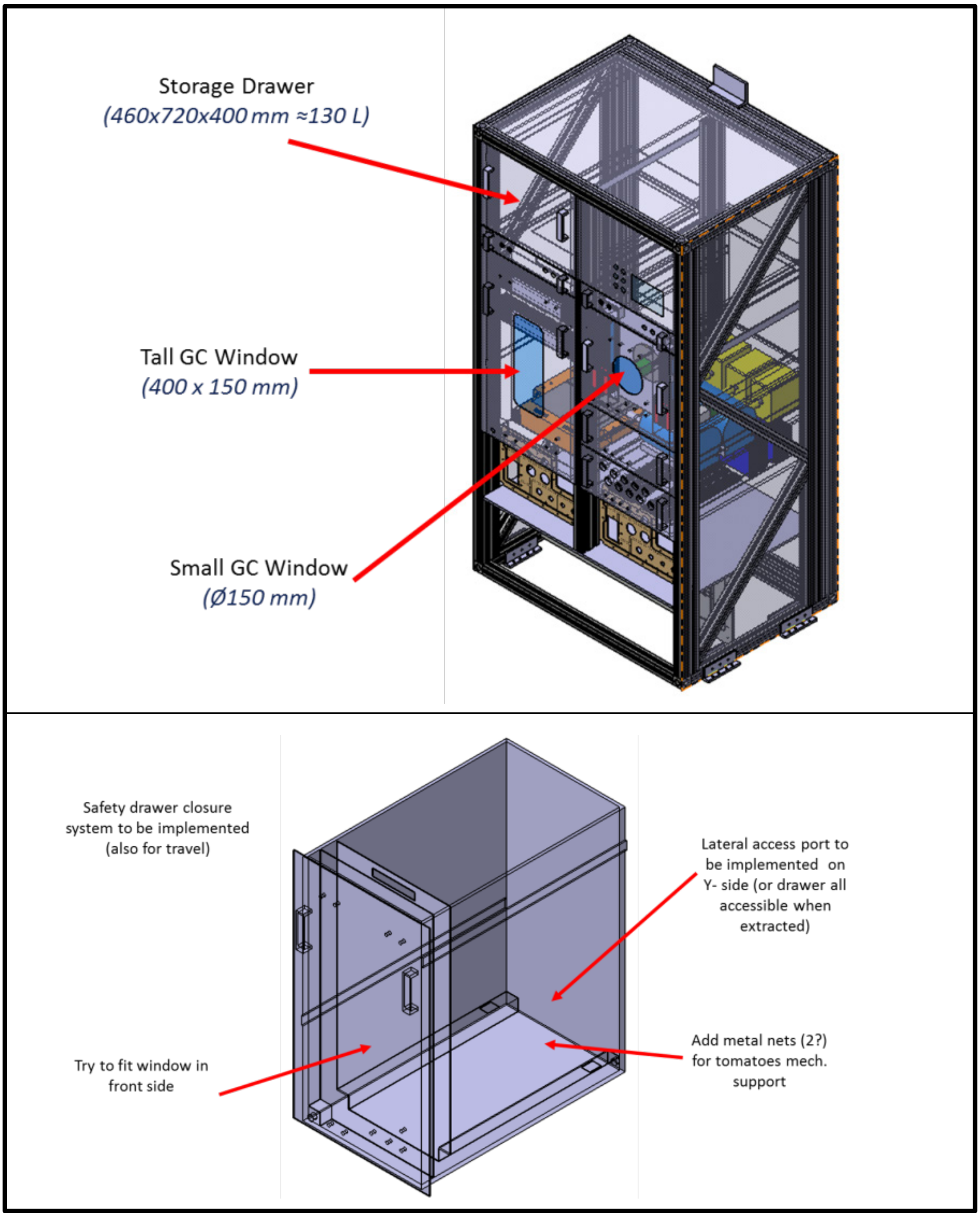


Figure 4-2: Major improvements to ISPR system preliminary design of the CE study.

4.1.1.c ISPR system interfaces with Mobile Test Facility (MTF)

The main interfaces preliminary identified between the ISPR system interfaces and the MTF are summarized as follows.

MECHANICAL INTERFACES WITH MTF

Fixation system /interface definition

- Fixation mainly to the bottom (minimize conductive paths through the lateral walls) – i.e. 4x bracket with 6x M8 screws each in the bottom and one bracket on the top
- Available structural fixation elements properties (i.e. mechanical interfaces position and typology, load allowable, material) are to be provided by DLR – consider current preliminary rack mass budget of 360 kg plus safety margin (1.5 TBC)
- Special transport loads (beside road and boat) are to be provided by DLR (i.e. G-load due to sledge on bumpy ice)

Access for maintenance/inspection

- Main structure (ISPR)
    - Current assumption is that maintenance can be performed always from the front side (eventually dismounting the drawers)
    - No lateral inspection ports are foreseen
    - No sliding mounting is foreseen (if it will become necessary, it will likely increase unit height)
- Drawers
    - Drawers will be completely removable
    - Plant cultivation drawers will be accessible for operations from port on the left side (right side blocked by MTF wall for one of the chambers)
    - The inclusion of a window for plants observation is recommended

Rack dimension:

- Width: 1060 mm (however clearance to the sides is required for operating the drawers)
- Depth: 800 mm (not including handles and drawer harness in the front; not including bracket in the back, currently not foreseen)
- Height: 1950 mm (not including elements for fixation to the ground; not including hangers for movement with crane)

POWER INTERFACES WITH MTF

- Electrical IF
    - Type: 230 VAC, 10 A
    - 230 VAC connector (plug) characteristics to be identified by DLR
    - Position: rack bottom-front side
- 116-126 VDC: no need identified, not to be provided to ISPR
- 230 VAC to 24 VDC conversion within ISPR:
    - Design and procurement is responsibility of TASI
    - DLR shall provide AC/DC converter models eventually used in FEG, in an effort to increase commonality and have common spare parts

- Preliminary power budget:
    - Nominal mode: 1.5 kW peak, 0.9 kW avg
    - Reduced mode: 0.65 kW peak, 0.35 kW avg
        - *Remark: peak power is calculated with 600 umoles/m^2-s illumination and 160 g/m^2-h water vapour production simultaneously from both growth chambers – staggered production and/or staggered photoperiods and/or lower light demanding crops will reduce considerably these peak values (assumed at least 35% reduction)*

COOLING INTERFACES WITH MTF

- Cooling water inlet: 190 kg/h flow and temperature of 16 – 20°C (pump not included in ISPR)
- Cooling water outlet: 25°C worst case (max water inlet temperature, peak power, no dissipation to environment)
- IF type: Self-locking ½" quick disconnect (QD)
    - QD model and P/N to be identified (standard model for all similar FEG equipment could be selected)
- IF position: rack bottom-front side (attached to 10-15 cm long flex tube portion)

DATA INTERFACES WITH MTF

- IF type: LAN socket (no cable)
- IF position: rack bottom-front side
- Single interface for command uplink and telemetry downlink assumed for Compact RIO controller
    - 50 sensors, 1 Hz, 16 bit preliminary estimation
    - 4 cameras, 2 MB/picture, 5 pictures/day
- Possible additional data IF for other telemetry data to be connected to the Argus system
    - i.e. power consumption measurement of critical subsystems via SOCOMEC Countis E meter

AIR EXCHANGE INTERFACES WITH MTF

Each growth volume will have an air inlet and outlet connected with the Service Section environment, thus Service Section environmental parameters are needed to model gas exchange:

- Temperature and RH range (incl. different modes):
    - Day values are T = 21°C, RH = 25-30%
    - Night values are T = 18°C, RH = 25-30%
- CO_2 concentration range
    - Nominal values are <750 ppm (FEG value)

4.1.2 Illumination System

The ISPR illumination system will provide the same performance and capabilities of the FEG system, but with a different dedicated shape factor to cope with the peculiar drawer-like geometry of the rack. The LED panel preliminary specifications are the following:

- LED panel (2 units plus 1 spare):

- Monolitic element (envelope < 600x400x75 mm)
- Water cooled (1/4" fluidic self-locking quick disconnect IF to be confirmed) via commercial of the shelf cold plate
- Cold plate shall be dismountable on-site from the panel
- Same light "recipe" as that of the FEG
- Working at 24 VDC (to be verified for feasibility by HS)
- Dimmable from 600 to 100 umoles/m2-s (with each wavelength independently controlled) via Ethernet SEA 9715 IF (into CompactRio module http://www.sea-gmbh.com/en/products/compactrio-products/networking/sea-9715-ethernet-switch/), including health status monitoring
- With mechanical IF that shall allow mounting to illumination drawer structure (input provided by TASI after preliminary design of panel will be available)

- 230 VAC to 24 VDC Dimmable power source (2 units plus 1 spare)
    - Monolitic element (envelope < 200x200x60 mm)
    - Power ON/OFF condition controlled by TASI (via LabVIEW)
- Illumination module structure (for fixation to ISPR mechanical IFs)
- Small video camera (video data management to be investigated)
- Lexan (polycarbonate) transparent (≈85% eff in the visible, cut at 400 nm) plate as division from the plant shoot zone

The first 2 items (LED panels, power source) are responsibility of Heliospectra, while the others will be procured by TASI. A preliminary representation of the illumination module is given in Figure 4-3.

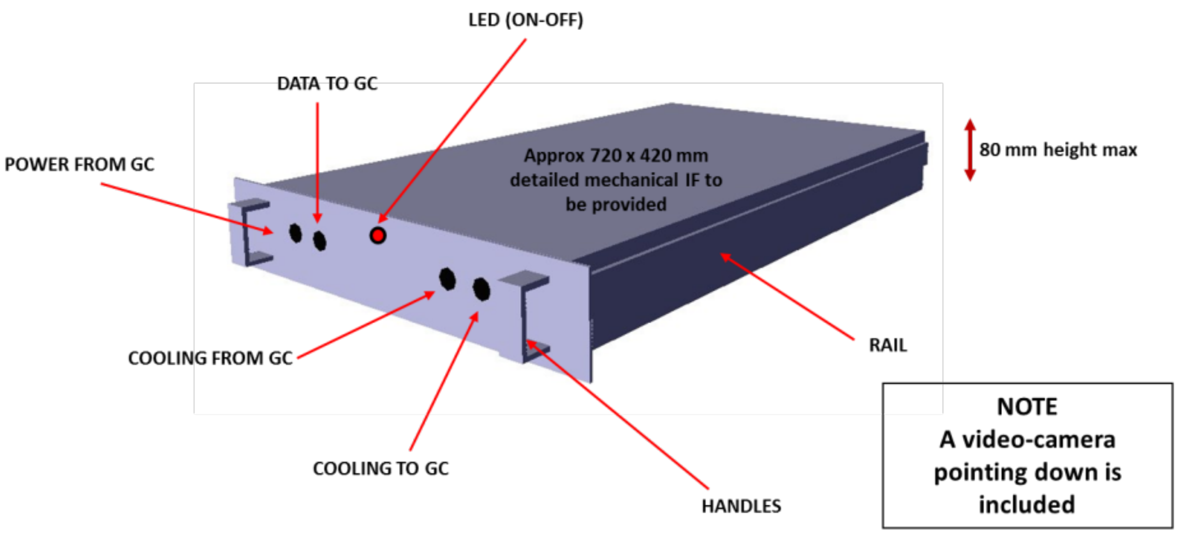


Figure 4-3: Illumination module preliminary representation, including interfaces to growth chamber (GC).

4.1.3 Atmosphere Management System and Thermal Control System

Each growth volume will have an independent air management system. The air management system will include:

- Temperature and humidity control system (THC)
- Major constituents control system (MCCS), managing the environmental pressure, as well as O_2 and CO_2 concentration
- Trace contaminants and microbiological control system (TCCS), removing organic gaseous contaminants (i.e. ethylene) as well as filtering out microbes and viruses

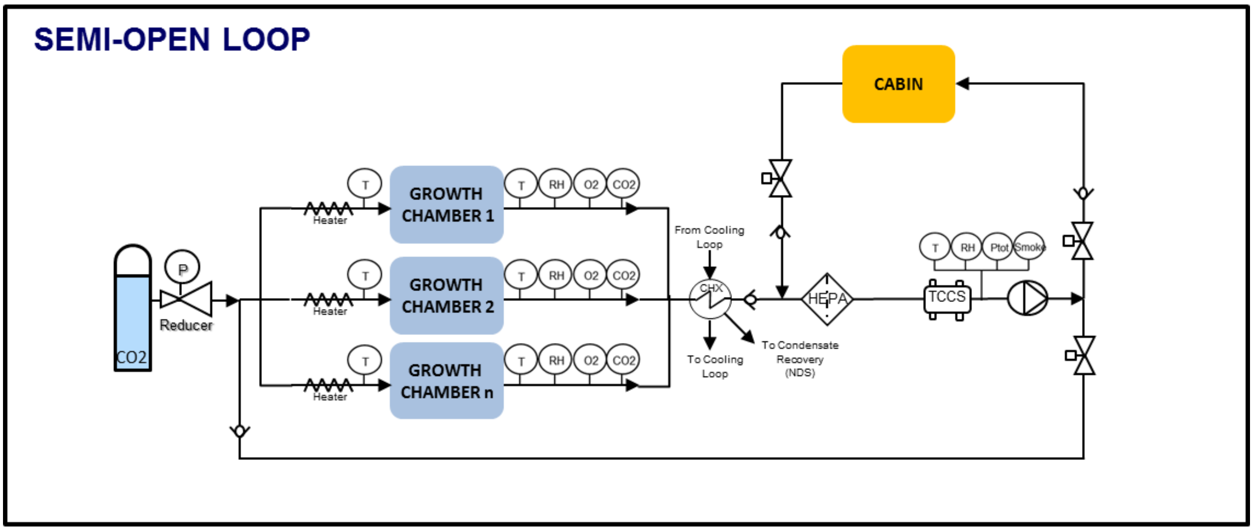


Figure 4-4: Overall air management system preliminary block diagram.

The air management system has been preliminary designed in order to be easily accessible and maintainable. Further upgrade of the selected technologies is also possible in this way.

The overall system preliminary block diagram is reported in Figure 4-4. Figure 4-5 reports a schematic of the technologies along the circulating air path as well as the preliminary distribution of the components within the growth chamber module volume. The commercial components preliminary identified and sized for each technology are then summarized in Figure 4-6. The system is described in more detail as follows.

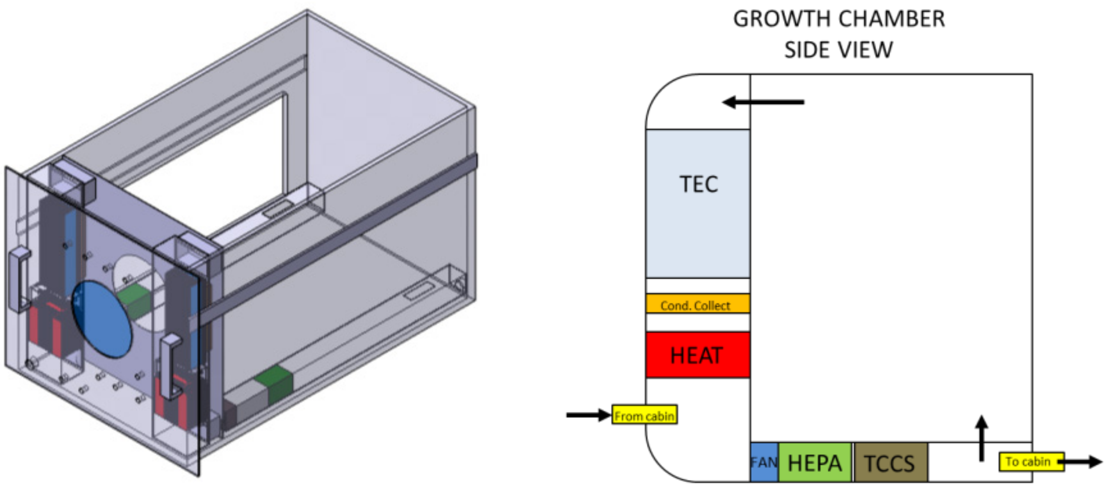


Figure 4-5: Schematic of the technologies along the circulating air path (right); preliminary distribution of the components within the growth chamber module volume, with redundant THC modules and TCCS modules per each chamber (left).

Temperature and humidity control

The air extracted from the shoot-zone volume is cooled by a thermo-electric cooler (TEC, using Peltier effect) to remove sensible heat loads as well as latent heat loads through condensation of water vapour. The water vapour is then collected by gravity in a custom made recipient, and then pumped through a UV-LED based disinfection system to the DI water reservoir within the Nutrient Storage Module. The over-cooled air is then reheated with a PTC heater. Both the TEC and PTC heater are insulated (i.e. with 2 mm thick Armaflex) to guarantee efficiency. The TEC is an air to water heat exchanger, and the heat collected at the water side is removed by cooling water with conditions as specified in section 4.1.1.c. Air temperature and humidity are monitored via a single multi-parametric sensor at the air extraction section, in order to provide feedback to the active control system.

Major constituents control

For oxygen and carbon dioxide concentration control, a semi-open loop strategy is implemented. In normal operations the shoot-zone air is circulated in a closed loop until the O_2 concentration rises to a certain threshold (i.e. not acceptable fire risk). Then air is exchanged with the (MTF by electro-valves) to equalize O_2 concentration and reach back normal levels. CO_2 is added as needed via a dedicated CO_2 bottle. However, the same strategy adopted for O_2 concentration control could be also applied, depending on MTF nominal CO_2 concentration (when the CO_2 level is too low in the ISPR, air is exchanged).

In order to limit the phenomenon of rejection to the MTF of the air just injected from the MTF, injection is performed only from one of the redounded air management lines and rejection from the other one.

Analysis will be performed by EnginSoft to consolidate the detailed design of the air exchange surfaces in order to guarantee:

- minimized air pockets within the shoot-zone volume (priority 1)
- an efficient air turn-over (priority 2)

Trace contaminants and microbiological control

After passing through the THC elements, air passes through a 0.2 µm membrane for filtering of bacteria, viruses and particulate. An additional passive filter for organic contaminants removal is then placed downstream, prior to the reintroduction of the air within the growth chamber shoot-zone volume.

Given the periodic air exchanges between the MTF crewed environment and the shoot-zone volume (as per semi-open loop strategy described above), the following precautions for limiting cross contamination have been implemented:

- Air collected from the MTF is introduced downstream the THC and upstream the TCCS (so no energy is wasted to cool/dehumidify air already at lower temperature and humidity)
- Air rejected to the MTF is first processed through both TEC and TCCS (to reduce system water loss and avoid rejection of contaminants to the outer environment)

This precautions have constrained the possible position of the fans, which need to be necessarily placed downstream the THC and upstream the TCCS, with air injection from the MTF upstream the FAN of line 1 and air rejection to the MTF downstream the TCCS of line 2.

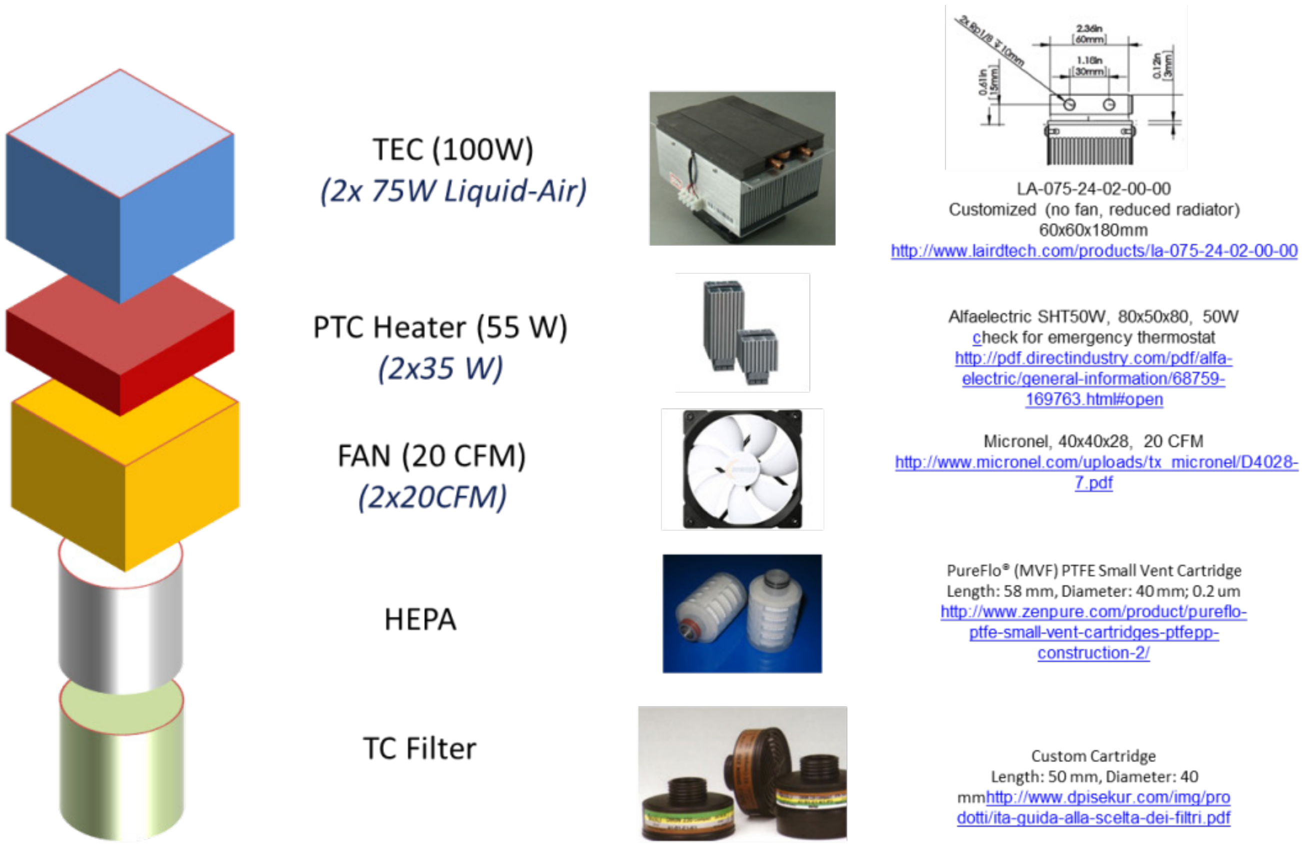


Figure 4-6: Air management system commercial components preliminary identified for each technology.

4.1.4 Nutrient Delivery System

The Nutrient Delivery System (NDS) is divided among multiple modules (ISPR drawers):

- The nutrient storage and distribution module/drawer, containing the reservoirs (stock solutions, acid/base, DI water, nutrient solution), the delivery pumps and the UV-C condensate bactericidal system
- The root module within each growth chamber module/drawer, containing the growth substrate, its container and the sensors and actuators needed to guarantee appropriate distribution of water and nutrient solution within the different area of the substrate

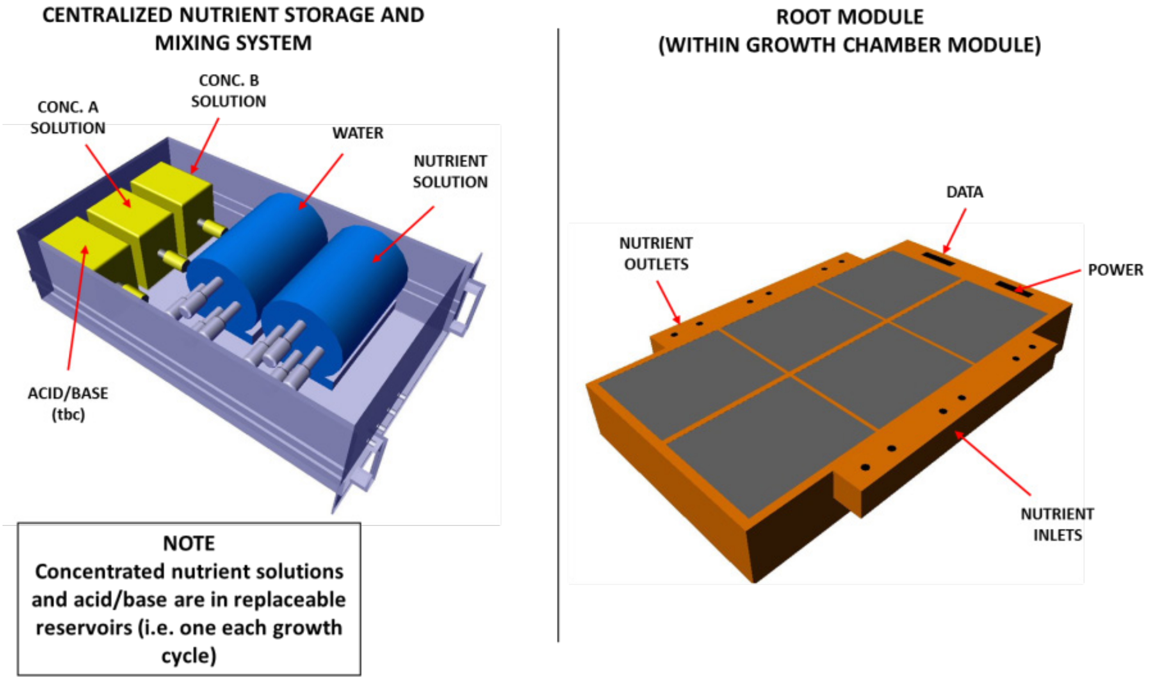


Figure 4-7: Nutrient storage and distribution module/drawer (left); root module (right).

The NDS block diagram is reported in Figure 4-8. Either DI water or nutrient solution can be delivered to the root modules. The block diagram is explained as follows.

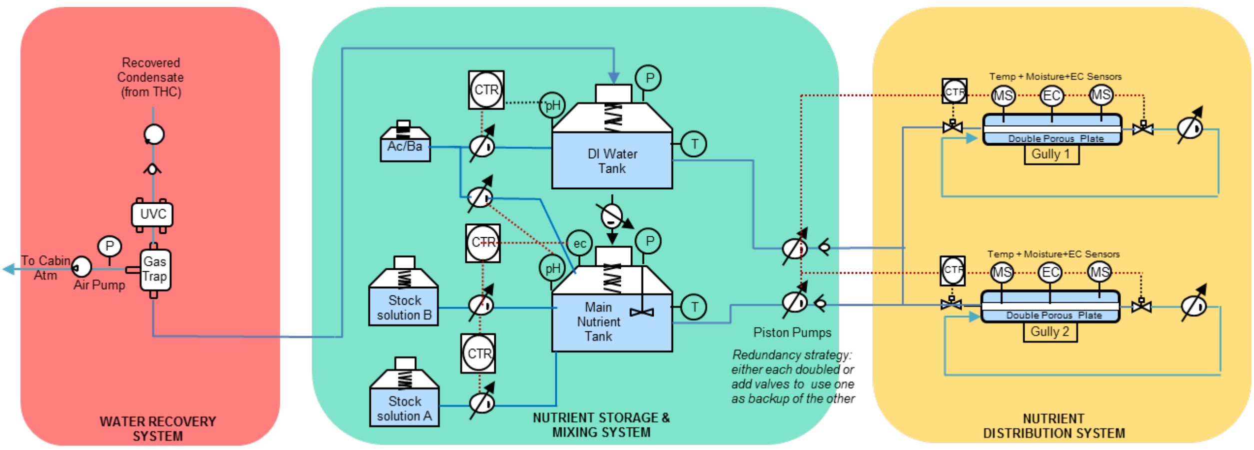


Figure 4-8: Nutrient Delivery System Block Diagram (baseline solution).

<u>Nutrient storage and distribution</u>

DI water is used in case of salt accumulation within the root module (EC increment within the substrate or porous elements cleaning to prevent clogging). The DI water pH will be monitored and controlled by acid/base injection. The nutrient solution EC and pH will be monitored and controlled by water, acid/base or stock solution (from dedicated reservoirs) injection. Injection will be allowed by

LabVIEW® controlled piston pumps. An electromagnetic or ultrasonic stirrer will allow homogeneous mixing of the nutrient solution within the reservoir. No temperature control is currently foreseen (only monitoring).

Concentrated solution tanks will be flexible, replaceable (self-locking QD), stored dry and filled with water only before use. Acid/base tank will be rigid (TBC) and replaceable (self-locking QD). Water and nutrient reservoirs current baseline solution is a bellow tank, either with AISI316L or Teflon bellow.

Water recovery

Condensate recovered from the THC will be disinfected with UVC-LEDs and then passed through a membrane contactor (gas trap) to separate the air from the water flow.

Root module

Particular attention is given to the root module. Currently two alternative solutions are still in place, and will be traded-off based on preliminary bread-boarding activities that will follow. Both solutions rely on porous stainless steel plates for nutrient solution distribution and reclamation (in case of over watering) throughout multiple (4) substrate pillows. The plates are passivated to favour priming of the pores. Substrate moisture, EC and temperature are monitored via sensors connected to a common data downlink port. Three moisture sensors per pillow will be used. EC will be monitored powering only one sensor each time, to prevent interference.

Electro-valves (or pneumatic valves), connected to a common power bus, regulate the water flow (with a single outlet and inlet per each root module) through the multiple porous plates Figure 4-9.

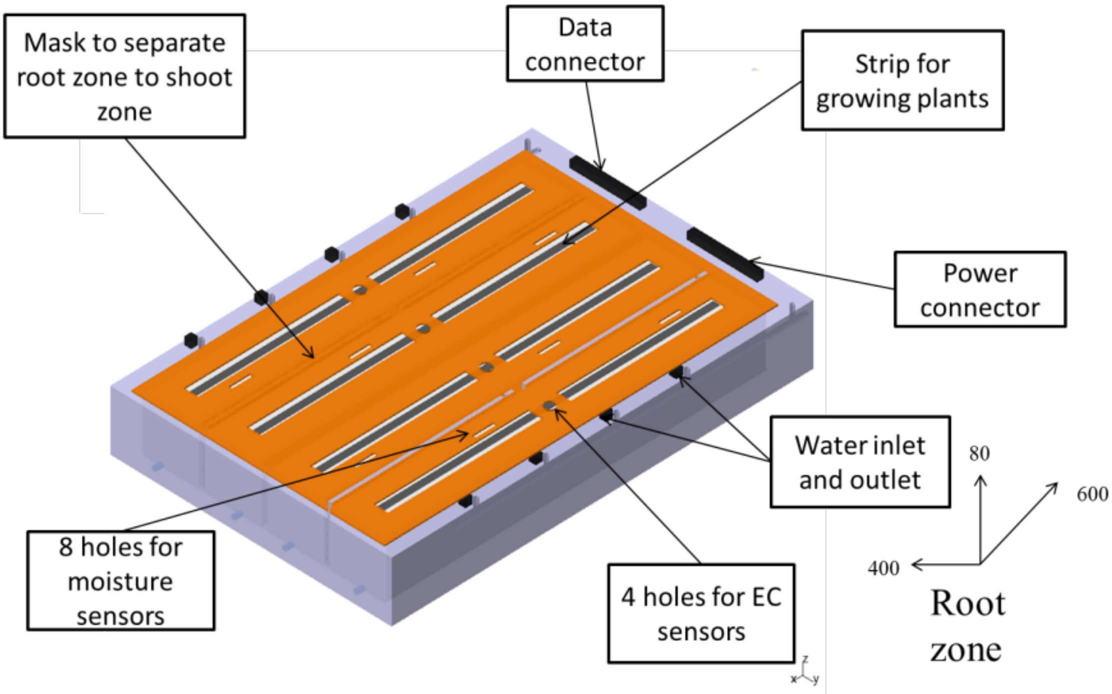


Figure 4-9: Root module main interfaces and elements.

Substrate height will be 50 mm for all selected crops Quantity of substrate used will vary for each crop (i.e. 1 L per tomato plant, 0.5 L per lettuce plant). Low density material that shall not get wet easily (i.e. hollow spheres, inflatable Kinar pillow) will be used to avoid having voids in the root module. Multiple substrates will be tested (also sensors shall be calibrated and their behaviour studied for each substrate, because they will behave differently). See Figure 4-10 for some example.

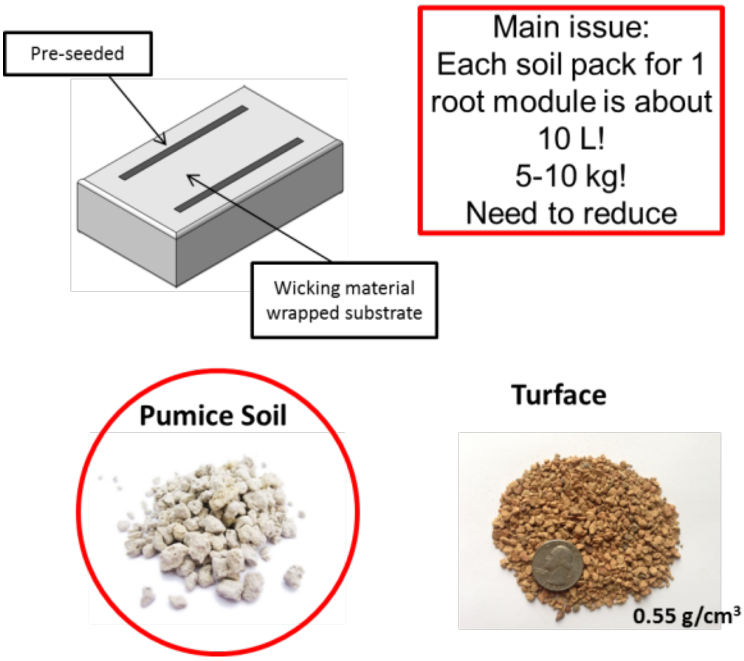


Figure 4-10: Examples of substrates that will be tested.

<u>Root Module I</u>

The baseline solution for the root module sees 4 (four) porous plates for nutrient solution distribution, placed parallel to the ground, on top of the substrate. Additional 4 (four) porous plates are placed in the bottom of the root module and, by removing nutrient solution for direct recirculation via piston pumps, they simultaneously recall air from the shoot-zone volume allowing aeration of the substrate Figure 4-11. Figure 4-12 reports a 3D preliminary drawing of this solution. Figure 4-13 reports the expected water distribution gradient.

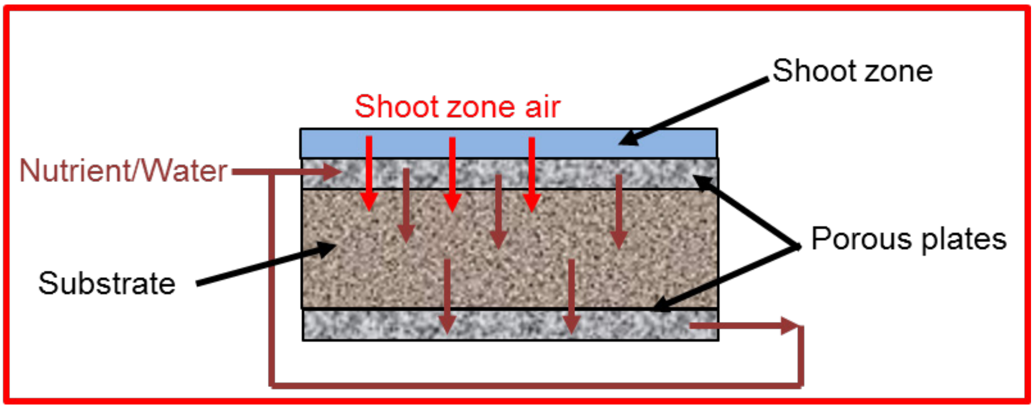


Figure 4-11: Root Module I operation schematic.

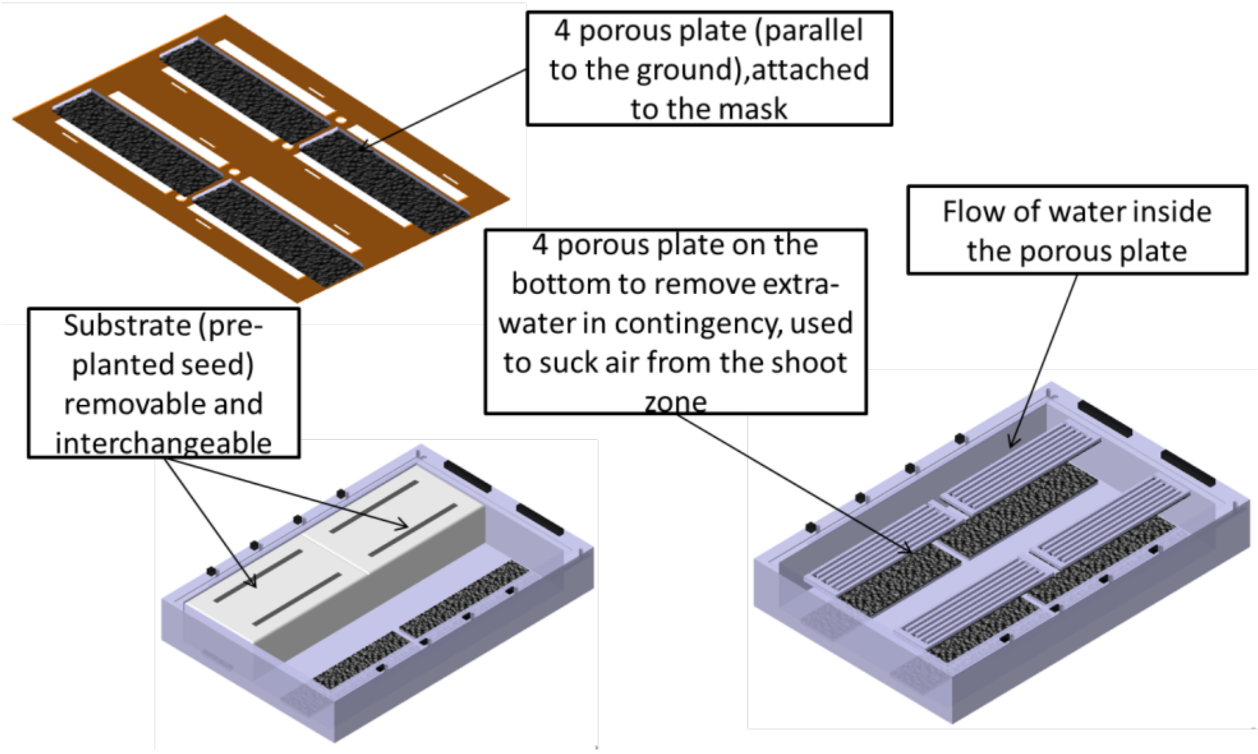


Figure 4-12: Root Module I preliminary drawing and main elements identification. 4 (four) porous plates for nutrient solution distribution, placed parallel to the ground, on top of the substrate. Additional 4 (four) porous plates are placed in the bottom of the root module and, by removing nutrient solution for direct recirculation via piston pumps, they simultaneously recall air from the shoot-zone volume allowing aeration of the substrate.

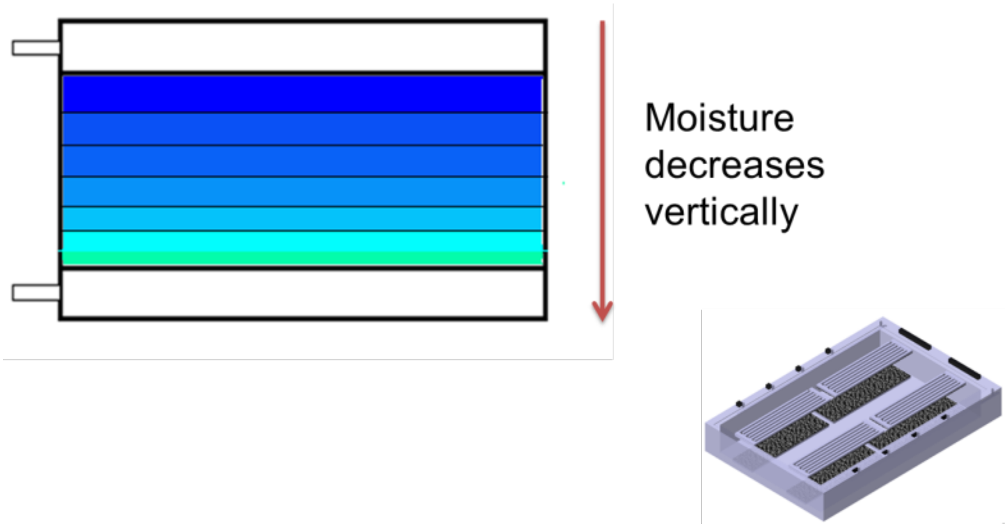


Figure 4-13: Root Module I substrate expected moisture profile. The moisture is expected to be at a maximum close to the top surface (where the seeds are placed), and decrease toward the bottom. The action of the porous plates at the bottom is expected to reduce the vertical gradient.

Root Module II

The backup solution for the root module sees 4 (four) porous plates for nutrient solution distribution, placed perpendicular to the ground, on top of the substrate. They can both add or remove nutrient solution (removed water dumped into waste tank). A porous tube on the bottom of the module distributes air through the substrate, pumped from the shoot-zone volume for root aeration. A block diagram of this solution is reported in Figure 4-14.

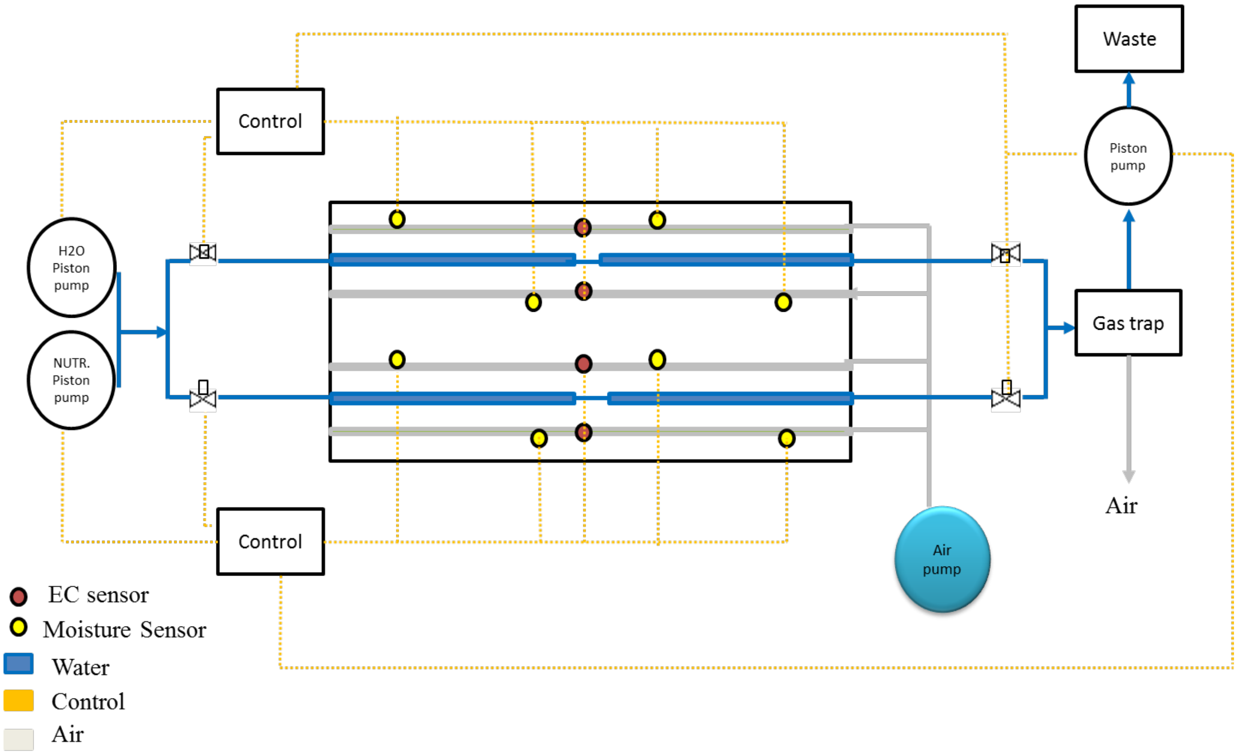


Figure 4-14: Root Module II block diagram.

Figure 4-15 reports a 3D preliminary drawing of this solution. Figure 4-16 reports the expected water distribution gradient. The substrate moisture is expected to be maximized near the porous plates, then decreasing in the sections parallel to the plate as the distance increases. A model with COMSOL Multiphysics® Modeling Software will be performed in order to identify proper breadboard sizing parameters.

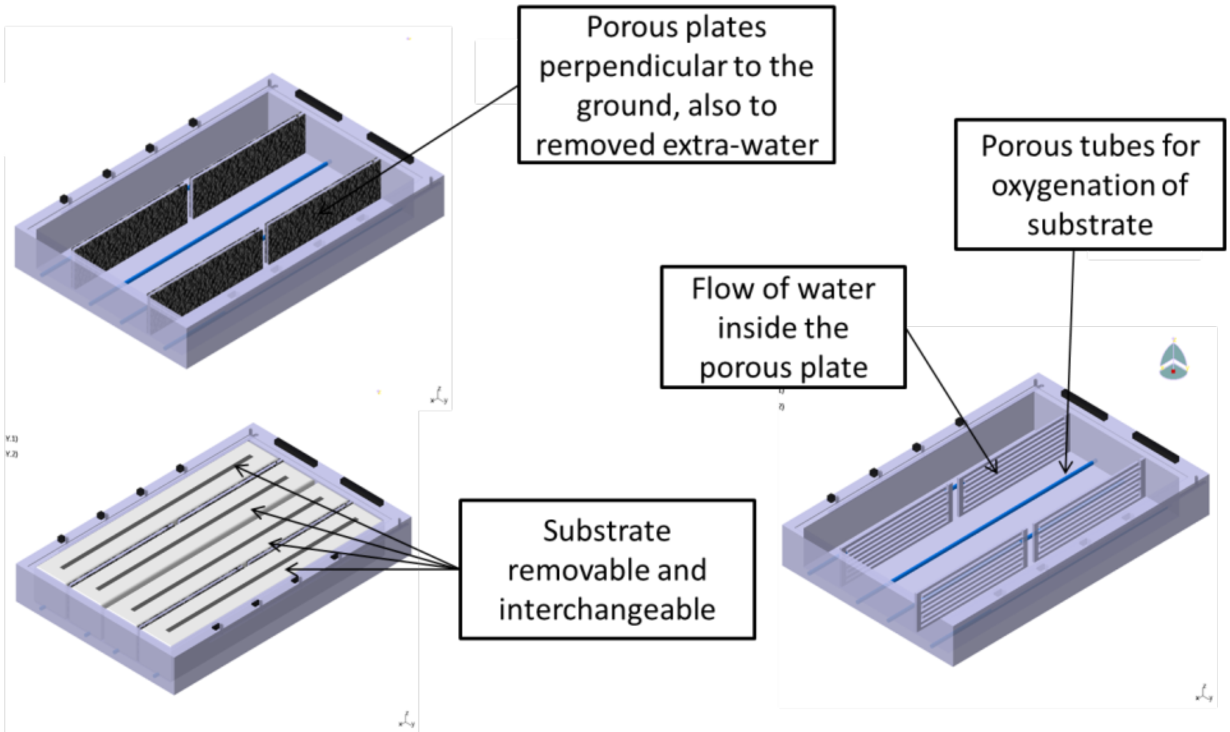


Figure 4-15: Root Module II preliminary drawing and main elements identification. The root module sees 4 (four) porous plates for nutrient solution distribution, placed perpendicular to the ground, on top of the substrate. They can both add or remove nutrient solution (removed water dumped into waste tank).

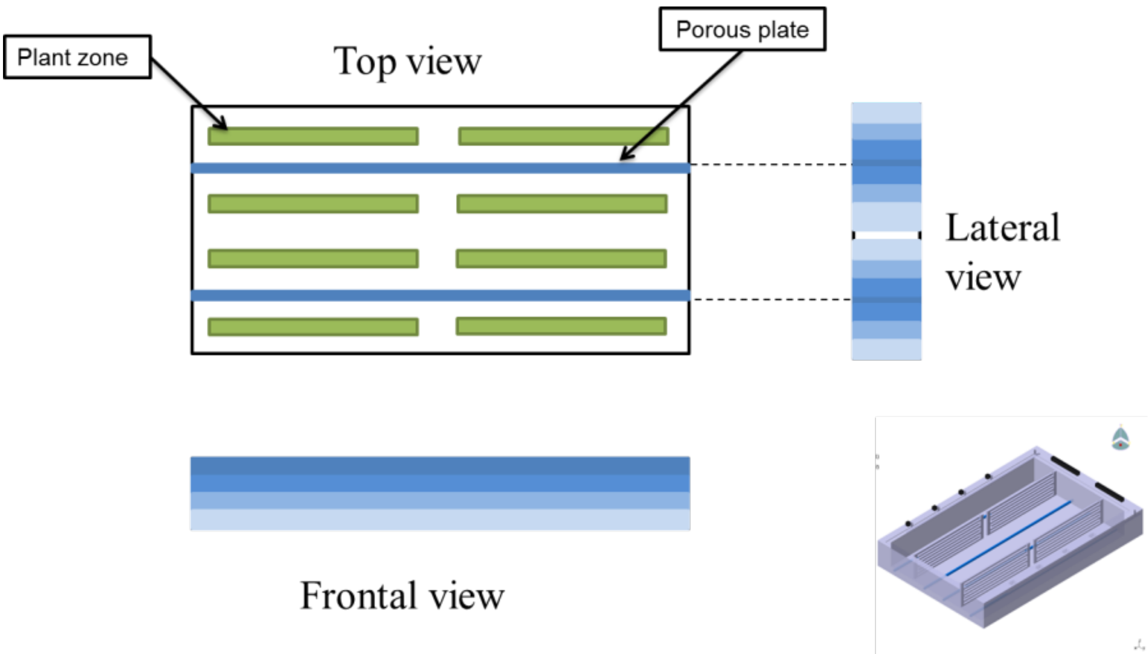


Figure 4-16: Root Module II substrate expected moisture profile. The substrate moisture is expected to be maximized near the porous plates, then decreasing in the sections parallel to the plate as the distance increases.

4.1.5 Command and Data Handling System

The Command and Data Handling (C&DH) System is housed in the Power, Command and Data Handling module/drawer (Figure 4-17).

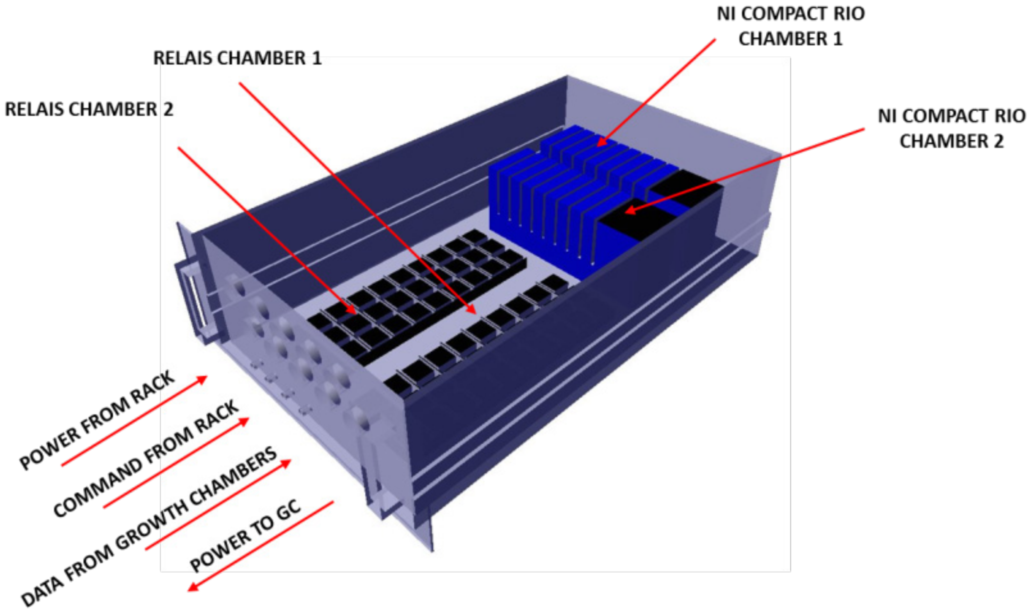


Figure 4-17: Power, Command and Data Handling module/drawer.

The general conceptual schematic of the C&DH system is given in Figure 4-18. Data are collected from the P/L drawer sensors into a NI Compact RIO (TBC) board via dedicated I/O modules. Commands are generated by feedback control implemented within the cRIO controller, and transferred to power relays via internal Digital Output (DO) modules. The different programs can be loaded onto the cRIO board via rack-external signal, generated by a LabVIEW based computer and transmitted by LAN interface. The same interface is used for telemetry downlink.

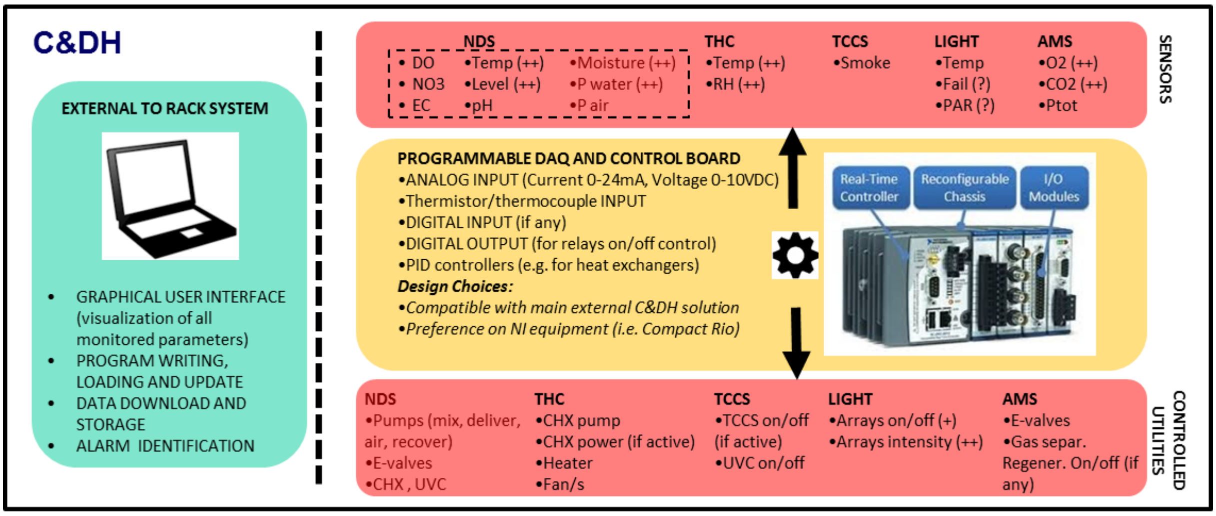


Figure 4-18: Command and Data Handling system conceptual schematic.

In order to have a preliminary estimate of the telemetry data budget, some assumption of the identified sensors requirements have been provided as per Table 4-1. In summary, the following data rate requirements are identified:

- 50 sensors, 1 Hz, 16 bit each
- 2 cameras, 2 MB/picture, 5 pictures/day

Possible additional data IF for other telemetry data to be connected to the Argus system are to be identified (i.e. power consumption measurement of critical subsystems via SOCOMEC Countis E meter).

Table 4-1: ISPR preliminary estimation of the telemetry data budget.

Sensors Function	Qty	Data size (assumed)
ISPR		
ISPR Structure		
Smoke sensor (TBC)	1	16 bit, 1 Hz
ISPR to MTF Interface Subsystem		
Water temperature thermistor	2	16 bit, 1 Hz
ISPR to P/L Interface Subsystem		
Water temperature thermistor	2	16 bit, 1 Hz
Power, C&DH Module		
10 kohm thermistor	2	16 bit, 1 Hz
Nutrient Storage Module		
Water outlet pH sensor	2	16 bit, 1 Hz
Nutrient outlet pH sensor	2	16 bit, 1 Hz
Nutrient outlet EC sensor	2	16 bit, 1 Hz
Water temperature thermistor	2	16 bit, 1 Hz
Water pressure sensor	2	16 bit, 1 Hz
Air pressure sensor	1	16 bit, 1 Hz
Growth Chamber Module (2x)		
Soil EC/temperature sensor	12	16 bit, 1 Hz
Soil moisture sensor	12	16 bit, 1 Hz
Multi-parametric air sensor	4	16 bit, 1 Hz
Illumination Modules (2x)		
LED panel health sensor	2	16 bit, 1 Hz
Video-camera	2	5 images/day (2 MB)

4.1.6 Power Distribution and Control System

Figure 4-19 reports the Power Distribution and Control System conceptual schematic.

Power will be delivered from the MTF to the ISPR via 230 VAC, 10 A electrical IF (230 VAC connector – plug - characteristics to be identified by DLR). 230 VAC to 24 VDC conversion will be provided within the ISPR volume, under the responsibility of TASI. DLR shall provide AC/DC converters models eventually used in the FEG, in an effort to increase commonality and have common spare parts.

The power will be then distributed to the different utilities via the commanded relays placed in the Command and Data Handling module/drawer (Figure 4-17).

Moreover, manual override of key utilities (i.e. illumination, irrigation) on/off conditions will be possible, especially to favour maintenance.

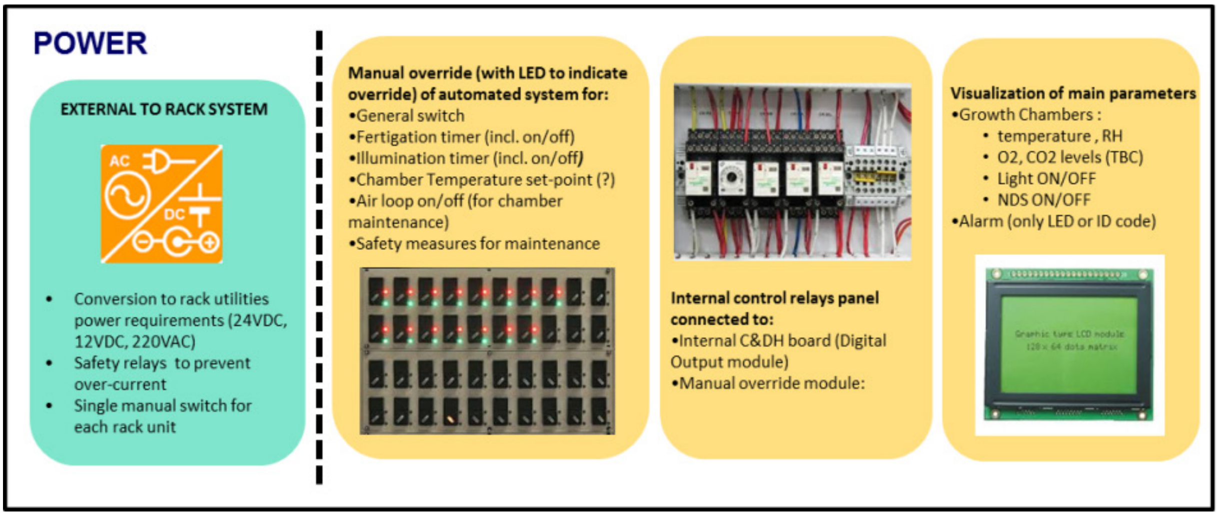


Figure 4-19: Power Distribution and Control System conceptual schematic.

The preliminary power budget has been estimated as follows:

- Nominal day mode: 1.12 kW peak, 0.67 kW avg
- Nominal night mode: 0.47 kW peak, 0.29 kW avg
- Reduced day mode (emergency): 0.67 kW peak, 0.53 kW avg

The reported peak power is calculated with 600 µmoles/m^2-s illumination and 160 g/m^2-h water vapour production simultaneously from both growth chambers. Staggered production and/or staggered photoperiods and/or lower light demanding crops will reduce considerably these peak values (assumed at least 35% reduction).

4.2 *Options and Trades*

The main trade-offs performed up to this phase of the study are summarized as follows:

- Nutrient Delivery System
  - Aeroponics vs porous media substrate irrigation → porous media substrate irrigation selected
- Atmosphere Management System
  - Open loop (continuous air exchange with MTF) vs close loop (including oxygen scrubbing from ISPR) → semi-open loop selected (see section 4.1.3)
- Illumination system
  - Dimming of whole lamp vs wavelength-specific dimming → wavelength-specific dimming selected in analogy with FEG
- Structure
  - Completely ISPR-like shape (rounded back) vs slightly simplified structure → slightly simplified structure selected as per section 4.1.1

4.3 *List of Equipment*

The ISPR Preliminary Equipment key values are reported in Table 4-2.

Table 4-2: Key values of ISPR system.

	Mass	Peak power	Peak Power day - nominal mode	Peak Power night - nominal mode	Costs
Mobile Test Facility	335 kg	1124 W	1124 W	470 W	N.A.
Neumayer Station III	-	-	-	-	-
Spares, consumables, tools	146 kg	n.a.	n.a.	n.a.	N.A.
TOTAL	481 kg	1124 W	1124 W	470 W	N.A.

4.4 *Requirements Adjustments*

Generally, ISPR interfaces requirements have been consolidated as discussed within section 4.1 of this report.

The main requirement-related adjustment that shall be recorded is the selection of the ISPR growth experiments target crops, which provide loads and target environmental parameters used from now-on for subsystems sizing. These choices and parameters are summarized in Table 4-3 below.

Table 4-3: ISPR growth experiments target crops and main related loads.

Crop	Planting density [plants/m^2]	Photo-period temp. /RH [°C/%]	Dark-period temp. /RH [°C/%]	Light Intensity / Photoperiod [PPF / hd^{-1}]	CO_2 conc. [ppm]
Dwarf Tomato cultivar TBC	2,5 but strongly depends on variety	16h 22 ^{o}C, 80%	8 h 17 ^{o}C, 80%	300 young plant-600 full grown	600 young plant-900 full grown
Rucula (cultivated) cultivar TBC	1000/m^2	16h 21 ^{o}C, 80%	8 h 17 ^{o}C, 80%	150 young plant-300 full grown	600 young plant-750 full grown
Chinese cabbage Tokyo Bekana	± 30 /m^2	16h 22 ^{o}C, 80%	8 h 18 ^{o}C, 80%	150 young plant-300 full grown	600 young plant-750 full grown
Outredgeous lettuce	± 40 /m^2	16h 20 ^{o}C, 80%	8 h 16 ^{o}C, 80%	150 young plant-300 full grown	600 young plant-750 full grown

5 Power Distribution and Control

5.1 *Baseline Design*

5.1.1 Overall design

The power distribution and control system consists of the main power box, cable channels for power and data cables, the power cables, and the internal and external lighting (excluding the plant illumination system). The main power box is located on the north side of the Service Section adjacent to the wall to the FEG. The box holds all circuit breakers, relays, wattmeter and DC converters and splits the power line incoming from Neumayer III into lines for each subsystem, which are then split into lines to the different components.

The primary cable channels are attached to the ceiling of the MTF and run along the walls of the Service Section and in the corridor of the FEG. The red lines in Figure 5-1 illustrate the positioning of the primary cable channels. In addition to the primary channels under the ceiling there are also secondary channels which run vertically at strategic points to direct cables to equipment located e.g. within the different level of the FEG.

Most of the power cables are for 230 VAC. For the distribution of the electricity, three-wire NYM-J installation cable certified for wet rooms will be used. There are also a number of components running at 24 VDC, which will be supplied by two-wire cables also certified for wet rooms.

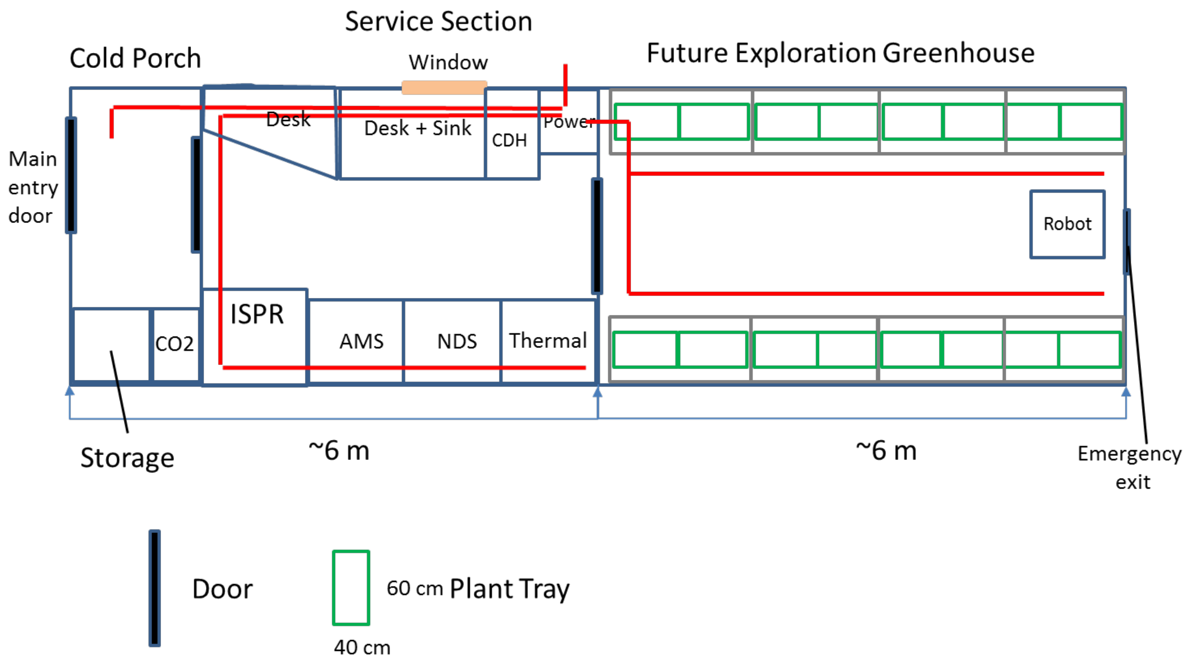


Figure 5-1: Overview of the MTF power distribution layout.

5.1.2 Main power box

The main power box is the heart of the MTF. It splits the incoming three-phase line from Neumayer into separate lines for the different subsystems and components. The baseline layout of the power box is based on the Rittal TS 8 modular power cabinet system (see Figure 5-2, left side). The used cabinet is 2000 mm high, 600 mm wide and 400 mm deep and has a glazed door. The main power line coming from Neumayer enters the cabinet through the north wall close to the bottom of the cabinet, is split up into separate lines for each subsystem, which are in turn split into lines for each component or group of components. The power distribution cables leave the cabinet through special openings in the roof of the cabinet.

The current layout foresees the following elements within the cabinet:

- 1x 4-pole RCD (residual current device)
- 9x 2-pole RCD
- 180x Three-level terminal blocks
- 58x 16 A C16 (or B16) breakers
- 1x three-phase wattmeter
- 24x single-phase wattmeter
- 2x 24 VDC converter (space also provided for 12 VDC if determined necessary)
- 56x 1-slot relays
- 10x 2-slot relays

All of the elements required for 230 VAC distribution are arranged in nine rows at the back wall of the cabinet, whereas the 24 VDC distribution components are arranged in two rows at one side wall of the cabinet. The right side of Figure 5-2 shows a preliminary arrangement of the different relays, switches/breakers, wattmeter, terminal blocks and DC converters.

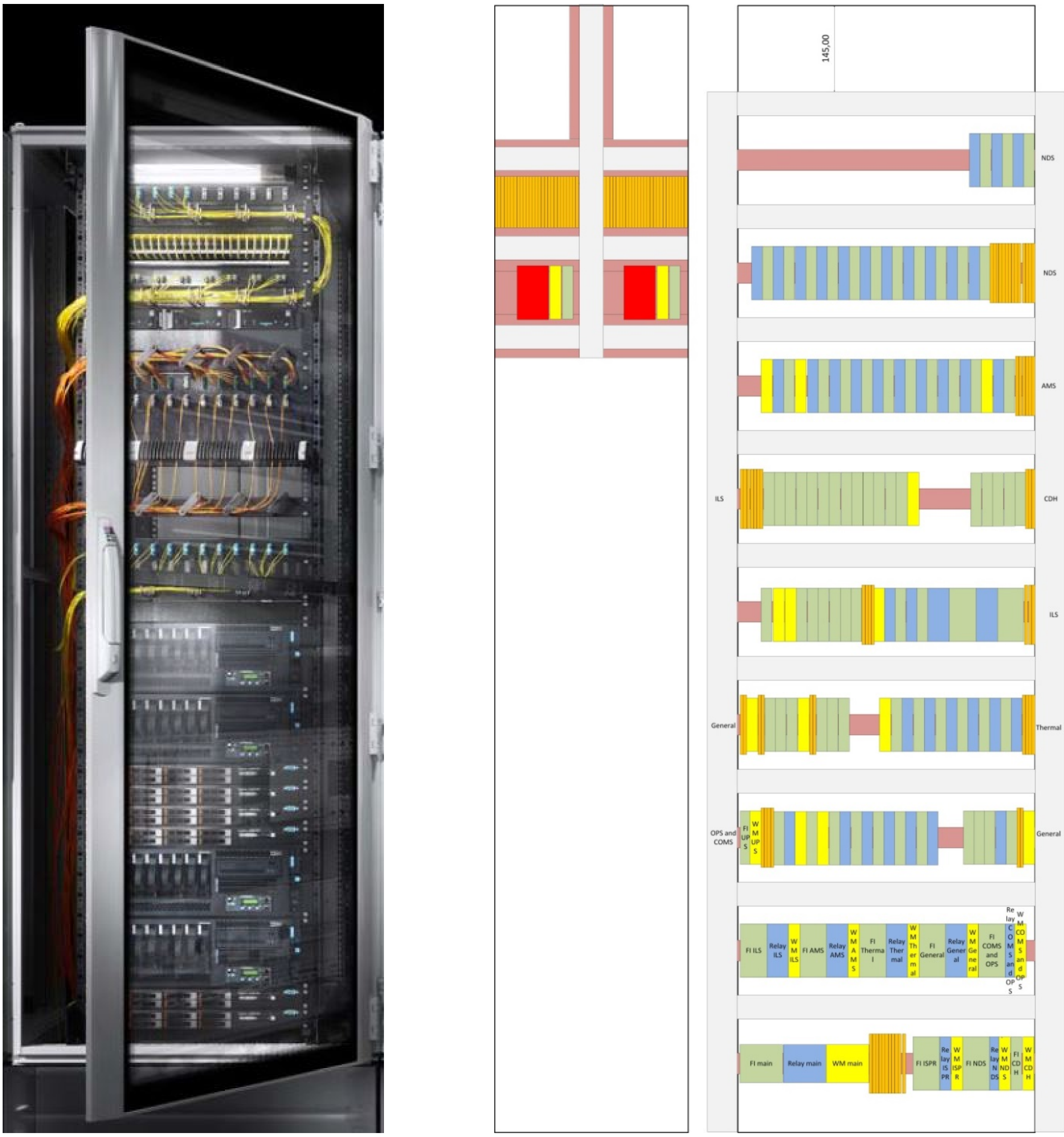


Figure 5-2: Rittal TS 8 modular power box system (left); draft layout of the main power box (switches/breakers in green, relays in blue, wattmeter in yellow, terminal blocks in orange, DC converters in dark red, rails in light red, cable channel in light grey) (right).

5.1.3 Cable channels

The cable channels within the MTF will be made out of the modular installation channel system of the company ITEM. The channels are made out of aluminium. Their modular system allows the construction of a wide variety of cable channels with different cross section dimensions.

5.1.4 Connectors

All cable connections within the MTF will be made out of QUICKON connectors of the company Phoenix Contact. QUICKON is a modular cable connection system which is rated IP68 and therefore suitable for the humid and wet environment within the MTF. Figure 5-3 shows an example of QUICKON connectors.

Figure 5-3: Example of QUICKON connection system.

5.1.5 Energy measurement

The overall energy consumption of the MTF as well as the consumption of each subsystem and selected components will be measured. The goal of the energy measurement system is to obtain better insight in the total electrical energy required to produce food in a closed environment. Furthermore, the measurement of each subsystem and selected components allows the identification of optimization potential with respect to energy efficiency, in addition to providing a means for failure identification.

Figure 5-4 shows the COUNTIS E measurement system by the company SOCOMEC as an example for a potential component. Similar systems are made by other companies e.g. Finder, Siemens. Different devices for measuring single-phase and three-phase lines exist. All measurement modules are connected either to a bus system or a centralized data acquisition module which is then connected to a computer with special visualization and analysis software.

Figure 5-4: SOCOMEC COUNTIS E energy measurement devices (left side single phase, right side three phase).

5.1.6 Backup power supply

Potential power shortages and voltage fluctuations have to be buffered to avoid the uncontrolled shutdown of the command and data handling system and the communication between the MTF and Neumayer. Therefore, a backup power supply (or uninterruptable power supply (UPS)) will be installed within the MTF. Table 5-1 shows the equipment which will be connected to the UPS.

Table 5-1: List of equipment which needs to be buffered by the UPS.

Equipment	Amount	Power demand
Argus PC	1	400 W
MTF Server	1	400 W
Access point	1	3,75 W
I/O module	15	22,5 W
Relay module	8	30 W
Safety systems	1	60 W
Network switch (connected to Argus PC, MTF server, access point, patch antenna, etc.)	1	28 W
Patch antenna	1	8 W
VoIP phone	1	10W
	TOTAL	**962,25 W**

The current baseline design foresees the installation of an EATON Evolution S 1750 UPS (see Figure 5-5) with the following specifications:

- Max. power: 1400 W
- Modular: 1-5 modules (1 module: 9 minutes at 70% max. power; 5 modules: 115 minutes at 70% max. power)
- Dimensions per module: 440 x 509 x 86.2 (2U) mm

Figure 5-5: EATON Evolution S 1750.

The maximum duration during which the equipment listed above needs to be supplied solely by the UPS is estimated on values of equipment currently installed at Neumayer. The station UPS lasts for around 30 minutes and the SPUSO UPS lasts for 15 minutes. Therefore, the baseline design foresees the EATON Evolution S main module and additional extension battery. This system has a capacity to run at 70 % of the maximum load for 36 minutes.

The capacity can be further increased up to 115 minutes by adding three more extension batteries to the main module. However, since space in the Service Section is very restricted and each extension battery requires 2U within the rack system, adding more batteries should be evaluated carefully.

5.1.7 Internal and external lighting

The interior of the MTF is illuminated by very thin (only 3 cm high) ceiling-mounted LED panels. Each panel requires 36 W power and generates 2400 lumens at a light temperature of 3500 K. Six panels will be installed in the MTF, one in the cold porch, two in the Service Section and three in the FEG. The amount of panels was estimated using the illumination standards for office space, which are met.

Figure 5-6: LED panel for interior lighting.

The exterior lighting consists of a powerful floodlight (around 1000 W) which is pointing towards the hand rail coming from Neumayer *(note: flood light removed post CE study)*, lighting above each door of the MTF and lighting around the MTF to illuminate the platform and the surrounding area.

5.2 *List of Equipment*

Table 5-2 shows the totals of the key values for the power distribution and control system. The high power values mainly result from the external lighting, which requires 1000 W for the floodlight, 500

W for the door lighting and 500 W for the platform lighting. The door lighting will be on permanently, whereas the floodlight and the platform lighting is only switched on, when required.

Table 5-2: Key values of the power distribution and control subsystem.

	Mass	Peak power	Power day - nominal mode	Power night - nominal mode
Mobile Test Facility	523 kg	2116 W		
Neumayer Station III	0 kg	0 W	0 W	0 W
Spares, consuma-bles, tools	~10 kg	n.a.	n.a.	n.a.
TOTAL	**533 kg**	**2116 W**		

5.3 *Power and energy budget*

The installed power of a facility is an important key value to lay out the interface (fuses, cables, etc.) between the power supply and the facility. The installed power represents the sum of all consumers of electrical energy when they are all running at 100% power. The MTF has a total installed power of around 25.5 kW and additional 2 kW for the non-permanently installed TransMADDS. Table 5-3 shows the installed power per subsystem. The AMS with 7.0 kW has the by far the highest power demand. According to the installed power values the subsystems were distributed over the three phases of the main power line with the purpose to have an almost equal distribution of installed power. Phase 1 has 8.4 kW, Phase 2 8.5 kW and Phase 3 8.1 kW installed power, which leads as a first estimate to a 40 A RCD per phase.

Table 5-3: Installed power per subsystem and the according phase of the main power line.

	Installed power	Phase No.
C&DH	1.7 kW	1
General	4.9 kW	1
Ops and Coms	1.8 kW	1
AMS	7.0 kW	2
NDS	1.5 kW	2
Thermal	3.0 kW	3
ILS	4.2 kW	3
ISPR	0.9 kW	3
TOTAL	**25.5 kW**	
TransMADDS	2.0 kW	

While the installed power is important to lay out the interface between Neumayer and MTF, the average power demand (and therefore the energy consumption) is important to estimate the additional fuel consumption of the diesel generators. The average power demand is also important to integrate the MTF in the Neumayer power control system.

The average power demand of the MTF calculated over one year is around 12 kW. However, the plants require a certain day-night cycle. Where day means the plants are illuminated and night means, that the plants are not illuminated. The cycle results in a different power demand during day and night, because some subsystems are not or only running at a low level. During day, the average power demand is around 15 kW and during night around 9 kW, as seen in Figure 5-7.

The day-night cycle is currently set at 16 hours day followed by 8 hours night. In Figure 5-7 the x-axis shows the normal time and the y-axis shows the power demand. There is one data point per hour and the value of the data point is the average power demand during that hour. From 00:00 to 08:00 is night and from 08:00 to 24:00 is day. Furthermore, it is assumed that from 09:00 to 17:00 crew is working in the MTF, which results in a rise of the power demand during that period.

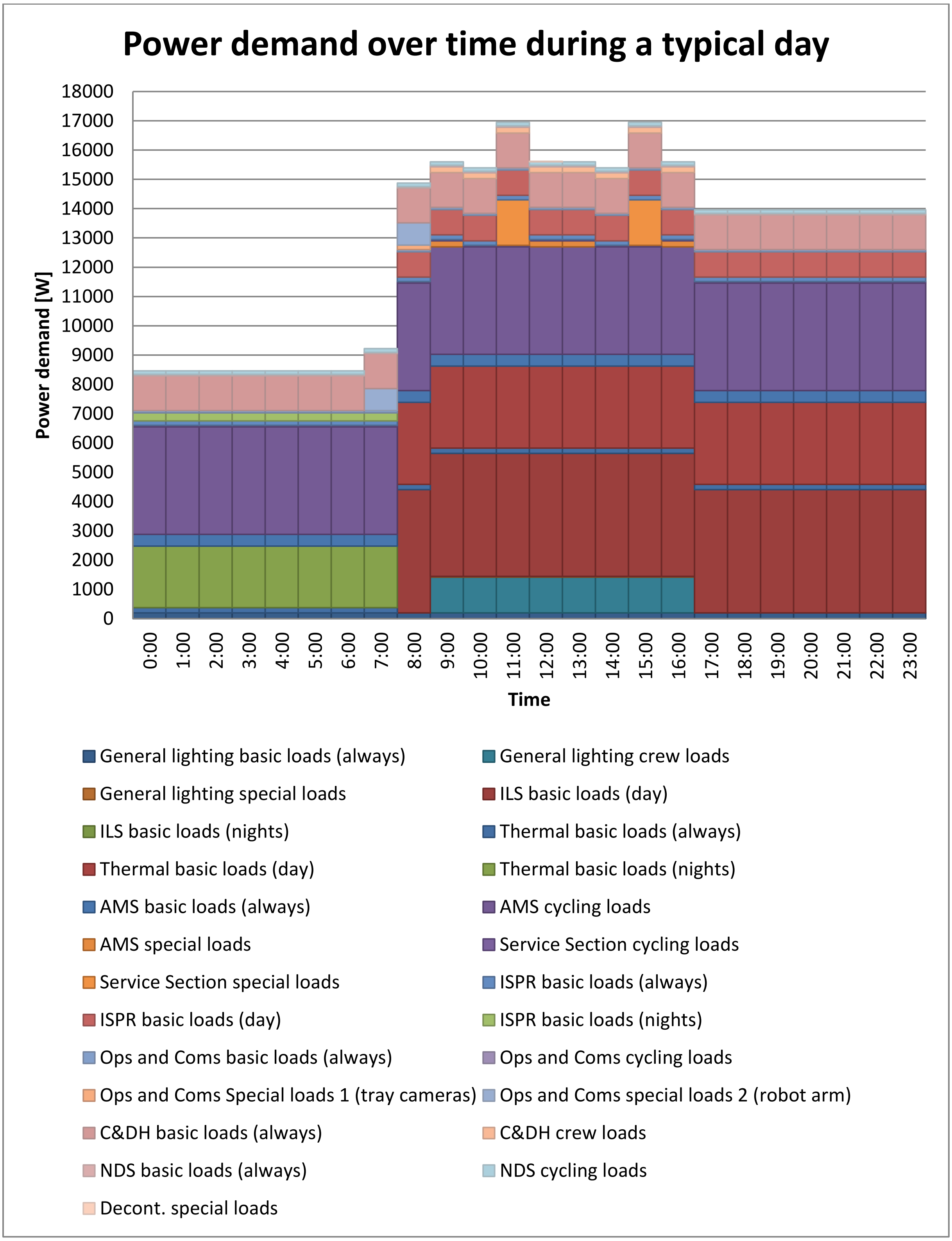


Figure 5-7: Power demand during a typical operation day.

6 Illumination System

6.1 *Baseline Design*

The baseline design for the illumination system is as follows:

- Each shelf will be equipped with LED controllable light sources. See 6.2 for light source design options.
- The light sources will be controllable via an IP based control protocol over Ethernet cable. Each wavelength in the light source can be controlled individually.
- The LED driver will be placed in proximity to the light sources.
    - Dimming will stay within the range where analogue dimming is sufficient (no pulse width modulation dimming should be used/required).
- The light spectrum will be produced by 450, 660 and 735 nm LEDs along with a broadband white 5700K LED. The resulting spectrum will have the following composition:
    - 15% blue (400-500nm)
    - 10% green (500-600nm)
    - 75% red (600-700nm)
    - 2% far-red (700-750nm)
- The same design will be used in the ISPR.
- Each light source will have a temperature sensor and over temperature protection.
- The light source per shelf will be contained within an 1130 x 425 x 50 mm envelope centred above each pair of shelves.
- Control boxes IP67 etc.
- Cooling:
    - The light sources will be water cooled with water at 20°C.
    - Each side of the FEG will have a separate cooling water circuit including a pump, main valve, pressure sensor, flow sensor and air bleeder valve.
    - Each vertical grow unit will have its own valve.
    - All valves will be manually operated.
    - The pressure and flow sensors will provide a 4-20 mA signal for monitoring purposes.
    - Materials used will be galvanically compatible.
    - Note: The LEDs can go up to 35°C without significant impact on light output.
- The light distribution pattern will be designed to create the best uniformity 15 cm above the plant tray.
- For telemetry, each shelf will be controlled via Ethernet (UDP/IP, TCP/IP) according to the following:
    - Each shelf has four LED channels that can be individually dimmed
        - Set point per panel S_450, S_660, S_735, S_5700
    - Each light source has a temperature sensor and an over temperature protection
    - The following data can be fetched from each shelf:
        - Status (Status)
        - Set point per panel (S_450, S_660, S_735, S_5700) [2 byte integer]
        - Temperature per bar in the panel (T1, T2, T3) [2 byte integer] 1/10 C
        - Current per bar (I1, I2, I3) [2 byte integer] milliamp
        - HW configuration HW_config [String]
        - FW version FW_version [String]

6.1.1 Power

The electrical power needed per tray is estimated as approx. 60 W for the 300 µmol/m2/s trays and 120 W per tray for the 600 µmol/m2/s trays. The estimates assume the system losses shown in Figure 6-1.

	Description	Power for 600umol/s/m2 case
Electrical power consumed by lamp	AC power to the lamp	250W
PSU efficiency 90%	Power conversion from AC to DC in the constant voltage power supply	225W, 25W loss
Plate DC/DC conversion efficiency 90%	Conversion from DC voltage to the DC current control per LED type	202W, 23W loss
LED efficiency 50%	Conversion from electrical to radiant power. A 50% average conversion is assumed across the LED configuration.	103W, 99W loss
Optical efficiency 90%	Loss exiting the fixture. Light is lost when it passes the lens.	93W, 10W loss
Delivery efficiency 80%	Loss delivering light to the target area. Light is spilled into aisle and on wall.	74W, 19W loss
Light on target	The light that hits the target area.	373umols/s or 600umols/m2/s across target area of 0.6m2

Figure 6-1: Estimated electrical power losses for the 600 µmol/m2/s intensity case on a per level basis (two trays).

The top-level power and cooling connections for the illumination system are shown in Figure 6-2.

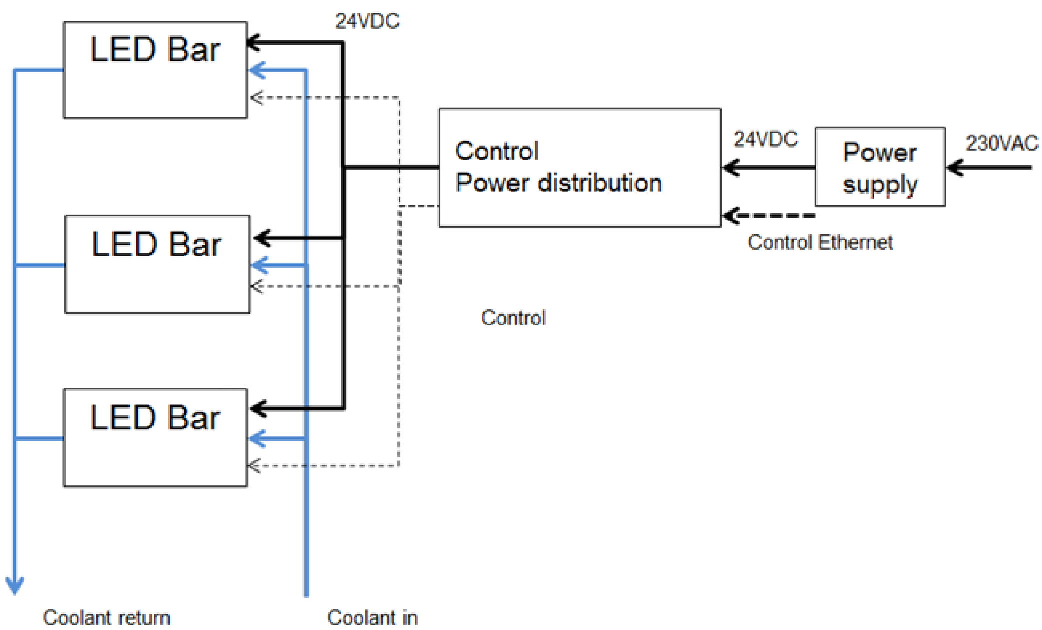
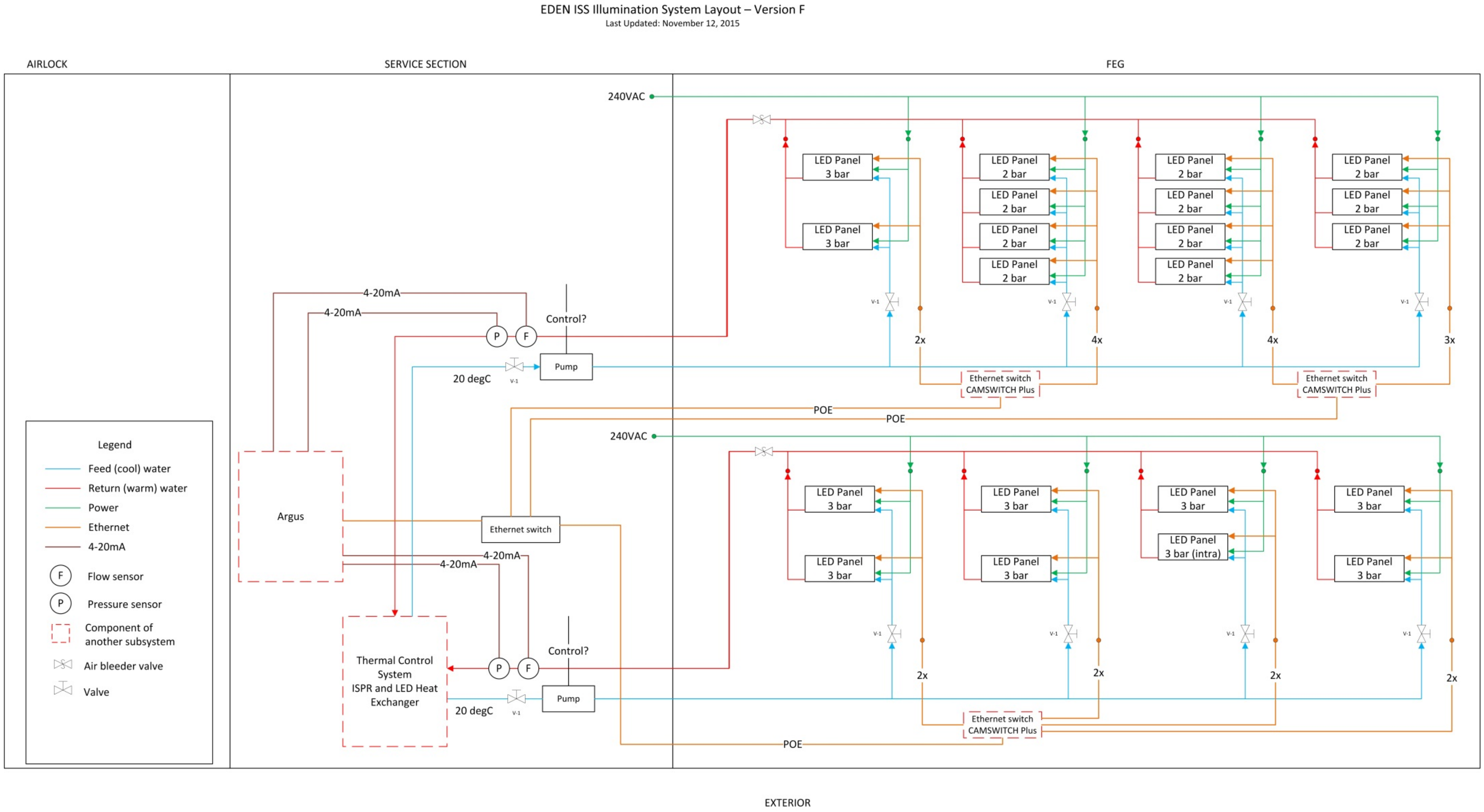


Figure 6-2: General power and coolant connection layout of the illumination system.

6.1.2 Block diagram



6.2 *Options and Trades*

There are two major options regarding the illumination system design related to its form factor.

6.2.1 Light bar

The first option, as discussed in during the CE study, is to use multiple water cooled light bars that run the length of a shelf covering 2 trays. For short plants in lower intensity trays, two light bars would be used. For the higher intensity trays and taller plants, three light bars would be used.

The benefits of the light bar design:

- As the light bars run almost the full length of the shelf and can be angled inward the coverage across the shelf can be good.
- A narrow bodied light bar allows a simple design of a water cooled fixture by creating a single water pathway in the fixture extrusion.

The light bar is a line source. To provide uniform coverage across a shelf several sources must be used. This has the following drawbacks:

- The length of tubing for water cooling becomes relatively longer than that of a compact light source. Longer tubing increases the pressure drop in the fixture.
- More water fittings are needed which is more expensive.
- Creating a uniform spectrum becomes more difficult with a linear source as the LEDs with the highest efficiency available in the wavelengths needed for horticulture are high power LEDs (1-3W). They can be placed in a line and driven harder to be more cost efficient but less uniform or they can be placed in multiple lines and driven less hard improving uniformity but also increasing cost.
- A separate design needs to be developed for the ISPR as the light bars will not fit the form factor of the ISPR.

6.2.2 LED plate

The second option is to use a water cooled LED plate that is centred on top of a tray. As the lights are dimmable the intensity across a shelf is controlled by the intensity setting and similar configurations can be used regardless if the tray is short/low or tall/high.

The benefits of the LED plate design:

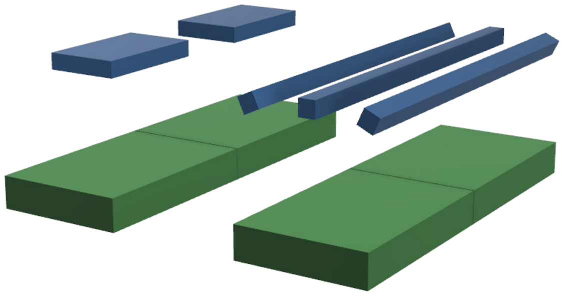
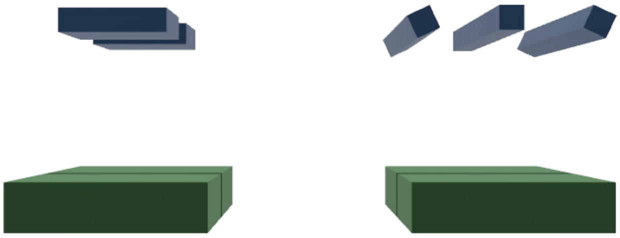
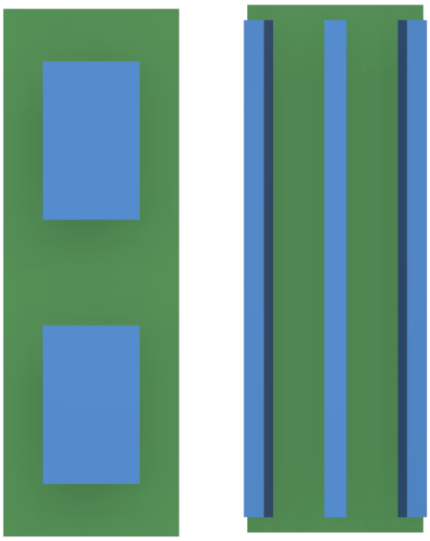
- The same design that is used in the current dimmable Heliospectra products can be used in the EDEN ISS project. There is synergy with commercial customers seeking a controllable water cooled system.
- A common mechanical interface can be used across all shelves and in the ISPR.
- Slightly fewer water fittings will be needed than in the light bar case.
- The spectrum will be more uniform as the relative distance between LEDs of different wavelengths will be smaller than in the linear case.

The drawback of the LED plate design:

- As the LED plate is smaller than the tray care needs to be taken so that light is distributed evenly across the tray and not too much light is lost to the walk way.
- Distributing water through the LED plate may be a bit more complicated than the case with the light bar.

The two concepts are shown side by side above two growth trays in Table 6-1.

Table 6-1: Comparison of the light bar and LED plate options.

	Comparison of the design concepts show side by side, each above two trays (green). The left configuration show the LED plate options. To the right the light bar option.
	Side by side comparison of the two concepts. The outer light bars are angled inward to reduce the spill of light outside the trays.
	Top view of concepts mounted above two trays each. Here it is clear that light bars almost cover the length of the trays. The light from the LED plates on the other hand is produced from a smaller area and has a more uniform spectral quality.

7 Thermal Control System

7.1 *Baseline Design*

The thermal control system has to dissipate the heat produced inside the entire MTF. In the SS the temperature is controlled by a specific unit which is able to heat up/cool down the air. Inside the FEG three separate cooling lines are foreseen to remove the heat produced by three systems: AMS, ISPR and ILS. In particular, the AMS has a cooling coil to remove the moisture from the air: the maximal cooling capacity of the dehumidifier is 5500 W. The ISPR needs a cooling line to collect a maximal power of 1100 W. In the ILS, the LED panels are partially cooled by water: 2600 W is the maximum amount of heat that can be removed with this procedure.

Three separate cooling systems are considered for the three different systems (AMS, ISPR, ILS) that have to be cooled (see block diagram in Figure 7-1). Each cooling system has the same structure: the heat is collected from the specific internal system through a cooling line, then a liquid –liquid plate heat exchanger provides the heat to a second cooling line. A passive external radiator is selected as an air-liquid heat exchanger to dissipate the heat into the external environment.

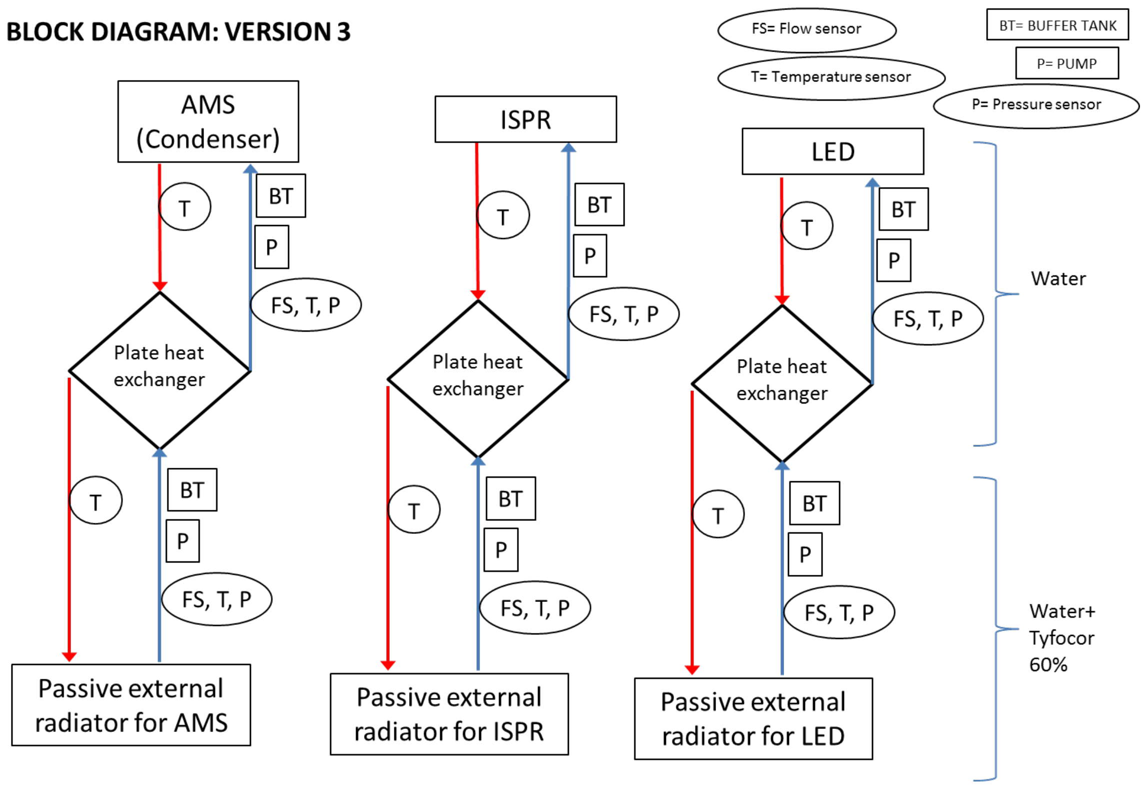


Figure 7-1: Block diagram of the thermal control system.

Two cooling fluids are used in the thermal system: water for the first part of the cooling lines (from each internal system to the plate heat exchanger) and a water mixture for the second part of the cooling lines (from each plate heat exchangers to the passive external radiator). The water line is supposed to have a temperature variation between 18°C and 28°C. The water-mixture line should have a temperature between -5°C to 10°C. The water mixture is composed of water and 60% of Tyfocor which is a no-toxic liquid based on propylene glycol (TYFOROP Chemie GmbH, 2015). Tyfocor is miscible with water in all proportion in order to avoid frost at temperatures of down to -50°C with a 60% of Tyfocor in a water mixture. At the freezing point, some crystals form, but there is no expansion of the fluid (see Table 7-1).

Table 7-1: Tyfocor freezing point and frost protection.

TYFOCOR® L Concentrate	Freezing point (acc. ASTM D 1177)	Frost protection (calculated)
25 vol. %	-10.7 °C	-11.5 °C
30 vol. %	-14.0 °C	-15.0 °C
35 vol. %	-17.6 °C	-19.0 °C
40 vol. %	-21.5 °C	-23.7 °C
45 vol. %	-26.0 °C	-29.6 °C
50 vol. %	-32.4 °C	-38.2 °C
55 vol. %	-40.4 °C	-48.5 °C
60 vol. %	-48.4 °C	< -50 °C

Each line of the cooling system needs a dedicated pump: a total amount of six pumps have to be set, one for each circuit. Considering the temperature range and the thermal loads, the pumps should be able to work in a range between 3 L/min and 10 L/min.

Inside each circuit a liquid buffer tank and pressure relief valves are also present. The maximal dimension of the buffer tank is 5 L which is sufficient to keep the circuit under pressure. The position of the plate heat exchangers (cooling coils), pipes and buffer tanks is shown in Figure 7-2 and Figure 7-3. All the pipes which have to be connected to the external radiator are placed close to each other (see Figure 7-4). This positioning reduces the distinct number of pass-throughs in the container wall.

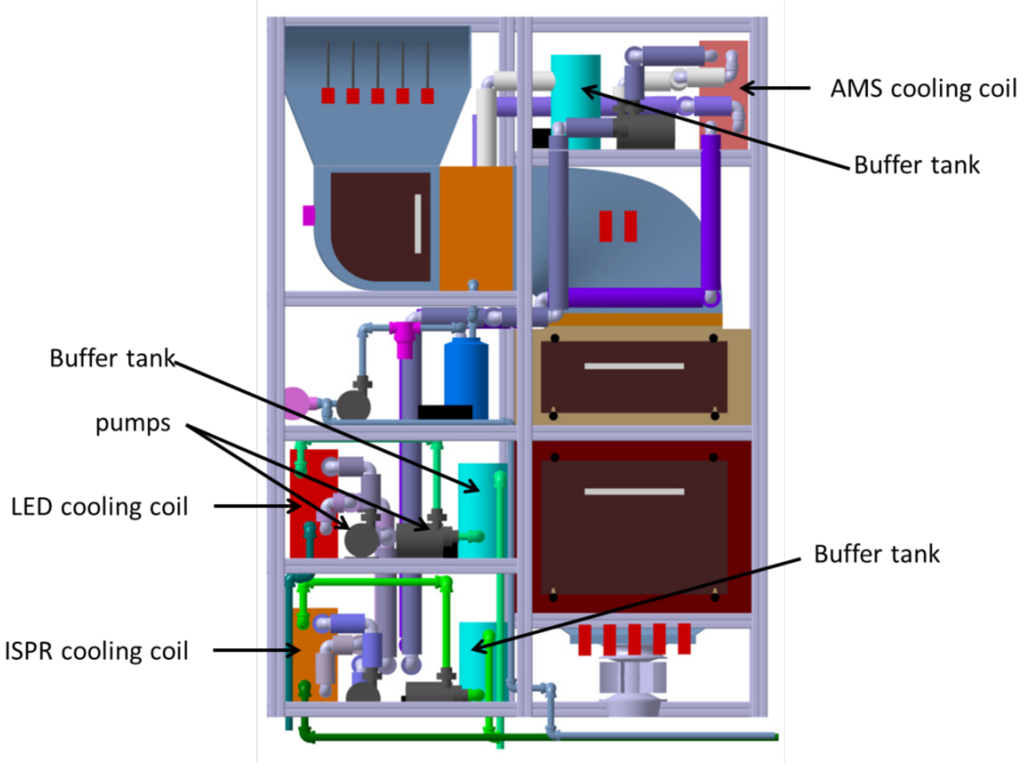


Figure 7-2: Position of cooling coils, pipes and buffer tanks.

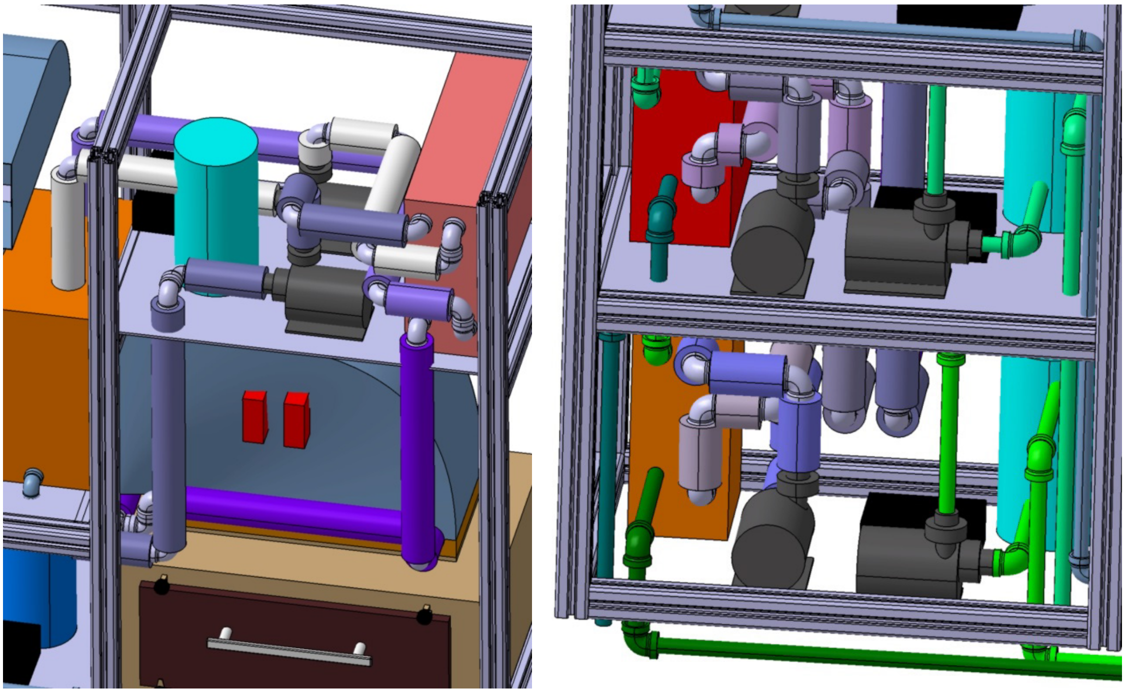


Figure 7-3: AMS cooling coil (left). LED and ISPR cooling coils (right).

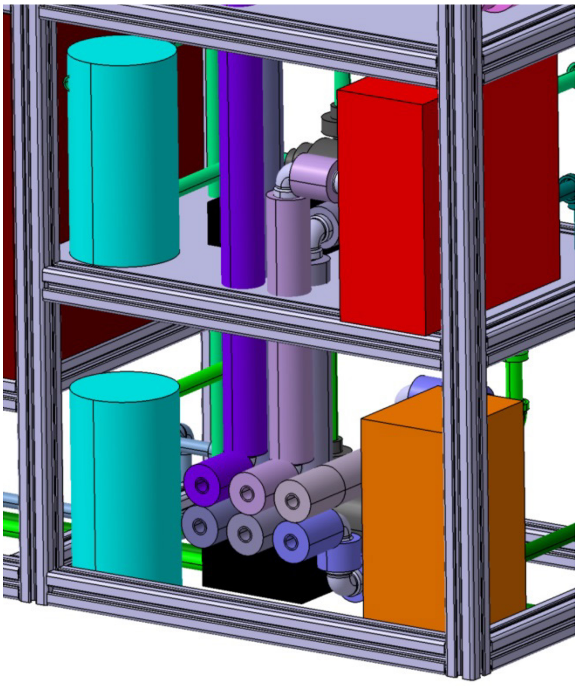


Figure 7-4: Six pipes connected to the external radiators.

The external radiators have to work as passive heat exchangers between the external air and the Tyfocor fluid. It can be designed as an external long pipe with fins which are used to increase the contact area between air and Tyfocor (see Figure 7-5).

Figure 7-5: Example of a pipe with fins.

The calculation of the necessary external area (fins included) of the pipe, and, consequently the length of the pipe, depends on the following formula:

$$Q = K_{global} A \, (T_{fluid1} - T_{fluid2})$$

where Q is the thermal load, A is the exchange area, T_fluid1 is the average temperature of the Tyfocor, T_fluid2 is the average temperature of the air and K_global is a global heat transfer coefficient. K_global depends on the thermal properties of the two fluids, the mass flows of the two fluids and the characteristic of the solid materials. Some estimates of coefficient K_global are usually provided by the industrial producers of these pipes. K_global values between 25-50 W/m^2 K are typical values for pipes with fins, considering water inside pipe and air for the external environment. When we assume K_global = 25 W/m^2 K and a temperature gradient of 5°C between the two fluids, the exchange area for the pipes with fins can be estimated as per Table 7-2.

Table 7-2: Estimates of required external radiator exchange areas.

External radiator	Thermal load	Estimated area of pipe with fins
AMS	5500 W	44 m^2
ISPR	1100 W	9 m^2
LED	2600 W	21 m^2

7.2 *List of Equipment*

Table 7-3: Key values of Thermal Control system.

	Mass	Peak power	Power day - nominal mode	Power night - nominal mode	Costs
Mobile Test Facility	307.6 kg	3278 W	3278 W	2442 W	n.a.
Neumayer Station III	n.a.	n.a.	n.a.	n.a.	n.a.
Spares, consumables, tools	60.5 kg	n.a.	n.a.	n.a.	n.a.
TOTAL	368.1 kg	3278 W	3278 W	2442 W	n.a.

8 Atmosphere Management System

8.1 *Baseline Design*

Aim of this section is to define all the parameters related to the air treatment inside the MTF:

- Air flow rate for FEG and SS
- Air inlet and outlet temperature
- Relative humidity
- Filtration and cleaning, with control and removal of VOC and dirt
- Control of O_2 and CO_2
- Air distribution in FEG and SS

A block diagram of the AMS can be found within Figure 8-1 and Figure 8-2 at the end of this chapter.

8.1.1 AMS for FEG: Inputs to Subsystem Sizing

Crop:

- Prod. area 12,3 m^2
- Transpiration rate: Day, 160 g/m^2h (total: 2050 g/h - all trays, fully mature crops) Night, 385 g/h
- CO_2 Requirements – 370 g/day (actual calculated)
- $ppEthylene_{max}$ = 15 ppb (continuous), 100 ppb (trans. – 30 min)
- Canopy level wind speed: 0,2 m/s preferable (long term) max wind speed 5 m/s for few hours min. wind speed 0.01 m/s

FEG internal parameters:

- Tnom = 22°C, Tmax = 30°C for one day with light; Tmax = 34 °C , Tmin = 8°C for 2 days
- RH = 70±5%, RHmin = 45% for 12 hours
- RHmax = 96% for 4 hours (assumed the distribution throughout the FEG is perfect)
- ppCO2 = 750 ppm (TBC) ppCO2 max = 1500 ppm (24 hours) (germination phase & cucumber is limiting)
- Leakage: 500% total FEG volumes per day (note that this considers leakage from the FEG – not the MTF overall).
- LED power: 4,5 kW

External environmental parameters:

- Summer: +5°C, max. temperature, with RH of 92% ref.
- Winter: -50°C, min. temperature, humidity negligible
- Solar radiation: min. 0 W/m^2 max. 960 W/m^2

8.1.2 Thermal Load Calculation

The internal air flow rate will be defined mainly on the basis of two factors:

- Thermal gradient of the air, function of the thermal load to be dissipated
- Number of air exchanges required by the crop

On the following table are summarized the results of the thermal load calculation:

	SENSIBLE HEAT	Light Period(W)	Dark Period (W)
ILS	ILLUMINATION SYSTEM- tot. 4.500 W		
	35% heating in the air	1.600	0
	20% of 65% cooled by liquid	600	0
NDS		0	0
AMS	Heated dissipated in air by AMS unit	600	600
TCS		0	0
	Total	2.800	600

Note: The 600 W of the AMS unit is obtained from the consideration that the ≈ 80% of two fans power goes into the flow rate as heating. This power depends on the work point of the fans, so this value has to be verified after the final calculation of the pressure drop of the entire loop. The two fans will be powered on 24 hours a day.

CROP	LATENT HEAT	16 h	8h
1*	Daily Water production	160 gr/m^2.h	30 gr/m^2.h
2*	Crop Surface	12,3 m^2	
3*	Water production per hour	2050 gr/h	385 gr/h
4*	Vaporization heating	540 cal/gr	540 cal/gr
5*	Conversion factor cal/h - W	1 W= 860 cal/h	
	Total = (3* x 4* / 5*)	1.250 W	240 W

		Light		Dark	
EL	EXTERNAL LOAD	Summer (W)	Winter (W)	Summer (W)	Winter (W)
	Conduction Heat (k= 0,4W/m^{2}K)	-387	-1.640	-387	-1.640
	Solar Radiation	160	0	160	0
	Internal Heat	2.800	2.800	600	600
	Total Sensible Heat	2.573	1.160	373	-1.040
	Latent Heat	-1.250	-1.250	-240	-240
	Crop Initial Balance	2.573	1.160	373	-1.040
	Crop Mature Balance	1.323	-90	133	-1.280

Cooling max requirement crop initial balance Summer + lights: - 2.573 W

Max. heating requirements: crop mature balance Winter + dark: +1.280 W

8.1.3 Air flow Calculation

Air Flow Rate estimation

First approach: the total heat is 2.573 W– latent heat 1.250 W = 1323 W

A gradient of temperature desirable for a crop can be ≈ 3°C

The consequent estimation of flow rate will be: 1323*0,86/3*0,24*1,2 = 1.370 m^3/h

The second parameter, number of air exchanges in a greenhouse, is normally assumed 1/min, the FEG volume is ≈ 31,05 m^3, as consequence the air flow rate should be: 1863 m^3/h.

Considering the small volume of the FEG, It will be selected a nominal flow rate of 1400 m^3/h - 1680 kg/h at 22°C (0,47 Kg/sec)

Starting from this flow rate of 1400 m^3/h:

Delta T due to Sensible Heat = 2573 /(1,2*1004,4*0,47) = **4,54 °C**

Effect of water evaporation:

Latent Heat: Delta T = -1.250 /(1,2*1004,4*0,47) = - 2,2 °C

Effective delta T: = 4,54 - 2,2 = 2,34 °C

With this flow rate the N° of air exchange per hour is : FEG volume 31,05 m^3 45 exch/h, 0,75 exch/min .

Internal balance temperature and RH:

- T nominal 22°C RH= 70%+-5
- Air inlet conditions : 20,5°C Hr 70% 10,58 g/kg Specific weight 1,2 kg/m^3
- Air outlet: Temperature increasing   2,34°C   T out 23 °C (22,84)
- Transpiration rate Day 160 g/m^2 h – total 2050 g/h all trays with full mature crops
- Maximum water content increasing   2050 /1680 = 1,22 g/kg
- Air outlet conditions : 23°C 11,8 g/kg Hr 65%

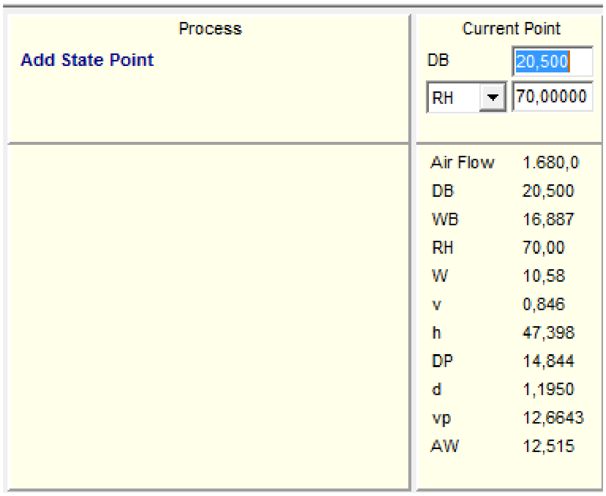
This value will be verified considering all the air transformation on the Mollier diagram.

8.1.4 Verification of air transformation parameters on the Mollier diagram

Those calculations was performed with a software "Psychrometric Analysis Design Suite" version 7.5.0.

For each process is reported the screen of the program:

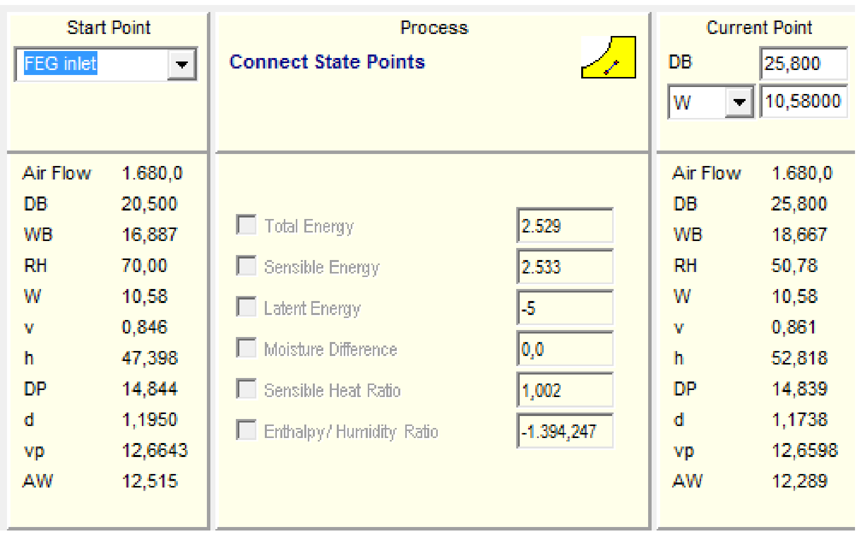
Starting point: Air inlet in FEG 20,5°C 70%Hr



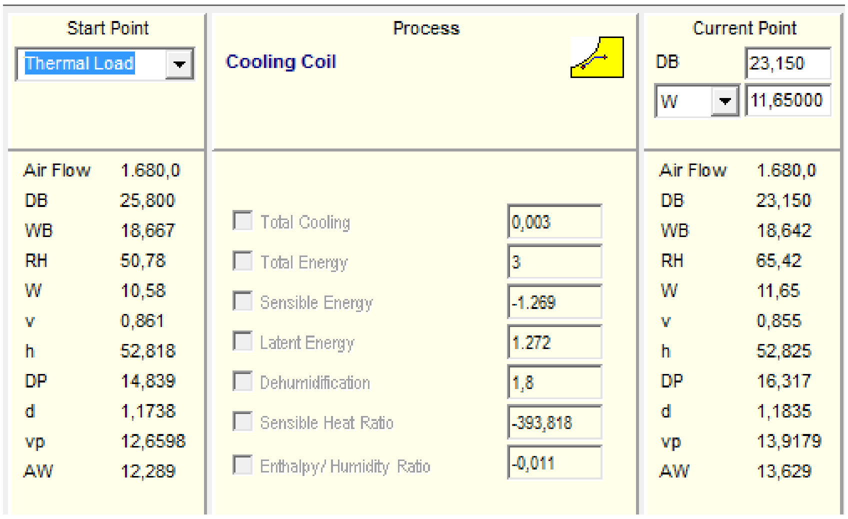
LEGEND
Air Flow kg/h
DB Dry Bulb temperature °C
WB Wet Bulb temperature °C
RH Relative Humidity %
W Water content gr/kg
v Specific Volume m^3/kg
h Enthalpy kJ/kg
DP Dew Point temperature °C
d density kg/m^3
vp Vapour pressure mmHG
AW Absolute Humidity gr/m^3

After the inlet, the air will be heated, as the result of thermal balance, with 2.573 W. This effect will be combined with the increase of humidity due to plants transpiration.

The first picture shows the increase of temperature, until 25,8°C, without transpiration:



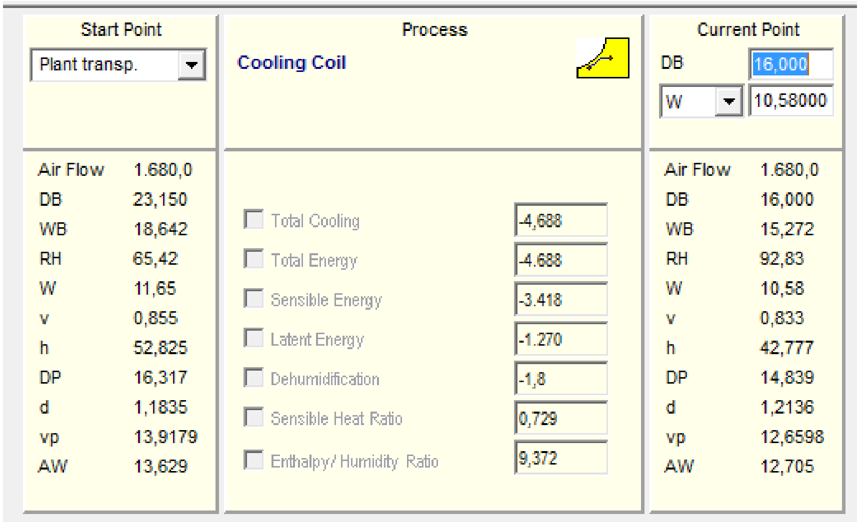
The transpiration of the plants cause an increase of humidity and a decrease of temperature:



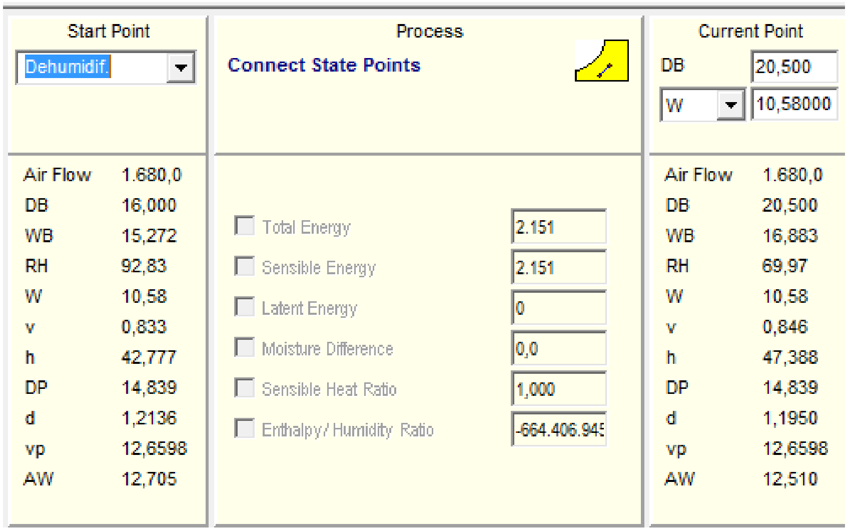
PROCESS PARAMETERS LEGEND
Total Cooling W
Total Energy W
Sensible Energy W
Latent Energy W
Dehumidification kg/h
Sensible Heat Ratio
Enthalpy/Humidity Ratio kJ/kg/gr/kg

Those are the conditions of the air at the outlet of the FEG: 23,15 °C and 65,4 % of RH

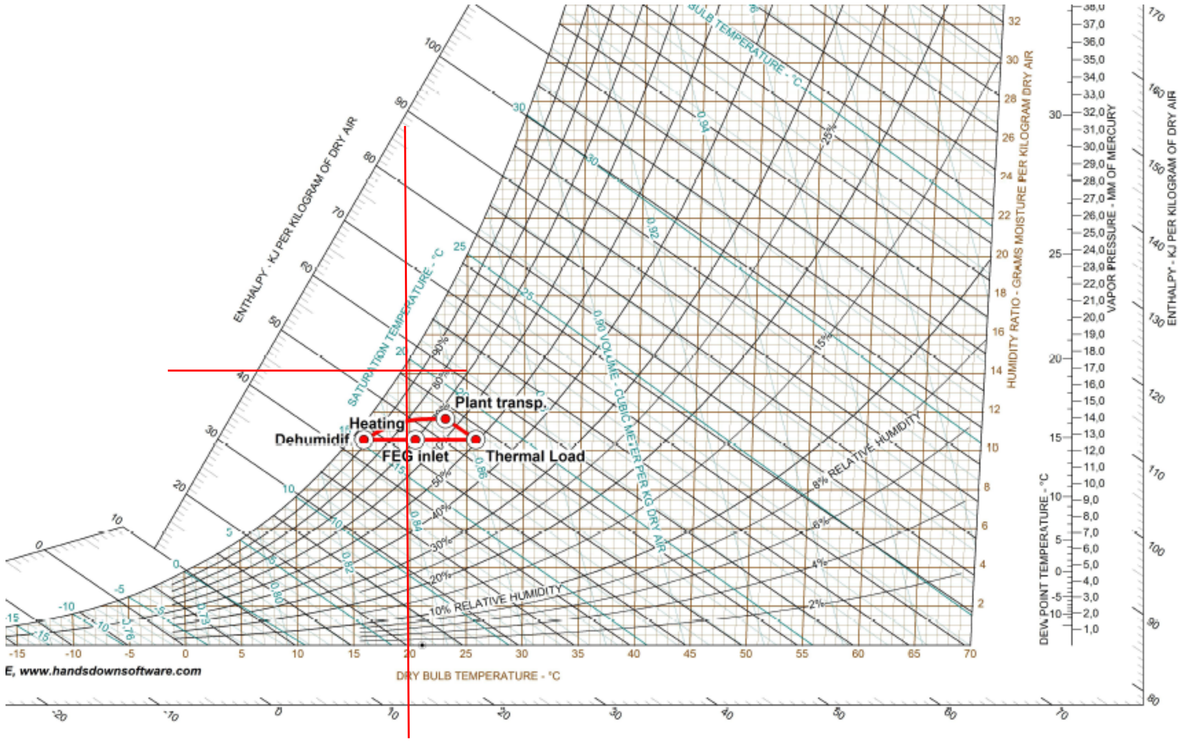
This air will come through the dehumidifier, where the water is recovered by condensation:



At the outlet of the dehumidifier, the air will be at 16°C with 92% of RH: before being reintroduced in the FEG, the air needs to be reheated.



The effective value required for the heaters is 2.151 W: the air will reach 20,5°C and 70% of RH, the FEG inlet conditions.



Air Transformation on Mollier Diagram

ENERGY BALANCE OF THE TRANSFORMATION

heating calculated in thermal balance	**+ 2533 W**
plant transpiration	-1269 W latent + 1272 W sensible
dehumidification	- 4688 w (- 3418 sensible - 1270 latent)
electrical heating	+2151 W
Total	0

CONDENSATION RISK

Dew point: 23,2°C with 65% (outlet of the FEG) = 16,3°C

Dew point: 23,2°C with 80% = 19,5°C Critical point for risk condensation on the FEG wall- lines red.

8.1.5 AMS Air Treatment – Coldest Case Winter & Dark Period

Starting point 18°C with 70% of RH, air conditions at the inlet in FEG

Process	Current Point	
Add State Point	DB	18,000
	RH	70,00000
	Air Flow	1.680,0
	DB	18,000
	WB	14,626
	RH	70,00
	W	9,03
	v	0,836
	h	40,910
	DP	12,450
	d	1,2063
	vp	10,8366
	AW	10,801

LEGEND
Air Flow kg/h
DB Dry Bulb temperature °C
WB Wet Bulb temperature °C
RH Relative Humidity %
W Water content gr/kg
v Specific Volume m^3/kg
h Enthalpy kJ/kg
DP Dew Point temperature °C
d density kg/m^3
vp Vapour pressure mmHG
AW Absolute Humidity gr/m^3

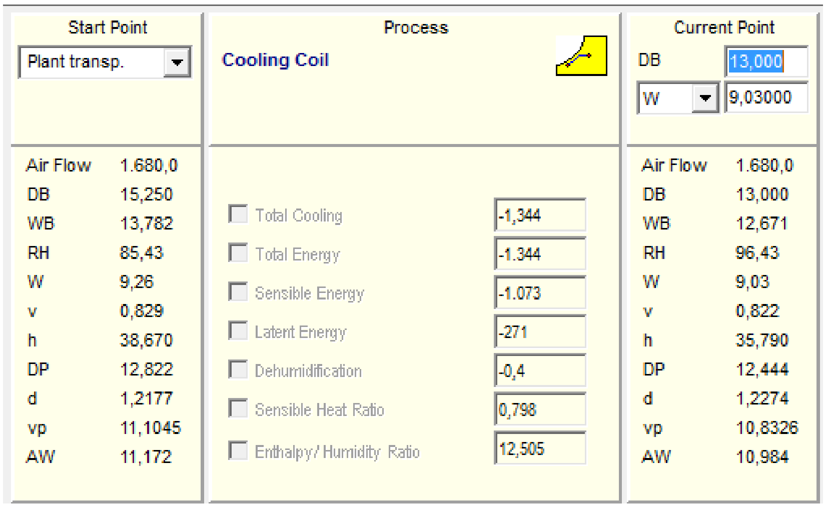
Loss of heat 1045 W (from thermal balance):

Start Point		Process		Current Point	
FEG inlet		Cooling Coil		DB	15,820
				W	9,03000
Air Flow	1.680,0			Air Flow	1.680,0
DB	18,000			DB	15,820
WB	14,626	Total Cooling	-1,045	WB	13,788
RH	70,00	Total Energy	-1.045	RH	80,35
W	9,03	Sensible Energy	-1.039	W	9,03
v	0,836	Latent Energy	-6	v	0,830
h	40,910	Dehumidification	0,0	h	38,671
DP	12,450	Sensible Heat Ratio	0,995	DP	12,444
d	1,2063	Enthalpy/ Humidity Ratio	481,787	d	1,2154
vp	10,8366			vp	10,8326
AW	10,801			AW	10,877

Effect of plant transpiration:

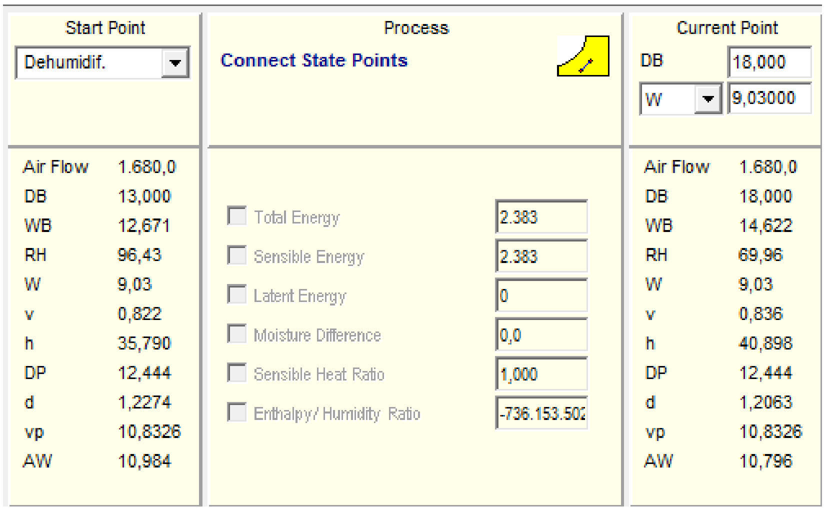
Start Point		Process		Current Point	
Thermal load		Connect State Points		DB	15,250
				W	9,26000
Air Flow	1.680,0			Air Flow	1.680,0
DB	15,820			DB	15,250
WB	13,788	Total Energy	0	WB	13,782
RH	80,35	Sensible Energy	-272	RH	85,43
W	9,03	Latent Energy	272	W	9,26
v	0,830	Moisture Difference	0,4	v	0,829
h	38,671	Sensible Heat Ratio	928,000	h	38,670
DP	12,444	Enthalpy/ Humidity Ratio	-0,020	DP	12,822
d	1,2154			d	1,2177
vp	10,8326			vp	11,1045
AW	10,877			AW	11,172

Dehumidification through the heat exchanger:



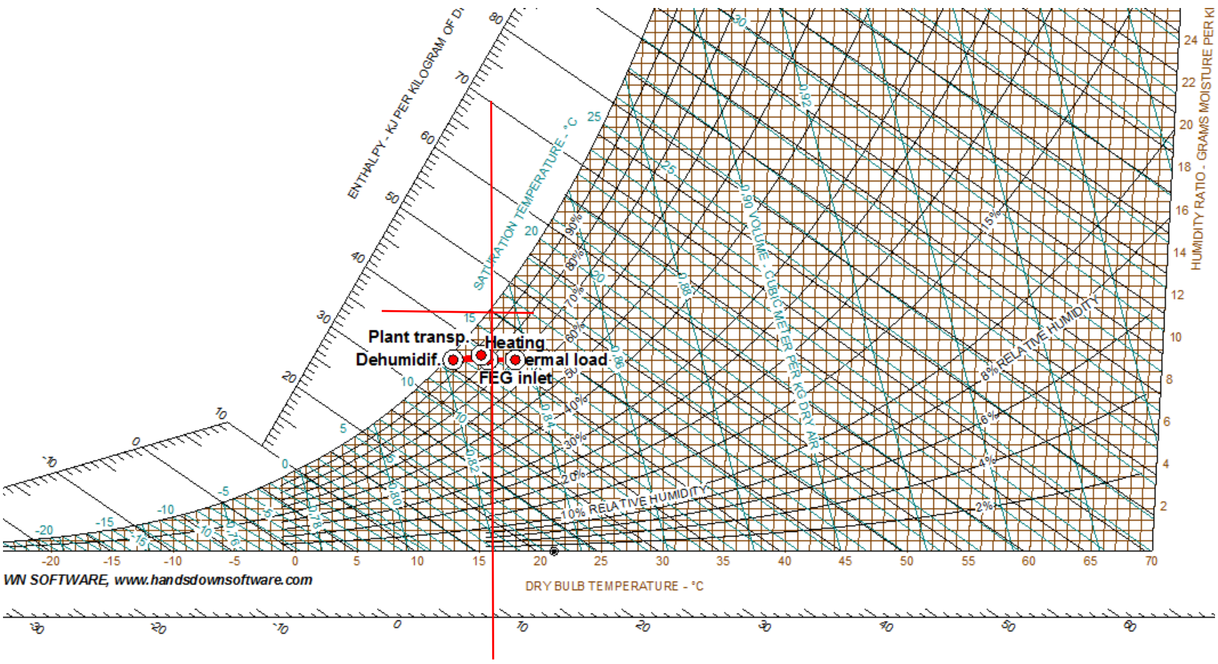
Start Point		Process		Current Point	
Plant transp.		Cooling Coil		DB	13,000
				W	9,03000
Air Flow	1.680,0			Air Flow	1.680,0
DB	15,250			DB	13,000
WB	13,782	Total Cooling	-1,344	WB	12,671
RH	85,43	Total Energy	-1.344	RH	96,43
W	9,26	Sensible Energy	-1.073	W	9,03
v	0,829	Latent Energy	-271	v	0,822
h	38,670	Dehumidification	-0,4	h	35,790
DP	12,822	Sensible Heat Ratio	0,798	DP	12,444
d	1,2177	Enthalpy/ Humidity Ratio	12,505	d	1,2274
vp	11,1045			vp	10,8326
AW	11,172			AW	10,984

After heating:



Start Point		Process		Current Point	
Dehumidif.		Connect State Points		DB	18,000
				W	9,03000
Air Flow	1.680,0			Air Flow	1.680,0
DB	13,000			DB	18,000
WB	12,671	Total Energy	2.383	WB	14,622
RH	96,43	Sensible Energy	2.383	RH	69,96
W	9,03	Latent Energy	0	W	9,03
v	0,822	Moisture Difference	0,0	v	0,836
h	35,790	Sensible Heat Ratio	1,000	h	40,898
DP	12,444	Enthalpy/ Humidity Ratio	-736.153.502	DP	12,444
d	1,2274			d	1,2063
vp	10,8326			vp	10,8326
AW	10,984			AW	10,796

Graphical representation on Mollier Diagram:



CONDENSATION RISK

Dew point: 18°C 70% (outlet of the FEG) = 12,5°C

Dew point: 18°C 80% = 14,5°C marked with red lines on diagram.

8.1.6 Conclusion

Stated Air flow rate: 1.400 m^3/h

Total thermal capability of the dehumidifier, sensible + latent: 4.488 W. Considering the efficiency of the heat exchanger, we can assume a nominal capacity of 5.000 W.

Heaters capability: 2.151 W, in the hot period and 2.383 W in the cold period, nominal 3.000 W

Humidifier capability: 2.050 g/h minimum when the plants are not yet mature, nominal 3.000 g/h.

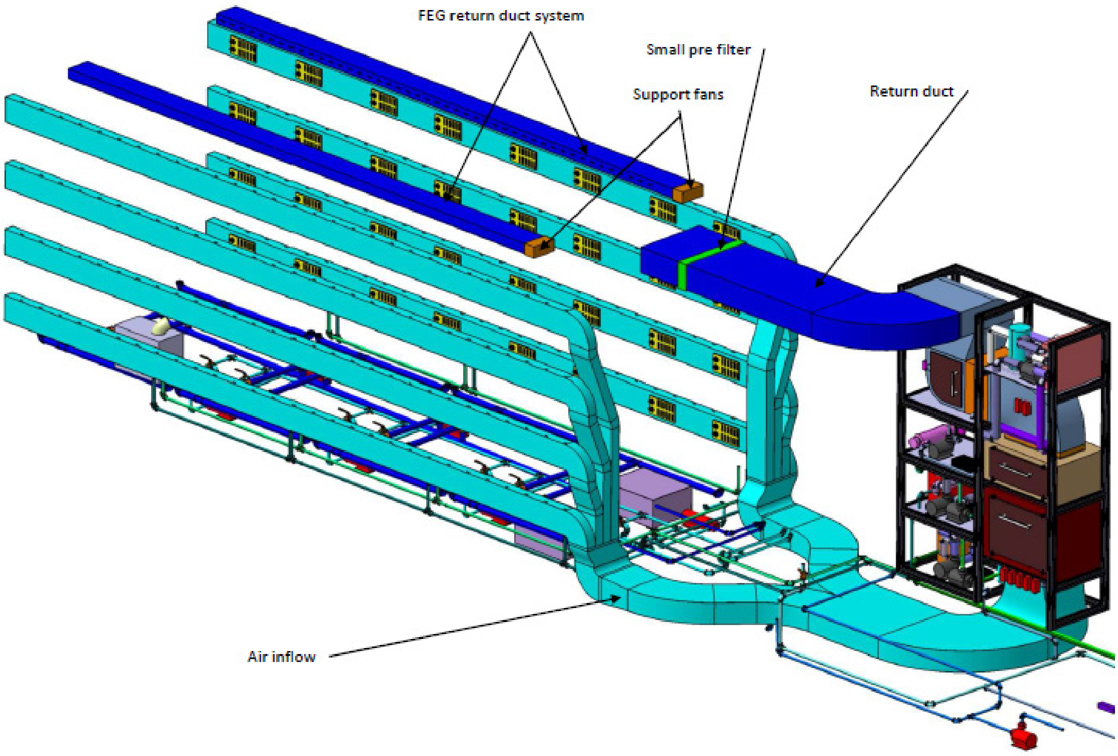
8.1.7 Air distribution Definition - Duct System

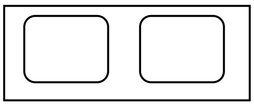
Driving parameters:

- Flow rate 1400 m^3/h
- Air speed inside ducts: 3 m/sec ref.
- Air speed on crop: 0,2 m/sec with a minimum launch of 600-700 mm, depth of the shelf

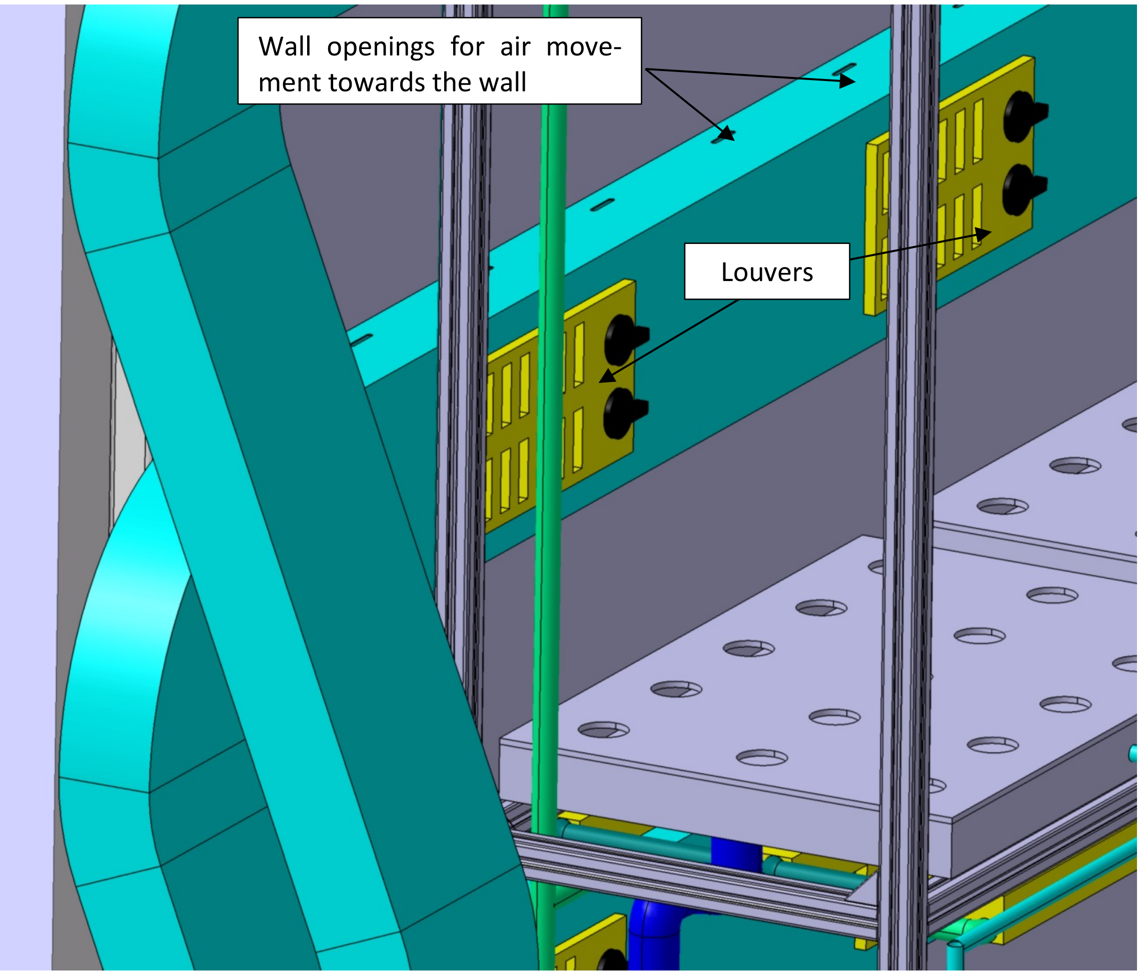
Duct dimensioning:

- Main duct: 700 x 170 mm, air speed 3,24 m/sec
- First subdivision: 2 duct, right and left, 700 m^3/h each, 350 x 170 mm air speed 3,24 m/sec, constant
- Second subdivision: 4 lines for each side, 175 m^3/h ea
- Dimension 200 x 80 mm: air speed 3,0 m/sec
- Each of these ducts will have side openings to spread the air at the speed close to 0,2 m/sec, so each opening will have a free area of 0,24 m^2 (175 $m^3/h/0{,}24\ m^2$ = 0,2 m/sec)
- Main Return air duct: 600 x 200 mm, air speed 3,24 m/sec.
  To avoid the risk of air stagnation, it is foreseen to include two suction ducts with one fan each, to move the air from the end section of the FEG. In first approach these ducts can have a flow rate of ¼ of the total, 350 m^3/h each. The dimensions can be 300 x 150 mm.
- Fan for the return ducts: 350 m^3/h with a small pressure drop





Example of two axial fans installed in the return ducts

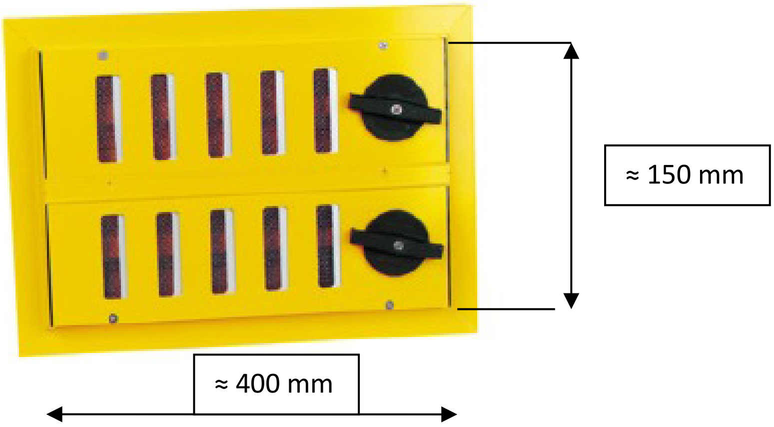


To spread the air at the speed close to 0,2 m/sec:

Each duct can have 8 louvers, each louver will have a flow rate of 175/8 = 22 m^3/h and with a free area of 22/3600/0,2 = 0,03 m^2

Example: 150 mm x 200 mm or 120 mm x 250 mm length.

Example of louver, on-off type, with those dimensions:



The correct selection of louvers can guarantee uniform distribution of the air between the ducts but in the case when one or more louvers will be closed, this distribution can change.

To avoid this, it is possible to evaluate the installation of constant flow valves in each duct. This type of valve, can be preset at a defined value, and will maintain this value also within a pressure change in the air: see para 11.2.1 of Options and trades section.

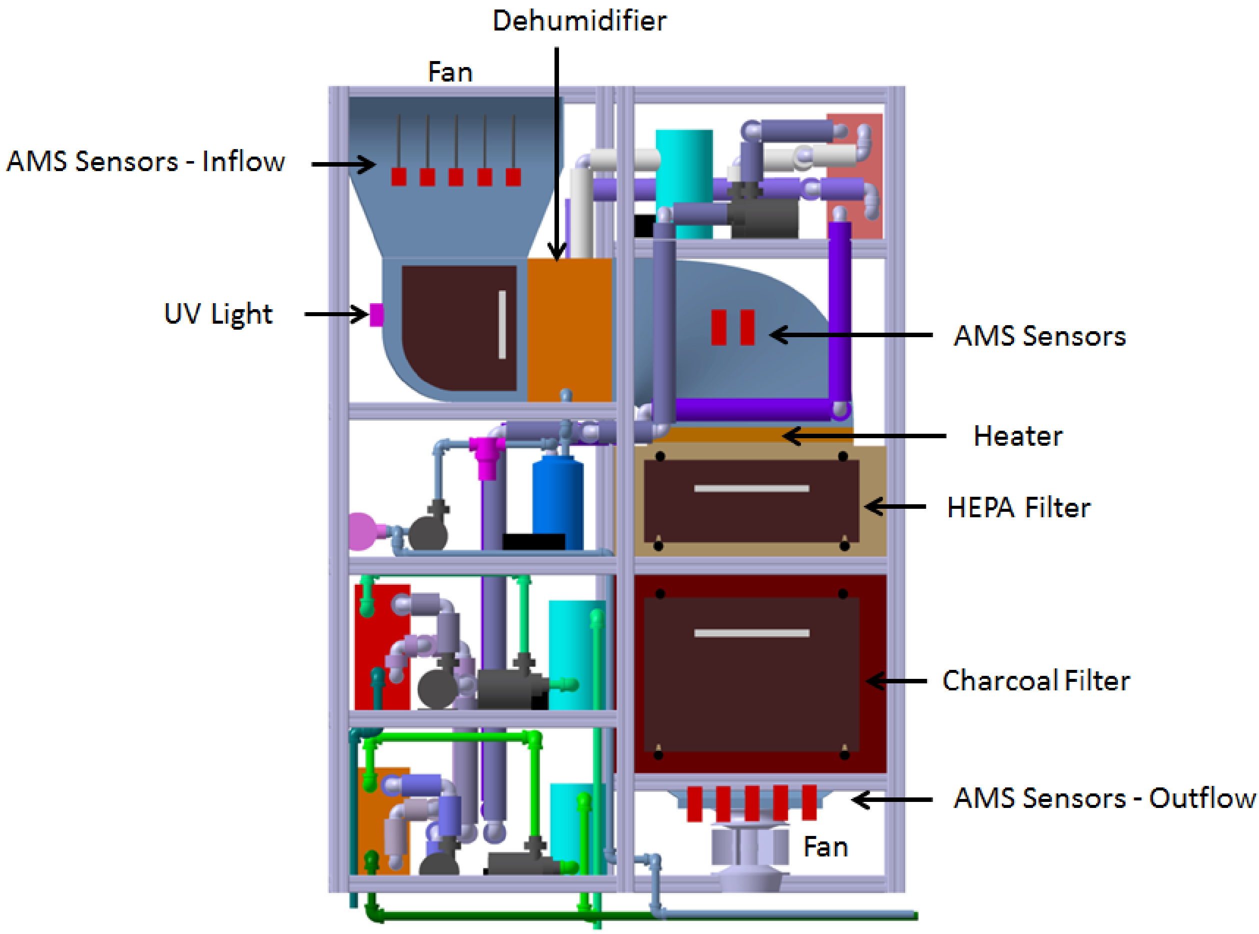
8.1.8 AMS Unit

All the functional components of the Air Management System are grouped in a rack.

The components and connections are shown in the schematic diagram, in Annex 1.

The AMS unit will contain the two fans, one on the air inlet and one on the outlet, the heat exchanger for dehumidification, the heaters, the UV-C lamps, filters and sensors.

The following picture shows a preliminary functional block layout of the AMS unit:



8.1.8.1 Fan selection

Fan selection driving parameters:

- Performances, flow rate versus pressure curve (two fans in series will have a total pressure which will be about the sum of the single pressure)
- Temperature range, functional and storage-transport
- Suitable shape for the application and construction materials

The selected fan can have two different motors, with the same shape and dimensions: on the base of final pressure drop calculation it will be possible to choose the model with 448 W of power, curve A, or the alternative with 750 W, curve B

So far, the estimated AMS unit Pressure drop is:

- Dehumidifier (heat exchanger) 150 Pa
- Prefilter + filter HEPA 280 filter new – 600 Pa filter clogged (type H14), when removed
- VOC filter 200 Pa (the chemical filter pressure drop is constant versus the clogging)

Total: min 630 Pa – max 950 Pa

Considering the pressure capability of two fan on curve A of 1.400 Pa (700 + 700), it remains 1.400 - 950 = 450 Pa for the pressure drop along the ducts of the air system.

EC centrifugal fans – RadiPac

backward curved, Ø 250

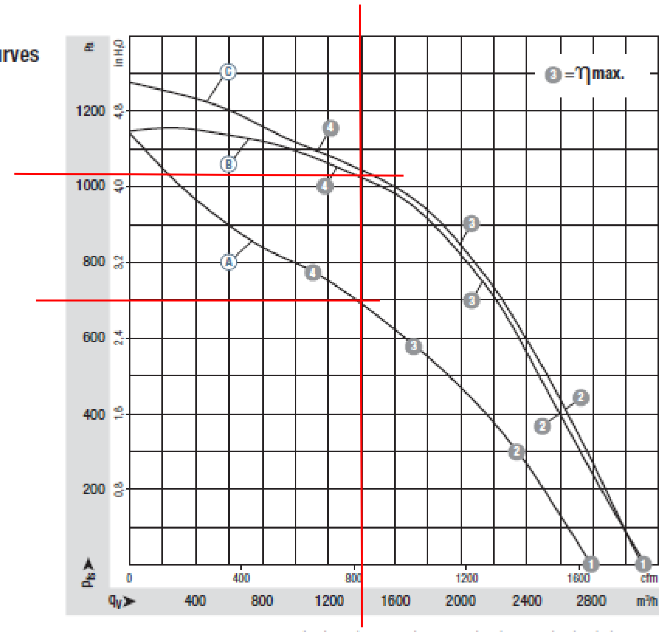
- **Material:** Support bracket: Steel, coated in black
  Support plate and inlet nozzle: Sheet steel, galvanised
  Impeller: Sheet aluminium
  Rotor: Coated in black
  Electronics enclosure: Die-cast aluminium
- **Number of blades:** 7
- **Direction of rotation:** Clockwise, seen on rotor
- **Type of protection:** IP 54 (acc. to EN 60529)
- **Insulation class:** "B"
- **Mounting position:** Shaft horizontal or rotor on bottom; rotor on top on request
- **Condensate discharges:** Rotor-side
- **Mode of operation:** Continuous operation (S1)
- **Bearings:** Maintenance-free ball bearings

Nominal data		Curve	Nominal voltage range	Frequency	Speed/rpm(1)	Max. input power(1)	Max. current draw(1)	Perm. amb. temp.	Technical features and electr. connection
Type	**Motor**		**VAC**	**Hz**	**rpm**	**W**	**A**	**°C**	
***3G 250**	M3G 084-DF	Ⓐ	1~ 200-277	50/60	3000	448	2,80	-25..+40	p. 88 / K1)
***3G 250**	M3G 084-FA	Ⓑ	1~ 200-277	50/60	3450	750	3,30	-25..+40	p. 91 / L7)
***3G 250**	M3G 084-GF	Ⓒ	3~ 380-480	50/60	3580	790	1,50	-25..+60	p. 93 / P2)

subject to alterations

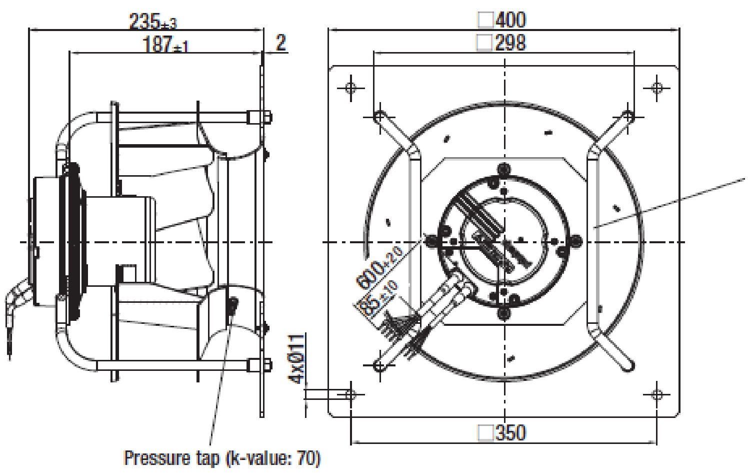
(1) Nominal data in operating point with maximum load and 230 or 400 VAC

Curves



Air performance measured as per: ISO 5801, installation category A, with ebm-papst inlet nozzle without protection against accidental contact. Suction-side noise levels: L_WA as per ISO 13347, L_pA measured at 1 m distance to fan axis. The acoustic values given are only valid under the measurment conditions listed and may vary depending on the installation situation. With any deviation to the standard setup, the specific values have to be checked and reviewed once installed or fitted! For detailed information see page 94 ff.

		n rpm	P_{ed} W	I A	L_WA dB(A)
Ⓐ	❶	3175	380	2,48	84
Ⓐ	❷	3045	436	2,72	80
Ⓐ	❸	3000	448	2,80	76
Ⓐ	❹	3020	436	2,72	80
Ⓑ	❶	3450	581	2,58	85
Ⓑ	❷	3450	673	2,98	82
Ⓑ	❸	3450	750	3,30	79
Ⓑ	❹	3450	691	3,07	86
Ⓒ	❶	3655	642	1,25	87
Ⓒ	❷	3605	735	1,40	84
Ⓒ	❸	3580	790	1,50	80
Ⓒ	❹	3635	709	1,38	88



Technical description	
Mass	9 kg
Size	250 mm
Surface of rotor	Coated in black
Material of electronics housing	Die-cast aluminium, coated in black
Material of impeller	Aluminium sheet, white plastic-coated
Material of mounting plate	Sheet steel, galvanised and coated in white
Material of support bracket	Steel, galvanised and coated in black
Material of inlet nozzle	Sheet steel, galvanised and coated in white
Number of blades	7
Direction of rotation	Clockwise, seen on rotor
Type of protection	IP 54
Insulation class	"B"
Humidity (F)/environmental protection class (H)	F5
Max. permissible ambient motor temp. (transp./ storage)	+80 °C
Min. permissible ambient motor temp. (transp./storage)	-40 °C
Mounting position	Shaft horizontal or rotor on bottom; rotor on top on request
Condensate discharge holes	Rotor-side
Cooling bore / aperture	On rotor sides
Operation mode	S1
Motor bearing	Ball bearing
Technical features	- Output 10 VDC, max. 1.1 mA - Alarm relay - Motor current limit - Soft start - Control input 0-10 VDC / PWM - Control interface with SELV potential safely disconnected from the mains - Over-temperature protected electronics / motor - Line undervoltage detection
EMC interference immunity	Acc. to EN 61000-6-2 (industrial environment)
EMC interference emission	Acc. to EN 61000-6-3 (household environment)
Touch current acc. IEC 60990 (measuring network Fig. 4, TN system)	<= 3,5 mA
Motor protection	Thermal overload protector (TOP) wired internally
Cable exit	Variable
Protection class	I (if protective earth is connected by customer)
Product conforming to standard	EN 61800-5-1 / CE
Approval	UL 2111 / EAC / CSA C22.2 No.77

This data refers to fan model K3G 250-AT39 -74 manufactured by Ebmpabst.

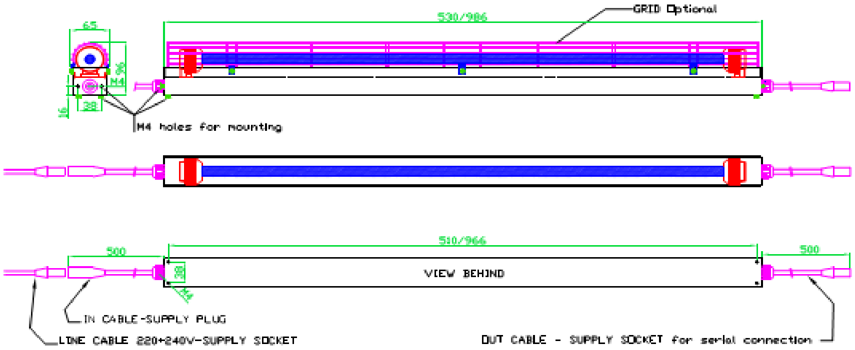
8.1.8.2 UV-C lamp

Aim of the application of an UV-C lamp 260 nm of wavelength is both the decontamination of the surface of the dehumidifier and the Airborne Inactivation, to eliminate the microbial load.

In these micro-areas of shadow, between the metal wings of the thermal batteries, colonies of fungi, algae, and bacteria are established, due to the high levels of humidity. The device works by direct irradiation of UV-C rays. When the tube is turned on, it reduces the microbial load in the air and on the surfaces enlightened by the UV lamp.

The fixture is a lamp contained in a channel, entirely in AISI 304 stainless steel, and fitted with a reflecting screen in mirror bright aluminum, to increase the power of radiation, through the reflection of UV-C proportion that would otherwise be wasted in the opposite direction to the useful ones.

A typical configuration places the UV-C lights upstream from the cooling coil to deal with the spore size micro-organisms and upstream of a high efficiency HEPA (High Efficiency Particulate Arrestance) filter to eliminate airborne bacteria and viral contaminants.



UV-STICK	E40H-NX-SCR	E75H-NX-SCR
LAMP AVERAGE LIFETIME (hour)	9000	9000
POWER (W)	40	75
DIMENSIONS LxSxH (mm.)	530 x 65 x 96	986 x 65 x 96
AVERAGE COVERED SURFACE OF COIL / FILTER (m2)	0,25 ÷ 0,50	0,50 ÷ 1,00
WEIGHT (Kg.)	1,5	2

For the disinfection efficiency compared with this flow rate, one 40 W is sufficient. Anyway to improve the reliability, two lamps are foreseen. Another improvement can be the use of a reflective internal surface in this section of the AMS (this issue will be analyzed during the final design activities). Manufacturer Ref: UV-STICK model E40-NX-SCR of Light Progress (www.lightprogress.it).

8.1.8.3 Dehumidifier

Utilizing the software package REcalc- Ver.1.2.37, it was calculated the size of a preliminary version of the heat exchanger for the dehumidification purpose.

As cooling fluid was considered a mixture of 40% water with 60% propylene glycol, very similar for the thermal characteristics of Tyfocor (Tyfocor is a mixture of propylene glycol). The inlet temperature of the cooling fluid was stated at 8°C (thermal control). A preliminary estimation of the flow rate can be done considering a desirable delta T of the cooling fluid of about 5-8°C. The specific heat of the mixture with Tyfocor at 60%, suitable for -40°C, is about 3 kJ/kgK, as shown in the table below:

Tyfocor mixture with water - Heat capacity (kJ/kgK)

T [°C]	25 % vol.	30 % vol.	35 % vol.	40 % vol.	45 % vol.	50 % vol.	55 % vol.	60 % vol.
120	4.152	4.138	4.085	4.022	3.949	3.866	3.753	3.641
110	4.132	4.108	4.055	3.982	3.909	3.816	3.714	3.601
100	4.112	4.078	4.015	3.952	3.869	3.776	3.674	3.562
90	4.082	4.048	3.985	3.912	3.830	3.737	3.634	3.522
80	4.062	4.019	3.955	3.883	3.790	3.697	3.595	3.483
70	4.032	3.989	3.916	3.843	3.750	3.658	3.555	3.443
60	4.012	3.959	3.886	3.803	3.710	3.608	3.506	3.403
50	3.982	3.919	3.846	3.763	3.671	3.568	3.466	3.364
40	3.962	3.889	3.816	3.734	3.631	3.529	3.426	3.324
30	3.933	3.859	3.776	3.694	3.591	3.489	3.387	3.285
20	3.913	3.830	3.747	3.654	3.552	3.449	3.347	3.245
10	3.883	3.790	3.707	3.615	3.512	3.400	3.308	3.206
0	3.863	3.760	3.677	3.585	3.472	3.360	3.268	3.166
-10	3.833	3.730	3.637	3.545	3.433	3.321	3.219	3.126
-20	-	-	-	3.505	3.393	3.281	3.179	3.087
-30	-	-	-	-	-	3.241	3.139	3.048
-40	-	-	-	-	-	-	3.100	3.008
-50	-	-	-	-	-	-	-	2.966

So, the flow rate P of the cooling fluid is given by this formula:

P = Q (heat to dissipate)/delta T x Heat Cap. = 5 /(5 x3) = 0,33 kg/sec =1.188 kg/h

The following calculation is an example of dimensioning of a heat exchanger, where the flow rate of cooling fluid, is 1082 l/h with an inlet temperature of 8°C and an outlet of 12,9°C (delta T 4,9°C) and the heat capacity, with a safety factor of 10%, is 5,13 kW.

Tube Material:	CU-.30	Ext. Surface:	18,1 m2	Volume:	3,6 dm3
Fin Material:	AL-.10	Int. Surface:	1,33 m2	Weight:	12,8 kg

External Gas:	Air Std / 101,33 kPa
Flow Rate	0,39 m3/s = 1400 m3/h 0,47 kg/s
Velocity	2,78 m/s
Inlet and Outlet Temp.	23,5 °C -> 15,9 °C
Inlet and Outlet Rel. Humidity	65,4 % -> 93,8 %
Inlet and Outlet Water Cont.	11,82 g/kg -> 10,56 g/kg
Condensed Water	0,59 g/s
Sensible Heat Factor	0,71
Pressure Drop	166 Pa
Internal Fluid:	Prop. Glyc. 60%
Flow Rate	0,3 l/s = 1082 l/h 0,32 kg/s
Velocity	1,43 m/s
Inlet and Outlet Temp.	8 °C -> 12,9 °C
Pressure Drop	220 kPa
Capacity:	5,13 kW CounterFlow Calculation
Safety Factor	10 %
Fluid Name:	Propylen Glycol 60%
Spec. Heat	3289 J/kg k
Spec. Weight	1053 kg/m3
Viscosity	16,41 mPa s
Conductivity	0,32 W/m k

The dimensions are 400 x 350 height x 225 mm depth, 8 rows.

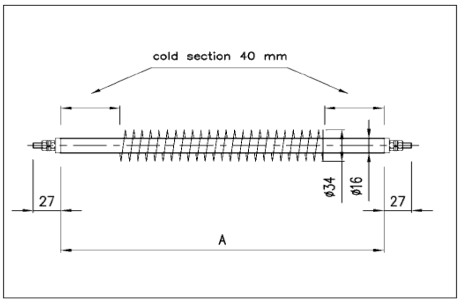
The condensed water is 0,59 g/sec, 2,2 l/h, (the minimum required value was 2 l/h).

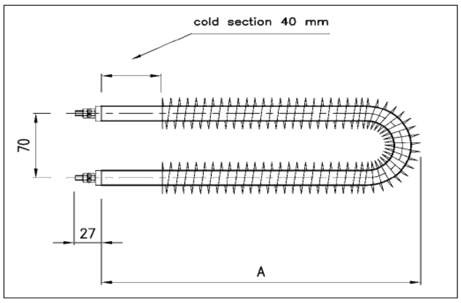
The materials are copper tube with aluminum fins: the cooling fluid is compatible with the copper.

To guarantee the external protection can be adopted a surface treatment of Ecofen (commercial name: Heresite, heat cured phenolic), very resistant against the salt spray and the erosion activated by the air flow through the fins. Note: the resistance against salt spray, measured in hours, is a way to measure the quality and reliability of a heat exchanger.

8.1.8.4 Heaters

Example of electric heaters suitable for this application:





TECHNICAL DATA

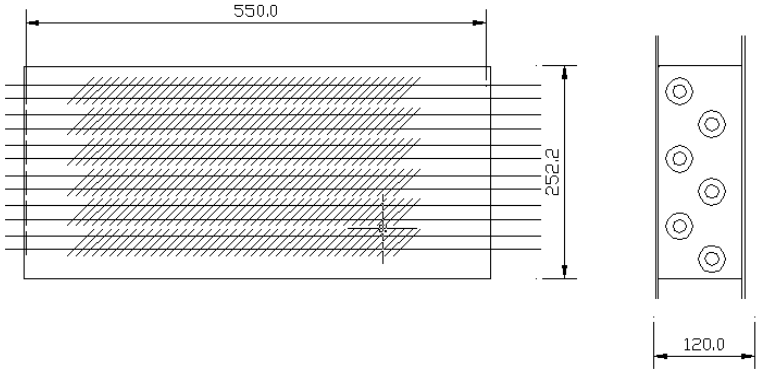
Sheath Material	= carbon steel
Fin Material	= carbon steel
Sheath diameter	= 16 mm
Diameter of the finned part	= 34 mm
Terminal Stud	= threaded M6 x 27 mm
Cold section at each end	= 40 mm
Distance between the studs	= 70 mm (series 5516U)
Power supply voltage	= 230 V
Length	= A (see Table 1)
Power	= P (see Table 1)

Straight heaters: 2 W/cm² – 230 V Suitable for static and forced flow air			
Code	A (mm)	Power (W)	Weight (kg)
5516L03500300	350	300	0.570
5516L05500500	550	500	0.900
5516L07500700	750	700	1.230
5516L08500800	850	800	1.300
5516L10501000	1050	1000	1.720

"U"-bent heaters: 2 W/cm² – 230 V Suitable for static and forced flow air			
Code	A (mm)	Power (W)	Weight (kg)
5516U02750500	275	500	0.900
5516U03750700	375	700	1.230
5516U04250800	425	800	1.300
5516U05251000	525	1000	1.720
5516U06251200	625	1200	2.050

For this application, is suitable the type 550 mm of length, straight type, capable of 500 W (needing 6 units) or 425 mm U shaped model, capable of 800 W (needing 4 units).

The next figure shows a possible installation of 6 straight heaters in a light alloy frame, disposed in two rows, to fit exactly the dimensions of the air passage:



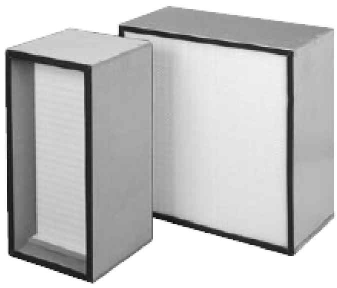
Note: this type of heater can work also in static air and this is a useful safety margin (in any case they are protected also by a thermostat). The solution with the straight type is selected to define dimensions and feasibility: in a later design phase it will be possible to do a comparison with the U bent type.

8.1.8.5 Filtration System

The filtration system will be composed by a HEPA filter, with a prefilter, and a VOC filter. The prefilter protects the HEPA filter from the coarse powder, with standard characteristics and a low pressure drop. Normally its space is obtained within the HEPA filter space.

An example of a HEPA filter is shown in the picture below:

Technical features		
Product	LLMB	KKMB
Efficiency MPPS	99,95 %	99,95 %
EN 1822:2009 classification	H13	H13
Suggested final pressure drop	600 Pa	600 Pa
Maximum pressure drop	1000 Pa	1000 Pa
Maximum operating temperature	70 °C	70 °C
Maximum relative humidity	90 %	100 %
CE mark		•
ATEX version on request		•



Those type of absolute filters are designed to work with high flow rates, 35% higher than other similar filters of equal size; at nominal air flow, they work with a frontal air speed of 2.00 m/s.

These filters have mini pleated microfiber glass filtering pack, top quality manufacture, high dust holding capacity and great mechanical resistance. Also available in H14 efficiency: LLMA model and KKMA model.

Type	Dimensions (mm)			Nominal air flow rate Q				Filtering surface		Initial pressure drop
				m^3/h		$m^3/s \times 10^{-3*}$		m^2		
LLMB - KKMB	A	B	C	LLMB	KKMB	LLMB	KKMB	LLMB	KKMB	Pa
3 X	305	305	149	550	580	153	161	4,9	5,4	280
42 X	305	610	149	1200	1250	333	347	10,3	11,4	280

Driving parameters for the VOC filter are:

- ➢ Quantity of VOC (Ethylene ref.) absorbed
- ➢ Speed of the air through the filtration bed

Assuming the ethylene production:

pp Ethylene$_{max}$ 15 ppb continuous (15 mg/m^3)

To guarantee a filter lifetime of 6 months with a safety margin of 20%, the quantity of ethylene to be stored will be 108 g.

The selected filter has a capability declared for n-butane (C_4H_{10}) of 117 g: it has to verify the capability for ethylene (C_2H_4).

The recommended speed of the air through the filtration bed for proper functioning is about 0,3 m/sec, that means a filter surface of 1,3 m^2 for 1400 m^3/h

Technical features	
Product	**RPC K**
EN 779 classification	**F7 (air outlet side)**
Frame	**Anti-crash polystyrene**
Filter media	**Activated carbons**
Filter pack	**Mini-pleats**
Sealant	**Polyurethane elastomer**
Maximum operating temperature	**≤ 40 °C**
Maximum relative humidity	**≤ 60 %**

Type	Dimensions (mm)			Carbon weight	Nominal air flow rate Q		Filtering surface	Initial pressure drop	**RPC..K**
RPC..K	A	B	C	kg	m^3/h	m^3/s x 10^{-3}*	m^2	Pa	€
55	595	287	292	3,0	1500	417	3,4	120	✔
56	595	490	292	5,2	2800	778	5,3	120	
54	595	595	292	6,3	3400	944	6,5	120	✔

✔ Product ready in Stock / *1 m^3/s x 10^{-3} = 1 l/s

Filter capacity	**Carbon type P 2.0**
Toluene organ. test gas	**g 952**
n-butane organ. test gas	**g 117**
SO_2 inorgan. test gas	**g 350**
H_2S** inorgan. test gas	**mg 5000**

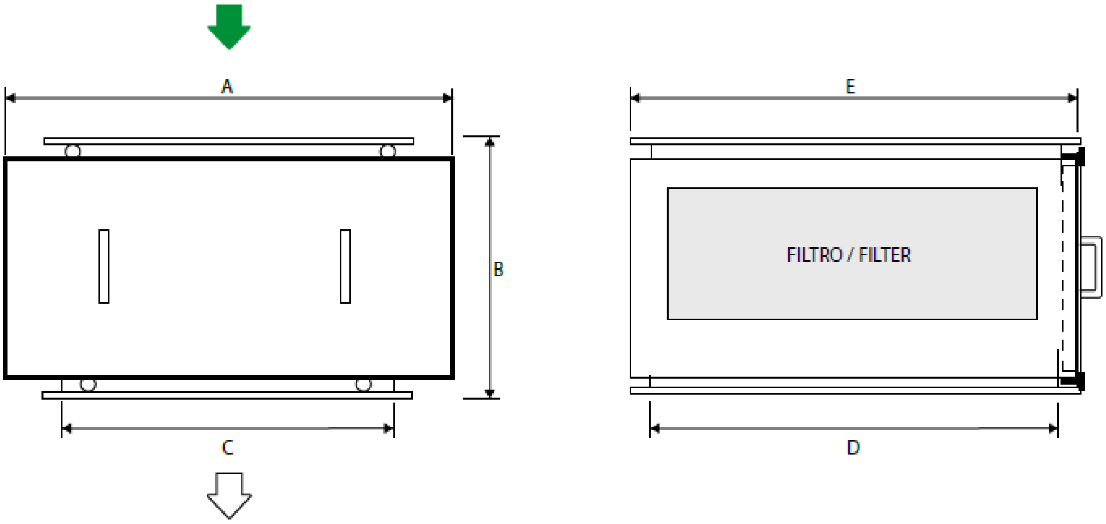
** With H_2S at a concentration of 400 ppb with 3400 mc/h air flow.

They are in phase of study other filtration materials, with high efficiency of filtration, in order to obtain the best compromise between the efficiency and dimensions.

The structure selected to contain the filters is composed by canister containers.

Canister containers are suitable for direct duct installation using the flanges they are fitted with. In this case the container is connected upstream of the polluted air exhaust duct and downstream of the filtered air outlet duct. Their main feature is to allow the maintenance personnel to safely replace the exhausted filters, both absolute and activated carbon. In fact the operator never touches the filters because they are insulated inside a protection bag where they are sealed and then disposed of. This operation is also very safe for the surrounding environment. The new filters are then handled without any direct contact. They are pulled out of their protection bags (bag-in, bag-out procedure).

The dimensions of the selected canister, standard types, are reported in the following table:



Canister for HEPA and prefilter 150 mm of depth:

Modello *Model*	Dimensioni filtro *Dimensions filter*	Dimensioni mm - *Dimensions mm*				
		A	B	C	D	E
CSR B2	610x305x150	756	330	558	253	495

Canister for VOC filter 300 mm of depth, based on the annexed carbon filter

CSR B1	610x305x292	756	573	558	253	495

Also the dimensions of filters are referred to standard types.

8.1.8.6 CO_2 control

Requirements:

Level of CO_2 = 750 ppm (TBC) $ppCO_2$, max = 1500 (24 hours) (germination phase & cucumber is limiting)

CO_2 Requirements – 370 g/day (actual calculated)

The CO_2 system will be constituted by a storage of CO_2, an injection system, sensor and controller.

The storage will be formed by 145 kg of CO_2 useable for 1 year of operations, kept in cylinders.

The sensors are shown in the next section and the controller will be realized with the Argus system.

CO_2 controller will inject bottled CO_2 gas into the FEG environment via a regulator attached to an electric solenoid valve.

CO_2 distribution inside the FEG will be investigated: the injection with liquid CO_2 or flue gas CO_2 can have a central header with small individual tubes (with evenly spaced holes) placed low in the crop canopy. The potential for low CO_2 levels inside a dense crop canopy makes it beneficial to supplement within the canopy. Air movement around the plants will also improve the CO_2 uptake because the boundary layer around the individual leaf is lessened bringing the CO_2 molecules closer to the leaf.

8.1.8.7 Sensors

The sensors foreseen on the AMS system are:

- Temperature and RH
- CO_2
- O_2
- VOC (ethylene)
- Air flow rate

Some example of sensors suitable for this application:

Temperature and RH:

The picture shows a model HMT 120/130 manufactured by Vaisala; where is needed only a temperature control the model can be HMD 60T.

The HMT120/130 with and without a display.

Performance

RELATIVE HUMIDITY	
Measurement range	0 ... 100 %RH
Accuracy including non-linearity, hysteresis, and repeatability	
temperature range	0 °C ...+40 °C (32 °F ... 104 °F)
0 ...90 %RH	±1.5 %RH
90 ...100 %RH	±2.5 %RH
temperature range	-40 ...0 °C, +40 ...+80 °C (-40 °F ...32 °F, 104 °F ... 176 °F)

Operating Environment

Operating temperature range	
transmitter body, no display	-40 °C ... +60 °C (-40 °F ... 140 °F)
transmitter body, with display	-20 °C ...+60 °C (-4 °F ... 140 °F)
HMP110 probe	-40 °C ... +80 °C (-40 °F ... 176 °F)
Storage temperature range	-50 °C ... +70 °C (-58 °F ... 158 °F)
Electromagnetic compatibility	EN 61326-1 and EN 55022

CO_2 Sensor

Vaisala GMT 222

IP66 / Remote Head

175x155x82mm

917g

GMT222 Carbon Dioxide Transmitter with Display for HVAC Use

GMT222 Carbon Dioxide Transmitter with Display for HVAC Use

The Vaisala CARBOCAP® Carbon Dioxide Transmitter GMT222 is designed to accurately measure carbon dioxide for HVAC systems in rooms and ventilation ducts.

Technical Specification	ST-IAM Standard
Power Supply	12/24 V a.c, 12/30 V d.c., 400mA maximum
Power Monitoring	Green LED
Visual Alarm	Orange LED for low level Red LED for high level
Analogue Outputs	0-5V, 0-10V, 4-20mA
Serial Data Interface	RS 485
Digital Outputs	2 Relays rated 1 Amp/24 V dc Selectable: NO/NC auto or manual reset, response delay 0, 1, 5 or 10 min
IP Rating	IP41 (Standard) or IP66 (optional)
Dimensions and Weight	145 x 185 x 80 mm - 850 g
Standard Compliance	WEEE RoHS EuP

UL 61010-1, CSA C22.2 No. 61010-1, IEC 61010-1, EN 61010-1, EN 55011, EN 50270, FCC Part 15, Subpart B, WEEE RoHS EuP

Qualified for Energy Technology List

Sensor Information	Electrochemical EC SC	Semiconductor with filter (multigas) CAT	Catalytic (multigas)	Infrared IR
TypicalMeasurement Range	Up to 1000ppm	Up to 1000ppm	Up to 30,000 ppm 100% LEL	Up to 10,000 ppm 1%vol
Humidity Range non condensing	0 to 95%	0 to 95%	0 to 95%	0 to 95%
Typical Sensor Life	3 yrs	5-8 yrs	5 yrs	5 yrs
* Alarm threshold T50	19 sec	76 sec (filtered)	28 sec	42 sec
T90	47 sec	215 sec (filtered)	46 sec	95 sec
Linearity	Linear over calibrated range			
Calibration Requirements	Local regulations may specify the procedure and frequency required. Standards generally require at least annual testing or calibration. Refer to Murco for instructions. Semiconductor sensors are non-selective, but calibrated to a specific gas.			

* Response times may vary based on temperature of operation, enclosure and environmental conditions.

Measurement parameter(s)	Carbon dioxide
Measurement range	0 ... 2000 ppm
Measurement accuracy	± (1.5 % of range + 2 % of reading)
Operating temperature	-20 ... +60 °C (-4 ... +140 °F)
Operating voltage	24 VAC/DC (nominal)
Analog outputs	0 ... 20 mA 4 ... 20 mA 0 ... 10 V
Housing classification	IP65 (NEMA 4)

O2 Sensor

O2Tracer 4 – 20 mA Loop Powered two wire Oxygen Transmitter
Ref: Roscid Technologies

Ordering Number	Range
O2T-1	0-10%
O2T-2	0-25%
O2T-3	0-100%

Housing: IP65
Size: 3.15 x 3 x 2.17 (B x H x T (mm))

Accuracy: +/- 2% FSD T= const.
+/- 5% FSD 0>T>50°C

Signal output: 4 -20 mA / DC

Voltage: 10 – 35 VDC

Ethylene

The sensor in phase of study is a Photoionisation Detection (PID) sensor technology

PPB MiniPID: range 1 ppb – 40 ppm

The PPB variant is used for high sensitivity in the part per billion (ppb) range with minimum detection limit of 1 ppb. The PPB sensor is optimized to deliver an exceptionally low background current allowing for optimum low-end sensitivity.

Performance

	PPB MiniPID	PPM MiniPID	10 eV MiniPID
Pellet colour	White	Blue	White + gold spot
Minimum detection limit	1 ppb	0.1 ppm	5 ppb
Range	40 ppm	6000 ppm	100 ppm
Linearity	>98% over measurement range	>98% up to 100 ppm 88% at 1000 ppm 75% at 4000 ppm	>98% over measurement range
T90 response time	3 s		
Typical responsivity	25 mV/ppm	0.7 mV/ppm	10 mV/ppm
Offset voltage	60 - 80 mV	52 - 55 mV	52 - 57 mV
Output voltage	Offset voltage to rail voltage - 0.1 V		
Power consumption	110 mW at 3.3V (150 ms 300 mV transient upon switch on)		
Temperature range	-40°C < T < 55°C		
Humidity range	0 - 99% RH, non-condensing		
Humidity sensitivity	Humidity resistant		
Expected life	> 5 years (excluding replaceable lamp and pellet)		
Warranty period	12 months		

Ref: www.ionscience.com

Air Flow Sensor

Temperature Limits	Process: -40 to 212°F Ambient: 32 to 140°F
Pressure Limit	100 psi (6.89 bar) maximum
Humidity Limit	Non-condensing
Power Requirements	12-35 VDC, 10-16 VAC. 1.5 A rating required on supply due to initial power surge drawn by transmitter
Output Signal	4-20 mA, isolated 24V source, 3 or 4-wire connection

Ref: Dwyer Instruments mod. 641-12

8.1.9 AMS for the Service Section

Environmental conditions (requirements)

21°C with 25%-30% of RH during the day and 18°C with RH TBD during the night.

Thermal loads from Thermal Control study:

Thermal balance SERVICE SECTION

THERMAL LOAD [W]	DAY (Tin=21°C)		NIGHT (Tin=18°C)	
	SUMMER (Text=5°C)	WINTER (Text=-50°C)	SUMMER (Text=5°C)	WINTER (Text=-50°C)
POWER UNIT	1000	1000	700	700
AMS (20% of nominal power)	300	300	300	300
THERMAL (20% of nominal power)	700	700	350	350
EXTERNAL LOAD	-387	-1640	-311	-1626
LIGHT	200	200	0	0
TOTAL	**~ 1700**	**~ 560**	**~ 1000**	**~ -200**

Need of cooling and heating with all the units in ON conditions is reported in previous table:

- maximum requirement of cooling is 1.700 W,
- maximum requirement of heating is 200 W.

If the units are in Off condition the max value of heating will be 1640 W.

The RH (within Neumayer Station III itself) will be set to 25-30% .

Two solutions will be investigated and a trade-off between them will be done:

- thermal control utilizing only external air as cooling system
- thermal control by cooling realized with a refrigerating liquid loop.

8.1.9.1 SOLUTION I, only external air

The Air flow rate is based on the delta T of the air: to obtain 21°C as average, we can fix the delta T at 10°C; it means 16°C the Temp. of the air inlet and 26°C the Temp. of the air outlet .

The maximum requirement of cooling was 1700 W, so in first approach the air flow rate will be:

1700 x0,86 / (1,2 x 10x0,24) = 507 m^3/h

The first limit for the dimensioning of this solution is when the external air is at the maximum value of 5°C:

- Heating 500 m^3/h from 5°C till 16°C: need of 1.850 W
- To obtain 25% RH with 21°C: is not necessary to use a humidifier

With the external air at the minimum value of -50°C, the heating to be dissipate will be 560 W, so the air flow rate to maintain the same delta T of 10°C can decrease till :

- air flow rate: 560 x0,86 / (1,2 x 10x0,24) = 167 m^3/h

the power needed to heat the air is:

- pre heat from -50°C till 16°C: 3.700 W

To obtain the required RH value of 25% the need of water vapour is:

- 0,8 kg/h of water vapour (250 W power)

The heating need of 3.700 W will increase to compensate also the cooling effect of humidification, with 580 W.

The feasibility of the above solution is based on the use of a fan with the variable flow rate, controlled for example by a thermoregulator.

The external opening to allow the inlet of air will be suitable for 500 m^3/h, example with a free area of 180 x 180mm the air speed will be 4 m/sec. (260 x 260mm with a protection grid with 50% of free area).

In the tube already installed, diam. 160 mm, the air speed will be: 7 m/sec.

The following table shows the calculations explained below, at the different external temperatures:

Ext. Air	Heating	Air inlet	Air outlet	Air flow r.	Air flow r.	Thermal load
°C	W	°C	°C	kg/h	m3/h	W
5	1608	16	26	609	508	1700
-4,2	2623	16	26	541	451	1510
-13,4	3337	16	26	473	394	1320
-22,6	3751	16	26	405	337	1130
-31,8	3864	16	26	337	281	940
-41	3677	16	26	269	224	750
-50,2	3188	16	26	201	167	560

In order to reduce the amount of air flow rate, and of consequence, the related dimensions and the heating capacity, in the following were made two different hypothesis of delta T between the air inlet in the SS and the air outlet:

1) Delta T 15°C with T. inlet 12°C and T. outlet 27°C, T average 19,5°C
2) Delta T 18°C with T. inlet 10°C and T. outlet 28°C, T average 19°C

In the following table are reported the condition with a delta T on air of 15°C : the air inlet is set at 12°C and the air outlet, consequence of the thermal load, at 27°C

Ext. Air	Heating	Air inlet	Air outlet	Air flow r.	Air flow r.	Thermal load
°C	W	°C	°C	kg/h	m3/h	W
5	682,2667	12	27	406,1111	338,4259	1700
-4,2	1402,488	12	27	360,7222	300,6019	1510
-13,4	1922,272	12	27	315,3333	262,7778	1320
-22,6	2241,619	12	27	269,9444	224,9537	1130
-31,8	2360,528	12	27	224,5556	187,1296	940
-41	2279	12	27	179,1667	149,3056	750
-50,2	1997,035	12	27	133,7778	111,4815	560

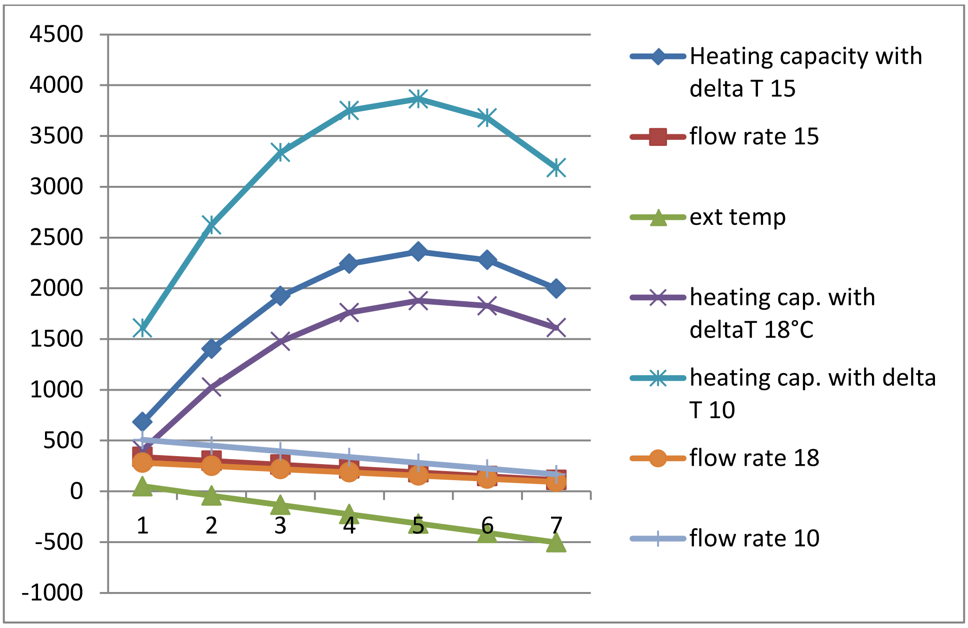
The flow rate decreases till 338 m^3/h max and 111 m^3/h min., and of consequence the heating need decreases too.

Increasing the deltaT, till 18°C, from 10°C till 28°C, the conditions will become:

Ext. Air	Heating	Air inlet	Air outlet	Air flow r.	Air flow r.	Thermal load
°C	W	°C	°C	kg/h	m3/h	W
5	406,1111	10	28	338,4259	282,0216	1700
-4,2	1024,451	10	28	300,6019	250,5015	1510
-13,4	1475,76	10	28	262,7778	218,9815	1320
-22,6	1760,038	10	28	224,9537	187,4614	1130
-31,8	1877,284	10	28	187,1296	155,9414	940
-41	1827,5	10	28	149,3056	124,4213	750
-50,2	1610,684	10	28	111,4815	92,90123	560

As shown, the flow rate can decrease till 282 m^3/h instead of 500 m^3/h, and the minimum till 92 m^3/h instead of 167 m^3/h; the heating power maximum will be 1.877 W instead of 3.700 W.

The following graphic summarizes the three conditions:

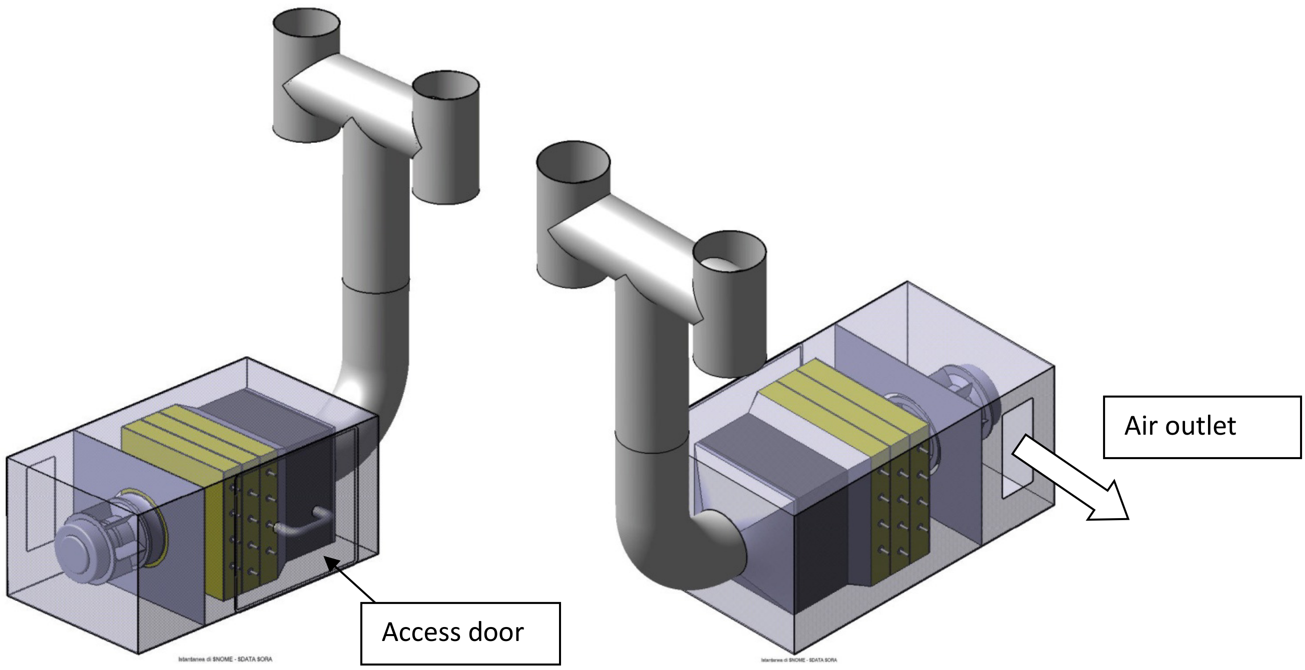


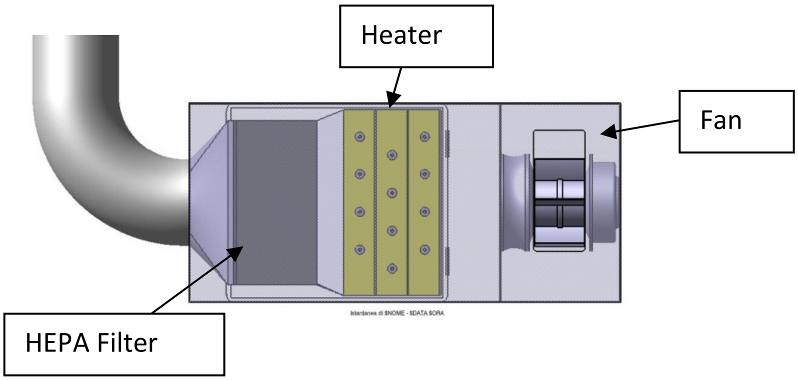
Note: the line "ext temp" is out of scale (x10) and is reported only to show the trend.

All the solutions satisfy the requirements, with different conditions about the internal comfort:

1. T In 16 out 26 with average of 21°C, maximum power supply 3864 W, min. 1.600 W
2. T In 12 out 27 with average of 19,5°C, maximum power supply 2.360 W, min. 683 W
3. T In 10 out 28 with average of 19°C, maximum power supply 1.878 W, min. 406 W

A preliminary layout of the unit is depicted in the following pictures.



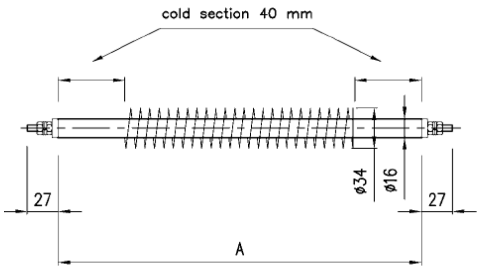


Main components

The main components reported in the following are referred to the worst condition of 500 m^3/h.

Heater

Heater for this solution: 3 frame with 4 heater each tot. 12 (or 9 or 6)

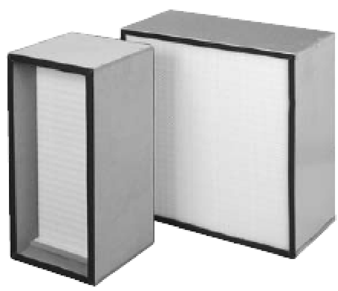


Straight heaters: 2 W/cm^2 – 230 V Suitable for static and forced flow air			
Code	A (mm)	Power (W)	Weight (kg)
5516L03500300	350	300	0.570

HEPA 13 Air Filter

Air flow rate to be filtered 500 m^3/h (or 406 or 338)

Technical features		
Product	LLMB	KKMB
Efficiency MPPS	99,95 %	99,95 %
EN 1822:2009 classification	H13	H13
Suggested final pressure drop	600 Pa	600 Pa
Maximum pressure drop	1000 Pa	1000 Pa
Maximum operating temperature	70 °C	70 °C
Maximum relative humidity	90 %	100 %
CE mark		•
ATEX version on request		•



DELTA series LLMB - KKMB absolute filters are designed to work with high flow rates, 35% higher than other similar filters of equal size; at nominal air flow, they work with a frontal air speed of 2.00 m/s.

These filters have mini pleated microfiber glass filtering pack, top quality manufacture, high dust holding capacity and great mechanical resistance.

Type	Dimensions (mm)			Nominal air flow rate Q				Filtering surface		Initial pressure drop
				m^3/h		m^3/s x 10^{-3*}		m^2		
LLMB - KKMB	A	B	C	LLMB	KKMB	LLMB	KKMB	LLMB	KKMB	Pa
3 X	305	305	149	550	580	153	161	4,9	5,4	280

Fan, Centrifugal

Max. flow rate : 500 m3/h   Delta P : HEPA filter initial pressure drop 280 Pa Final suggested 600 Pa

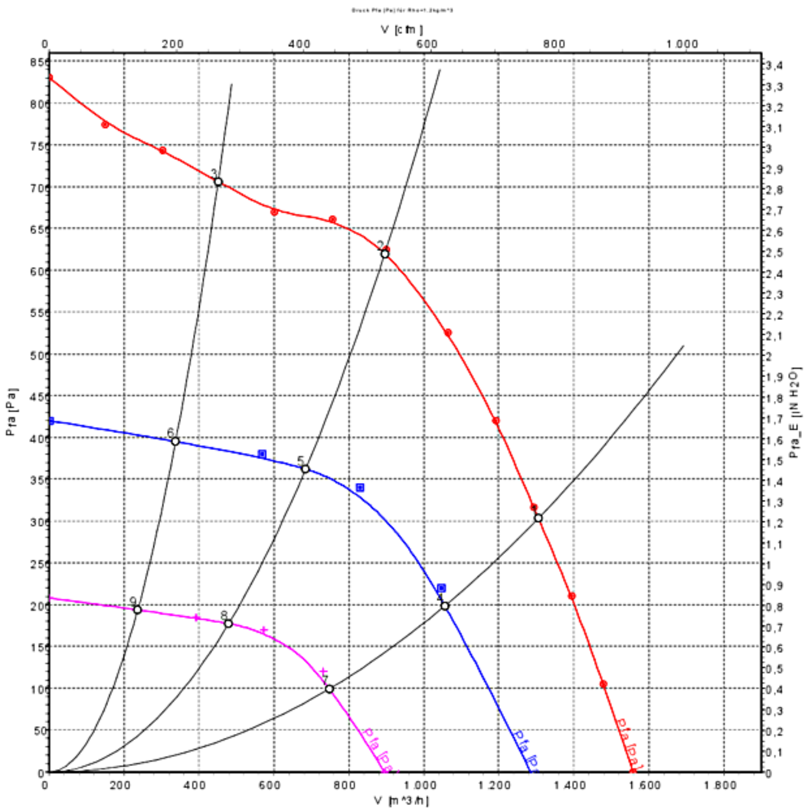
The selected fan can be:

R3G180-AD43-71

EC centrifugal fan

Motor: M3G084-FA

Technical description	
Weight	4.6 kg
Fan size	180 mm
Rotor surface	Painted black
Electronics housing material	Die-cast aluminum
Impeller material	Sheet steel, galvanized
Number of blades	38
Direction of rotation	Clockwise, viewed toward rotor
Degree of protection	IP54
Insulation class	"B"
Moisture (F) / Environmental (H) protection class	F3-1
Max. permitted ambient temp. for motor (transport/storage)	+80 °C
Min. permitted ambient temp. for motor (transport/storage)	-40 °C
Installation position	Any



Note: The second solution with cooling fluid is depicted and investigated in the section 11.2 Options and Trades.

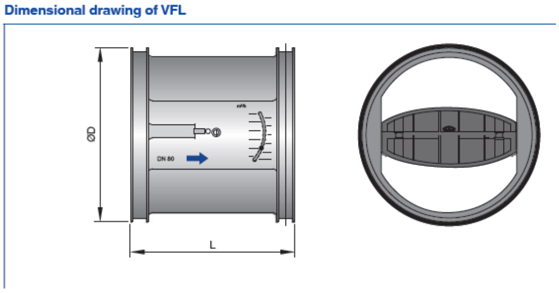
8.2 *Options and Trades*

In this section will be reported two solutions objects of trade off:

- Installation of constant flow valves on the ducts system
- Oval ducts instead of rectangular type
- Use of a liquid cooled system to control the conditions of SS

8.2.1 Constant flow installation

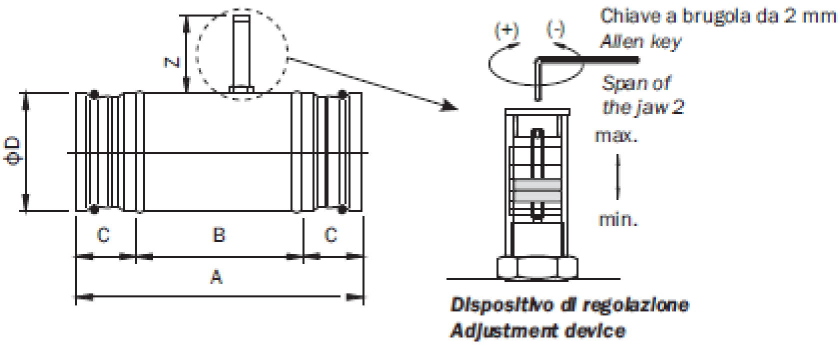
First example of constant flow valve:



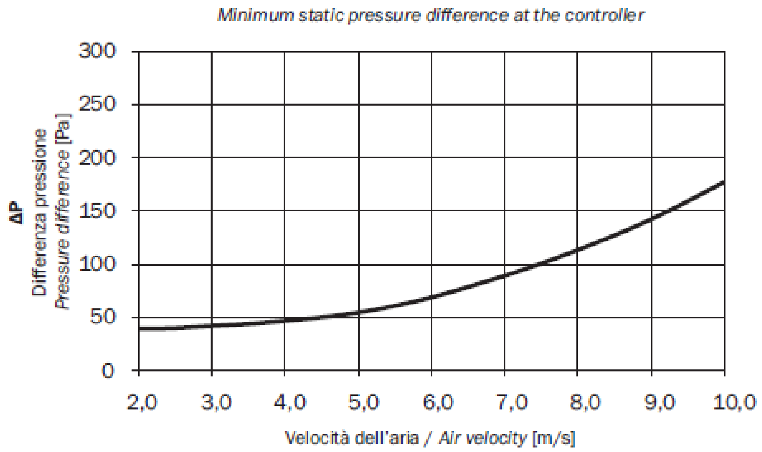
Dimensions [mm] and weight [kg]

Nominal size	ØD	L	m
	mm	mm	kg
80	78	86	0.10
100	98	100	0.15
125	122	118	0.25
150	143	148	0.35
160	156	148	0.40
200	196	175	0.50
250	246	220	0.70

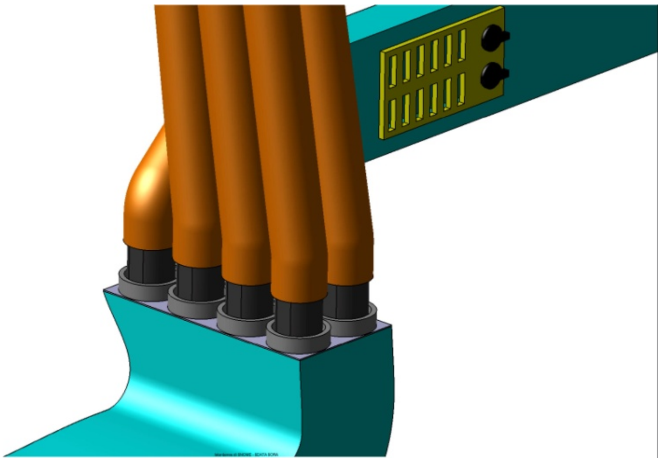
Second example of constant flow valve:



Dati dimensionali/*Dimensions* RV							
Grandezza/*Size*	Qmin [m³/h]	Qmax [m³/h]	A [mm]	B [mm]	C [mm]	Z [mm]	ΦD [mm]
80	40	125	200	120	40	70	79
100	70	220	250	170	40	70	99



Comparing the characteristics of the selected constant flow with the dimensions of the ducts and the flow rate, the possible configuration is shown in the below picture:

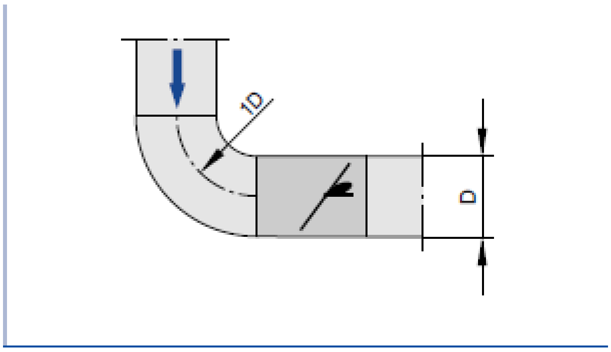


The flow rate for each duct is 175 m^3/h and the size of the duct 200 x 80 mm.

To fit the dimensions of each duct of 200 x 80 with the dimensions of the valves, it need to install two valves, 80 mm of diameter, set at 175/2 ≈ 90 m^3/h, for each duct.

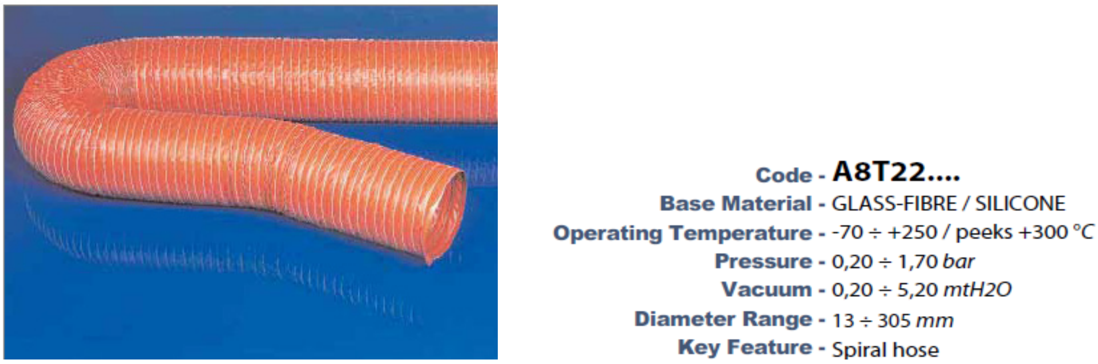
Set the volume flow rate

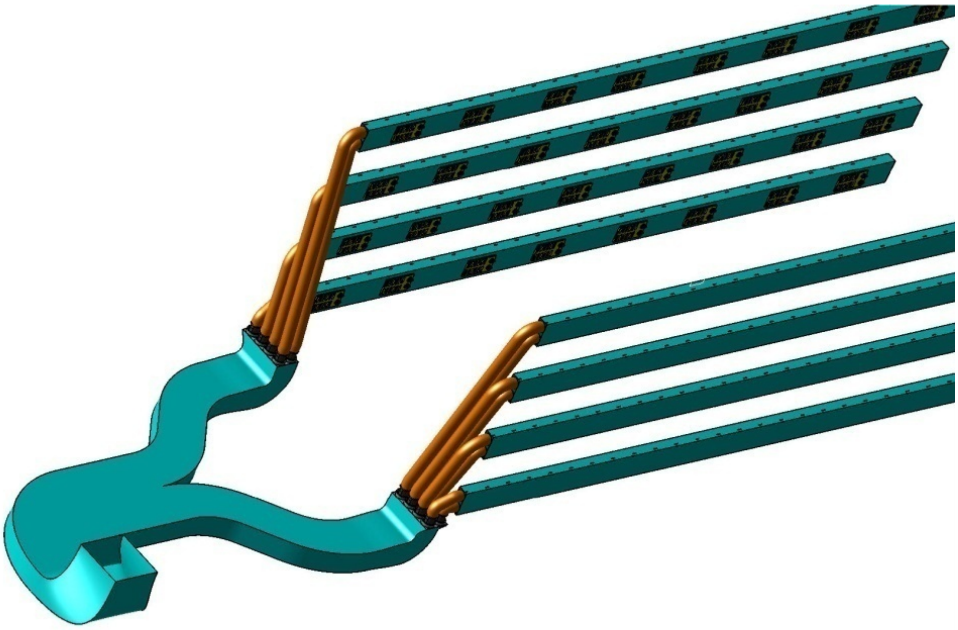
Another issue: to define the correct position of the valves against the curve of the duct:



A bend with a curvature radius of at least 1D – without an additional straight duct section upstream of the volume flow limiter – has only a negligible effect on the volume flow rate accuracy.

Starting from the size of those valves, it is possible to adopt circular duct to connect those valves with the side ducts. The next example shows a type of flexible tube instead of a metallic duct to realize this type of connection:





8.2.2 Oval ducts

Another improvement in phase of study and verification is the use of oval ducts instead of rectangular ducts. The pictures below show some example of this:

Flat Oval Duct
Available Lengths, Materials, and Thicknesses

Uni-Seal™ Duct
(spiral lockseam)

Lengths (1)	Materials (2,3)	Thicknesses
1-12 feet	Galvanized Steel	28-18 gauge
	Stainless Steel	>26-20 gauge
	Aluminum	0.025-0.063 inch

Longitudinal Seam Duct
(solid welded)

Lengths (1)	Materials (2,3)	Thicknesses
1-6 feet	Galvanized Steel	20-10 gauge
	Stainless Steel	22-10 gauge
	Aluminum	0.040-0.090 inch

Minor Axis (inches)	Major Axis (inches)		
	Minimum	Maximum Spiral Lockseam	Maximum Longitudinal Seam or Fitting Size
3	8	22	30
4	7	21	40
5	8	21	46

8.2.3 AMS for the Service Section - Alternative II

Air treatment with internal fan coil.

The assumption is to take a flow rate of cooling liquid from return piping of FEG cooling circuit, at the temperature max of 16°C (foreseen 14°C). In this manner is not influenced the AMS cooling circuit: it will increase only the thermal load in the external condenser dedicated to AMS system and the pressure drop for the related pump.

External air flow needed: 25 - 30 m^3/h, necessary only for air renewal (the minimum for life is 8 m^3/h for each person).

The humidification will be done in the air in closed circuit.

Internal recirculation of air: 700 m^3/h

Cooling fluid from AMS return line: T = 16°C

Starting from this liquid temperature, the minimum temperature of the air can be ≈ 18°C.

Considering the thermal load of 1.790 W, we have made a simulation of a possible heat exchanger:

Cooling Coil: Roen Est Code		6.30.CU.10.AL.10.03.0400.16.W.X.X.001.030.R 3/8" T			
Tube Material:	CU-.30	Ext. Surface:	7,4 m2	Volume:	1 dm3
Fin Material:	AL-.10	Int. Surface:	0,36 m2	Weight:	5,7 kg
External Gas:		Air Std / 101,32 kPa			
Flow Rate		0,19 m3/s = 700 m3/h 0,23 kg/s			
Velocity		1,94 m/s			
Inlet and Outlet Temp.		27 °C -> 18,9 °C			
Inlet and Outlet Rel. Humidity		20 % -> 32,6 %			
Inlet and Outlet Water Cont.		4,4 g/kg -> 4,4 g/kg			
Condensed Water		0 g/s			
Sensible Heat Factor		1			
Pressure Drop		46 Pa			
Internal Fluid:		Water			
Flow Rate		0,2 l/s = 717 l/h 0,2 kg/s			
Velocity		2,85 m/s			
Inlet and Outlet Temp.		16 °C -> 18,3 °C			
Pressure Drop		230,3 kPa			
Capacity:		1,92 kW CounterFlow Calculation			

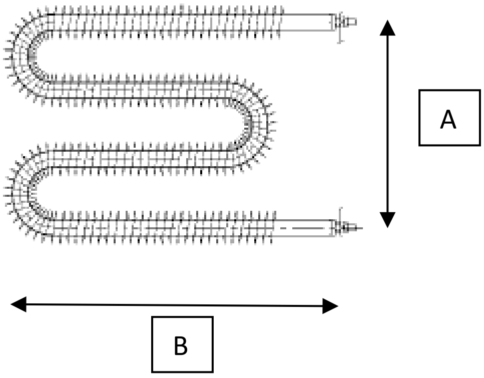
1- Thermal load dissipated: T in 27°C 20% Tair out 18,9°C 32,6 % T Av: 23°C 25%
2- The capacity of 1.920 W has to be compared with the thermal load of 1.790 W
3- Fresh air 30 m^3/h at 5°C: mixing with 18,9°C 32,6% , the result will be 18°C with 34,5%
4- No need for a humidifier

At -50°C

1- 30 m^3/h of fresh air from -50°C till 5°C: pre heat 0,55 kW
2- To obtain 25% RH: the water content needed is 4,4 gr/kg. That means 0,2 kg/h of water vapour (120 W of power supply)

Heater

The heater in this case will work only on 30 m^3/h, with a power of 0,55 W:



POWER W	A (mm)	B (mm)
800	160	150

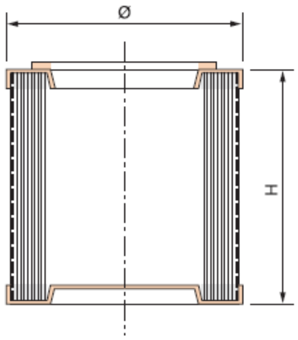
Air Filter

The air flow rate to be filtered will be 30 m^3/h:

Technical features		
Product	**CB**	**CA**
Efficiency MPPS	**99,95 %**	**99,995 %**
EN 1822:2009 classification	**H13**	**H14**
Suggested final pressure drop	**400 Pa**	**400 Pa**
Maximum pressure drop	**600 Pa**	**600 Pa**
Maximum operating temperature	**70 °C**	**70 °C**
Maximum relative humidity	**100 %**	**100 %**
CE mark	•	•
ATEX version on request	•	•

CB and CA cartridge absolute filters, HEPA class, are made of a perforated aluminum sheet cylinder which holds the fiber-glass filter media, mini-pleated with constant pitch and continuous thermoplastic spacers. The medium is fixed inside the casing through a polyurethane sealant. The air inlet, mounted on one side of the filter body, has on the external side single piece closed cell neoprene gasket. The air to be filtered enters from the open inlet and expands through the radial filtration medium, passes through the medium itself and goes out of the holes of the external aluminum sheet. The bottom of the cartridge is closed, with an anodized aluminum sheet cap.

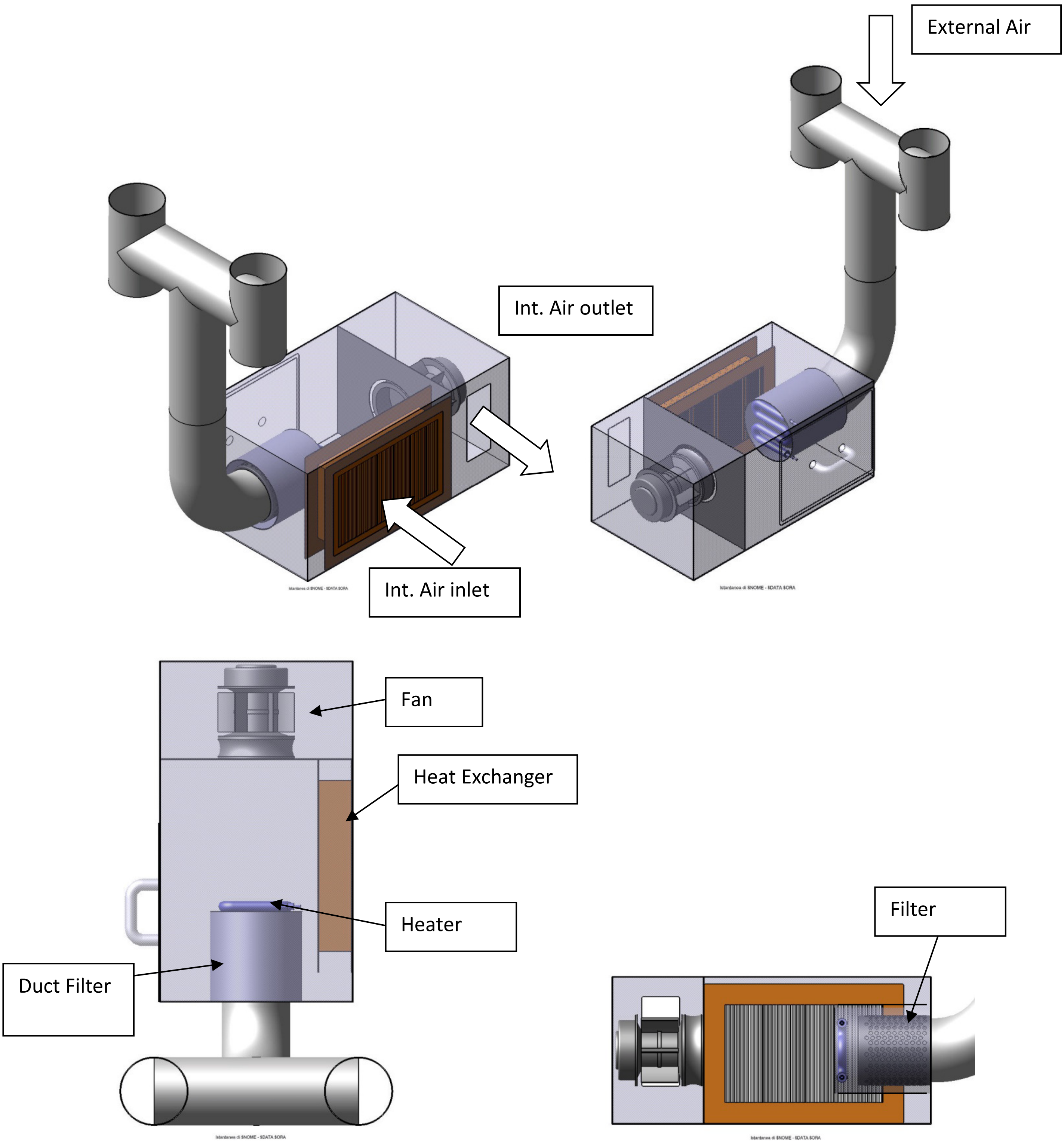
Technical draft



Type	Dimensions (mm)		Nominal air flow rate Q		Initial pressure drop Pa	
	ø	H	m³/h	m³/s x 10⁻³*	CB	CA
90	175	180	90	25	200	270
130	175	180	130	36	200	270
170	175	230	170	47	200	270

✔ Product ready in Stock / *1 m³/s x 10⁻³ = 1 l/s

The following picture shows a possible layout of the unit:



TRADE OFF BETWEEN SOL.I ANS SOL. II

	DeltaT	Ext. Air Flow Rate		Int. Air Flow Rate	Heaters Power		Humidifier	Wall Opening	Complexity
		max	min		min	max		Diam.Eq.	Max 3
	°C	m^3/h	m^3/h	m^3/h	W	W	kg/h	mm	Min 1
SOL. I	16-26	500	167	Same of ext.	1.600	3.800	0,8	240	1
	12-27	338	110	Same of ext.	680	2.360	0,5	200	1
	10-28	280	90	Same of ext.	400	1.600	0,4	180	1
SOL. II	18-27	30	30	700	0	550	0,2	60	3

COMMENTS

The worst characteristics of the Solution I are the power supply needed, 3 times in the best case against the Solution II, the humidification, 2 times, and the opening in the wall: the dimensions reported in table are the diameter equivalent to obtain the air speed of 3 m/sec.

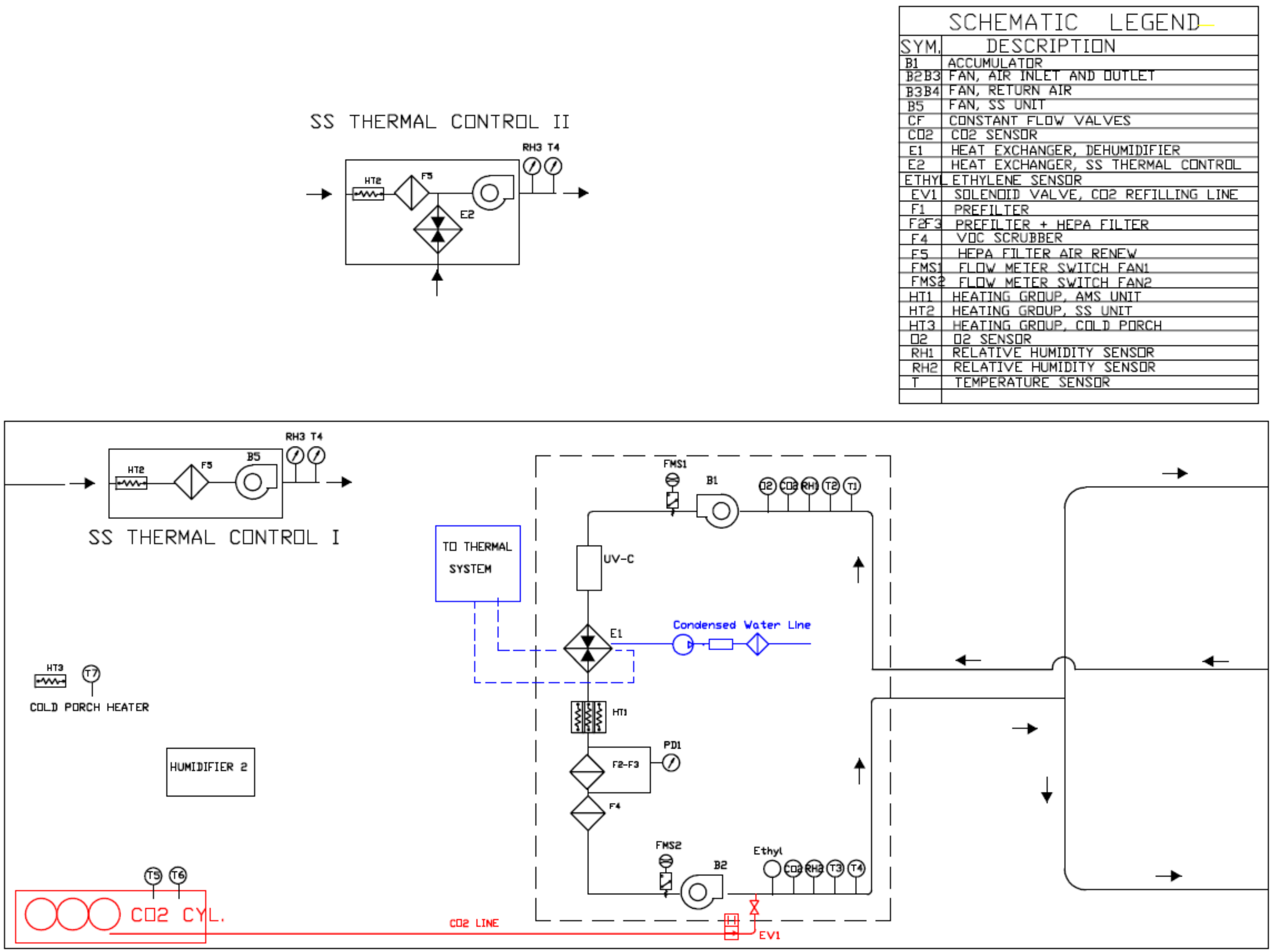
The better characteristic is the less complexity, without liquid cooling piping.

The better characteristics of the Solution II are the power supply, the humidification and the dimensions of the opening in the wall; the worst the complexity, for the needing of two hydraulic lines.

8.3 *List of Equipment - Key Values*

Table 8-1: Key values of Air Management System.

	Mass	Peak power	Power day - nominal mode	Power night - nominal mode
Mobile Test Facility	628.9 kg	9833 W	TBD	TBD
Neumayer Station III	0	0	0	0
Spares, consumables, tools	209.7 kg	N/A	N/A	N/A
TOTAL	838.6 kg	**9833 W**	**TBD**	**TBD**



SYM.	DESCRIPTION
B1	ACCUMULATOR
B2B3	FAN, AIR INLET AND OUTLET
B3B4	FAN, RETURN AIR
B5	FAN, SS UNIT
CF	CONSTANT FLOW VALVES
CO2	CO2 SENSOR
E1	HEAT EXCHANGER, DEHUMIDIFIER
E2	HEAT EXCHANGER, SS THERMAL CONTROL
ETHYL	ETHYLENE SENSOR
EV1	SOLENOID VALVE, CO2 REFILLING LINE
F1	PREFILTER
F2F3	PREFILTER + HEPA FILTER
F4	VOC SCRUBBER
F5	HEPA FILTER AIR RENEW
FMS1	FLOW METER SWITCH FAN1
FMS2	FLOW METER SWITCH FAN2
HT1	HEATING GROUP, AMS UNIT
HT2	HEATING GROUP, SS UNIT
HT3	HEATING GROUP, COLD PORCH
O2	O2 SENSOR
RH1	RELATIVE HUMIDITY SENSOR
RH2	RELATIVE HUMIDITY SENSOR
T	TEMPERATURE SENSOR

Figure 8-1: Block diagram of Service Section AMS elements.

SCHEMATIC LEGEND	
SYM.	DESCRIPTION
B1	ACCUMULATOR
B2B3	FAN, AIR INLET AND OUTLET
B3B4	FAN, RETURN AIR
B5	FAN, SS UNIT
CF	CONSTANT FLOW VALVES
CO2	CO2 SENSOR
E1	HEAT EXCHANGER, DEHUMIDIFIER
E2	HEAT EXCHANGER, SS THERMAL CONTROL
ETHYL	ETHYLENE SENSOR
EV1	SOLENOID VALVE, CO2 REFILLING LINE
F1	PREFILTER
F2F3	PREFILTER + HEPA FILTER
F4	VOC SCRUBBER
F5	HEPA FILTER AIR RENEW
FMS1	FLOW METER SWITCH FAN1
FMS2	FLOW METER SWITCH FAN2
HT1	HEATING GROUP, AMS UNIT
HT2	HEATING GROUP, SS UNIT
HT3	HEATING GROUP, COLD PORCH
O2	O2 SENSOR
RH1	RELATIVE HUMIDITY SENSOR
RH2	RELATIVE HUMIDITY SENSOR
T	TEMPERATURE SENSOR

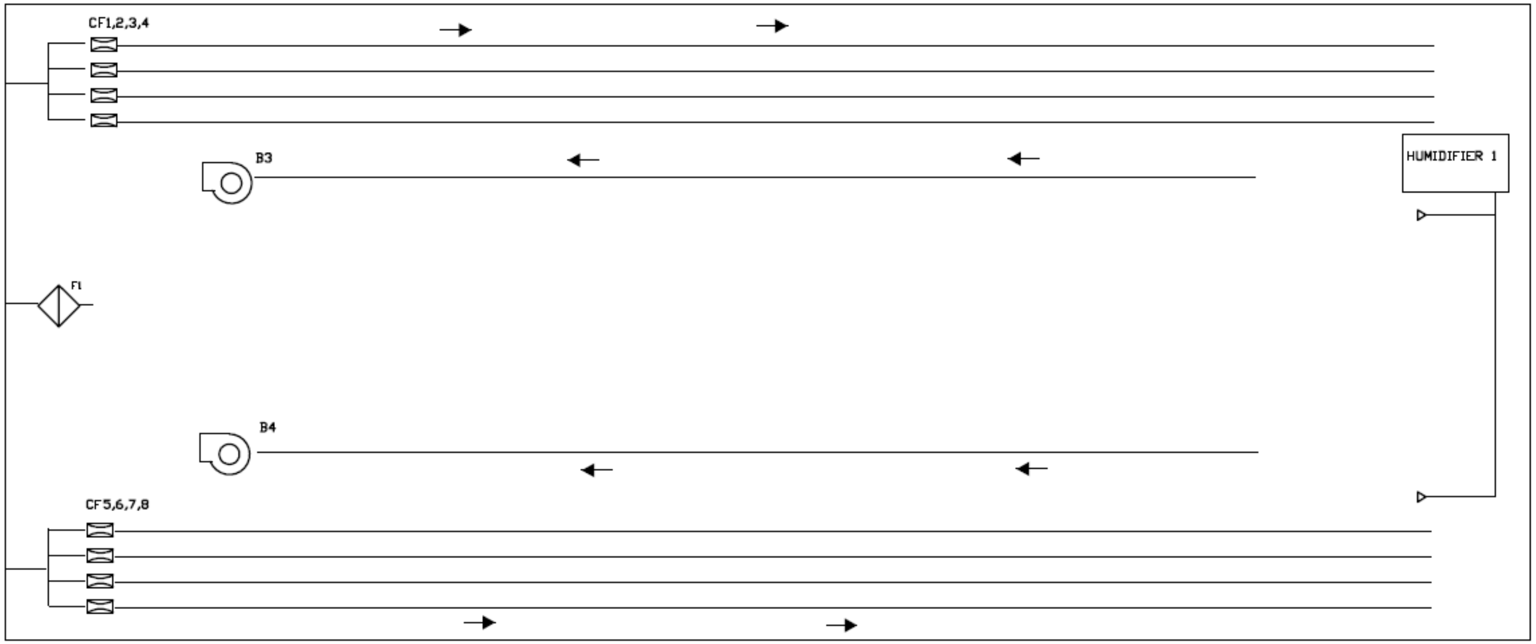


Figure 8-2: Block Diagram of FEG AMS elements.

9 Nutrient Delivery System

9.1 *Baseline Design*

Preliminary design choices concerning the NDS described in the EDEN ISS CE Study Scope document (extracted here) were:

Two plant cultivation areas in the FEG (one major area and one smaller area)

The main cultivation/ production principle is the use of the same grow trays (~40 x 60 cm) throughout the entire FEG but in a different orientation when comparing the cultivation area on one side of the FEG with that of the other.

The FEG-NDS should provide two different nutrient solutions to the FEG

Each grow unit should be able to be connected to either one or the other nutrient line (and the respective return line).

The FEG plant trays should be outfitted with an aeroponic/ NFT irrigation system

Within the FEG, a hybrid aeroponic/NFT (nutrient film technique) irrigation system is foreseen. TBD if the whole FEG or only some plant trays are equipped with aeroponics/ NFT and others with a pure NFT system.

With the exception of the first design choice regarding major and smaller cultivation areas, these criteria were followed during the design study. Design changes are detailed in section 9.2.

The overall NDS is based on an existing hydroponic concept developed by DLR that is a hybridization of NFT and aeroponics. The system utilizes standardized 400 x 600 x 120 mm food grade polypropylene containers (growing trays), adapted covers and high pressure misting to achieve an appropriate degree of plant water delivery and root zone oxygenation.

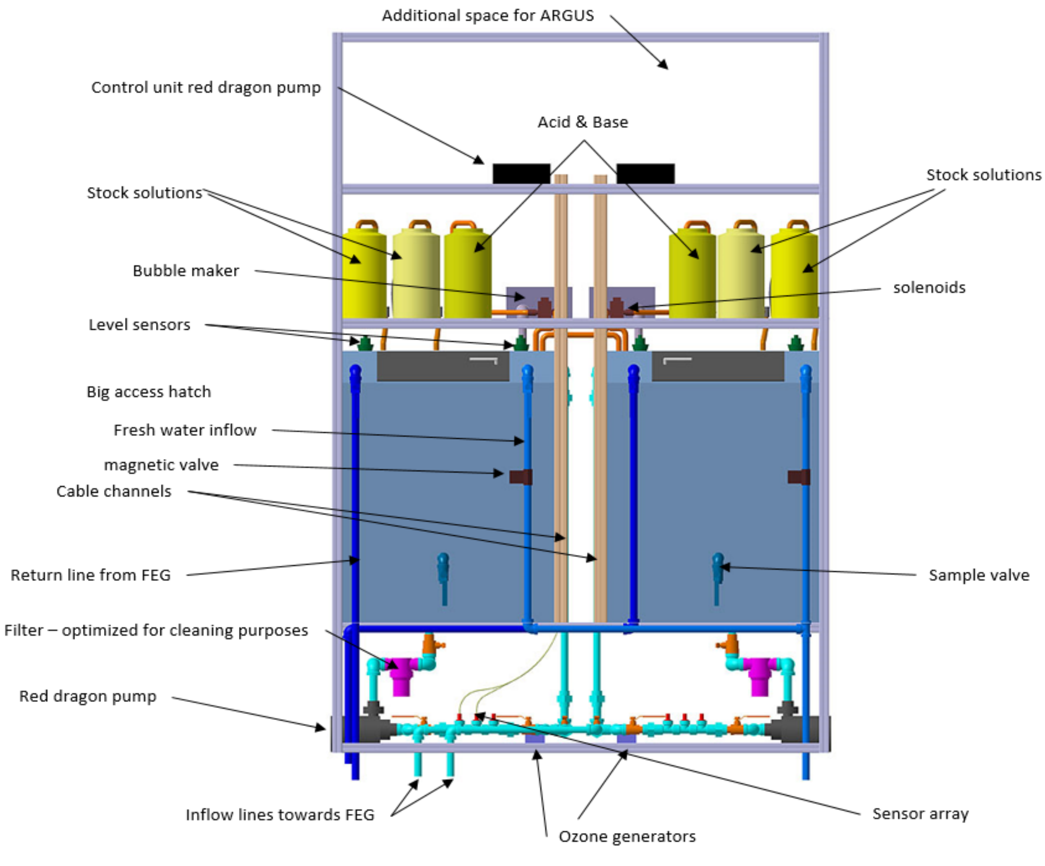


Figure 9-1: Front view of the main NDS rack components within the Service Section.

The main component rack (Figure 9-1) located within the Service Section contains two 250 litre nutrient solution tanks and primary variable speed mixing/delivery pumps. Sensors include pH, DO, temperature, water level and water flow, while system disinfection can be achieved with an integrated ozonation system. Stock nutrient reservoirs, acid/base control solutions and dosing pumps are contained above the main tanks, and delivery pumps are controlled by the Argus Control System. Both tanks have redundant sensors to ensure system reliability. Each nutrient tank is operated independently and can have different nutrient solution compositions that depend on experiment and plant requirements. Each nutrient tank has two separate stock supply tanks (traditionally known as A and B, but in this case the second tank will have solutions C and D). Both are supplied from the same acid and base reservoirs for pH control. All components in the NDS Service Section rack are placed to allow easy access and simplified maintenance.

The main NDS rack feeds the growing systems located in the FEG (Figure 9-2) which contains four growing rack systems on each side of the central corridor. Each rack can be operated/isolated separately as each has its own high pressure primary pump for delivery to the growing tray fog/mist nozzles. Growing racks consist of either 8 grow trays (short plants e.g. lettuce, basil, etc.), four grow trays (medium plants, e.g. tomato) or two grow trays (tall plants e.g. cucumber). The final block diagram Figure 9-5 indicates the position and configuration of the racks. Each stack can be fed by either nutrient tank through manually operated 3-way valves on both delivery and nutrient return. The 3-way valves are located in the floor of the FEG and are accessible via removable floor panels. Solution compositional changes do not occur very often, so access through flooring panels is appropriate and helps alleviate space constraints.

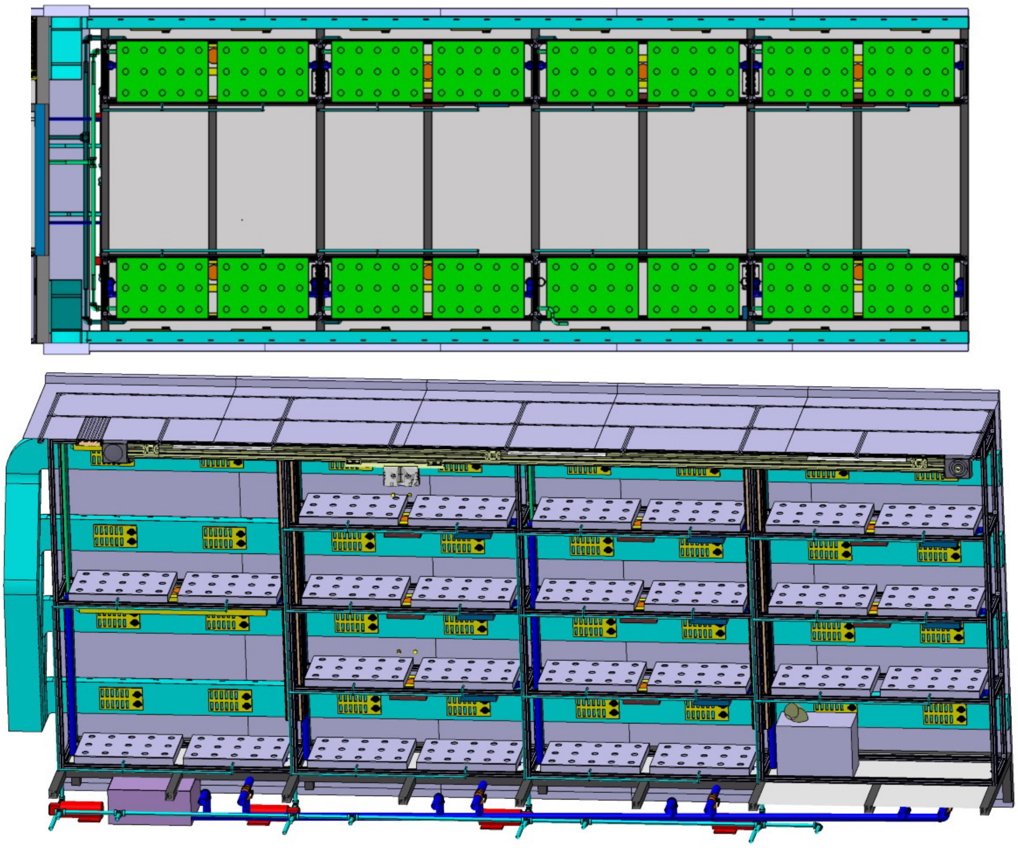


Figure 9-2: Location of plant growing racks within the FEG showing the top view (top) and side view (bottom).

Return of the nutrient feed stream from the growing tray is by a combination of gravity return to a central lower reservoir (Figure 9-3) and active pumping with redundant submersible pumps which engage in response to water level sensors located within the sump reservoir (Figure 9-3– sump pump). The entire NDS solution loop is closed (recirculating). Water lost to evaporation and transpiration will be recovered by the condenser located in the Atmosphere Management System rack in the Service Section. Recovered water will be directed to the fresh water tank located in the floor of the airlock. Recovered water from the fresh water tank will be injected into the nutrient tanks as required to maintain a predetermined water level.

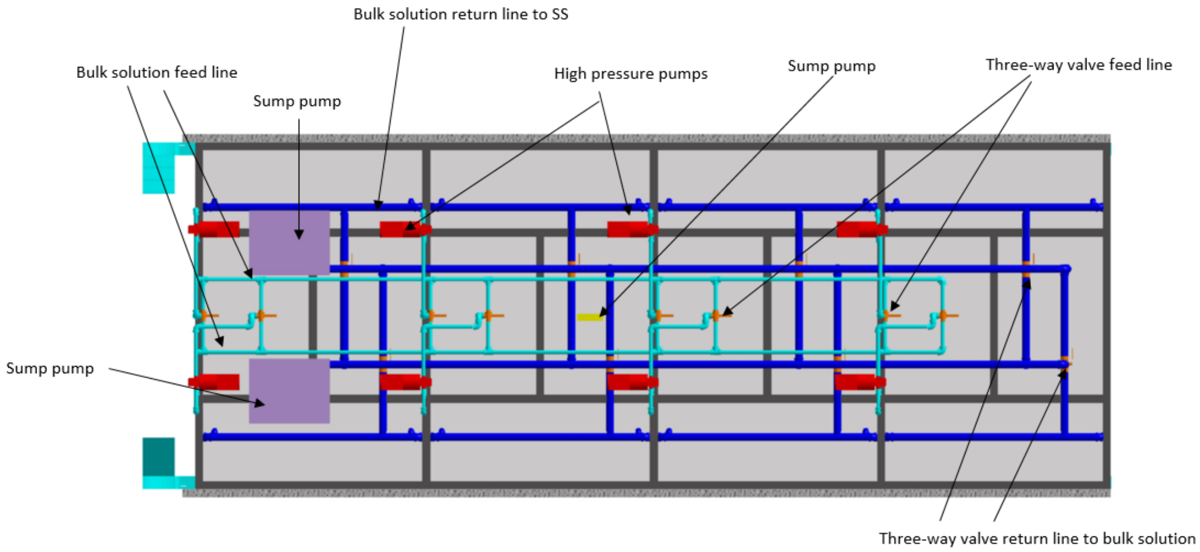


Figure 9-3: Under-floor layout of the NDS supply and return piping.

Water delivery to each growing tray from the high pressure feed pump will be via ¼" flexible tubing (polypropylene) connected to eight 0.5 – 0.9mm fog/mist nozzles in each tray. To avoid root blockage of the drain and potential flooding, a large diameter 1 ½" drain pipe will be used. The drain outlet will be on the centre side of each tray and will be constructed to allow easy drop-in placement of the tray within the system. The centre side drain placement allowed for spatial compatibility with the LED lighting system. When needed, the nutrient solution reservoirs can be drained to the waste water tank located within the airlock vestibule. The waste tank will be equipped with a 'level high' float switch to alert the system user(s) that the tank must be emptied (manual waste removal with transport back to the research station).

During the CE Study, group members were made aware of construction material limitations with respect to plant growth and productivity. The most notable common construction materials that should not be used in a closed plant growth system include; copper, zinc, iron and aluminum if those materials will be in contact with water (e.g. nutrient system components and condensate water collection components) and polyethylene (ethylene) based plastics or any material that has high VOC off-gassing. Favourable materials include stainless steel, glass, and Teflon. Materials not in contact with water collection or the NDS have no limitations other than those outlined above. One of the components in the NDS will be an ozone generator for disinfection so materials are to be selected with consideration of resistance to ozone (Table 9-1). As use will be minimal within the system, chosen materials rated better than 'severe effect' will be suitable.

Table 9-1: Ozone compatibility for a variety of common materials.

Material	Rating (Source: Cole Parmer) [Ozone Concentrations not specified]
ABS plastic	B - Good
Acetal (Delrin®)	C - Fair
Aluminum	B - Good
Brass	B - Good
Bronze	B - Good
Buna-N (Nitrile)	D - Severe Effect
Butyl	A - Excellent
Cast iron	C - Fair
Chemraz	A - Excellent
Copper	B - Good
CPVC	A - Excellent
Durachlor-51	A - Excellent
Durlon 9000	A - Excellent

EPDM	A - Excellent up to 100-deg F
EPR	A - Excellent
Epoxy	N/A
Ethylene-Propylene	A - Excellent
Flexelene	A-Excellent
Fluorosilicone	A - Excellent
Galvanized Steel	In Water (C - Fair), In Air (A - Excellent)
Glass	A - Excellent
Hastelloy-C®	A - Excellent
HDPE	A- Excellent
Hypalon®	C - Fair
Hytrel®	C - Fair
Inconel	A - Excellent
Kalrez	A - Excellent up to 100-deg F
Kel-F® (PCTFE)	A - Excellent
LDPE	B - Good
Magnesium	D - Poor
Monel	C - Fair
Natural rubber	D - Severe Effect
Neoprene	C - Fair
NORYL®	N/A
Nylon	D - Severe Effect
PEEK	A - Excellent
Polyacrylate	B - Good
Polyamide (PA)	C-D (Not recommended)
Polycarbonate	A - Excellent
Polyethylene	In Water (B-Good), In Air (C-Fair)
Polypropylene	C - Fair
Polysulfide	B - Good
Polyurethane, Millable	A - Excellent
PPS (Ryton®)	N/A
PTFE (Teflon®)	A - Excellent
PVC	B - Good
PVDF (Kynar®)	A - Excellent
Santoprene	A - Excellent
Silicone	A - Excellent
Stainless steel - 304	B - Good/Excellent
Stainless steel - 316	A - Excellent
Steel (Mild, HSLA)	D - Poor
Teflon	A - Excellent
Titanium	A - Excellent
Tygon®	B - Good
Vamac	A - Excellent
Viton®	A - Excellent
Zinc	D - Poor
Source: http://www.ozoneapplications.com/info/ozone_compatible_materials.htm	

9.2 *Options and Trades*

A number of design changes from the preliminary block diagram concept (Figure 9-4) were made during the September 2015 workshop and are summarized as follows:

- The orientation of the grow trays along one side of the FEG was changed to increase the size of the corridor for safety (egress) reasons. All trays now include their longest dimension (60 cm) parallel to the longitudinal access of the FEG.
- Removal of UV disinfection – generally UV sterilization offers little or no control of established microorganisms within biofilms that are not in direct contact with the UV irradiation source. Ozonation, already included in the system design, can provide suitable bacterial load reduction throughout the growing system. Mass and power is reduced with the removal of the UV system.
- Addition of 'C' and 'D' nutrient stock tanks – in order to have two nutrient solutions of differing composition, rather than just differing concentration, two additional stock tanks and associated hardware were added to allow independent control over the nutrient composition in each main NS tank.
- Additional misting/fog emitters – increased plant density derived from horticultural requirements resulted in a need for additional misting capacity in order to ensure complete coverage within the root zone. Emitters were doubled from four per growing tray to eight.
- Because of space constraints, custom-made nutrient, fresh water and waste tanks will be constructed. Custom tanks will allow for a better use of rack space, improve component layout and decrease the potential for leaks with the use of welded fittings.
- A dedicated plant nursery was abandoned for additional growing levels that can be adapted to nursery use with additional minor modifications.
- The preliminary NDS concept included the use of four 2-way manual valves to switch between nutrient tank inlet and outlet flows to each growing stack. The design was changed to utilize two 3-way valves to simplify the design configuration, reduce the part count (mass and cost reduction) and to make switching between nutrient tanks less prone to potential user error.

An updated block diagram can be found in Figure 9-5.

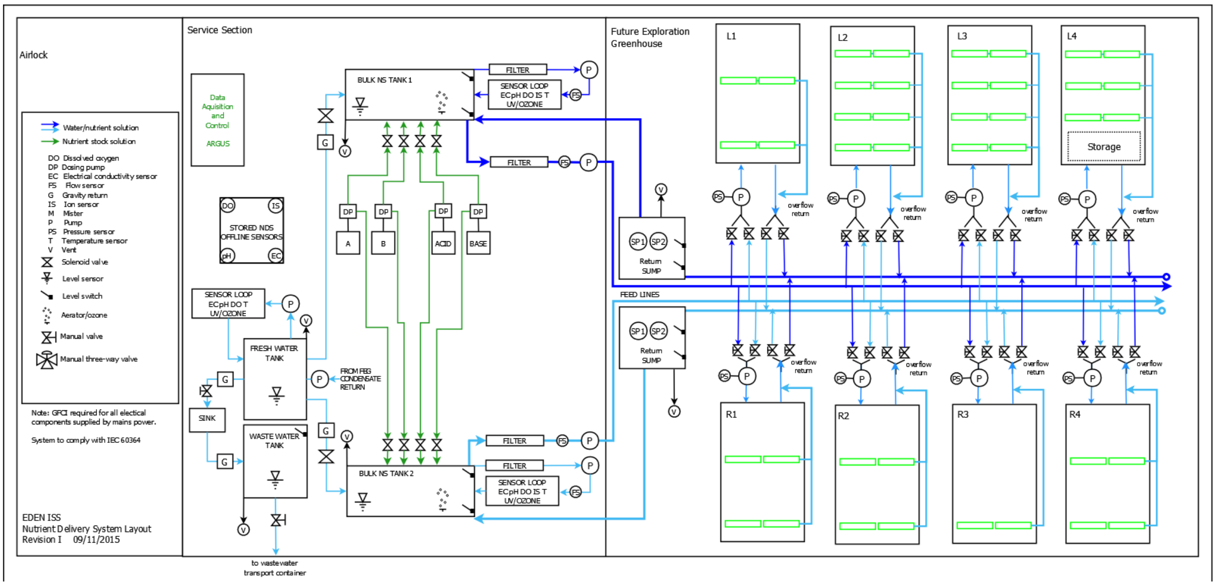


Figure 9-4: Preliminary block diagram concept of the EDEN ISS NDS system.

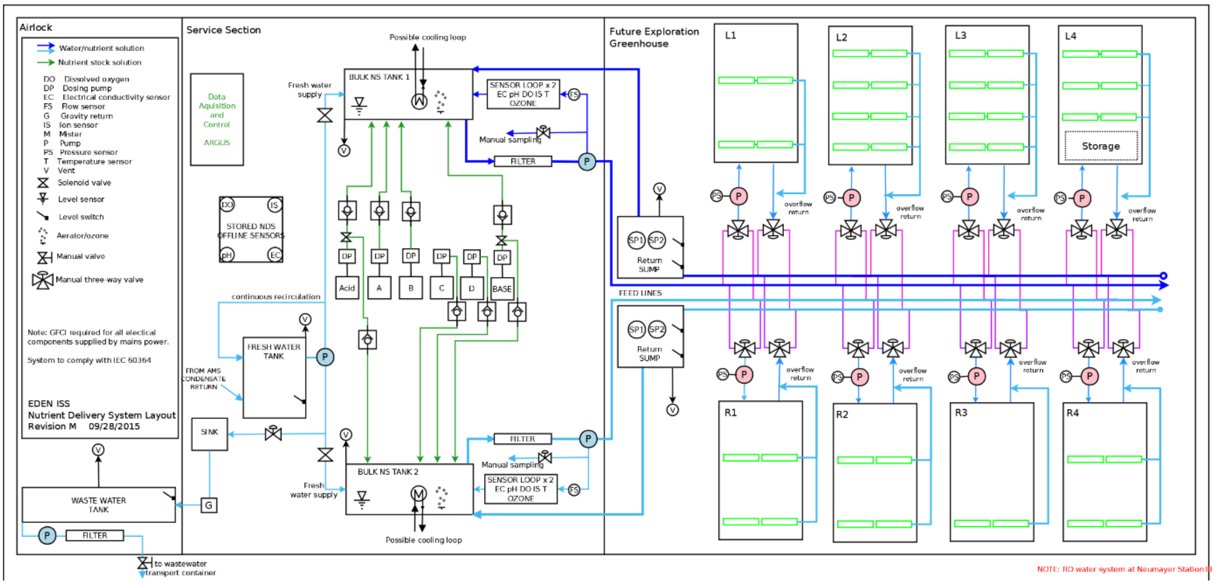


Figure 9-5: Final block diagram that resulted from changes made during the CE design study.

9.3 *List of Equipment - Key Values*

Table 9-2: Key values of the nutrient delivery subsystem.

	Mass	Peak power	Power day - nominal mode	Power night - nominal mode	Cost (€)
Mobile Test Facility	470.5 kg	221.4 W	116.5 W	115.9 W	48683.25
Neumayer Station III	TBD	N/A	N/A	N/A	TBD
Spares, consuma-bles, tools	TBD	N/A	N/A	N/A	8984.34
TOTAL	**470.5 kg**	**221.4 W**	**116.5 W**	**115.9 W**	

10 Command and Data Handling

10.1 *Baseline Design*

During the CE study the command and data handling system was designed for the Mobile Test Facility and for NM-III. In the following chapters the layout for those two locations is described in detail.

10.1.1 Mobile Test Facility

The command and data handling system of the MTF (see block diagram Figure 10-3) is subdivided into:

- Control and monitoring system,
- Camera system,
- Safety system and
- Miscellaneous network infrastructure

Control and Monitoring System

The control and monitoring system of the MTF consists of two PCs and one Laptop connected over an Ethernet switch to the MTF network. This local network is connected to the Neumayer III Ethernet network via 2 patch antennas (see Figure 10-1), one installed outside the MTF facing NM-III and one installed outside NM-III facing the MTF.

Figure 10-1: Patch antenna: PowerBridge M5 - Carrier Class 5GHz MIMO Bridging Solution (Ubiquiti Networks).

The command and data handling PCs (see Figure 10-4) are installed in a 19'' rack system box with the dimensions of 600 x 600 x 900 mm (see Figure 10-4) located in the Service Section (see Figure 10-2). The 24 port network switch and the UPS of the power control system are also installed in this box. The total amount of sensors connected to the command and data handling system is 220 and the total amount of actuators is 94.

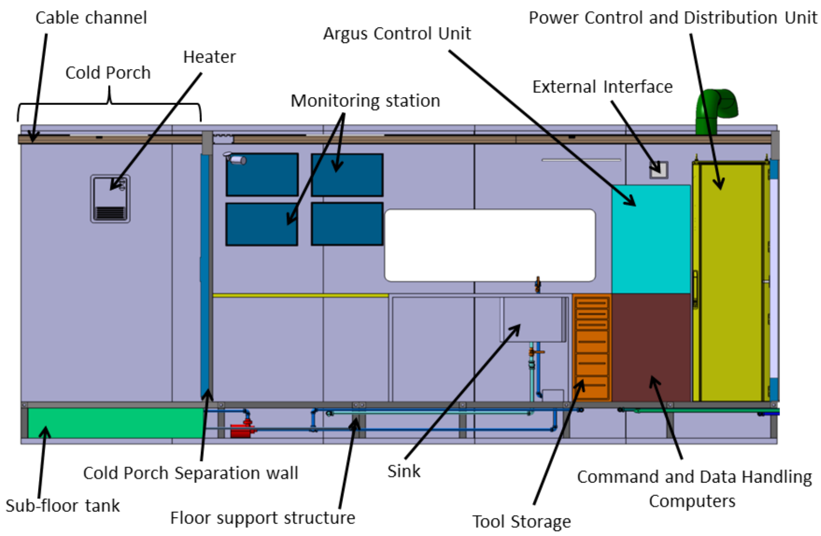


Figure 10-2: Command and data handling system in Service Section.

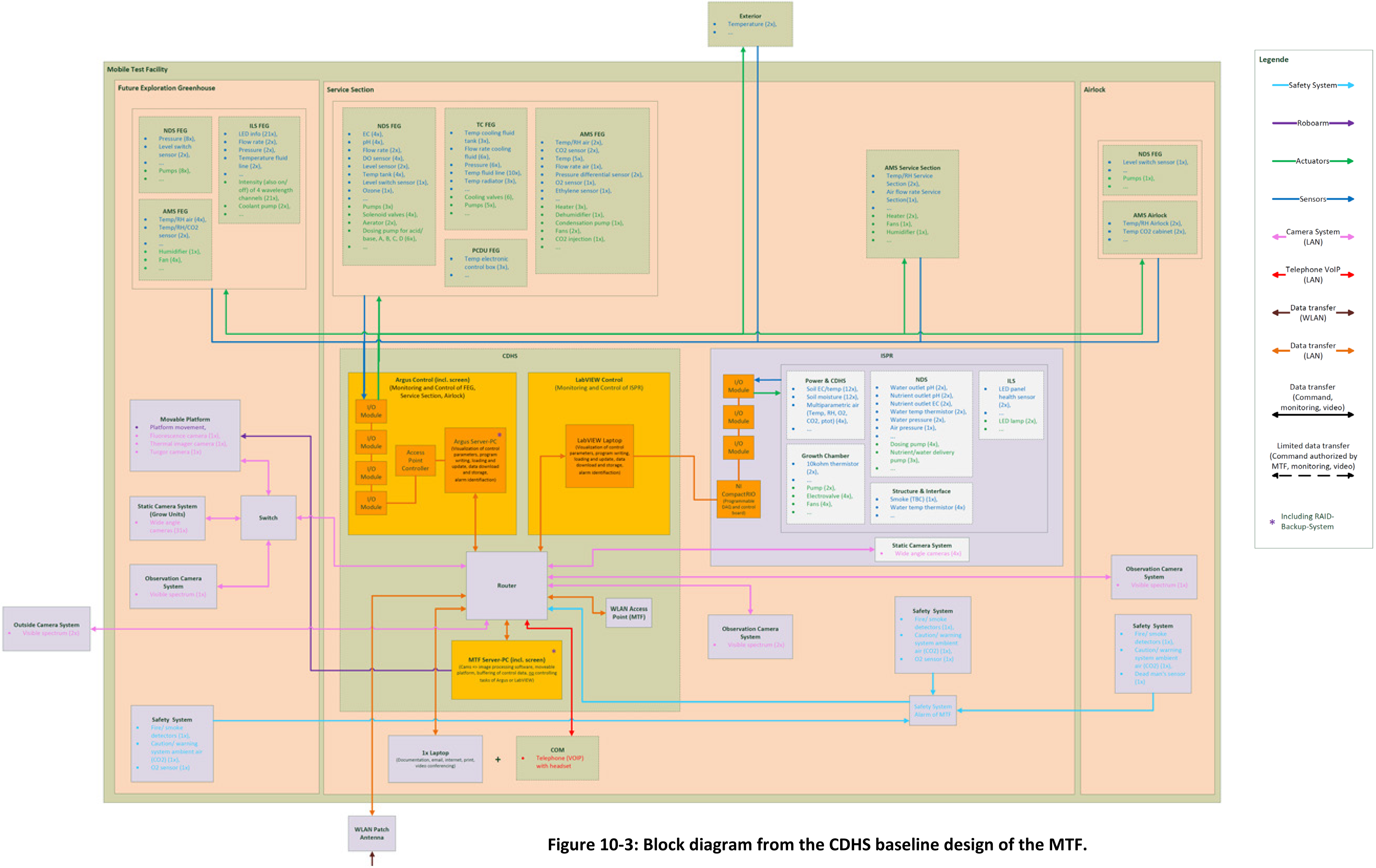


Figure 10-3: Block diagram from the CDHS baseline design of the MTF.

Figure 10-4: 19"-rack system from RITTAL - 18 HE (left). Possible CELSIUS M740 command and data handling PC from FUJITSU (right).

The **LabVIEW Laptop** can be used to visualize the control parameters of the ISPR, to write or upload new program code for the ISPR and to download and store ISPR data. It is only connected to the ISPR system in the described situations. Normally the whole ISPR system is controlled by the programmable data acquisition and control board NI CompactRIO integrated into the ISPR system using LabVIEW software.

The following table shows the amount of sensors and actuators connected to the LabVIEW control system.

Table 10-1: Sensors and actuators connected to the LabVIEW control system.

LabVIEW		
Subsystem	**Location**	**Sum**
ISPR Structure	ISPR	1
ISPR to MTF Interface Subsystem	ISPR	2
ISPR to P/L Interface Subsystem	ISPR	2
Nutrient Storage Module	ISPR	11
	ISPR	7
Illumination Modules (2x)	ISPR	6
	ISPR	2
Growth Chamber Module (2x)	ISPR	2
	ISPR	10
Power, C&DH Module	ISPR	28
	Sensors:	**52**
	Actuators:	**19**

For more detailed information regarding the type of sensors and actuators see Table 10-9.

One of the above mentioned PCs – the **Argus Server PC** inclusive RAID system – is used to control and monitor all systems inside and outside the MTF except the ISPR, the safety system, the camera system and the mobile platform (see Figure 10-3) using the Argus control software. It can also be used to visualize the control parameters on the connected screen located on one wall of the Service Section (Figure 10-2), to write or upload new program code to the Argus control system and to download and store Argus control data.

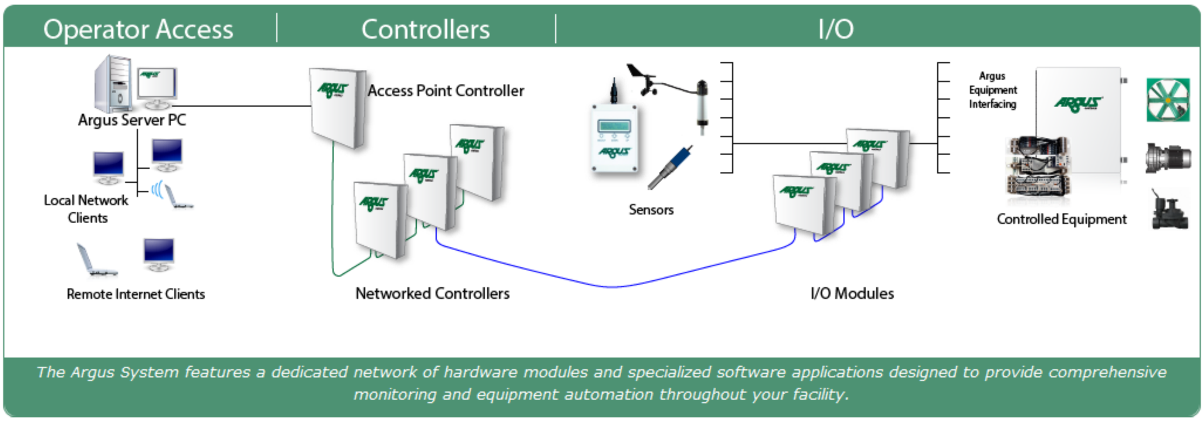


Figure 10-5: Overview of exemplary Argus control system.

Argus provides a complete hardware and software solution for monitoring and equipment automation purposes (see Figure 10-5). The designed hardware is an essential component for handling the wide range of applications that the Argus system is capable of. It is exceptionally serviceable, scalable, and flexible.

As part of the Argus services, they select and preconfigure all of the control components required to meet the user's specifications. The user only needs to supply information about the equipment they need to control and the processes they need to manage. Argus supplies the user with a complete end-to-end control system tailored to their facility.

The **Argus Server PC** provides password-protected access to the Argus control system enabling authorized users on other PCs (like user home bases) to connect to the system via wired or wireless Ethernet networks and the Internet. The multi-user option lets multiple users connect for simultaneous access to the control system. Remote clients have access to all of the features authorized by their password level no matter where they access the system from.

As can be seen in Figure 10-5, the Argus control system to which the Argus Server PC is connected, consists of:

- Access point controller,
- I/O modules,
- Relay modules and
- Sensors and actuators.

Figure 10-6: Argus access point controller.

The Access point (see Figure 10-6) is equipped with a Titan controller and components to facilitate Ethernet connection to the Operator PC, external alarm output relays, an included automatic alarm dialer, a battery for emergency backup power, and power supply circuitry for operating the controller and the first segment of the connected I/O Communications Network. The system is then expanded as needed by simply adding additional controllers connected together by a highly flexible communications network. Wired and wireless controller connection options are available. For maximum safety and reliability, each controller operates autonomously and all controllers are continuously monitored.

Titan controllers are industrial computers designed by Argus. All control programs are executed from the controllers. When an Argus system is accessed from a PC the communication is directly established with the controllers. When the user is not on-line, the Titan controllers automatically operate all of the controlled equipment in accordance with the dedicated settings and control targets.

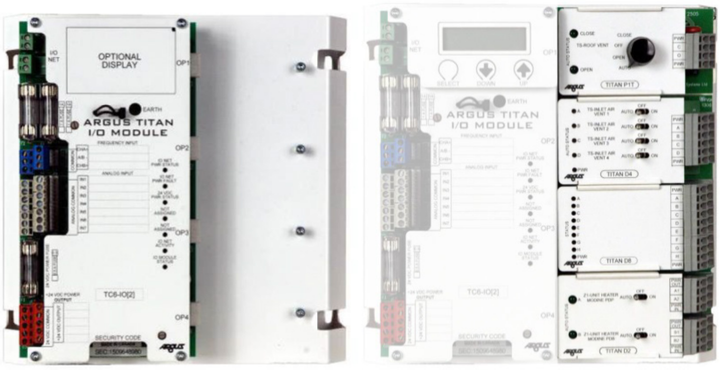


Figure 10-7: Argus I/O module (left). Argus relay module (right).

Argus I/O modules (see Figure 10-7) function as seamless extensions of each Argus controller, acquiring data from connected sensors and executing all equipment control operations. Large numbers of I/O modules can be linked together to match the applications under control and physical locations of the controlled equipment and sensors. They can be ganged together in panels or distributed individually throughout your operation as required.

Argus I/O modules have addressable connectors for automated equipment control signals. Any combination of Argus output relay boards (see Figure 10-7) can be connected to provide control signals that are precisely matched to the controlled equipment. Depending on the application, each I/O module can operate between 4 and 32 discreet outputs.

As mentioned, the above the whole Argus control system will be customized to the needs of the user by Argus. Argus will put the control system in a customized Argus box including e.g. the controllers and I/O modules (see Figure 10-8).

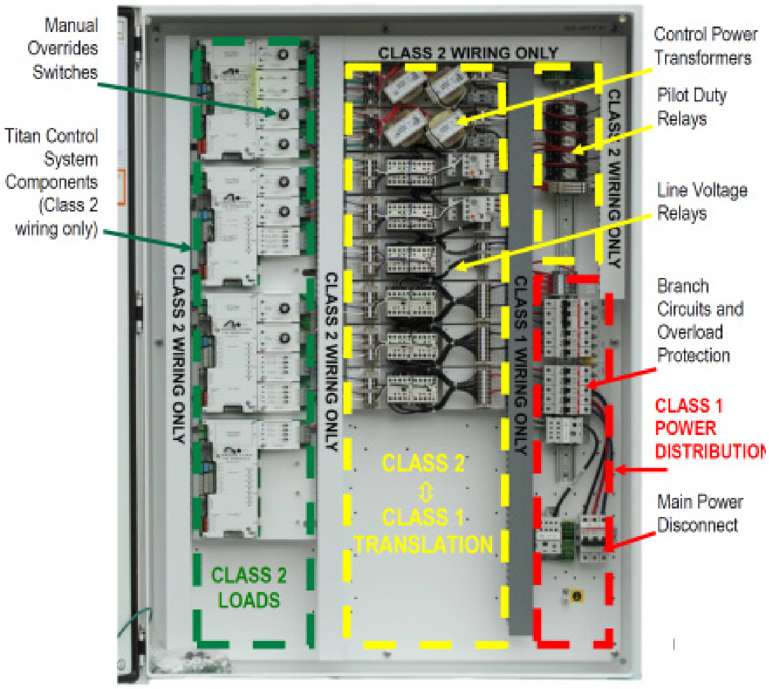


Figure 10-8: Exemplary Argus box.

The following table shows the amount of sensors and actuators connected to the Argus control system.

Table 10-2: Sensors and actuators connected to the Argus control system.

ARGUS			
Subsystem	**Location**	**Amount**	**Sum**
NDS FEG	Future Exploration Greenhouse	10	33
	Service Section	22	
	Airlock	1	
	Future Exploration Greenhouse	8	24
	Service Section	15	
	Airlock	1	
ILS FEG	Future Exploration Greenhouse	29	29
	Future Exploration Greenhouse	23	23
TC FEG	Outside	3	28
	Service Section	25	
	Service Section	11	11
Exterior	Service Section	2	2
AMS Airlock	Airlock	4	4
AMS FEG	Future Exploration Greenhouse	6	20
	Service Section	14	
	Future Exploration Greenhouse	5	13
	Service Section	8	
AMS Service Section	Service Section	3	3
	Service Section	4	4
		Sensors:	**119**
		Actuators:	**75**

For more detailed information regarding the type of sensors and actuators see Table 10-8.

Taking all the sensors and actuators of Table 10-2 into account the Argus box will have the dimensions of 152,4 cm x 91,44 cm x 20,32 cm. A bunch of the Argus standard I/O modules are replaced with the new modbus units to reduce the dimensions. It could also be imagined to have multiple smaller Argus boxes for e.g. FEG, NDS or AMS instead of one larger box containing the whole control system.

The second above mentioned PC is the **MTF Server PC** (including screen). This PC has also a RAID system and has various tasks including:

- Processing of images from camera system using dedicated software,
- Control the moveable platform (further information is provided in chapter 11) and
- Buffering of control data (but no controlling task of Argus or LabVIEW).

Camera System

The cameras listed in the following table are connected to the MTF network via Ethernet switches located in the FEG and the Service Section. As mentioned above, they are controlled by the MTF Server PC due to dedicated image processing software.

Table 10-3: Cameras connected to the MTF network*.

Camera System				
Subsystem	**Comments**	**Location**	**Amount**	**Sum**
Outside Camera System	Visible spectrum	Outside	2	2
Growth Unit Camera System	Wide angle camera	Future Exploration Greenhouse	31	31
Observation Camera System	Visible spectrum	Future Exploration Greenhouse	1	4
	Visible spectrum	Service Section	2	
	Visible spectrum	Airlock	1	
Moveable Platform System	Fluoresence Camera	Future Exploration Greenhouse	1	3
	Thermal Imager Camera	Future Exploration Greenhouse	1	
	Turgor Camera	Future Exploration Greenhouse	1	
			Total Cameras:	**40**

* Outside cameras are connected to the internal MTF network via Ethernet cable => using e.g. 7931A Multi-Conductor – Category 6 DataTwist; Twisted Pair Cable from Belden (installation temperature range -55°C to +150°C and operating temperature range -70°C to +150°C).

For detailed information concerning the camera system of the MTF see chapter 11 (Operations and Communications).

Safety System

The following table lists the various subsystems of the MTF safety system and their locations in the container with their dedicated amount:

Table 10-4: Safety System of the MTF.

Safety System			
Subsystem	**Location**	**Amount**	**Sum**
Fire/ smoke detectors	Future Exploration Greenhouse	1	3
	Service Section	1	
	Airlock	1	
Caution/ warning system ambient air (CO2)	Future Exploration Greenhouse	1	3
	Service Section	1	
	Airlock	1	
O2 sensor	Future Exploration Greenhouse	1	2
	Service Section	1	
Dead man's sensor	Airlock	1	1
			9

The systems are described in detail in the following sections.

Fire/ smoke detectors

The fire/ smoke detection system of the MTF will be incorporated in the overall Siemens fire/ smoke alarm system of NM-III. For that purpose the fire alarm system of the MTF has to be connected via a 350 m copper cable to the NM-III fire/alarm system. In case of fire or smoke in the MTF an alarm will occur in the MTF, the NM-III observation room or in the radio room and a SMS will be sent to a group of predefined people.

Further details have to be discussed with Siemens and AWI.

Caution/ warning system ambient air (CO_2)

The CO_2 Safety System from LogiCO2 is designed to measure CO_2 concentration in confined environments. It provides an alarm in the event of a CO_2 level considered unhealthy or dangerous in accordance with existing safety codes.

The basic CO_2 Safety System is a precision instrument comprising of one central unit (with a digital display), one (up to eight) sensor unit, one horn/strobe. A separate electronic transformer supplies power to the system. The sensor unit uses infrared analysis for detecting CO_2. The system monitors STEL as well as TWA levels of CO_2. The system also provides visible indication of CO_2 levels and temperature in the area where the remote sensor is located. It is displayed on a screen of the Central Unit in most languages. The CO_2 Safety System performs a self-calibration at regular intervals ensuring calibration under normal circumstances.

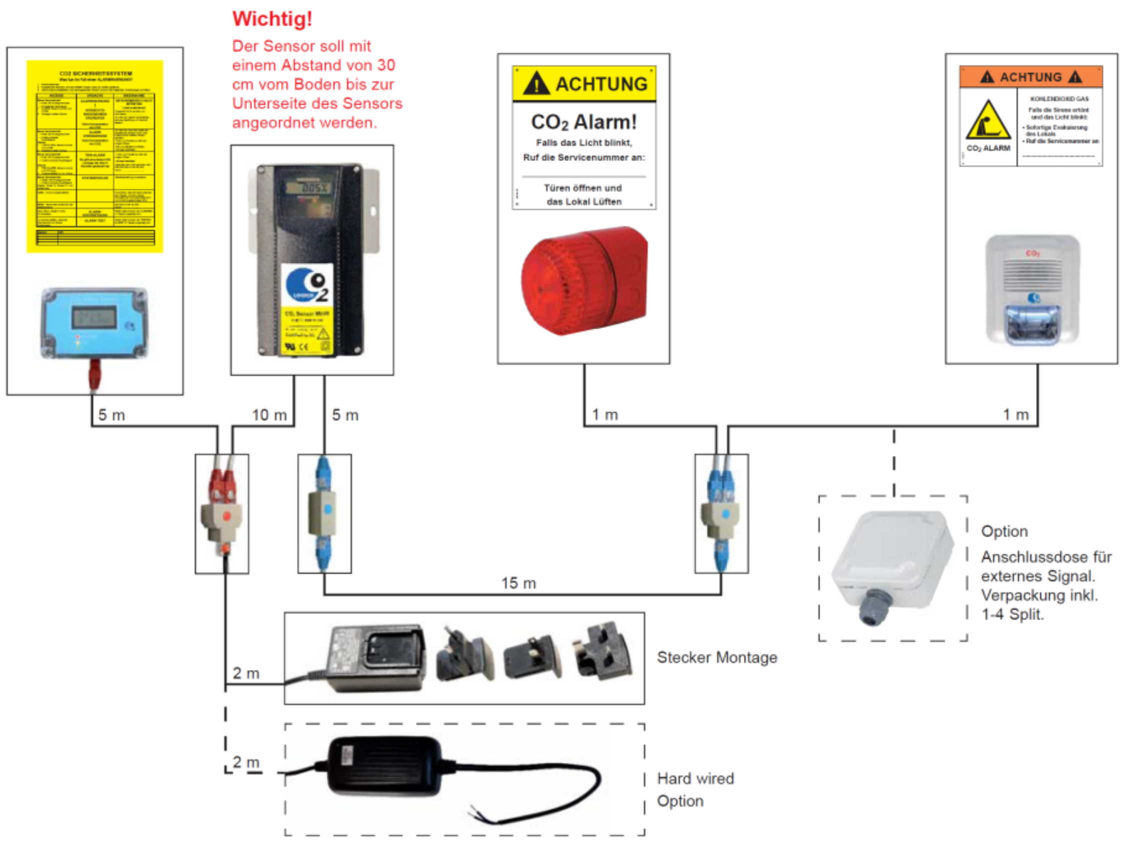


Figure 10-9: Connection diagram for the CO_2 Safety System from LogiCO2.

When installed properly, the CO_2 Safety System will continuously monitor the CO_2 concentration and temperature wherever a sensor unit is located. A green LED on the central unit indicates normal safe conditions. If ambient conditions at the sensor unit reach a CO_2 concentration level of 1.5% (preset low alarm), the central unit will emit an intermittent audible tone and the « low alarm » red LED will blink. A remote horn/strobe will be activated. This will also happen if the TWA for 8 hours also surpasses 5000 ppm. The difference can be acknowledged on the display.

O_2 sensor

Figure 10-10: O_2 Enrichment Monitor and Alarm (QFM331 from Quantum Cryogenics).

The O_2 Enrichment Monitor and Alarm (QFM331) continually monitors the air surrounding the sensor filter on its base and provides visual and audible alarms when the monitored concentration of oxygen rises above pre-set alarm levels.

The QFM331 oxygen monitor may be used as a stand-alone device with its own audible and visual alarms, or linked to other repeater modules to mimic the condition of the monitor. Repeater modules can be connected to the QFM331 and located outside the monitored area to warn users at the point of entry. The system can be fully customised to allow multiple location monitoring and further modules can be easily added at a later date to expand the scope of the system.

Key Features:

- Oxygen monitor unit operates continuously for two years and cannot be switched off, giving maximum user protection.
- Built-in visual and audible alarms with separate 'low' and 'critical' alarm states.
- Internal audible alarm is 85 dBA at 30 cm.
- Long life oxygen sensors provide 24 months operation in normal use.
- Audible/visual alarms at the monitoring point not only at a remote location.
- Oxygen enrichment, deficiency and high/low monitoring options.
- Simple and secure connections to repeater modules using a pre-wired plug in connector (up to a maximum of 100 m).
- Modular system which allows the user to completely design and customize the system to suit their exact requirements.
- Suitable for use in high magnetic fields.

Dead man's sensor

Figure 10-11: Dead man's sensor: Left: Loner® 900 employee-worn safety monitoring device (left). Loner® Bridge portable satellite & cellular base station (right).

The Loner Bridge System is the world's most comprehensive employee safety monitoring system for remote operations and is comprised of two parts: the Loner® Bridge portable satellite and cellular base station and the Loner® 900 employee-worn safety monitoring device.

The Loner Bridge System works anywhere, especially on the road and in the field where cellular coverage is often spotty or doesn't even exist. Using an industrial-quality 900 MHz radio link, the Loner Bridge base station communicates with up to 10 Loner 900 devices up to 2 km away at once. Self-powered and portable, Loner Bridge allows users to quickly move it from one place to another in seconds.

The employee-worn Loner 900 safety monitoring device features a combination of automatic incident detection and manual triggers that enable employees to call for help at any moment. It automatically detects falls, and, if one of your crew members is unable to request help manually, it automatically alerts when the employee is motionless or fails to respond to a check-in request. If the employee is in need of help and can trigger an alert manually, it's as simple as pulling a fire alarm—even if his or her vision is compromised. In case of an emergency, low battery or power off the system will send an alert text messages (SMS) to configurable numbers.

The system is also capable to deal with the harsh environment in Antarctica:

- Storage temperature: -50 to 75°C
- Operating temperature: -40 to 55°C
- Charging temperature: -20 to 45°C

Many industries encounter environments with the potential for an explosive atmosphere of gases or dusts. Loner 900 is also certified UL913 Class I, Division 1 and Class II, Division 1 intrinsically safe for use in such hazardous environments.

Miscellaneous network infrastructure

In addition to the above mentioned items, a mobile workstation laptop will be used in the MTF for documentation purposes, using the internet, sending as well as receiving emails and video conferencing.

The CDHS also will contain a WLAN access point (see Figure 10-12), which is also connected to the MTF network switch and provides WLAN access to the network/Internet in the whole MTF.

Figure 10-12: PoE WLAN Access-Point 300 MBit/s 2.4 GHz Intellinet 525251.

Another item used in the CDHS is the VOIP telephone including headset (see Figure 10-13).

Figure 10-13: Cisco IP-Telefon 7970G.

10.1.2 Neumayer Station III

The CDHS in NM-III (see Figure 10-14) is connected as mentioned above via the two patch antennas and switches with the local MTF network. It consists of:

- One PC, which is used to control the robotic arm and the cameras in the MTF remotely from the station (including screens),
- One PC, which is used to receive data from and send commands to the Argus and the LabVIEW system (including screens) and
- One so called NM-III Main Server PC on which all the MTF data is stored.

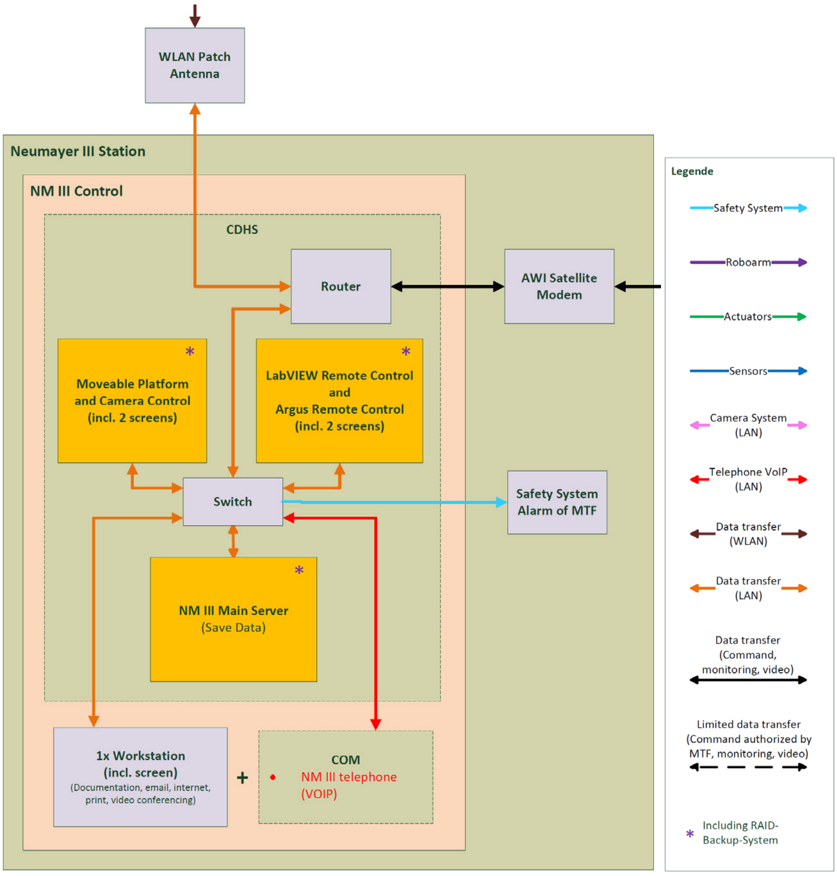


Figure 10-14: Block diagram for CDHS baseline design of NM-III.

All three computers have a RAID system to guarantee reliable function throughout the mission.

In addition to those computers a workstation PC including a screen will be used in the NM-III Control Center for documentation purposes, printing, using the internet, sending as well as receiving emails and video conferencing. Another item used in the CDHS of the NM-III Control Center is the VOIP telephone including headset.

The AWI satellite modem, which is connected to a satellite antenna, will provide the connection to the EDEN Control Center in Bremen and the other user home bases. The network at NM-III as well as the AWI Ground Station in Bremerhaven is protected by a firewall. But it is no problem to get access to those net-works (in case of sending/ receiving commands/data to/from Antarctica) after discussion with AWI.

10.2 *Spares, Consumables and Tools*

To run the CDHS during the whole mission the following spares, consumables and tools are needed:

Table 10-5: Spares, Consumables and Tools of the CDHS.

SPARES, CONSUMABLES TOOLS	
Element/Component	**Qty**
Spares	
Access Point Controller	1
I/O Module	3
Relay Module	2
VOIP telephone (incl. Headset)	1
Patch antenna	2
Cables	1
Switch (48 ports)	1
Fire/ smoke detector	1
CO2 warning system	1
O2 warning system	1
Dead man's sensor	1
WLAN Access Point (MTF)	1

10.3 *List of Equipment - Key Values*

The mass, cost and power needed in the various modes for the MTF, NM-III and the required spares, consumables and tools are listed in the following table:

Table 10-6: Overview of mass, cost and power for the MTF, NM-III and the spares, consumables and tools.

MOBILE TEST FACILITY					Nominal Operations Mode			Day Nominal Mode			Night Nominal Mode		
	Mass (MTF)		*Cost (MTF)*		Total Power	Avg. Power		Total Power	Avg. Power		Total Power	Avg. Power	
Subtotal	333	kg	34.690	€	1.188	1.057	W	1.188	1.188	W	993	993	W
Margin	10	%	10	%	10	10	%	10	10	%	10	10	%
Grand total:	**367**	**kg**	**38.159**	€	**1.306**	**1.163**	**W**	**1.306**	**1.306**	**W**	**1.092**	**1.092**	**W**

NEUMAYER STATION III					Nominal Operations Mode			Day Nominal Mode			Night Nominal Mode		
	Mass (NM III)		*Cost (NM III)*		Total Power	Avg. Power		Total Power	Avg. Power		Total Power	Avg. Power	
Subtotal	83	kg	6.060	€	1.503	1.185	W	1.503	1.503	W	1.028	1.028	W
Margin	10	%	10	%	10	10	%	10	10	%	10	10	%
Grand total:	**91**	**kg**	**6.666**	**€**	**1.653**	**1.303**	**W**	**1.653**	**1.653**	**W**	**1.131**	**1.131**	**W**

Spares, Consum., Tools	*Mass (NM III)*		*Cost (NM III)*	
Subtotal	69	kg	10.227	€
Margin	10	%	10	%
TOTAL:	**75**	**kg**	**11.250**	**€**

As can be seen in Table 10-7, the total mass of the CDHS is 533 kg, the total costs amounts to approximately 56 k€ and the needed total power in nominal day mode is approximately 3 kW and approximately 2,2 kW during nominal night mode (note that these values include both MTF and NM-III hardware).

Table 10-7: Overview of total mass, cost and power for the whole CDHS in Antarctica.

Antarctica					Nominal Operations Mode			Day Nominal Mode			Night Nominal Mode		
	Mass		*Cost*		Total Power	Avg. Power		Total Power	Avg. Power		Total Power	Avg. Power	
Subtotal	485	kg	50.977	€	2.691	2.242	W	2.691	2.691	W	2.021	2.021	W
Margin	10	%	10	%	10	10	%	10	10	%	10	10	%
TOTAL:	**533**	**kg**	**56.075**	**€**	**2.960**	**2.466**	**W**	**2.960**	**2.960**	**W**	**2.223**	**2.223**	**W**

Table 10-8: Detailed description of sensors and actuators connected to the Argus control system.

			ARGUS					
Subsystem	**Sensor/Actuator**	**Location**	**Amount**	**Sum**	**Controlled by**	**Control Type**	**Argus Input**	**Argus Output**
NDS FEG	Pressure	Future Exploration Greenhouse	8	33	ARGUS	Analog	4 to 20 mA	none
	Level switch sensor (sump tank)	Future Exploration Greenhouse	2		ARGUS	Digital	Contact	none
	EC	Service Section	4		ARGUS	Analog	4 to 20 mA	none
	pH	Service Section	4		ARGUS	Analog	4 to 20 mA	none
	Flow rate	Service Section	2		ARGUS	Analog	Frequency	none
	DO sensor	Service Section	4		ARGUS	Analog	4 to 20 mA	none
	NDS Tank continuous level sensor	Service Section	2		ARGUS	Analog	Potentiometer	none
	Temp tank	Service Section	4		ARGUS	Analog	Thermistor	none
	Level switch sensor (fresh water tank)	Service Section	1		ARGUS	Digital	Contact	none
	Ozone sensor	Service Section	1		ARGUS	Analog	4 to 20 mA	none
	Level switch sensor (waste water tank)	Airlock	1		ARGUS	Analog	Potentiometer	none
	Pump (high pressure - aeroponic)	Future Exploration Greenhouse	8	24	ARGUS	Relay	none	24V
	Sump pump (4x)	Future Exploration Greenhouse	0		autonomous	-	-	-
	Solenoids (3-way for acid/base feed)	Service Section	2		ARGUS	Relay	none	24V
	Pumps	Service Section	3		ARGUS	Relay	none	24V
	Solenoids (fresh water feed)	Service Section	2		ARGUS	Relay	none	24V
	Aerator	Service Section	2		ARGUS	Relay	none	24V
	Dosing pump for acid/base, A, B, C, D	Service Section	6		ARGUS	Relay	none	24V
	Pumps	Airlock	1		ARGUS	Relay	none	24V
ILS FEG	Temp per bar LED	Future Exploration Greenhouse	21	29	ARGUS	Helispectra Ethernet	Helispectra Ethernet	none
	Current per bar LED	Future Exploration Greenhouse			ARGUS			
	Set points per panel LED	Future Exploration Greenhouse			ARGUS			
	Status per panel LED	Future Exploration Greenhouse			ARGUS			
	HW configuration LED	Future Exploration Greenhouse			ARGUS			
	FW version LED	Future Exploration Greenhouse			ARGUS			
	Flow rate sensor	Future Exploration Greenhouse	2		ARGUS	Analog	4 to 20 mA	none
	Pressure sensor	Future Exploration Greenhouse	2		ARGUS	Analog	4 to 20 mA	none
	Temperature fluid line sensors	Future Exploration Greenhouse	4		ARGUS	Analog	Thermistor	none
	Intensity (also on/off) of 4 wavelength channels LED	Future Exploration Greenhouse	21	23	ARGUS	Helispectra Ethernet (see above)	Helispectra Ethernet (see above)	none
	Coolant pump	Future Exploration Greenhouse	2		ARGUS	Relay	none	24V
TC FEG	Temp radiator	Outside	3	28	ARGUS	Analog	Thermistor	none
	Temp cooling fluid tank	Service Section	3		ARGUS	Analog	Thermistor	none
	Flow rate cooling fluid	Service Section	6		ARGUS	Analog	4 to 20 mA	none
	Pressure	Service Section	6		ARGUS	Analog	4 to 20 mA	none
	Temp fluid line	Service Section	10		ARGUS	Analog	Thermistor	none
	Cooling valves	Service Section	6	11	ARGUS	Relay	none	24V
	Pumps	Service Section	5		ARGUS	Relay	none	24V
Exterior	Temperature	Service Section	2	2	ARGUS	Analog	Thermistor	none
PCDU FEG	Power demand	Service Section	0	0	ARGUS	-	-	-
	Power supply status	Service Section	0		ARGUS	-	-	-
AMS Airlock	Temp/RH Airlock	Airlock	2	4	ARGUS	Analog	Argus sensor	none
	Temp CO2 cabinet	Airlock	2		ARGUS	Analog	Thermistor	none
	Heater inlet air (3x manual)	Airlock	0	0	autonomous	-	-	-
AMS FEG	Temp/RH (PHM)	Future Exploration Greenhouse	4	20	ARGUS	Analog	Argus sensor	none
	Temp/RH/CO2 sensor (PHM)	Future Exploration Greenhouse	2		ARGUS	Analog	4 to 20 mA	none
	Temp/RH	Service Section	2		ARGUS	Analog	Argus sensor	none
	CO2 sensor	Service Section	2		ARGUS	Analog	4 to 20 mA	none
	Temp	Service Section	5		ARGUS	Analog	Thermistor	none
	Air flow sensor	Service Section	1		ARGUS	Analog	4 to 20 mA	none
	Pressure differential sensor	Service Section	2		ARGUS	Analog	4 to 20 mA	none
	O2 sensor	Service Section	1		ARGUS	Analog	4 to 20 mA	none
	Ethylene sensor	Service Section	1		ARGUS	Analog	0...5 V	none
	Humidifier 3kg/h	Future Exploration Greenhouse	1	13	ARGUS	Relay	none	24V
	Fan, return air	Future Exploration Greenhouse	4		ARGUS	Relay	none	24V
	Dehumidifier	Service Section	1		ARGUS	Relay	none	24V
	Recovery cond. water: pump	Service Section	1		ARGUS	Relay	none	24V
	Heater	Service Section	3		ARGUS	Relay	none	24V
	Fans	Service Section	2		ARGUS	Relay	none	24V
	CO2 injection valve	Service Section	1		ARGUS	Relay	none	24V
	UV lamp (1x always on)	Service Section	0		allways on	-	-	-
AMS Service Section	Temp/RH of Service Section	Service Section	2	3	ARGUS	Analog	Argus sensor	none
	Air flow rate SS	Service Section	1		ARGUS	Analog	4 to 20 mA	none
	Fan, fresh air	Service Section	1	4	ARGUS	Relay	none	24V
	Heater, inlet air	Service Section	2		ARGUS	Relay	none	24V
	Humidifier	Service Section	1		ARGUS	Relay	none	24V
			Total Argus Sensors:	**119**				
			Total Argus Actuators:	**75**				

Table 10-9: Detailed description of sensors and actuators connected to the LabVIEW control system.

LabVIEW					
Subsystem	**Sensor/Actuator**	**Location**	**Amount**	**Sum**	**Controlled by**
ISPR Structure	Smoke sensor (TBC)	ISPR	1	1	LabVIEW
ISPR to MTF Interface Subsystem	Water temperature thermistor	ISPR	2	2	LabVIEW
ISPR to P/L Interface Subsystem	Water temperature thermistor	ISPR	2	2	LabVIEW
Nutrient Storage Module	Water outlet pH sensor	ISPR	2	11	LabVIEW
	Nutrient outlet pH sensor	ISPR	2		LabVIEW
	Nutrient outlet EC sensor	ISPR	2		LabVIEW
	Water temperature thermistor	ISPR	2		LabVIEW
	Water pressure sensor	ISPR	2		LabVIEW
	Air pressure sensor	ISPR	1		LabVIEW
	Dosing pump	ISPR	4	7	LabVIEW
	Nutrient/water delivery pump	ISPR	3		LabVIEW
Illumination Modules (2x)	LED panel health sensor	ISPR	2	6	LabVIEW
	Video-camera	ISPR	4		LabVIEW
	LED Lamp		2	2	LabVIEW
Growth Chamber Module (2x)	10kohm thermistor	ISPR	2	2	LabVIEW
	Fan	ISPR	4	10	LabVIEW
	Pump (condensate recovery)	ISPR	2		LabVIEW
	Electrovalve (air exchange with	ISPR	4		LabVIEW
Power, C&DH Module	Soil EC/temperature sensor	ISPR	12	28	LabVIEW
	Soil moisture sensor	ISPR	12		LabVIEW
	Multiparametric air sensor (Temp, RH, O2, CO2, ptot)	ISPR	4		LabVIEW
			Total LabVIEW Sensors:	**52**	
			Total LabVIEW Actuators:	**19**	

10.4 *Open Points*

Open points require further investigation include:

- The cabling for the whole CDHS,
- Software/interfaces to user home bases and
- Firewall => will be discussed in detail with AWI.

11 Operations and Communications

11.1 *Baseline Design*

Among its general aims, EDEN ISS has the objective to develop and test the MTF greenhouse (hereinafter named Future Exploration Greenhouse – FEG) remote control technologies. The involvement of the experts in the control loop is deemed necessary since it is not possible to deploy all the expertise on site. As matter of fact, the EDEN ISS operations will be performed by one single operator, which cannot own all the needed skills and competencies to manage in autonomy all the EDEN ISS operations.

Space missions have similar constraints, ISS operations, even if tended by 6 astronauts, are clearly underlining the need to have support from ground operators due to the fact that the crew cannot train for each and every possible procedure/activity and due to crew time constraints. That will be even more critical for missions on planetary outposts.

From a scientific point of view, one of the key points of the FEG performance monitoring 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 to provide to the agronomists a tool to take pictures of the plants every day, or as required, for their analysis.

Of course, images are only a (limited) part of the scientific parameters. For that reason the agronomists will receive the FEG scientific telemetry (temperatures, CO_2 level, light intensity, etc.) for data analysis and cross correlation with the images, but also with the other data coming from the harvested plants.

Another key point of the MTF control is the monitoring of the health and status of all the equipment. Also in this case, the engineering expertise cannot be owned by the single operator on site (nor by astronauts on a space mission), and that because the big number of different subsystems that require expertise in several engineering fields, and of course because the complexity of the system. In general, the responsibility of the onsite operator should be limited to the nominal operations of the greenhouse, anomaly resolution in case of known issues and/or malfunctions and safing actions in case of major issue. Of course, the remote engineering support can be ensured if the housekeeping and H&S telemetry are provided to the remote experts.

For these reasons, a system shall be designed to provide all the necessary data to the remote users distributed in several countries.

The layout of the Command and Data Handling System and of the Communications system, as well as the list of EDEN ISS sensors is provided in Chapter 10.

This chapter will therefore deal with the Plant Monitoring System videomonitoring system and with a high level ground segment architecture (including the analysis on the data traffic). The top level ground segment architecture is displayed in Figure 11-1.

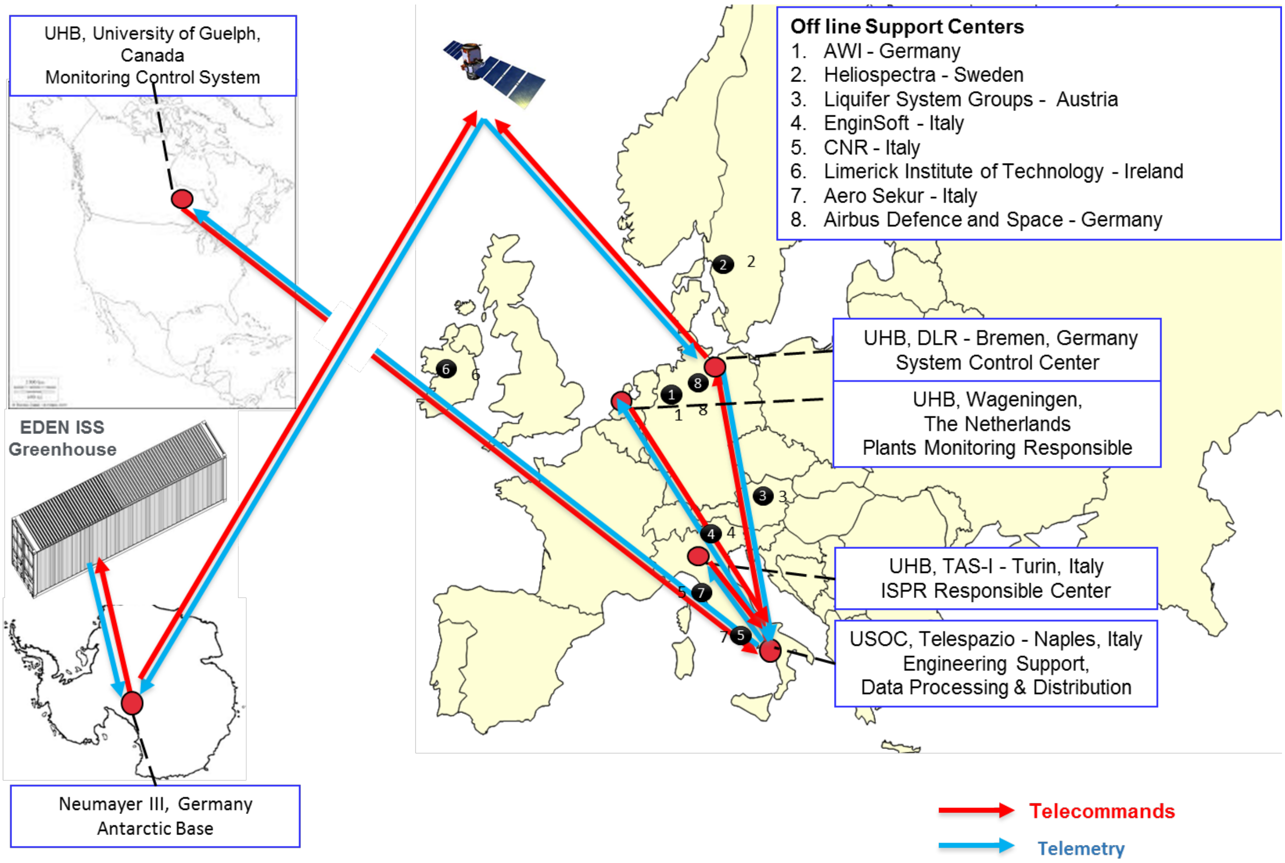


Figure 11-1: EDEN ISS Control Network.

11.2 *Plant Monitoring System Baseline Design*

The preliminary design of the plant monitoring system has been done against the following requirements:

1. The system shall provide top view image and lateral view images
2. The system shall provide visual HD images with a resolution of 2 MP
3. The system shall be able to take top view images from a distance of approx.:
    a. 400 mm for short plants and nursery
    b. 920 mm for tall plants
    c. 1960 mm for very tall plants
4. For lateral views, three kind of images shall be taken: HD, infrared and fluorescent images
5. The system shall record plants images on site and deliver to remote UHB one image per day and per tray.

11.2.1 Top View Camera Analysis

The FEG design foresees several growth racks with the layout shown in Figure 11-2.

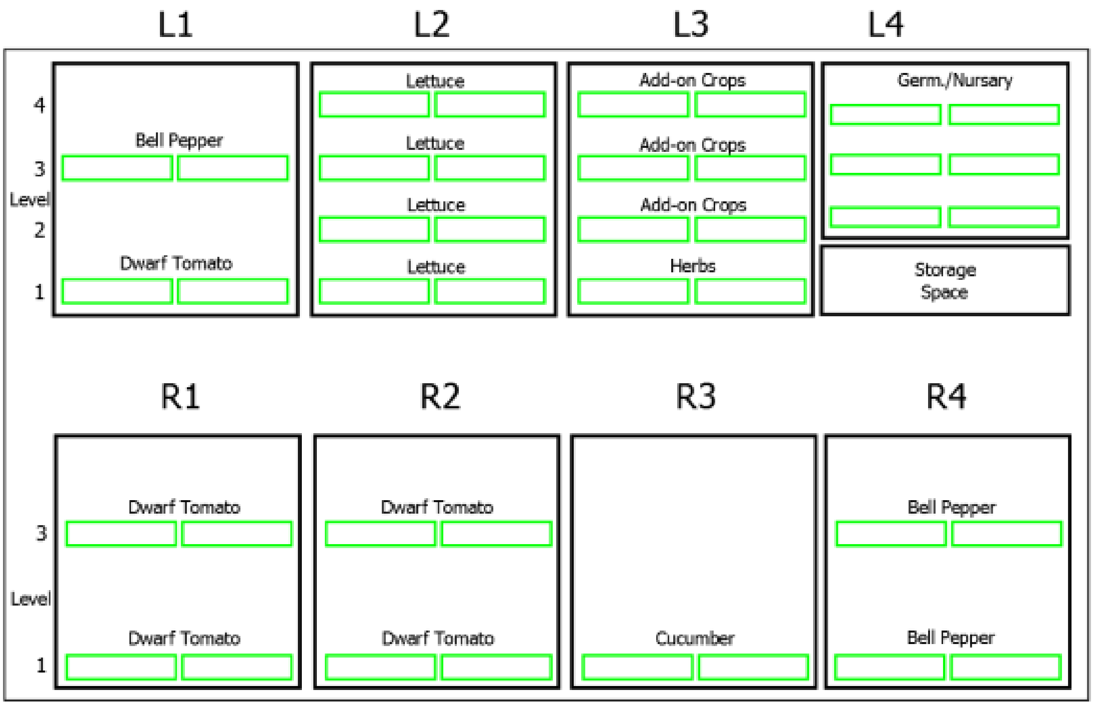


Figure 11-2: FEG plant growth layout.

There are different racks, each of them devoted to the growth of different plants, and therefore with different requirements to be satisfied in terms of camera selection.

The system is composed of a total of 40 plant growth trays and in particular of:

- 16 trays for short plants growth (racks L2 and L3)
- 6 trays for germination (rack L4)
- 16 trays for long plants (rack L1, R1, R2 and R4)
- 2 trays for very tall plants (rack R3)

Considering this layout, the most important considerations for the selection of the camera for top view are angle of view and the focal length, and therefore the capability to cover the whole tray surface but also to modify these parameters to cover the growth of the plant over time to the extent possible.

The analysis has taken into account two options:

- **Option1:** One camera used for one tray
- **Option2:** One camera for one level (i.e. one camera for two trays)

and has been carried out with the objective to calculate:

1. The required angle of view

$$\text{Angle of view} = 2*\tan^{-1}(\text{target size}/2/\text{target distance})*(180/3.14)$$

2. The required focal length

$$\text{Focal Length} = (\text{CCD length}/2) * \tan[(\text{angle of view}/2)*(3.14/180)]$$

and with the objective to compare the results with the datasheet of a CCD varifocal camera (1/3” CCD with a focal length variable in the range 2.8 -12mm). Figure 11-1 shows the results.

Table 11-1: Top view camera analysis results.

Option	Comment	Target (mm)	Plant height (mm)	Distance from camera (mm)	Angle of view	Focal (CCD 1/3")	Varifocal Camera (2.8 - 12)
Short Plants and Nursery (L2, L3 and L4 compartments)							
Option 1	1 camera x 2 trays	1200	0	400	112.7	1.6	NOK
Option 2	1 camera x tray	600	0	400	73.8	3.2	OK
Option 2	1 camera x tray	600	50	350	81.2	2.8	OK
Option 2	1 camera x tray	600	100	300	90.0	2.4	OK
Option 2	1 camera x tray	600	150	250	100.4	2	OK
Option 2	1 camera x tray	600	200	200	112.7	1.6	OK
Option 2	1 camera x tray	600	250	150	126.9	1.2	NOK
Tall Plants (L1, R1, R2 and R4 compartments)							
Option 1	1 camera x 2 trays	1200	0	920	66.3	3.68	OK
Option 1	1 camera x 2 trays	1200	100	820	72.4	3.28	OK
Option 1	1 camera x 2 trays	1200	200	720	79.7	2.88	OK
Option 1	1 camera x 2 trays	1200	300	620	88.2	2.48	OK
Option 1	1 camera x 2 trays	1200	400	520	98.2	2.08	OK
Option 1	1 camera x 2 trays	1200	450	470	103.9	1.88	OK
Option2	1 camera x tray	600	0	920	36.1	7.36	OK
Option2	1 camera x tray	600	100	820	40.2	6.56	OK
Option2	1 camera x tray	600	200	720	45.3	5.76	OK
Option2	1 camera x tray	600	300	620	51.7	4.96	OK
Option2	1 camera x tray	600	400	520	60.0	4.16	OK
Option2	1 camera x tray	600	450	470	65.1	3.76	OK
Very Tall Plants (R3 compartments)							
Option 1	1 camera x 2 trays	1200	0	1960	34.1	7.84	OK
Option 1	1 camera x 2 trays	1200	300	1660	39.8	6.64	OK
Option 1	1 camera x 2 trays	1200	600	1360	47.6	5.44	OK
Option 1	1 camera x 2 trays	1200	900	1060	59.1	4.24	OK
Option 1	1 camera x 2 trays	1200	1200	760	76.6	3.04	OK
Option 1	1 camera x 2 trays	1200	1250	710	80.4	2.84	OK
Option 1	1 camera x 2 trays	1200	1300	660	84.6	2.64	OK
Option 1	1 camera x 2 trays	1200	1350	610	89.1	2.44	OK
Option 2	1 camera x tray	600	0	1960	17.4	15.68	NOK
Option 2	1 camera x tray	600	300	1660	20.5	13.28	OK
Option 2	1 camera x tray	600	600	1360	24.9	10.88	
Option 2	1 camera x tray	600	900				
Option 2	1 camera x tray	600	1200	760	43.1	6.08	OK
Option 2	1 camera x tray	600	1250	710	45.8	5.68	OK
Option 2	1 camera x tray	600	1300	660	48.9	5.28	OK
Option 2	1 camera x tray	600	1350	610	52.4	4.88	OK

The calculation shows that:

- For short plants, Option 1 has to be discarded i.e. it is not possible to cover two trays with a single camera.
- Short plants are in the field of view (FOV) only when they are shorter than 5 cm. When this limit is exceeded, some of the plants (or plant leaves) are out of the FOV and out of focus.
- For tall plants, it is possible to use one camera for two trays, but accepting the limitation that some plants (or plant leaves) will be out of the FOV and out of focus when the height of 22 cm is exceeded. This limit can be increased to 57 cm using one camera per tray.

- For tall plants, it is advisable to use one single camera per two trays. Also in this case, there is a limitation in the maximum height of the plant to be "covered" with a single camera (12, 60 cm).

Considering these results, and considering budget limitations, the best option appears to be a mix of Option 1 and Option 2, i.e. with a single camera per tray for the short plants compartments and with one camera per level for the tall plants compartments. Therefore:

- Nursery (L4 compartment): 1 camera per tray, i.e. 6 cameras in total
- Short plants (L2, L3 compartments): 1 camera per tray, i.e. 16 cameras in total
- Tall plants (L1, R1, R2, R4 compartments): 1 camera per level, i.e. 1 camera per 2 trays. Therefore 8 cameras in total
- Very tall plants (R3 compartment): 1 camera per level, i.e. 1 camera per 2 trays. Therefore 1 camera in total.

This leads to the suggestion of **31 cameras** being required for top view image acquisition.

11.2.2 Lateral view camera analysis

The lateral view of the plants will be taken using cameras mounted on a mobile platform, able to reach any compartment and any level of the compartment. During the CE study it was agreed that it is not necessary to move the cameras on any single plant, but rather it is required to only take pictures from the centre of the corridor to assess e.g. the plant water status. As already stated, three cameras have to be mounted on the mobile platform:

- HD Visual camera
- Infrared camera
- Fluorescent camera

As previously done for the calculation of the angle of view and the camera focal, the key parameters to do that are the target dimensions and the distance form target. The calculation will be done once again looking at two options:

- **Option1:** picture taken for any single tray
- **Option2:** picture taken for the whole level (i.e. for two trays)

For the preliminary calculation it is assumed 40 cm as target distance (distance from the centre of the corridor minus the dimensions of the camera)

Table 11-2: Lateral view camera analysis.

Option	comment	Target (mm)	Distance from target (mm)	Angle of view	Focal (CCD 1/3")	Varifocal Camera (2.8 - 12)
Option 1	1 picture x 2 trays	1200	400	112,6769874	1,6	NOK
Option 2	1 picture x 1 trays	600	400	73,77719719	3,2	OK

The Table 11-2 shows that with commercial cameras (both visual, thermal, and fluorescent) it is possible to cover the requirement to take one picture per one tray.

The selection of camera for side view appears to be not a big problem. Rather, the main effort has to be spent on the realization of the camera positioning system. The following requirements have been considered for design.

1. The positioning system shall carry three cameras at the same time, a visual HD camera, a thermal camera, and a fluorescent camera
2. The system shall be mounted on the ceiling of the FEG to avoid rails, and or other obstacles for the human operators activities
3. The system shall not prevent the access to the emergency exit

4. The system shall provide the power (12/24 V) and data interface (Ethernet and/or USB) to the cameras, and the cabling management
5. The system shall be able to move the cameras in front of each tray/level of each compartment of the FEG and to fine tune the camera position with respect the target (shall provide the camera tilting and rotation capability.
6. The system shall be able to perform operations in autonomy as per predefined sequences, and/or to be manually commanded
7. The system shall automatically stop the operations and come back to the home position when a human operator is entering in the FEG
8. The home position of the system is at the end of the corridor (on the opposite site of the entrance door from the Service Section to the FEG)
9. The system shall prevent any movement remotely commanded when the operator is inside the FEG

Based on that, two options (Figure 11-3 and Figure 11-4) have been identified during the CE study as part of the preliminary design.

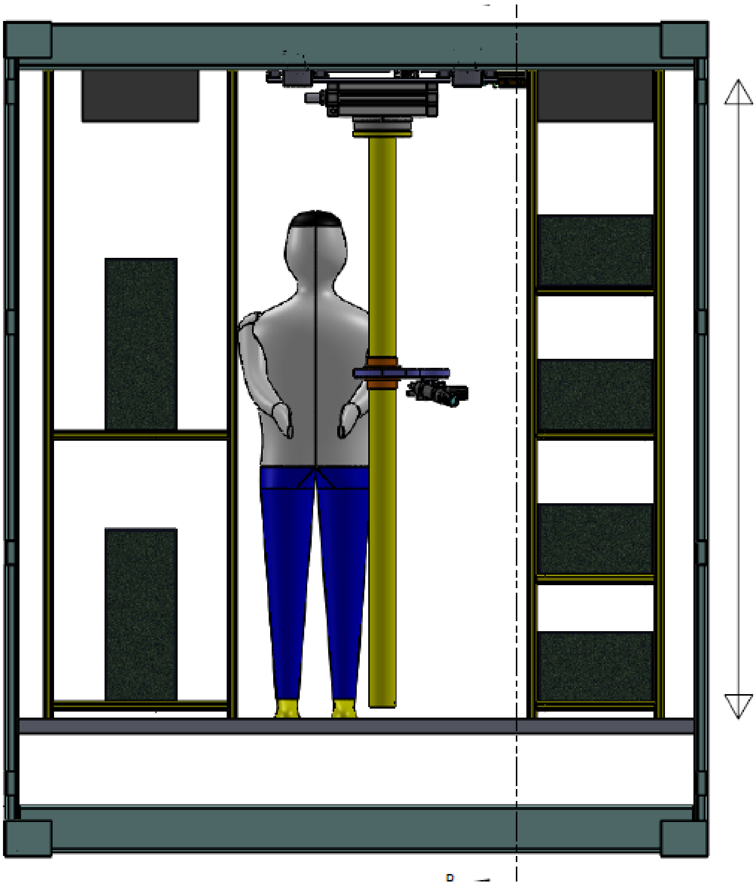


Figure 11-3: Pointing System Option 1 - Pole System.

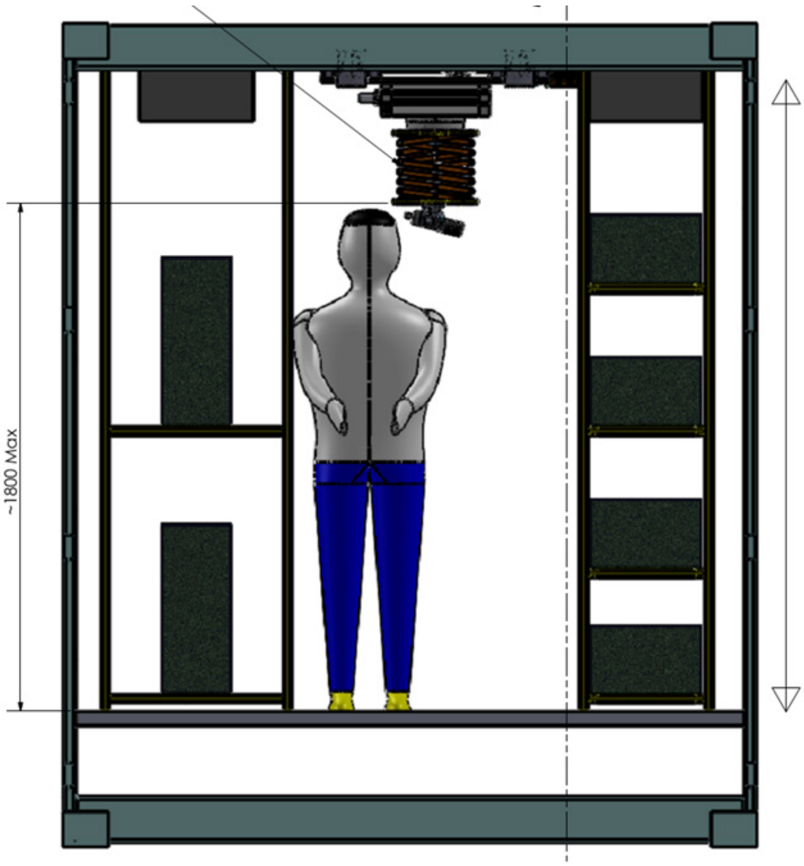


Figure 11-4: Pointing System Option 2 – Pantograph System.

The first option foresees a rail system attached on the FEG ceiling with a mobile platform that can move along the corridor carrying a pole. On such a pole, a second mobile platform is carrying the three cameras, can ascend/descend to reach the desired level, and can rotate 180 degrees to move the cameras towards the compartments on the right and on the left side of the FEG.

The second option foresees once again a rail system the FEG ceiling with a mobile platform that can move along the corridor. On this mobile platform is mounted a rotating plate (180 degrees) carrying a pantograph system were the cameras are attached. Similar to the first option, the pantograph can move the cameras vertically to reach the desired level.

From functional point of view, the two systems have the same capabilities, i.e. the capability to move the cameras along the corridor of the FEG, the capability to reach any compartment/level on both the right and left side of the FEG itself. Both of them can be equipped with SW for automatic operations, both of them can satisfy the most part of the listed requirements without any problem. But both are not satisfying all the requirements. In particular the pole system poses a safety issue, preventing a free access to the emergency exit, on the other hand the pantograph system could be not able to reach the upper level of the short plant compartment because its vertical dimension.

Some solutions have already been identified for the described problems and are under assessment:

- For Option 1 the possibility to have a quick disconnect for the pole, or the possibility to have a home position that is not in front of the emergency exit.
- For Option 2 the possibility to have a pantograph with longer levers to reduce the number of these last and therefore to reduce the vertical dimension for the closed system

The analysis is still ongoing and will be completed within the phase C study.

11.3 *Ground Segment*

As already explained, EDEN ISS has among others goals, the objective to introduce the distributed control in the greenhouse control field. That could appear similar to the remote control of a greenhouse, but on the other hand there are some differences that make EDEN ISS similar to a space program. For example:

- The distance between the remote user and the greenhouse and the distance between the remote users themselves is preventing the intervention on site of the experts
- The different monitoring and control requirements of the different remote users, leads to the need of different tools or displays (for example the plants experts need data that are different of those necessary for S/S monitoring and control)
- The bandwidth limitation. The EDEN ISS communication to/from Europe is done via satellite link that has physical/economical limitations. As learned during the CE study, a bandwidth of 100 kbps is available for EDEN ISS. This limit can be exceeded upon agreement with satellite service provider with an increase of costs.
- The need to define control processes with the clear identification of control hierarchy, responsibilities and tasks.

11.3.1 Operations Entities

EDEN ISS will be installed at the German Antarctica site Neumayer Station III and is designed to be operated by one single on site operator. Five locations will be configured as User Home Bases, i.e., will be provided with systems and tools to receive the EDEN ISS images and data for real time support.

The **On-site operator** will be mainly responsible of the nominal operations as for example sowing/harvesting, plants growth monitoring, sample preparation for off line analysis, S/S management, etc. In case of anomalies, it is expected that the on-site operator will manage them as according predefined procedures if any, otherwise he is only requested to take safing actions and rely on the remote experts indication on how to proceed.

It is worth to noting that the Service Section and Neumayer Station III will be equipped with workstations for MTF and FEG control. In particular, the Neumayer Station will be configured as the DLR control room to provide the on-site operator with the same capabilities of provided at the DLR control centre, i.e. the capability to interact with the FEG, with the ISPR and with all the related subsystems.

AWI as responsible of the NM-III station, will receive the EDEN ISS data as part of the NM-III data stream over satellite and will make them available to DLR over Internet. AWI is directly involved in the EDEN ISS MTF operations, but will provide any support for all NM-III matters, as concerned

DLR is the EDEN ISS Responsible Center and will accommodate the Mission Control Center, i.e. a control room equipped with:

1 x Workstation for the MTF monitoring and control

1 x Workstation for the ISPR monitoring and control

1 x Workstation for image processing

1 x Router and workstation for data distribution to the UHB and data archiving.

DLR is responsible for the all the EDEN ISS operations. For that reason it will coordinate the entire EDEN ISS team operations, will be responsible for planning activities and the primary responsible for all the commanding activities. Moreover, DLR will be the prime in communication with the on-site operator. It will coordinate all the remote operations as necessary, enabling/disabling the other remote site for commanding. DLR will also coordinate all the troubleshooting activities and recovery actions.

TAS-I is responsible for the ISPR operations and will be configured as UHB. It will be equipped with a console for the ISPR rack monitoring and with the dedicated displays for TM/TC management. In this role and upon coordination with DLR it will be responsible for all the remote operations of the ISPR, including the commanding of the facility. It is the prime in anomaly handling, troubleshooting activities and recovery actions.

University of Wageningen (DLO) is responsible for plant health monitoring. It is configured as UHB, with a workstation for scientific data visualization and image processing tool for plant status monitoring and early detection of plant disease. In case of anomaly detection, DLO will coordinate with DLR all the necessary actions to solve the issue, from the change in system settings (for example light intensity) to the definition of plants medical treatments. If new procedures for anomaly management are required, DLO will provide inputs for procedures development.

University of Guelph is responsible for the EDEN ISS control system (Argus). It is configured as UHB with the workstation and displays to manage the control system performances and to interact with it via commands if necessary.

TPZ is responsible for user segment monitoring and control. It will be equipped with all the consoles and displays as distributed to the other entities to be able to solve issue and/or to updated the SW applications, including displays as required. TPZ, as procedures development will participate to all the anomaly resolution team, to collect inputs and recommendations for anomaly procedures management.

All the other entities will provide off-line support as required.

Heliospectra for the lighting system

EnginSoft for the Thermal Control System

Aero Sekur for the Air Management System

CNR and Limerick Institute of Technology for food quality and safety analysis and related evaluation procedures

Airbus for the E-Nose and TransMADDS activities

Liquifer for Systems Engineering

All the UHBs will be connected to DLR for data reception. On the other hand, whenever required, all the commands will pass through DLR to reach EDEN ISS in Antarctica site. A graphical representation of the EDEN ISS User Segment is displayed in Figure 11-5.

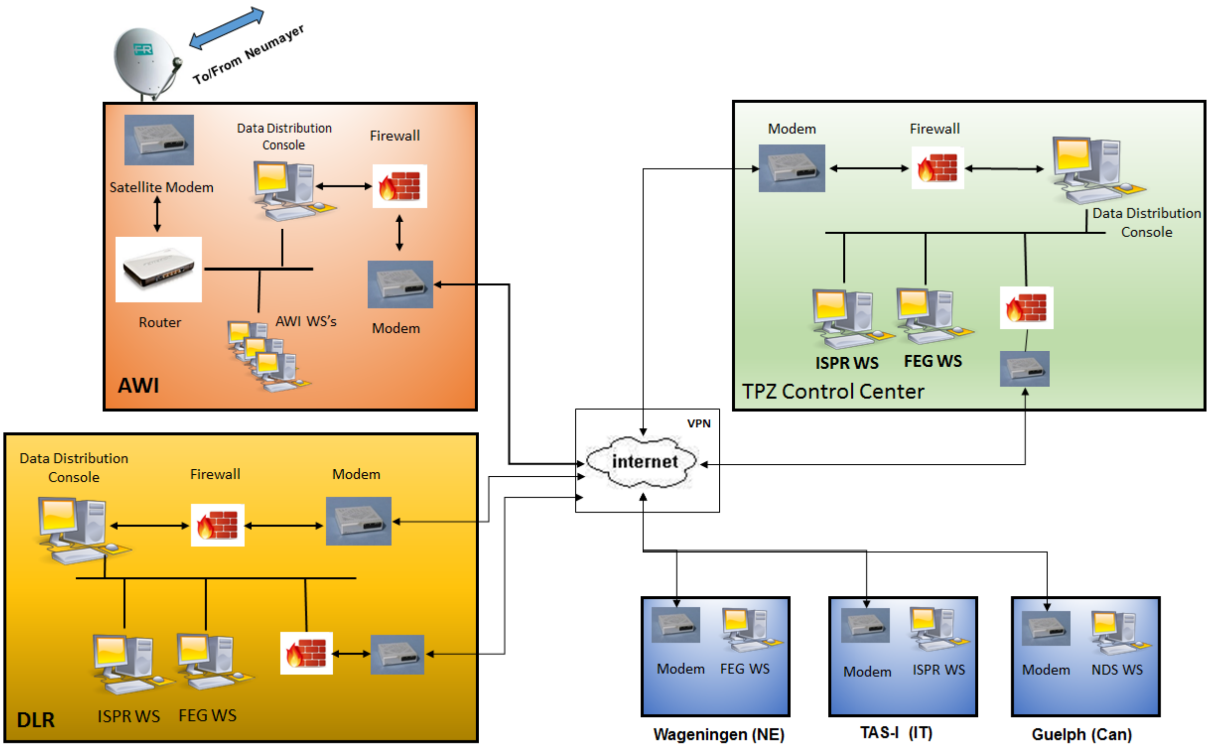


Figure 11-5: Layout of the EDEN ISS User Segment.

11.3.2 Data Traffic Analysis

As seen in the previous paragraph, several entities are supposed to receive data from the EDEN ISS MTF and to interact with it via commands. That approach of course is effective only if the allocated bandwidth is compatible with the amount of data generated during the MTF operations.

It is worth to remind that EDEN ISS has to cope with a NM-III satellite link bandwidth of 100 kbps. The following analysis will show that, considering all the sensors and the videocameras used in the MTF, remote control is possible provided that some limitations in image transmission are adopted. In particular, it is assumed that whatever the image generation rate will be, only one image per day and per tray will be transferred to Europe. Moreover, the transmission will occur overnight. In this way the remote experts (in principle DLO experts) can process the images and provide feedback during office hours.

The following items have been considered for the analysis as learned/agreed during the CE study:

- In total ca. 220 sensors will be installed in the MTF (including for exterior monitoring) as per last findings of the CE study. These include (approximate numbers provided):
    - Argus system (119)
    - ISPR (52)
    - Safety system (9)
    - Cameras (94)
- In total ca. 94 actuators will be installed in the MTF. These include (approximate numbers provided):
    - Argus system (77)
    - ISPR (19)
- Plant health monitoring conducted by 31 fixed cameras (note: although the final conclusion of the CE study was actually a total of 20 fixed cameras within the FEG this is presently being reassessed and the pros and cons of 20 or 31 cameras are being considered) for top view and 3 cameras for side view installed on the mobile platform, 4 general interior MTF observation cameras and 2 observation cameras installed outside the MTF as agreed during the CE study
- E-Nose data considered
- Cameras in the ISPR rack for plant health monitoring
- 1 audioconferencing system
- 1 videoconferencing system

The worst case has been considered (all the data transferred during a single day). The following tables provide an indication on what generated during the EDEN ISS operations:

Table 11-3: EDEN ISS Data Generation.

System	Controller	Items/Sensors #	Frequency	Data (MB/day)
FEG NDS	Argus	34	1Hz	5,87
FEG ILS	Argus	25	1Hz	4,32
FEG TC	Argus	28	1Hz	4,83
FEG PCDU	Argus	3	1Hz	0,52
FEG AMS	Argus	20	1Hz	3,45
AMS SERVICE SECTION	Argus	6	1Hz	1,03
AMS AIRLOCK	Argus	2	1Hz	0,34
EXTERIOR	Argus	5	1Hz	0,86
Safety Sensors	Dedicated HW/SW	9	1Hz	1,55
E-Nose Sensor	Dedicated HW/SW	1		30 (but 1 day/month)
FEG PMS – Fixed Camera	Dedicated HW/SW	40 Visual Camera	1image (2MB)/camera/day	640
FEG PMS – Cameras on Mobile Platform	Dedicated HW/SW	1 Visual Camera 1 Infrared Camera 1 Fluorescent* Camera	1 image (2MB)/camera/tray/day * Only 5 images per day	640/camera 10
MTF Observation Camera	Dedicated HW/SW	6 Visual Camera	3images(2MB)/camera/hour (during the day) 1 image(2MB) /camera/hour (during the night)	864 (day) 288 (night)
ISPR (Sensors)	National Rio+Labview	52	1Hz	8,6
ISPR (Camera)	National Rio+Labview	2 Visual Camera/camera	5 images (2MB)/camera/day	40
Audio conference	Dedicated HW/SW	N/A	2hours/day@64Kbps	0,4
Video Conference	Dedicated HW/SW	1 dedicated Camera	2hours/day@192kbps	1,38

Table 11-4: Data Transfer over 24 hours: Worst Case.

Sensors/cameras	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Top images (40 images x 2MB)	17,778	17,78	17,78	17,78	17,78	17,78	17,78	17,78															17,778	17,778
Side Images (40 images x 2MB)	17,778	17,78	17,78	17,78	17,78	17,78	17,78	17,78															17,778	17,778
Fluorescent (5 images x 2MB as example)		4,444	4,444	4,444	4,444	4,444																		
IR camera (40 images x 2MB)	17,78	17,78	17,78	17,78	17,78	17,78	17,78	17,78															17,778	17,778
ISPR (5 images x 2MBx 2 view x 2 chambers)	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70	3,70
ISPR	0,83	0,83	0,83	0,83	0,83	0,83	0,83	0,83	0,83	0,83	0,83	0,83	0,83	0,83	0,83	0,83	0,83	0,83	0,83	0,83	0,83	0,83	0,83	0,83
FEG NDS	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54	0,54
FEG ILS	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40
FEG TC	0,45	0,45	0,45	0,45	0,45	0,45	0,45	0,45	0,45	0,45	0,45	0,45	0,45	0,45	0,45	0,45	0,45	0,45	0,45	0,45	0,45	0,45	0,45	0,45
FEG PCDU	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
FEG AMS	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32
Service Section AMS	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10
Airlock AMS	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
MTF Exterior	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08	0,08
Safety Sensors	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14	0,14
External day (2 camera x 2 MB x 3 images/hour)									26,67	26,67	26,67	26,67	26,67	26,67		26,67	26,67	26,67	26,67	26,67				
Internal day (4 camera x 2 MB x 3 images/hour)									53,33		53,33	53,33	53,33	53,33		53,33	53,33	53,33		53,33				
External night (2 camera x 2 MB x1 images/hour)	8,889	8,89	8,89	8,89	8,89	8,89	8,89	8,89													8,89	8,89	8,89	8,89
Internal night (4 camera x 2 MB x 1 images/hours)	17,78	17,78	17,78	17,78	17,78	17,78	17,78	17,78													17,78	17,78	17,78	17,78
FEG Camera for audio conf. (1MB each 5 sec.)										200,00									200,00					
Audio Teleconference 64 Kbps										64,00					64,00				64,00					
Video Teleconference 192 Kbps															192,00									
E-NOSE (30MB x 1 day/month)	2,78	2,78	2,78	2,78	2,78	2,78	2,78	2,78	2,78	2,78	2,78	2,78	2,78	2,78	2,78	2,78	2,78	2,78	2,78	2,78	2,78	2,78	2,78	2,78
	89,43	93,87	93,87	93,87	93,87	93,87	89,43	89,43	89,43	300,09	89,43	89,43	89,43	89,43	265,43	89,43	89,43	89,43	300,09	89,43	36,10	36,10	89,43	89,43

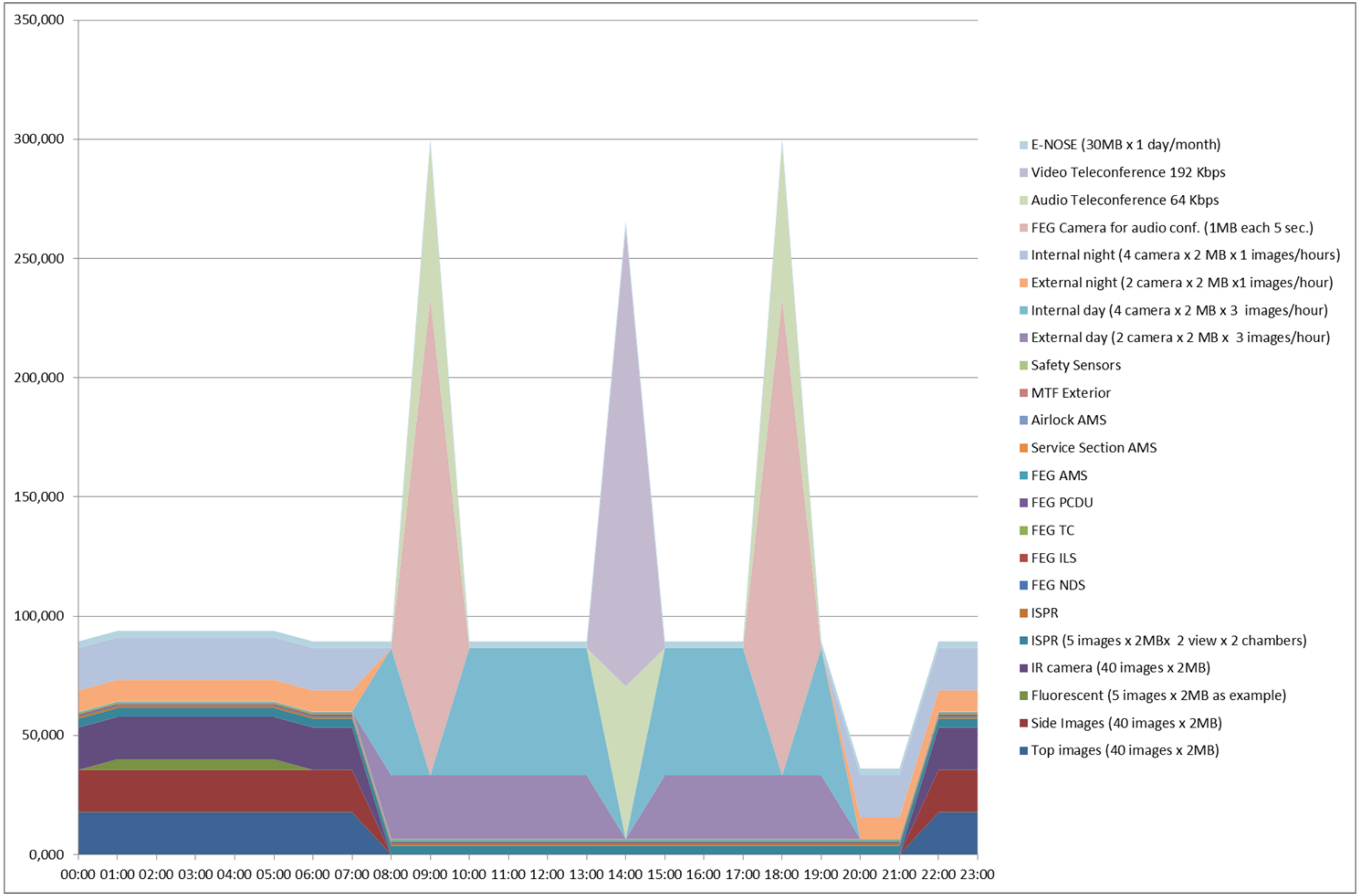


Figure 11-6: Telemetric Data Volume – Worst Case.

Table 11-5: List of cameras under analysis.

Objective	Manufacturer	Model	Sensor	Focal Lenght (mm)	Dimensions mm (LxWxH)	Mass (Kg)	Power	Maximum Power (W)	Operating Conditions	Videocompression	Resolution	frame rate (fps)	Price (euro)
Interior monitoring	ZAVIO	ZAVIO B6210 2MP	1/2.8" CMOS	3.6 mm, F1.8	89x165x66	0,5	POE or 12VDC, 1A	4 (???)	-10 to 50 degC IP66	MJPEG H-264	5 from 1920x1080 to 320x240	up to 25	180
Exterior monitoring	ZAVIO	ZAVIO B8210 2MP	Sony Exmor CMOS sensor	Motorized 3.0-9.0 mm, F1.3 P-iris, Smart focus	243x152x383	2,17	POE or 12VDC, 1,5A	13	-40 to 60 degC IP66	MJPEG H-264	2 from 1920x1080 to 320x240	up to 30	600
Top view	Arecont Vision	MicroDome AV1455 DN-F	1/2,7" CMOS	4	ϕ100x78,5	0,6	POE	5,6	-40 to 50 degC IP66	MJPEG H-264	1280x1024 or 640x512	up to 42	500 (TBC)
Top view	DSE Italia	DSE RKDCC5	1/2.8" CMOS	2,8 to 12	ϕ 131x93	0,8	POE or 12VDC	5	-10 to 50degC IP67	H-264	1920x1080	25	195,5
Top view	AVIGILON	2.0-H3-DO1 HD H264 Outdoor Dome	1/3" CMOS	3 to 9	152,3 x 109	1,28	POE or 12/24VDC	9	-30 to +50 degC RH 0 - 95% not condensing	MJPEG H264	2Megapixel (1080)	30	480
Top view	HIKVISION	DS-2CD2522F I 2MP	1/3" CMOS	2,8 - 6	99,3 x 96,7 x 52,8	0,6	POE or 12VDC	5	-30 to +50 degC RH 0 - 95% not condensing	MJPEG H264	2Megapixel (1080)	up to 30	200
Rob. Arm Visual Camera	GOPRO	TBD			59x30x41	0,15	Battery USB powered 5V, 0.5A	2,5		H.264 MPEG-4	5 from 1920 x 1080 to 848 x 480	up to 60	approx. 300
Rob. Arm Thermocamera	Microepsilon	ThermoImager TIM 200/230		72° / f = 3.3mm (min. distance 20mm); 48° / f = 5.7mm (min. distance 20mm); 23° / f = 10mm (min. distance 20mm); 6° / f = 35.5mm (min. distance 500mm)	45x65x45	0,32	USB powered 5V, 0.5A	2,5	0 to 50 degC IP 67 Storage Temperature: -40 to 70	N/A	160x120 (IR) 640x480 (visual) Temperature Range: -20 to 100degC Spectral Range: 7 to 13 µm Accuracy: ±2	128 32	6000 - 10000
Rob. Arm Fluoresc. camera	GOPRO+filter	TBD			59x30x41	0,15	Battery USB powered 5V, 0.5A	2,5		H.264 MPEG-4	5 from 1920 x 1080 to 848 x 480	up to 60	approx 300

The analysis clearly shows that the data/images transmission never exceeds the 100 kbps assumed available for EDEN ISS. Video/audioconferencing requires more bandwidth and thus negotiation with the Neumayer Station III operators.

11.4 *Options and Trades*

As described, two options for the robotic arms are under analysis. The final selection will be done during the phase C study.

During the CE study different options for top view images acquisition were discussed.

1. One camera for each tray (for a total of 40 cameras)
2. One camera for each level (for a total of 20 cameras)

The analysis has demonstrated that a good compromise is the one to have a mix of the two options with one camera for those trays where the short plants are accommodated, and one camera for those levels were the tall plants are accommodated.

Also in this case, the final selection will be done during the phase C study.

11.5 *List of Equipment*

The Table 11-5 shows the list of cameras under analysis with the main features. It is not excluded that during the phase C study different cameras will be selected as outcome of a deeper analysis and or test. One of the driving factors should be the selection of one single supplier to facilitate the videocamera system design, the camera management, and the problem analysis and resolution. That applies to all the visual cameras (for both the scientific images acquisition and the interior/exterior monitoring). For example HIKVISION cameras could replace the Zavio Cameras and the GoPro cameras.

As far as the robotic arm, as described, two options are under analysis. For the moment during the CE study it has been decided to not go through all the components of such a system, but to consider it as a single entity with the following main characteristics:

Mass: < 200Kg (for both configurations)

Power: < 1,5 KW (for both configurations)

Cost: 50000€ (pole) or 60000€ (pantograph) +/-10000€

Something not considered during the CE analysis is the UHB configuration. It is expected that:

DLR is equipped with:

- 1 workstation for MTF control
- 1 workstation for ISPR rack control
- 1 workstation for image acquisition and management
- 1 workstation for robotic arm management

Plus the system for data routing and safe access to the Internet for data distribution (modem, router, switch, firewall).

TAS-I is equipped with:

- 1 workstation for ISPR rack control

Plus the system for safe access to the Internet.

DLO is equipped with:

- 1 workstation for FEG scientific telemetry monitoring
- 1 workstation for plants images acquisition and processing

University of Guelph is equipped with:

- 1 workstation for control system monitoring

TPZ is equipped with:

- 1 workstation for MTF control
- 1 workstation for ISPR rack control
- 1 workstation for images acquisition and management
- 1 workstation for robotic arm management
- 1 workstation for ground systems control

11.6 *Requirements Adjustments*

Based on the CE study outcome, the next version of the System Requirements Document shall consider the new requirements related to the top view images acquisition, i.e. the need of fixed camera inside each plant growth compartment.

12 Plant Health Monitoring and Horticulture

12.1 *Introduction*

In the CE study several subjects regarding plant health monitoring were discussed. In the following sub-sections the challenges in cultivating the various crops/cultivars within FEG and ISPR will be named and briefly discussed. The numbers given in the sub-sections for various parameters are based on estimations from literature or own calculations. They are intended to be used as provisional guidelines, but actual numbers for some of the parameters will be derived from the plant experiments in WP4.2.

12.2 *Spacing/optimal plant density*

To maximize production it's important to make optimal use the limited space in the FEG and ISPR. Therefore spacing is one of the main factors to optimize (Amundson, et al., 2012), and the main challenge here is to optimize spacing during the different plant developmental stages. Seeding in their final position means a huge drawback in the potential crop yield in time. The two main factors to be considered are light use efficiency and plant-plant effects in relation to the physical space between plants. In general, the slower crop growth (e.g. sweet pepper) the higher the eventual drawback in total yield will be. Calculation of potential yield loss according this non spacing should not be considered as it would be substantial. In order to optimize light use efficiency, small germinating plantlets should be placed as closely as possible to each other to minimize the amount of light lost to the ground surface. As they grow, they should be spaced to maintain the light use efficiency and minimize undesired plant-plant effects, e.g. changes in plant form or direction. Whenever plants, especially leafy plants, touch each other they will elongate and grow more vertically. But, spacing requires moving the plants in their tray, and this may present a major challenge depending on the cultivation method.

The cultivation method will impact the possibility to space. In an aeroponic cultivation system this may result in the breaking of often rapidly growing root systems. Rapid root growth may also lead to the blocking of drain pipes or interfere with nozzles. It may also result in a heterogeneous distribution of water and nutrients in the rooting environment, salt accumulation in poorly distributed water areas or alter the assimilate partitioning and lower the harvest index. There is no known literature addressing these issues, but it is a subject commonly discussed by growers. In crops with a short crop cycle these challenges are probably manageable. However, it is unknown what the effect will be on longer crop cycles of more than several months. The main issue with a hydroponic cultivation system is the substrate and its removal after harvest (e.g. Rockwool substrate). Calculations show that a substrate volume of 880 L year round can be used in the FEG (see Appendix I).

12.2.1 Tray layout

As the plants will be grown in tray boxes with defined dimensions of 0.4 x 0.6 m and are covered to prevent algae growth, seven different tray covers have been designed. In Appendix IV the layout design is shown.

12.3 *Conditions to be considered during cultivation in the FEG*

12.3.1 Temperature

Crops have an optimal temperature at which they grow best, what even can differ on the variety level. In both the ISPR and FEG, a choice will have to be made for a general temperature regime as all plants will grow in the same space. This means that a 'happy medium' will have to be chosen and this will mean that some plants may grow slower than under optimal conditions. The temperature will likely be 20-22°C during day time and 16-18^{o}C during night-time, a constant mean temperature for all species. Day time is defined as the period when lights are switched on. The plant species requiring a different temperature are mainly strawberry, lettuce and radish, all requiring 2-3°C lower daily mean temperatures. The FEG will also require some cooling for an optimal temperature for the lighting.

Although the lamps will be water cooled, about half of the electrical power input still needs to be cooled by the air. Depending on the air velocity allowed for “optimal” crop growth in the FEG and the control temperature of the FEG (20-22°C during daytime), the inlet and outlet temperature will be defined. In order to realize this, it’s important to decrease the temperature difference between inlet and outlet air as much as possible. In case the inlet air temperature is more than 4-5°C below the control temperature and this airflow of “cold” air is directed towards the plants, it will likely inhibit crop growth. An equal temperature distribution over the plant tray is thus important. While plant trays are only 0.6 m wide, temperature difference over the tray should be less than one degree.

12.3.2 Relative humidity and condensation

A relative humidity (RH) of 70±5% is a commonly used set point for most crops. This can be realized given adequate insulation of the outer walls of the FEG in the cold climate of Antarctica. However, insufficient insulation in relation to the FEG air volume may result in too of a low dew point temperature of the FEG (side-walls) resulting in excessive condensation on the walls and an undesired (low) relative air humidity. This can be detrimental to crop development and growth, especially when humidity levels drop below 50-55%. Whenever plants experience this type of “drought” stress they close their stomata which affects the uptake of CO_2. On the other hand, a high relative humidity (>90 %) can be a starting point for fungal diseases of which botrytis is the most common. Botrytis spora require only a few hours of humidity at 96% to germinate. An equal temperature distribution and a humidity level of less than 90% should avoid spots in the FEG where Botrytis spora can germinate. There is nevertheless one possible uncertainty. Plants placed directly beside the side-wall will have a high view factor towards the side-wall. In case the surface temperature of the FEG side-wall is low, radiative heat losses between plant and side-wall can increase, meaning the plant tissue surface temperature can come nearby the dew point. Plants with an open structure can warm up more easily in the FEG air than plants with a more dense structure, e.g. iceberg lettuce. At the same time, as long as the side-wall temperature remains below the plant temperature, condensation will take place on the side-wall first.

12.3.3 Light intensities

A maximum light intensity of 600 µmol/m^2/s can be realized in both the FEG and ISPR with the available LED technology. However, the amount of electricity available in the FEG will only allow for half of that on average, given a full utilization of the plant area. Thus, in order to maximize the light use efficiency, ways must be found to either use different intensities for different crops, or use different intensities at different plant growth stages, or to use the lighting at different times of the day. Especially after germination, young plants prefer light intensities of less than 300 µmol/m^2/s (150 µmol/m^2/s will be sufficient). With a day length of 16 hours, the daily photon flux will be more than 15 mol/m^2 which is much too high for these small plantlets. For temperature control (for the plants) and for the system in general, the most practical photoperiod will be max 16 hours per day. While there is no natural light in the FEG one is free to choose when during the day the dark period for the plants will be.

12.3.4 VOC’s and air quality

Especially during stress conditions, plants may emit VOC’s (volatile organic compounds), components with a detrimental effect on plant growth and production, e.g. stimulation of flower/fruit abortion by “stress ethylene”. New plastics are often known to emit VOC’s like softeners and butyl-phythalates. Greenhouse horticulture has had many bad experiences with new or re-painted heating tubes in the past. Therefore, prior to the test phase, the whole facility (FEG) should be heated for several weeks to force the emission of potential VOC’s before plants are placed in it. Excessive concentrations (>1500 ppm) of CO_2 in the air may also be detrimental during germination in general, and for cucumber plants in particular. CO_2 control level at 600-700 ppm is recommended.

The effect of VOC’s on crop health depends on: sensitivity of the crop, and the exposure duration and concentration. Lettuce is a less sensitive crop, but peppers and radish are known as the more sensitive crops to be grown in the FEG. In general, during flowering crops like tomato, pepper, and cucumber become more sensitive as well. Long term ethylene concentrations for bell pepper of 11 ppb are considered to result in an increased 'risk threshold', visible effects occur at 15 - 20 ppb and flower and fruit abortion at 40 ppb. High concentrations for a limited time, half an hour at 100 ppb, is not a problem. NOx is not to be expected in the FEG as no gas combustion is involved. Some other VOC thresholds indicated in the literature are SO_2 (11 ppb), HF (4 ppb) and aldehydes (16 ppb).

Due to the high costs of sensitive analysers, only few and probably none are expected to be installed in the FEG. That means that the plants will have to suffice as VOC "monitors". In the case of phytotoxic concentrations, the plants will show visible damage and in the worst case, will die. However, there remains a 'grey area' in which the plants may experience increased VOC concentrations resulting in growth inhibition. This will often not be noticed and can then lead to the production of less fresh food for the crew.

12.4 *Crop maintenance and hygiene protocol*

During entry into and working in the FEG, care must be taken to avoid bringing diseases/pathogens, i.e. bacteria, viruses, into the plant compartment. Crew members that work in the plant compartment should disinfect their hands and wear plastic gloves and plastic overshoes or use shoes only to be worn inside the FEG (this will reduce waste of plastic overshoes). This will prevent disease transmission to a large degree. In Appendix II, an example of a hygiene protocol is shown. This protocol is based on the idea that for working and visiting in your own facilities the measures for hygiene are "low" but as soon as you have 'external' visitors, the measures are high.

12.5 *Waste handling*

In the designing of the FEG and ISPR, care must be taken to avoid excessive disposal. During cultivation of plants, this applies most heavily to aspects like crop maintenance, plant substrate used, drain water and nutrient recycling.
The crops selected to grow in the FEG require various amounts of plant maintenance. Crops like cucumbers and tomato however, once well growing, will require a round of leaf picking every 4 and 14 days respectively, in which 2-3 leaves per stem per treatment have to be removed and disposed of. All other plant treatments (pruning, side shoot removal) will cause small amounts of waste.
After harvest, cucumber, tomato and pepper plants as a whole, become waste. The total waste flow of these plants will be around 50% of the total fresh weight growth (is not equal to yield) and will be around 100 kg/year for the FEG. If the plant waste can be dried within a reasonable time, the risk of secondary pathogens, i.e. fungi will also decrease while keeping the dry mass waste to a minimum.
An irrigation system will be a closed loop system is foreseen, to maximize the use of resources (nutrients). Water and nutrient discharge from the system will occur only in case of cleaning the irrigation system (not of the trays) or in case the nutrient solution is inadequate (not considered). The expected nutrient waste flow from the irrigation system is less than 200 L per year.
Cleaning the trays will cause more waste flow. Figure 14-2 in Appendix I shows ca. 250 tray- batches will be used during one year and must be cleaned after each harvest. The estimated water use for cleaning per tray 4 L, which means 1000 L of cleaning water per year will be discharged.
In section 12.2 a volume of 900 liters substrate has been calculated for use per year in the FEG. This volume will become waste if the substrate cannot be re-used or decomposed. The total amount of this mass has not been calculated due to the large number of unknown parameters, e.g. specific weight of the substrate, water content and root mass in the substrate, but is not expected to exceed 1000 kg per year. Changes in substrate volume (see Appendix I Table 12-4), will have an effect here as well.
Depending on the choices made for the hygiene protocol to be used (section 12.4), the hygienic measures will cause a waste flow of ca. 15-25 kg per year, mainly plastic gloves, overshoes etc. Clothes (coats) of a decent quality should be re-used e.g. for a week before being disposed of.

12.6 *Sensor location in the FEG*

Three parameters related to climate control will be measured in the FEG: temperature, humidity and CO_2 concentration. Because there will be some "high" radiation levels from the lamps, the temperature and humidity sensors need to be ventilated for reliable measurements. Although the Atmosphere Management System is equipped with temperature and humidity sensors for control in the FEG, it's recommended to add some extra sensors. In Appendix III the location of these extra sensors is shown. While all climate control suppliers sell these sensors in a ventilated climate box, this equipment should come from the supplier of other monitoring systems (recommended), like the irrigation controller of Argus. An accurate CO_2 measurement (accuracy <10 ppm) requires an expensive monitor, which is not foreseen. The standard CO_2 sensor used in agriculture has an accuracy of ca. 45 ppm. For the control of the CO_2 concentration in the AMS, a CO_2 sensor will also be installed. Cost benefit wise it's not worthwhile to invest in one good monitor and multiplexer system for a very accurate CO_2 measurement. Although the FEG is a relatively small room, it's recommended to install more than one CO_2 sensor, one at least, on both sides of the FEG. Control of the AMS will need one of these sensors in the FEG. With a number of smart climate controllers, the average, minimum or maximum value of several sensors can be used for the control. In the sensor layout shown in in Appendix III, two levels of quantity of sensors mentioned. A is the absolute minimum number and B is a preferable number.

12.7 *Growth analysis*

Growth analysis is an important factor not only to measure the yield, but also as a factor to steer crop growth. If for example, it's known that the fruit load of the plant is very high, pruning measures can be taken to control the plant load to maintain yield and crop quality. The best factor to measure the efficiency of the system is dry weight (DW [g]) production in time, where genotype can cause differences. Together with the input of light (light sum [mol]) the LUE can be calculated mol / grams DW. The Neumayer Station III will not be provided with a professional stove to dry plant material (note: a small drying oven may be taken by the project team to NM-III for the duration of EDEN ISS – TBD). An alternative to dry the freshly harvested plant material and place it in a warm alloy bin (40-50°C), but wind free for several days and weight the mass. The dried samples can be saved in a dry location and analysed later. For reliable results, 5-10 measurements are need so this can cost a lot of your harvest. Another alternative is to use the average fresh weight: dry weight ratio's measured during experiments at DLO in Wageningen in WP4.2. Once these ratios for each crop have been determined, fresh weight measurements and calculations at the FEG will suffice. In each case, all fresh weight of the harvested material should be determined. This will give the relative growth values. The measures for the leafy crops will be limited. For flowering crops however, especially peppers and cucumbers, additional measurements will be helpful to analyse crop growth. Of the most important are measurement/registration of the number of fruits, time of flowering and flower or fruit abortion. In the test phase "bench mark" figures can be determined to help with the cultivation of a healthy and high yield crop.

12.8 *Fresh weight harvest*

Crop productivity is greatly affected by the efficiency of using the absorbed radiation for photosynthesis, or the light use efficiency (LUE). In general, the light intercepted is not used with the same efficiency by different crops, thus crops have different LUE's. The crops grown in the FEG (all C3 crops) however, will have a similar LUE. For a full grown good functioning crop, the LUE will be around 1 to 1.25 gram dry weight (DW) per mol intercepted PAR light.

Canopy structure, and particularly the spatial distribution of (angles of) leaves, has an important bearing on canopy light climate and energy conversion. An even distribution of PAR at leaf surfaces is advantageous for canopy photosynthesis and improves the LUE over canopies where upper (horizontal) leaves intercept most radiation and lower leaves experience greatly attenuated levels. Light absorption, the percentage of the offered light that is finally absorbed by the crop, will never be 100%. Leaves reflect ca. 5% of the PAR light and leaf structure, distribution and density are not able to intercept all light. Spacing of the plants is also an important factor for light interception. The light absorption will vary during the different stages of crop growth and is estimated to be on average around 60%. Not all dry matter will be edible. This fraction is called the Harvest Index (HI), and varies between the species from 0.95 (lettuce) to 0.45 (strawberry). In Appendix VI the crop production for the different species has been estimated. The estimated Fresh Weight (FW) production per tray per day varies between 8 g (strawberry) and 76 g (cucumber) per tray per day, meaning the choice of different species has an enormous effect on the edible crop production of the FEG. Combining the results as shown in Appendix VI and the tray use as shown in Figure 14-2 (Appendix I) results in an estimation of the overall fresh weight production of the FEG. An initial calculation suggests that the potential crop production of the FEG varies between 0 g (first three weeks after start up) and 750 g of fresh weight per day, with a total of ca. 170 kg fresh food per year.

12.9 *CO_2 use in the FEG*

The CO_2 level inside the FEG is influenced by the following sources and sinks:

1. Crop uptake (during light period) ==> Sink
2. Crop dark respiration (during night time) ==> Source
3. Breath of employees ==> Source
4. Leakage from the FEG towards the environment ==> Depending on CO_2 concentration difference this will be Sink or Source

The total crop uptake during daytime depends on the total biomass amount in the FEG, the light intensity on the crop and the CO_2 concentration inside the FEG. As long the crop is not experiencing stress and the CO_2 concentration is around 700 ppm, the maximum daily uptake by the crop can be calculated. There are three different light levels in the FEG; 600, 300 and 150 µmol/m^2 s over three different areas; 4.9, 5.5 and 1.8 m^2 for the small, tall and germination area respectively. These areas are calculated by the number of trays (Figure 12-1, Appendix I) and a surface area per tray of 0.24 m^2 (Table 12-1). The estimated efficiency of the crop, the quantum yield is 4%. This is rather low because all crop phases are inside the FEG and the LUE will not be perfect. For the germination phase this is even very high because on a part of the area no leaves are present at all, which affects the total use. In case the FEG is completely filled, the lights are on and the crops are functioning properly, the CO_2 use can run up to 32 g/h for the FEG. Even though all crops will be grown together in the FEG, it can't be controlled optimally, see section 12.3.1. This will result in an inefficiency of at least 20%, bringing the CO_2 uptake by the crop to 25 g/h.

Table 12-1: Estimated CO_2 requirement by the crop for the three types of plant growth racks.

Plant growth rack type	Surface area [m^2]	Light intensity [µmol/m^2 /s]	Quantum yield [%]	CO_2 requirement [g/h]
Short	4.92	300	4	9.4
Tall	5.54	600	4	21
Germination	1.84	150	4	1.7

During the photoperiod, set at 16 hours per day, the maximum CO_2 uptake will be 400 g for the FEG per day. During night, due to the dark respiration, some CO_2 will be released by the crop into the FEG. This flow is assumed to be 5 g/h for the whole FEG and for an eight hour night this will result in 40 g. In addition to the dark respiration source, people who enter and work in the FEG will be a CO_2 source as well. In case only light work is being done, the CO_2 production is estimated at around 50 g/h/person. For maintenance of the crop, seeding, spacing and finally harvesting an estimated work load of ca. 1.5 hours per day inside the FEG, will result in a daily CO_2 supply of 75 g/day. Most of the labour such as cleaning, seeding, harvesting will mostly be done outside the FEG. The sink of CO_2 by leakage (controlled and uncontrolled) from the FEG towards the environment will depend on the leakage of the FEG and the concentration difference inside – outside the FEG. The background outside CO_2 concentration is around 400 ppm, or 770 mg/m^3. The inside CO_2 concentration will be controlled at 700 ppm (1350 mg/m^3). Per volume exchange of the FEG, 34.5m^3, 19.8 g of CO_2 will be lost. With a daily leakage of the FEG of 500% the CO_2 loss by leakage is around 100 g. Overall the CO_2 use of the FEG is 400 g uptake by the crop – 40 g dark respiration -75 g from employees +100 g leakage is 415 g per day.

In a perfectly closed environment the use of CO_2 is exactly the amount of what is fixated by the crop in dry matter. Because bottled CO_2 will be supplied, by weighing, the gas bottle once the FEG is in full operation the daily CO_2 need can be measured easily for several days, especially over days when no one will enter the FEG.

12.10 *ISPR interfaces to MTF – Crop loads*

In the ISPR, a comparable, but limited number of crops as in the FEG will be grown. This facility is even more limited in space than the FEG. For the control of this facility, one would like to have more detailed information about CO_2 and water use for this facility besides the preferable temperatures and CO_2 concentration. In Appendix V an overview of the projected plant parameters is presented. For the calculation of the crop transpiration, several issues have to be taken into account from which some will have a large impact on transpiration but of which the extent is largely unknown: wind velocity around the crop in the ISPR, light intensity on the crop and the Leaf Area Index (LAI) development over time. With model calculations, estimates have been made for the transpiration rate (de (Stanghellini, 1987; Zwart, 1996). The effect of wind velocity inside the canopy has not been taken into consideration in these calculations, while in greenhouses the wind speed is low, and is assumed to be 0.15 m/s.

12.11 *Nutrient solution and EC control*

Two irrigation systems will be installed in the FEG and each irrigation system will have its own nutrient solution. Although it's not the optimal solution, we expect it's possible to fertilize all crops with two nutrient solutions, also because the climate conditions are very stable and several crop stages will be fed by the same nutrient solution. Likely, one nutrient solution will be used for the vegetable crops tomato, pepper and cucumber, and one for the "leafy" crops.

In the experiments for WP 4.2 the water and nutrient use will be monitored. The EC, pH control and nutrient solution are assumed to be part of the NDS tasks.

12.12 *List of Equipment*

This list will overlap with several other domains. Many simple tools or equipment are mentioned for the Service Section and are needed for plant handling, personal/plant safety and simple measurements.

For the FEG, only some additional measuring boxes for T, RH and CO_2 are mentioned at 2 levels, a minimum and a preferable level, see Appendix III, sensor layout and section 12.6.

The following subjects are considered to belong in other tasks, meaning they are not taken into account in the equipment list:

- The control and default measurements for EC and pH are subject of the NDS. Some handheld devices for additional measurements (e.g. EC and pH) are considered in other subsystems/domains.
- The sensors and actuators for the plant health monitoring are part of the robot arm and thus belong to the Command and Data Handling System task.
- All data logging of, temperatures, humidity, CO_2 concentration, lights on/off. Irrigation control and so on are subject of the Command and Data Handling System.
- The control of temperature, humidity and CO_2-concentration in the FEG are subject of the Atmosphere Management System.

In Table 12-2 the main issues for the FEG are mentioned.

Table 12-2: Some equipment needed for plant health control in the FEG.

FUTURE EXPLORATION GREENHOUSE								
Subequipment 1 - FEG climate sensors								
combined temp . & RH sensor (ventilated box)	4	1	4		10 x 5 x 20	10	40	
combined temp . & RH sensor & CO2 (ventilated bo	2	1	2		10 x 5 x 20	10	20	
							0	

In Table 12-3 some of the most important additional equipment needed for plant health control and crop growth to be stored in the Service Section are mentioned.

Table 12-3: Some equipment needed for plant health control and crop growth in the Service Section.

Element/Component	Qty	Mass per element (kg)	Total mass (kg)	Mass comments	Dimensions per element (mm) (L x W x H)	Power per element	Total power - all on	Power comments
SERVICE SECTION								
Subequipment 1 - Name								
T & RH & CO2 (hand held)	1		0		17 x 6 x 4		0	battery, rechargable
PAR sensor (Hand Held), Sensors LI-190SA	1		0.28		14 x 8 x 4	2	2	battery, rechargable
balance (accuracy 1 gram)	1		0			2	2	
meter & caliber	1		0				0	
IR camera (hand held)	1		0				0	battery, rechargable
tweezer (seed handling)	1		0.1			1	1	
measuring cup 1 liter	3		0.2				0	
measuring cup 5 liter	1		0.5				0	
labels for crop growth control	1000		1				0	
CO2 calibration gas http://www.brinkman.nl/catalog	1		1				0	
CO2 absorber (zero point of the CO2 monitor) nece	1		0				0	
Hygiene protocol stuff (overalls, cloves, shoes)	??? Depending on level of hygine protocol, to be discussed							
sticky plates / traps	20							
plastic bags (DIFFERENT SIZES) for food/ sample storage / plant waste								
knife for harvest								
scissor for harvest								
rope for growth support (m)	100							
sticks for growth support	150							
clips for the cucumber http://www.bato.nl/clipper-1	300							
cleaning of the plant trays?								

12.13 *Plant Heath Monitoring Appendix*

12.13.1 Appendix I - Substrate volume use

The foreseen layout of the FEG is shown in Figure 12-1.

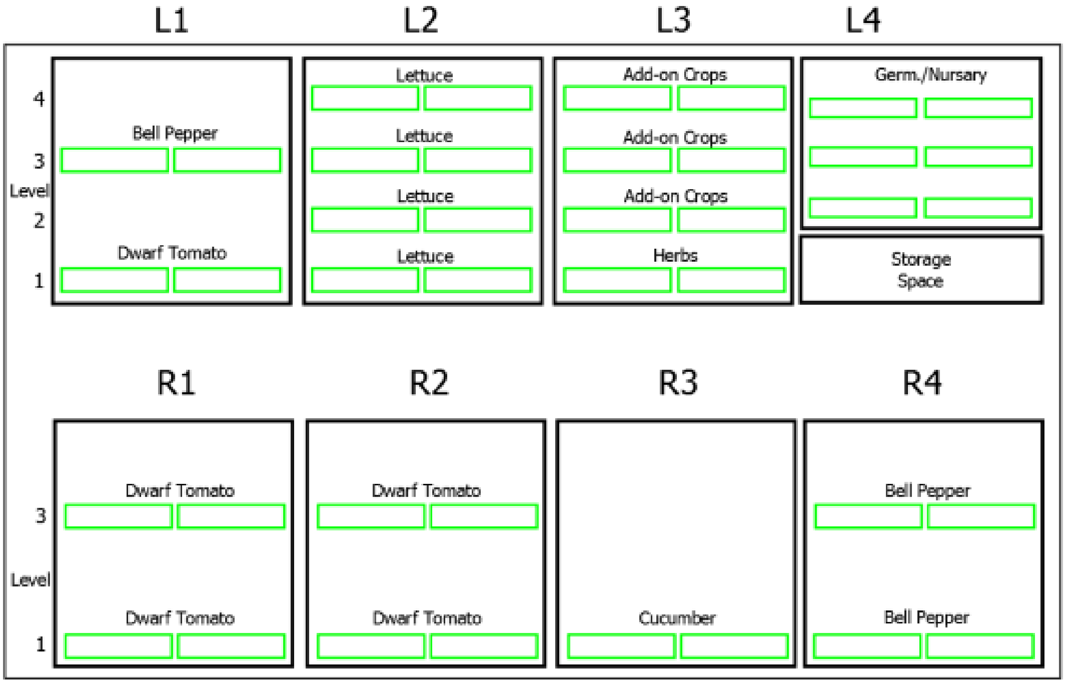


Figure 12-1: Layout of the shelves in the FEG.

Each crop has its own crop cycle length, plant density and minimal substrate volume. The crops to be cultivated in the trays are shown in Figure 14-2. Three levels of use from empty, mainly at the beginning of the year to startup the FEG, growing and harvesting period are coloured respectively purple, yellow and green. From this scheme, the number of crop cycles per tray has been calculated. In Table 12-4 an overview of the number of plants and volumes per plug is presented. For lettuce and dwarf tomato, the final plug use per tray has been chosen slightly higher than the final plant density per tray, while between germination and harvest a success rate of 100% will not be reached. For the plant density and plug volume see section 12.2 as well and the tray layout.

Table 12-4: Overview of the number of plants and substrate volumes per plug and tray.

Crop	Final plant density per tray [-]	Volume per plug L x W X H [L]	Final plug use per tray [-]	Volume per tray [L]
Lettuce	5-8	0.18	10	1.8
Dwarf tomato	2	0.72	3	2.16
Cucumber	2	0.72	2	1.44
Dwarf bell pepper	3	0.72	3	2.16
Red mustard	250	1	7	7
Radish	100	1	7	7
Spinach	250	1	7	7
Swiss chard	250	1	7	7

Based on this table, the calculated the annual substrate volume will be 880 L.

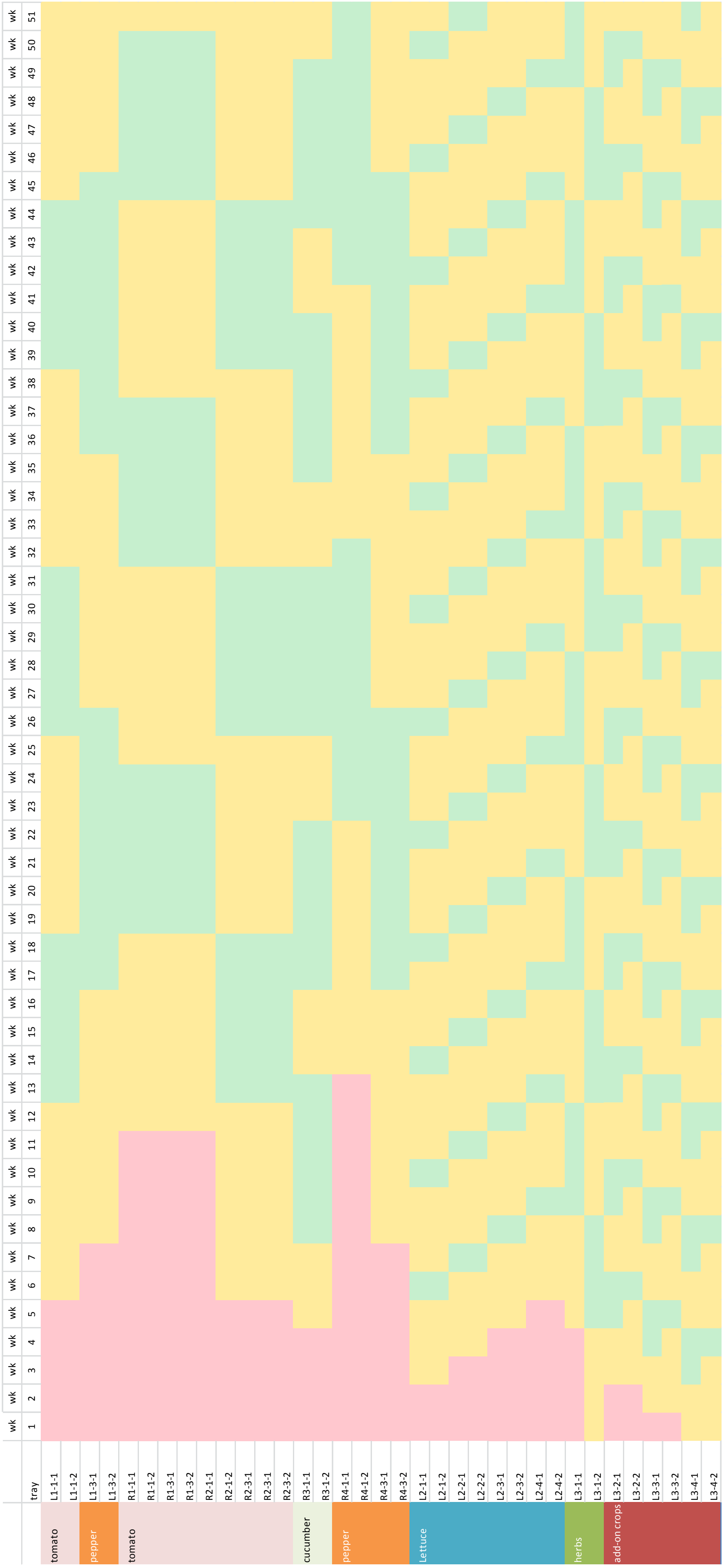


Figure 14-2: Status per tray for each week of the use of the FEG for three levels, empty, growing and harvesting week colored respectively purple, yellow and green.

12.13.2 Appendix II - Hygiene protocol

The following points must be taken into account for the purposes of general hygiene and to prevent and/or reduce the spread of disease and pests. These rules apply to all entering the MTF where plant material from both ISPR and FEG will be handled. The MTF is composed of:

1. a **Cold Porch**, the entrance to the MTF serving to keep the Service Section and FEG protected from the external environmental conditions. Upon entering, crew will store their gear in a storage cabinet and don protective gear (e.g. lab coats and overshoes) to minimize contamination of the MTF.
2. a **Service Section**, which houses the majority of the subsystem components, the ISPR plant cultivation system, and provides working space for the crew.
3. The **FEG**, which houses growth racks where plants will be cultivated.

General rules for anyone entering the MTF:

1. A protocol for each section should be posted on/next to the door of the Service Section and FEG.
2. Smoking is not permitted.
3. Animals are not allowed.
4. Food is not permitted *(specific exceptions under discussion)*
5. It is obligatory to wash your hands with soap after using the toilet.
6. It is obligatory to wear clean (work) clothing in the MTF.
7. Any wounds must be covered with a waterproof plaster.
8. Any rubbish must always be placed in the appropriate bins and must be separated into:
    a. cardboard/paper;
    b. organic waste;
    c. other refuse;
9. Any damage noticed or caused must be reported.
10. Everyone should be aware of his/her responsibility to keep the facility clean and tidy.

Upon entering the **cold porch**:

- Outdoor clothing and boots should be exchanged for lab coats and shoes dedicated only for use in the MTF.

When moving from the cold porch into the **Service Section:**

- Hands should be disinfected with a detergent prior to entering or leaving the Service Section.
- Shoes should be periodically cleaned with a sterilizing agent.
- For work in the Service Section other than with plant material (technical, computer), plastic gloves are not required.
- Only sterilized seeds and sterile nutrient (solutions) should be used.
- Old/dead plant material should be dried and sealed for removal from the MTF.

ISPR

- The ISPR should be cleaned externally periodically with a sterilizing agent, and internally following each growth cycle.
- HW from storage and/or the cold porch should be properly cleaned prior to installation in the ISPR.
- When handling plant material in the ISPR plastics gloves should be worn. When handling plant material from ISPR to be returned to it, the table surface and handling equipment should be cleaned (with a detergent to destroy any virus).

Cleaning schedule

- Floor – should be cleaned regularly (*weekly - TBC*) with a sterilizing agent.
- Table surface – should be wiped clean with a sterilizing agent after use (end of the day).

- Equipment e.g. weigh scale, pruning shears – should be cleaned with a sterilizing agent after use (end of the day).

When entering the **FEG:**

- Plastic gloves and plastic overshoes will always be donned when entering/working in the FEG, as well as a lab overall. When leaving the FEG back into the Service Section, these articles will be removed and can be reused for another visit (*a trade-off between overalls requiring regular cleaning/washing versus disposable overalls will be conducted*).
- Equipment like pruning shears will remain in the FEG, and should be cleaned (with a sterile agent) regularly.

12.13.3 Appendix III - Sensor layout

In Figure 12-3 the overview of the sensor layout is given. The figure shows two different sensor types; red circles a combination of T, RH and CO_2 and green triangle with only T and RH. The figure also shows two levels of number of sensors. Level A is the absolute minimum and level and level B is preferable.

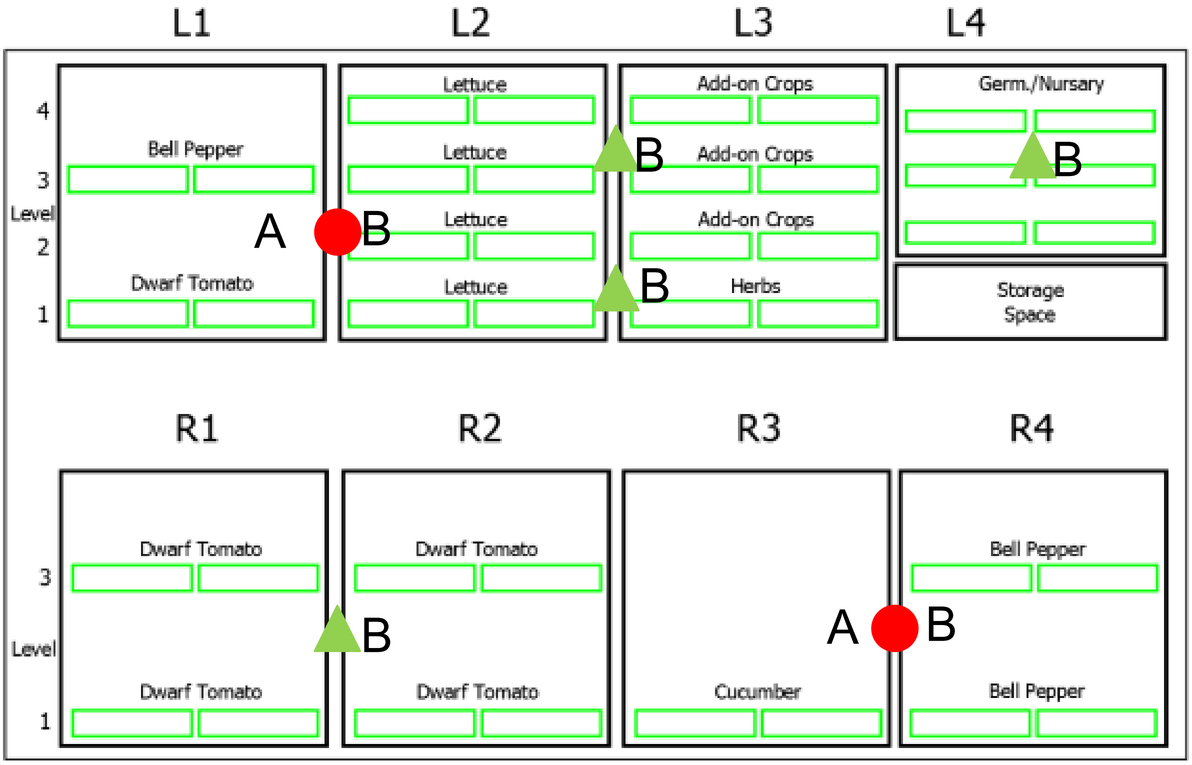


Figure 12-3: Overview of FEG sensor layout (red circles: combination T, RH and CO_2 sensors; green triangles: combination T and RH sensors).

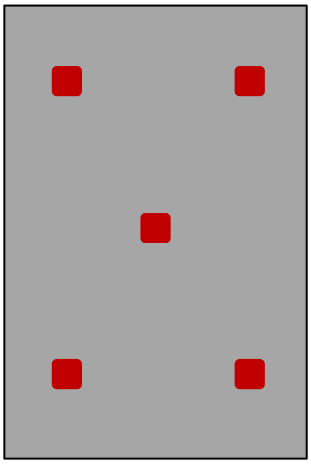
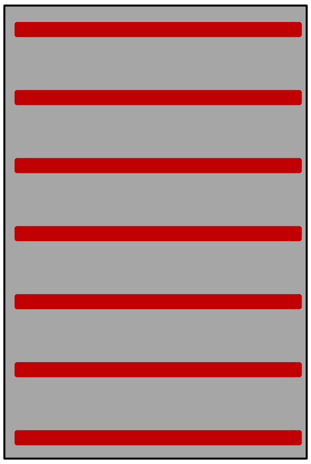
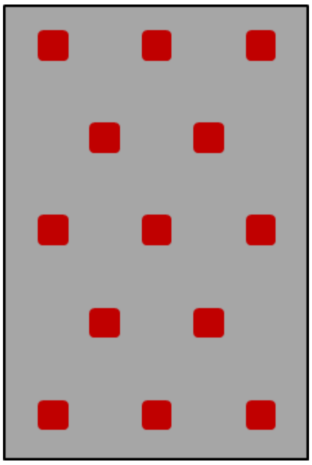
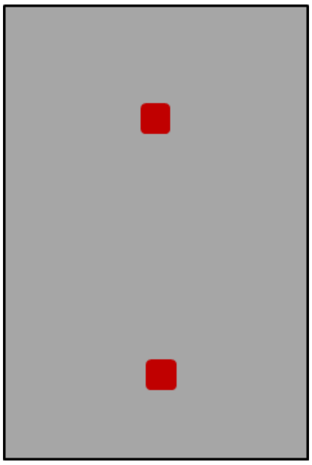
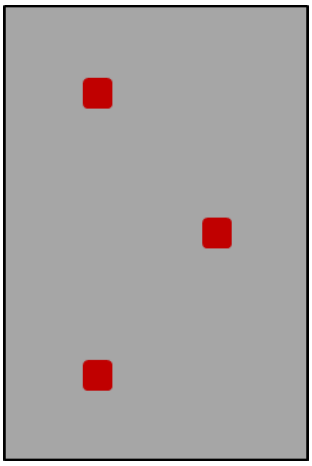
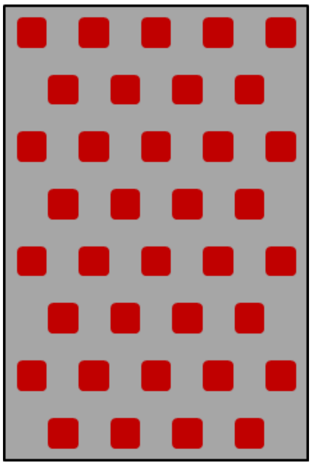
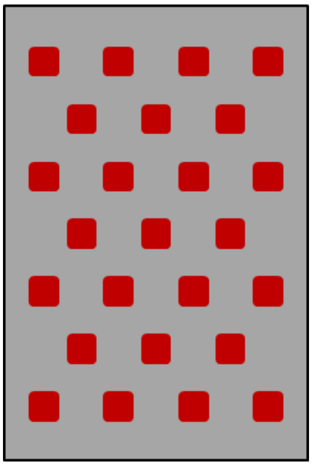
In Figure 12-4 an example of a measuring box is shown. Dimension can increase in case the CO_2 sensor needs to be integrated as well.

Figure 12-4: Example of a ventilated measuring box.

12.13.4 Appendix IV - Tray layout

In total, seven different tray layouts are defined, Table 12-5.

Table 12-5: Tray cover layout for the different crops.

Tray 1	Tray 2	Tray 3	Tray 4
			
5 plants, for example lettuce	7 Lines, for high plant densities, for example spinach	13 plants, typical for continues harvesting	2 plants, cucumber
Tray 5	Tray 6	Tray 7	
			
3 plants, dwarf tomato and pepper	36 plants, radish	25 plants, swiss chard	

12.13.5 Appendix V - ISPR Interfaces to MTF – Crop loads

Crop	Planting density [plants/m²]	Photo-period temp. /RH [°C/%]	Dark-period temp. [°C]	Light Intensity / [µmol/m²/s]	CO_2 conc. [ppm]	Water vapour prod. 1) [g/m²-h]	CO_2 cons. 2) [g/m²-h]
Dwarf Tomato cultivar ?	2,5 but strongly depends on variety	16h 22°C, 80%	8 h 17°C, 80%	300 young plant-600 full grown 16h	600 young plant-900 full grown	115 day 17 night	15
Rucula culivated cultivar ?	1000/m²	16h 21°C, 80%	8 h 17°C, 80%	150 young plant-300 full grown 16h	600 young plant-750 full grown	60 day 10 night	10
Chinese cabbage Tokyo Bekana	± 30 /m²	16h 22°C, 80%	8 h 18°C, 80%	150 young plant-300 full grown 16h	600 young plant-750 full grown	95 day 17 night	12
Outredgeous	± 40 /m²	16h 20°C, 80%	8 h 16°C, 80%	150 young plant-300 full grown 16h	600 young plant-750 full grown	95 day 17 night	12

1) The calculations are made as if the crops are "full grown", the light intensity is assumed to be the upper end of the given range.
2) The CO_2 consumption is considered to be the uptake by the crop. No leakage and CO_2 from breathing inside the ISPR is taken into account.

12.13.6 Appendix VI - LUE and fresh weight production

Crop	LUE	Light intensity	Day length	Light absorption	Light absorbed	HI	Production edible	DM edible tissue	Production	Production	Tray area	Production
	gDW/mol	µmol/m²/s	hours	(20-60%)	mol/m²/d	%	gDW/m²/d	%	gFW/m²/d	gFW/mol	m²	gFW/tray/d
Lettuce	1	300	16	0.6	10.37	0.95	9.85	0.05	197	19	0.24	47.3
Dwarf tomato	1	500	16	0.6	17.28	0.55	9.50	0.05	190	11	0.24	45.6
Cucumber	1	500	16	0.6	17.28	0.55	9.50	0.03	317	18	0.24	76.0
Bell pepper	1	300	16	0.6	10.37	0.5	5.18	0.08	65	6	0.24	15.6
Radish	1	400	16	0.6	13.82	0.6	8.29	0.06	138	10	0.24	33.2
Strawberry	1	400	16	0.6	13.82	0.4	5.53	0.17	33	2	0.24	7.8
Spinach	1	400	16	0.6	13.82	0.8	11.06	0.08	138	10	0.24	33.2
Swiss chard	1	400	16	0.6	13.82	0.8	11.06	0.08	138	10	0.24	33.2
Red mustard	1	400	16	0.6	13.82	0.9	12.44	0.05	249	18	0.24	59.7
Chives	1	400	16	0.6	13.82	0.9	12.44	0.08	156	11	0.24	37.3
Coriander	1	400	16	0.6	13.82	0.4	5.53	0.15	37	3	0.24	8.8
Mint	1	400	16	0.6	13.82	0.7	9.68	0.12	81	6	0.24	19.4
Parsley	1	400	16	0.6	13.82	0.7	9.68	0.16	60	4	0.24	14.5
Basil	1	400	16	0.6	13.82	0.9	12.44	0.2	62	5	0.24	14.9

13 Food Quality, Safety and Processing

13.1 *Species to be selected for quality measurements*

During the CE study, the process of species and cultivar selection by DLO was illustrated. Although quality attributes did not play a role in species and cultivars (S/C) selection, the list of S/C was sufficiently large enough for CNR and LIT to delve into in order to choose S/C to test for the effect of growth in FEG and ISPR on nutritional and organoleptic quality attributes as well as for safety characteristics.

One of the aims of the EDEN ISS project is that crops will be grown in a fully controlled environment so that not only growth and productivity as a function of growth environmental parameters can be assessed, but also the nutritional and organoleptic quality and safety. This is a crucial step forward with respect to plant food production in space because it could allow future space growers to optimise the growing environment to maximise the production of key dietary nutrients required; rather than growing only to maximise biomass.

CNR and LIT have analysed the list of species and decided to qualify species for “Quality Driving Attributes” (QDAs). QDAs are the relevant compounds or group of compounds that are the most important determinant of the quality of a certain species or group of species. In the case of tomato, for example, lycopene can be considered one of the tomato’s QDA. Lycopene is a carotenoid that is responsible for the red colour of tomato, which largely affects the tomato’s antioxidant capacity, and has relevant attributed beneficial effects on human health. The lycopene accumulation is affected by the genotype, the ripeness stage, and by the growth environment, including light and ion concentration in the nutrient solution, two parameters that will be modulated in the FEG and ISPR. The QDAs can also be associated to negative compounds. Plants have an incredibly rich metabolism and can accumulate compounds that have a negative effect on human health. Obviously cultivated plants are not toxic, nevertheless horticultural species can accumulate nitrate ions (NO_3) and oxalic acid (OXA), both must be considered anti-nutritional compounds for humans. NO_3 is normally taken up by plants from the soil nutrient solution, to undergo a two-step reduction to ammonium that is incorporated into organic compounds via amino acid synthesis. Plants can accumulate NO_3 ions in the vacuole to high concentrations under high NO_3 availability conditions, this might occur particularly in leafy vegetables (like lettuce and rocket) under limited light intensity growth condition. In the EU, there are legal limits for the presence of NO_3 in lettuce and rocket. It is highly desirable that these limits are not exceeded by NO_3 accumulation in MTF produce. OXA, is a two carbon dicarboxylic acid able to chelate divalent cations such as Fe^{++} and Ca^{++} thereby reducing their bio-availability during human digestion. Furthermore, oxalic acid consumed with food, accumulates with that produced by normal metabolism eventually representing a threat to human health due to excessive OXA in the blood and its precipitation to form kidney stones. Presence of OXA in space grown vegetables has to be considered particularly negative since it exacerbates the problem of Ca^{++} availability and possibly skeletal demineralisation. Accumulation of OXA is genetically determined in certain plant species, but it can be fostered by environmental factors like calcium availability, low light and nitrogen reduction. For these reasons, NO_3 and OXA are included among the quality parameters to be detected on samples of vegetables produced at the MTF during the NM-III campaign. The content of NO_3 and OXA, are related to quality, but can be considered also as aspect linked to food safety. QDAs for the selected species are listed in Table 13-1.

Table 13-1: Quality Driving Attributes (QDAs) for selected species.

Species	Cultivar /type	QDA 1	QDA 2	QDA 3	Comments
Lactuca sativa L.	TBD	NO_3	OXA	FOS	Fructans are reported for roots of Lactuca, we will verify with home lab activities if fructans and particularly FOS are present also in leaves

Eruca sativa Mill.	Cultivated	ANTIOX	GLUCO ANTIOX	ASCO	During home-lab activity we should verify the extent of Ascorbic acid degradation during storage
Raphanus sativus L.	TBD	GLUCO	ANTIOX	NSC	
Spinacia oleracea L.	TBD	ASCO	NO_3	NSC	During home-lab activity we should verify the extent of Ascorbic acid degradation during storage
Cucumis sativus L	TBD	PTRO	BRIX		
Brassica spp.	Red mustard	ANTO	CLUCO		
Solanum lycopersicum L. (*Lycopersicum esculentum* Mill.)	TBD	LYCO	DM	NSC	
Capsicum annuum L.	TBD	SCARO	NSC	ASCO	During home-lab activity we should verify the extent of Ascorbic acid degradation during storage

It is generally accepted that nutritional quality will be one of the driving forces for fruit and vegetables acceptance by the market. On selecting the species and defining the quality aspects to analyse in MTF produce we decided to be guided by the nutritional and nutraceutical quality attributes that are most likely to be relevant for each species, for acceptance by the NM-III crew, for future space based consumers and for the general market. The last focus is important if research outputs of EDEN ISS are to be disseminated to general growers and consumers on Earth.

We should be aware that while we defined a list of species and quality attributes to be measured on them in EDEN ISS, on the basis of the aforementioned parameters, the feasibility of our planned activity will strongly depend on specific circumstances and not solely defined during the project itself. The NM-III station has space for a laboratory, but no equipment in that space, so all chemical analysis should be performed after the NM-III mission on samples that should be collected stored and transported back to home laboratories. The amount of samples produced by the FEG and ISPR is only an estimate at the moment, so we don't know if enough plant material will be available to complete all analysis planned. Cold storage is efficient to stabilise samples with respect to most quality parameters, but not all. In particular, we have to test during the home lab activity (pre-Antarctic) if sampling and storage, where possible in EDEN ISS, would be a good method to preserve ascorbic acid content, its oxidation state and in general, the antioxidant potential of the plant tissue samples.

In conclusion the pre-mission home lab activity will be crucial to revise the number of samples, amount of samples, type of quality parameters to be measured and in general the planned activities and the expected output.

13.2 *Activities (experimental) and their location*

13.2.1 Pre-Antarctica

Quality

Growing conditions expected in the MTF are unusual, hence growth and productivity can only be estimated at this stage, as are the characteristics of produce that will be obtained in the FEG and ISPR. In order to properly verify estimates of plant performances, activities in home laboratories will be conducted in preparation for the mission. IBAF, CNR and LIT (as well as DLO) have their own plant growth facilities with capacity to control growth conditions.

Each of the IBAF-CNR chambers (Sanyo SGC, 2 twin chambers +1 spare) is equipped with:

- 8 x Osram, Power Star HQI-TS—250 W/NDL, in addition to 8 x 60 W tungsten lamps.
- Temperature control spans between +7°C and +40°C with all lights on.
- CO_2 is measured with IRGA technology (± 1 ppm) and can normally be controlled with a precision of ± 10 ppm after injection from cylinders.
- RH can be nominally controlled between 40 and 90% depending on temperature setting with a precision of ± 5%.
- Vertical flux of air is 0.2 m/s.
- Light can be scaled up in the morning (with the tungsten lamp or using 4 HQI lamps) to avoid a photo-inhibitory shock to plants passing from zero to full light intensity in a few seconds. This could also be considered for the light bars to be used in the MTF. A 5-10 minutes linear ramp of light increment would allow photosystems and the biochemistry to “warm-up” in a coordinated way avoiding damages to the PSII photosystem that would cause long lasting decrease of the quantum yield.
- Light intensity can be reduced by switching off a fixed fraction of the lamps or by using neutral net filters.

The CELLS Research Laboratory at LIT contains 4 growth chambers manufactured by EGC, Ohio, USA. Two M48 Walk in chambers with 16 m^2 internal area and two M12 Reach in chambers with 4m^2 internal area. All chambers provide chamber temperature uniformity within ±0.5°C of setpoint throughout the operating range of 4°C to 40°C. Lighting ranges from 500 µmoles (at 36" from lamps) with the standard fluorescent/ incandescent array up to full sunlight brilliance with high-intensity discharge fixtures. CO_2 is controlled by PPE Systems controller, and humidity range is comparable to those in CNR. CELLS also have three LED micro arrays, two of which were manufactured by Heliospectra. Two growing tents can also be utilised for ambient room temperature growth tests. Figure 13-1 illustrates the CELLS chambers in use.

Figure 13-1: CELLS M12 & EGC M48 Growth Chambers.

A crucial environmental parameter determining plant performances is light, both as quantity and quality. Although light intensity inside the IBAF growth chambers is far higher (close to 1 K µmol m^{-2} s^{-1} at 30 cm from the light compartment) than that in the FEG and ISPR, its quality is different. For this reason during the CE study Heliospectra and IBAF started to evaluate the possibility to upgrade the IBAF chambers with Heliospectra lamps having light quality similar to the LED lamp bars that Heliospectra will produce for implementation in the FEG. After the CE meeting, Heliospectra simulated scenarios with two of their LED lamps (LX60) with two optics and two different crop distance from the lamps.

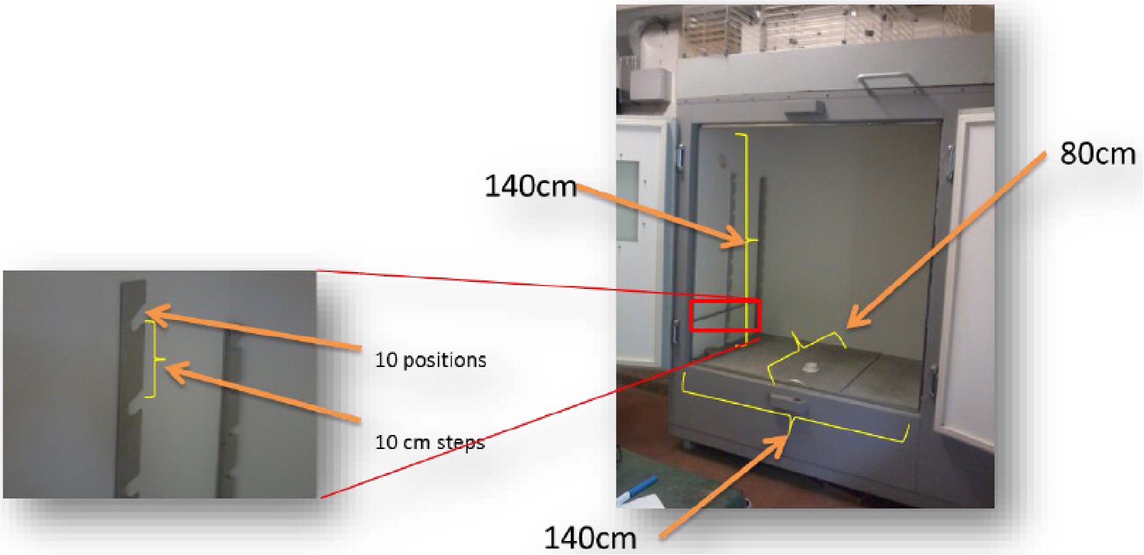
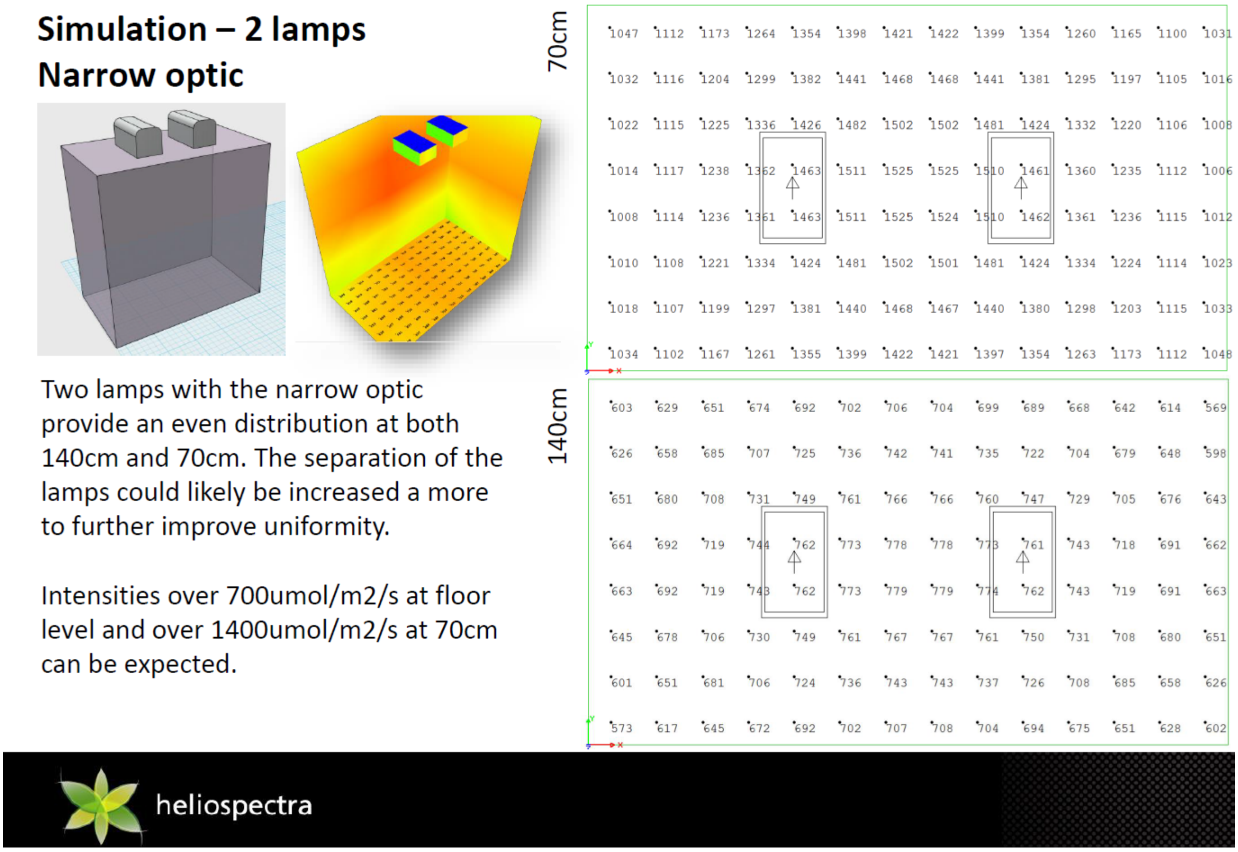


Figure 13-2: Sanyo SGC Chambers at IBAF CNR.

After simulation Heliospectra suggested the use of two lamps with narrow optic and also defined the optimal position and spacing of the lamps with respect to light intensity and distribution inside the IBAF growth chambers Figure 13-2.



Heliospectra is producing an upgraded version of their LX60 lamp that will be provided to IBAF for implementation in the growth chambers. IBAF is working on a versatile solution for the implementation of the LX60 lamps in the chambers to maximise the experimental potential to confront and contrast light environment effects on plant quality performances. LIT will shortly negotiate with Heliospectra to have this process implemented for all four CELLS chambers.

As in-house pre-Antarctica activities CNR and LIT will perform growth cabinet experiments on selected species and varieties, to test their response to growth conditions that will be used in the MTF in terms of productivity of biomass for sampling and quality. This will allow the test of all the procedures associated with samples harvesting, subsampling, stabilisation, storage end analysis. Particular care will be devoted to the procedure necessary for positive integration of activities performed at the two laboratories (IBAF and LIT). This would increase the efficiency of operation and the result outcome. For the list of species among which we will select the one to test and for the list of tests to be performed refer to the list of species table (Table 13-1).

Safety

During home laboratories activities, procedures of sample harvest sub-sampling, stabilisation storage and testing will be revised and applied by ISA to vegetables produced at the IBAF laboratory. If not all types of plant material will be produced from the IBAF experiments commercial product will be used.

Long term storage

LIT will need to determine the effect of short term and long term storage on food quality with respect to Sensory Analysis. The minimum duration after harvesting that sensory analysis can take place is 5 days. Therefore cold storage of produce of predetermined mass will be stored in ziplock bags at 4^{o}C. Long term storage of plant tissue for Sensory Analysis will not be required as it is planned that training of the NM-III crew in sensory analysis will be carried out by LIT specialist Dr. Tracey Larkin in Bremen pre Antarctic departure.

In preparation for the assessment of MTF and ISPR produce by a trained sensory panel, assessment of microbial profiles and mapping to potential toxin production must first be carried out, to ensure the safety of sensory panel members. Simple washing protocols post-harvest (agreed with IBAF, CNR) will be utilised and followed by stringent microbial investigation. Those microbes identified will then be mapped with known bio toxins that they may produce. If such a microbe / toxin profile is identified, a bio toxicological protocol will be developed and utilised to ensure that toxin is not present on the produce. To ensure no unknown microbe toxin profile is identified, a full screening of all produce from the home lab pre Antarctic testing will be completed in the first round of growth tests for all S/C.

Long term storage of all samples for compositional analysis will be investigated using sub-zero temperatures. As explained above, some nutraceutically important molecules are damaged by some freezing techniques. LIT will investigate several sub-zero storage protocols prior to the initiation of the project on the MTF. Should no protocol be identified for the safe storage of plant tissue that will not affect sensitive molecules of interest, then simple lab based tests will be investigate to aid the crew of NM-III to potentially determine some of the molecules in question on the fresh produce.

During the CE study, the possibility to test the effect of storage on the fresh produce for delayed consumption at the NM-III was discussed. LIT, with the contribution of CNR, plans to test storage of fresh produce of selected species for a period of 30 days in sealed bags with modified atmosphere at temperature in the range of 0-5°C. The possibility to use biodegradable plastic bag will be tested in in house activities thanks to contacts with a leading Italian industry on the field of bio based polymers. The plan is to select a few species (a selection of leafy and fruit), sanitise them, collect initial samples for quality and safety and seal in a controlled atmosphere and low temperature and store for up to 30 days. Transparent bags should allow visual testing of the produce to verify its appearance during storage. If no visual degradation is detected, samples of produce for quality and safety analysis will be taken at the end of the storage cycle, and treated as those obtained from a normal production cycle. (Stabilisation by freezing and transport to home laboratories for analysis will also be involved). Home laboratories pre-mission activities will be crucial in defining feasibility of the proposed approach and the choice of the S/C selected and the number of samples required.

13.2.2 Antarctica

After harvest, on a limited number of harvests and on selected species, a quantity of the produce should be saved for samples to be used for quality, safety and post processing activities.

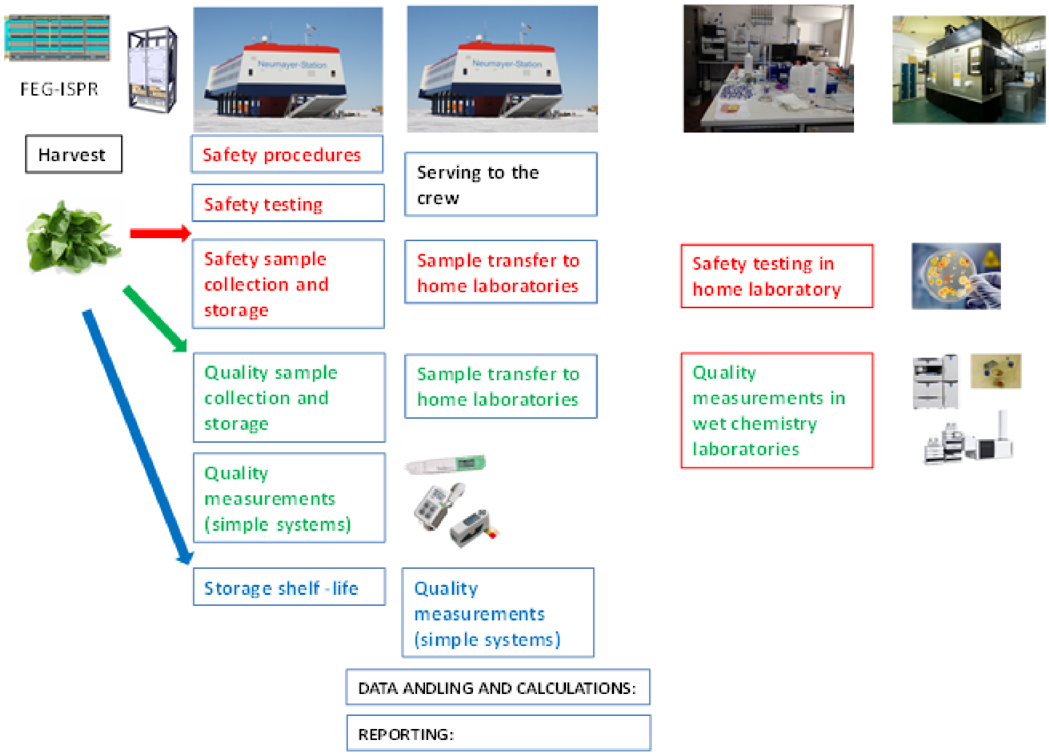


Figure 13-3: Activities to be performed after harvest on FEG produce.

Quality

The production of vegetables at the MTF will last for several months, even during the period of isolation. One person will be responsible of all activities related to EDEN ISS project hence due to limited time availability, to limited skills and to absence of on-site equipped laboratory facilities, CNR and LIT, as a result of the discussion undertaken during the CE study decided to limit as much as possible the duties related to food quality (and safety) charged to the EDEN ISS person in Antarctica. The best way to achieve this result is to limit NM-III activities to:

a) on-site simple quality parameter determination
b) collection, sub-sampling, stabilisation storage and transport of samples

On-site simple quality parameter determination

As on-site simple quality parameters measurement, the person in charge will be using simple instruments such as:

a) Chlorophyll SPAD Meter
b) Nitrate Cardy Meter
c) Portable Lab Refractometer (Brix%)
d) Hand held Colorimeter
e) Hand held Penetrometer

This instrument will be tested during the pre-Antarctica activities, and procedures for equipment testing will produced and tested with the DLR personnel during the MTF testing in Bremen.

Collection, sub-sampling, stabilisation storage and transport of samples

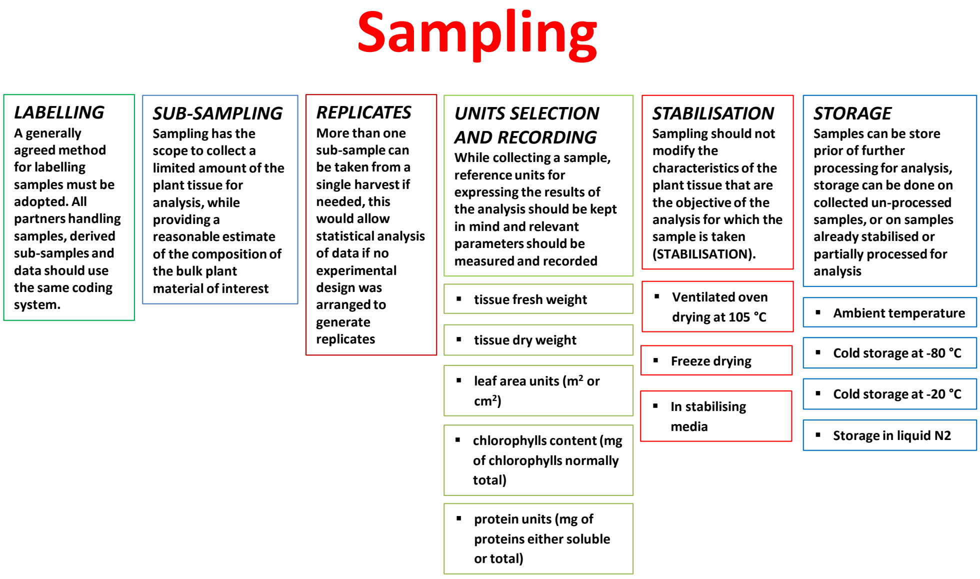


Figure 13-4: Example of aspects related to sampling procedures.

This is one of the most crucial activities that will be performed at the NM-III station during the project. Plant tissues maintain living cells as far as tissues are hydrated and temperature is favourable to metabolism. Plant tissues also respond to the environment very rapidly, and this can contribute to modifying the quality parameters of plant food if appropriate procedures are not adopted. Under normal laboratory conditions the fastest way to quench plant metabolism and stabilize plant tissue samples is to freeze them in liquid N_2 (-190°C) or at least in dry ice (-70 to -90°C). This can't be done at the NM-III station. Procedures need be written in order to standardize the handling of plant tissues from harvest to stabilisation while working in Antarctica (Figure 13-3 and Figure 13-4). For different samples harvested at different times to be comparable to each other it is important that procedures are identical for all of them (e.g. in terms of time, temperature conditions, light conditions between harvest and freezing).

Following the CE study in Bremen a number of species have been selected for growth in the MTF. Not all plants grown in the MTF will be used for quality and safety assessment. A list of those that CNR and LIT are planning to test for quality is in Table 13-2.

Due to the absence of a freeze drier at the NM-III station, samples will be stored as fresh material. Samples will be shared between CNR and LIT either as fresh or dry material after drying in home laboratories. Aluminium hand-made and pre-weighed bags will be provided to store samples. As a preliminary estimate, we assume that 100 g of fresh material should be sufficient to perform all analysis, taking into consideration that the dry matter content of the tissues we will be working on is normally close to 5%. Collecting 100 g of fresh material should provide approximately 5 g of dry matter.

Table 13-2: List of species to be tested and related information.

Species	Cultivar /type	N° of harvest sampled	N° samples per harvest	Type of sample	Tissue (and total amount of samples to transport in g)	stabilisation	Storage	Analysis type	Site of analysis
Lactuca sativa L.	TBD	3	4	Fresh material (FM)	Leaves (1200 g)	Freezing	-20°C	CHL.; TCARO; DM;	CNR IBAF

								TPROT.; SPROT NSC; ASH; FRUCS; FOS OXA ASCO	
								MIN	LIT
								NO_3	NM-III
Lactuca sativa L.	TBD	1	5	FM	Roots (500 g)	Freezing	-20°C	TCARO; DM; TPROT.; SPROT NSC; ASH; FRUCS; FOS OXA ASCO	LIT
								NO_3	NM-III
Eruca sativa Mill.	Culti-vated	3	4	FM	Leaves (1200 g)	Freezing	-20°C	CHL.; TCARO; SCARO; ASCO; DM; TPROT.; SPROT NSC; ASH TPOLY	CNR IBAF LIT
								TGLUC; SGLUC; ORAC; SANTHO MIN SPOLY	LIT CNR
								NO_3	NM-III
Raphan	TBD"	3	4	FM	Tap root	Freezing	-20°C	TGLUC;	LIT

us sativus L.					(1200 g)			SGLUC; ORAC; SANTHO	
								PTRO BRIX	NM-III
								NSC	IBAF
Spinacia oleracea L.	TBD	3	4	FM	Leaves (1200 g)	Freezing	-20°C	CHL.; TCARO; SCARO; ASCO; DM; TPROT.; SPROT NSC; OXA	LIT
								NO3	NM-III
Brassica spp.	Red mustard	3	4	FM	Leaves (1200 g)	Freezing	-20°C	CHL.; SCARO; DM; NSC; ASH; ANTO; ASCO	IBAF
								NO3	NM-III
Solanum lycopersicum L. (*Lycopersicum esculentum* Mill.)	TBD	3	4	FM	Fruit (1200 g)	Freezing	-20°C	DM; NSC; ORGA; LYCO;	IBAF
								PTRO BRIX	NM-III
								SANTHO	LIT
Capsicum annuum L.	TBD	3	4	FM	Fruit (1200 g)	Freezing	-20°C	CHL.; SCARO; DM; NSC; ASCO	IBAF
								PTRO BRIX	NM-III

Cu-cumis sativus L	TBD	3	4	FM	Fruit (1200 g)	Freezing	-20°C	NSC ASH	IBAF
								MIN	LIT
								PTRO BRIX	NM-III

Table 13-3: Analysis type and related information.

Type of analysis	Type of sample	Unit	Extraction	Main equipment	Laboratory	Data handling	CODE
Dry matter percentage	Fresh material (FM)	%	No	Freeze-drier/ventilated oven	IBAF	IBAF	DM%
Nitrate ion content	FM	mg kg^{-1} FM	Squeezing	Nitrate Cardy Meter	NM-III	NM-III/IBAF/LIT	NO_3
Chlorophylls	FM	mg kg^{-1} FM	80%acetone /water	Wet chemistry lab, VIS-Spectrophotometer/Plate reader	IBAF	IBAF/LIT	CHL
Total carotenoids	FM	µg . g FM^{-1}	80%acetone /water	Wet chemistry lab, VIS-Spectrophotometer/Plate reader	IBAF	IBAF/LIT	TCARO
Total proteins	FM	% or µ g gFW^{-1}	Buffer	Wet chemistry lab Plate reader/VIS-Spectrophotometer	IBAF	IBAF	TPROT
Carotenoid identification	FM	µg . g FM^{-1}	Acetone	Wet Chemistry Lab. and HPLC UV/VIS detector	IBAF	IBAF/LIT	SCARO
Soluble proteins	FM	% or µ g gFW^{-1}	Buffer	Wet chemistry lab Plate reader/VIS-Spectrophotometer	IBAF	IBAF	SPROT
Ascorbic acid	FM	µg . g FM^{-1}	Trichloroacetic acid	Wet Chemistry Lab. and HPLC UV/VIS detector	IBAF	IBAF	ASCO
Non-structural carbohydrate (Glucose fructose, sucrose and others)	DM	% or µ g gDM^{-1}	80% ethanol /water	Wet Chemistry Lab. Plate reader and Ion chromatography system	IBAF	IBAF	NSC
Ash content	DM	% of DM	No	Muffle furnace	IBAF/LIT	IBAF/LIT	ASH
Fructans	DM	% of DM	80°C Buffer	Wet Chemistry Lab. And Ion chromatography system	IBAF	IBAF	FRUCS
Oligo-Fructosides	DM	% of DM	80 °C Buffer	Wet Chemistry Lab. And Ion chromatography system	IBAF	IBAF	FOS
Mineral composition	DM	% of DM	No	Wet Chemistry Lab, AAS, GFAA, Lachette	LIT	LIT	MIN
Antocyanidin	DM	µg . gDM^{-1}	Methanol	Wet Chemistry Lab. and HPLC UV/VIS detector	IBAF	IBAF/LIT	ANTO
Organic acid	DM	µg . gDM^{-1}	80% ethanol /water	Wet Chemistry Lab. Plate reader and Ion chroma-	IBAF	IBAF	ORGA

				tography system			
Oxalic Acid	DM	µg . gDM^{-1}	Water	Plate reader Spectro star nano (BMG) and HPLC UV/VIS detector	IBAF	IBAF	OXA
Lycopene	FM	µg . g FM^{-1}	Acetone	Wet chemistry lab, VIS-Spectrophotometer/Plate reader	IBAF	IBAF	LYCO
Total polyphenols	DM	mg gallic acid equivalent gDM^{-1}	Methanol	Wet chemistry lab UV/VIS-Spectrophotometer	IBAF	IBAF/LIT	TPOLY
Polyphenols	DM	µ g gDM^{-1}	80% Ethanol/water	Wet Chemistry Lab. LC w/ tandem UV-Vis-Mass Spec Detector	LIT	LIT	SPOLY
Carotenoid identification	FM	µg . g FM^{-1}	Acetone; SCFE	Wet Chemistry Lab. LC w/ tandem UV-Vis-Mass Spec Detector	LIT	LIT	SCARO
Total Glucosinolate	DM	% or µ g gDM^{-1}	80% Ethanol/water	Wet chemistry lab Plate reader/VIS-Spectrophotometer	LIT	LIT	TGLUC
Glucosinolate identification	DM	% or µ g gDM^{-1}	80% Ethanol/water	Wet Chemistry Lab. LC w/ tandem UV-Vis-Mass Spec Detector	LIT	LIT	SGLUC
Antioxidant Capacity	DM	Trolox equiv	60% Acidified Methonal/Water	Wet chemistry lab Plate reader/VIS-Spectrophotometer	LIT	LIT	ORAC
Antioxidant identification	DM	% or µ g gDM^{-1}	60% Acidified Methanol/Water; SCFE	Wet Chemistry Lab. LC w/ tandem UV-Vis-Mass Spec Detector	LIT	LIT	SANTHO
Oils/Fats	FM	% or µ g gFM^{-1}	SCFE	Wet Chemistry Lab. LC w/ tandem UV-Vis-Mass Spec Detector	LIT	LIT	FATS
Hardiness	Whole Fruit	Kgf	No	Penetrometer	NM-III	NM-III	PTRO
Soluble solids	Tissue juice	°Brix	Tissue juice squeezing	Refractometer	NM-III	NM-III	BRIX

It is important to note that planning for the activities to be conducted at the NM-III has to be verified for feasibility and details during the activities in CNR and LIT home laboratories and during the test phase of the MTF at the SDLR site in Bremen. This also includes the acquisition of the necessary skills by the project dedicated person from DLR.

Safety

Sanitisation of produce

There are no specific reasons to imagine that microbial contamination would occur in the MTF, because the surrounding environment is practically sterile, because MTF premises and subsystems are largely not organic and would be monitored and cleaned to avoid microbial growth and because the FEG and ISPR would be also monitored and kept as clean as possible to avoid microbial interference with plant growth and productivity. Nevertheless, the crew will be isolated and the risk of health treat due to microbial contamination of plant food produced in the FEG should be kept as low as possible. For this reason we plan to sanitize all produce before consume. Sanitisation of salad produced for space consume is also part of the procedures enforced by NASA.

We plan to use commercial hypochlorite solution to sanitise non-leafy vegetables by immersion and washing prior to consume by the NM-III crew. Considering, as indicated in the Bremen Kick off meeting, 180 kg of product, we hypothesise to make easier the operation: all vegetables must be washed in abundant water, also two-three times, with a solution made at the time of use using the commercial hypochlorite solution, at a 1.5% (vol/vol) concentration. Washing should be made in common washing basin or, if available at the Antarctica station, in a closed sink. Vegetables will be kept for at least 20 minutes, then washed continuously to eliminate any trace of hypochlorite. In the case of leafy vegetables, sodium bicarbonate will be use instead of hypochlorite. Vegetables will be treated with sodium bicarbonate. The leafy vegetables will be firstly washed using abundant water, then treated with sodium bicarbonate in water (concentration TBD with pre-Antarctica activity), finally washed again with water. If necessary, vegetables will be washed with sterile water, prepared by using filter units and vacuum pump.

Sample collection

As for the quality analysis, samples will be collected and stored for microbial contamination analysis (Table 13-4). The material will be stored after washing with pure water (commercial deionised water or local water filtered by filter units), and prior to cutting. The operator will work by using sterile slicers and gloves. Slicers will be sterilized by using a domestic pressure cooker, which simulates the operating conditions of an autoclave, if used for a longer time (45 minutes instead than 15). Slicers will be enclosed in aluminium foil and marked with sterilization indicator strip, which, as is well known, changes colour when the sterilization takes place. The collection of samples, (as there is no laminar flow hood on NM-III), will be made using many precautions or a portable Bunsen, so to sterilize, as is practicable, the strict external environment. When the sterilization of slicers will be not possible by using the domestic pressure cooker, a portable Bunsen can be used to treat them. In this case, slicers should be quickly passed on the flame and then cooled before used. All these operations will be made taking into account the safety of the operator.

For each type of vegetables, the number of sample is identical to that used for quality evaluation (Table 13-4) and about 10 grams/sample will be stored in sterile tubes of 50 ml volume. CNR foresaw the possibility of using scratches and/or sterile cotton woods for adding a degree of certainty to sampling and the possibility to test safety, just in case that sample transport undergo problems). Furthermore, CNR foresaw also the possibility of collecting samples in sterile plastic bags. Both tubes and/or sterile plastic bags will be kept in a freezer, at -20°C/-30°C. The same procedures will be adopted on long term storage experiments.

The analysis will be performed aimed to monitor the following microorganisms:

Per crop type
Common Pathogens
Total microbial count
Yeasts and moulds
Total Coliform
Escherichia coli
Salmonelle spp.
Staphylococcus aureus
Bacillus cereus
Emerging Pathogens
Enterobacter sakazakii
Listeria innocua
Clostridium spp

These will be monitored using specific culture media, sometime also by using media which use specific chromogenic compounds, specific for genera. In the case of the electronic nose, this analysis will be performed using enzymatic systems, specific for genera.

Table 13-4: Analysis to be performed for safety.

Species	Analysis type	Site of analysis
Lactuca sativa L.	TMC, TC, EC, SALM, SA, BA, ES, LI, CL, YM,	CNR ISA,
Eruca sativa Mill.	TMC, TC, EC, SALM, SA, BA, ES, LI, CL, YM,	CNR ISA;
Raphanus sativus L.	TMC, TC, EC, SALM, SA, BA, ES, LI, CL, YM,	CNR ISA
Solanum lycopersicum L. (*Lycopersicum esculentum* Mill.)	TMC, TC, EC, SALM, SA, BA, ES, LI, CL, YM,	CNR ISA;
Capsicum annuum L.	TMC, TC, EC, SALM, SA, BA, ES, LI, CL, YM,	CNR ISA;
Cucumis sativus L	TMC, TC, EC, SALM, SA, BA, ES, LI, CL, YM,	CNR ISA;
Brassica spp.	TMC, TC, EC, SALM, SA, BA, ES, LI, CL,YM,	CNR ISA;
Spinacia oleracea L.	TMC, TC, EC, SALM, SA, BA, ES, LI, CL, YM,	CNR ISA;
Samples will be prepared at NM-III, then sent to the CNR labs.		

Coding for analysis of safety parameters is in Table 13-5.

Table 13-5: Coding for safety analysis and related information.

Type of analysis	Type of sample	Unit	Extraction	Main equipment	Laboratory	Data handling	CODE
Total microbial count	Fresh Material	CFU/g	no	Spectrophotometer, incubator, Stomacher	ISA	ISA	TMC
Total coliforms	FM	CFU/g	no	Spectrophotometer, incubator, Stomacher	ISA	ISA	TC
Escherichia coli	FM	CFU/g		Spectrophotometer, incubator, Stomacher	ISA	ISA	EC
Salmonelle	FM	CFU/g	no	Spectrophotometer, incubator, Stomacher	ISA	ISA	SALM
Staphylococcus aureus	FM	CFU/g	no	Spectrophotometer, incubator, Stomacher	ISA	ISA	SA

Bacillus cereus	FM	CFU/g	no	Spectrophotometer, incubator, Stomacher	ISA	ISA	BA
Enterobacter sakazakii	FM	CFU/g	no	Spectrophotometer, incubator, Stomacher	ISA	ISA	ES
Listeria innocua	FM	CFU/g	no	Spectrophotometer, incubator, Stomacher	ISA	ISA	LI
Clostridium spp	FM	CFU/g	no	Spectrophotometer, incubator, Stomacher	ISA	ISA	CL
Yeasts and moulds	FM	CFU/g	no	Spectrophotometer, incubator, Stomacher	ISA	ISA	YM

Long term storage

As indicate in the pre Antarctic discussion, long term freezing affects can disrupt molecular bonds of cold sensitive nutraceutical compounds. The pre mission testing will identify which compounds are vulnerable to long term freezing and which are not. Variation of temperature in a sub-zero range of between -20^{o}C to -50^{o}C may offer insight to specific compound sensitivities over several time periods whether they be days, months or years. Initial thoughts were to use a freeze dryer in the MTF, but this is not feasible for procurement, transport and training of NM-III crew. Therefore, utilisation of what is commonly employed by Antarctic missions for transportation of ice cores will be investigated, including maximum sample number and weight. Our final sample numbers will be based on this study. If this transportation facility is available, our proposal is to store a predetermined amount of plant tissue for each S/C, including replicate analysis tissue, at -50^{o}C in NM-III until shipment to a South African transport facility. From there the samples can be placed on dry ice and shipped to both home labs for further analysis. The feasibility and cost of this must be investigated, but as there will be no opportunity of analysis of plant tissue for nutraceutical content on NM-III, some combination of sub-zero storage followed by rapid transport to CNR and LIT will be required.

Sensory Analysis

Long term storage of fresh plant material for consumption has long been ruled out due to many issues including frost burn, extremophile microbe activity and physical damage to plant cell walls due to water crystallisation within the plant fluids. These issues make the plants unpalatable ruining texture, flavour and visual appeal. As storage is therefore not an option in the area of sensory analysis, it will be necessary for the crew of NM-III to be trained in the protocols and assessment techniques of food flavour, texture and overall sensory output from the produce after harvest. As indicated earlier, this will be carried out in Bremen by Dr. Tracey Larkin of LIT prior to the NM-III crews' departure.

Dr Larkin, having developed the protocols in the pre Antarctic investigation stage will then liaise with the NM-III crew via video communications on the harvest output and assist the crew during the mission on any queries that may occur. The data recorded will be analysed during the mission by Dr. Larkin and scientists in both CNR and LIT to determine if any chemical change is required to the NDS recipe and forward these results to UoG for review and further feedback to the NM-III crew if necessary. This will ensure a dynamic and evolving produce and protocols for final application to the ISPR.

13.2.3 Post-Antarctica

Quality

CNR and LIT will complete analysis of all plant tissue produced during the MTF stage of EDEN ISS and determine both compositional and nutraceutical content of the tissue using protocols previously developed and validated pre mission departure. Conclusions will be based on effects of NDS content, growth protocols and storage/transport methods.

Safety

Analysis of microbial contamination on collected samples will be performed in home laboratory (ISA-CNR). This part of the activity will have very limited time span to be performed, since sample would be available at the very last part of the project activity. Pre-mission activities to set up final protocols, final selection of S/C and pathogen to be tested, will be very relevant to allow fast and efficient work on recovered samples.

13.3 *Equipment to be used*

Quality

Main equipment	Laboratory	Value (1000 €)	Purchase
Wet chemistry lab,	IBAF/LIT	50	NO
Uv/VIS-Spectrophotometer	IBAF/LIT	15	NO
Plate reader Spectro star nano (BMG)	IBAF	11	3/5 of cost
Micro titre Plate Reader with Fluorescence	LIT	20	NO
Freeze-drier	IBAF/LIT	10	NO
Ventilated oven	IBAF/LIT	7	NO
Nitrate Cardy Meter	NM-III	0.3	YES
HPLC UV/VIS Detector Thermo-Ultimate 3000	IBAF	25	NO
SPAD Meter	NM-III	2.2	YES
Penetrometer	NM-III	0.3	YES
Hand Held Colorimeter	NM-III	0.3	YES
Thermo (Dionex) Ion chromatography system ICS 500 Plus Combined HPLC	IBAF	100	NO
Thermo (Dionex) Anion IC System	LIT	20	YES
Muffle furnace	IBAF/LIT	3	NO
Agilent 1200 Series LC System w/ 6450 QTOF MS	LIT	400	NO
Atomic Absorption Spec-trometer	LIT	60	No
Graphite Furnace AA	LIT	50	No
Lachette Ion Detector	LIT	30	No

Gas Chromatography Mass Spec	LIT	100	No
Supercritical fluid Extraction (SCFE)	LIT	80	No
Agilent 1200 Series RapidRes LC with RI Detection	LIT	60	No

Safety

Main equipment (Safety)	Laboratory	Value (1000 €)	Purchase
Incubator	ISA	10	NO
Incubator*	ISA	10	NO
VIS-Spectrophotometer	ISA	10	NO
Freezer	ISA	7	NO
Freezer	NM-III	1	yes
Stomacher	ISA	2	NO
*Two incubators			
Analytical balance	NM-III		Yes
Vacuum pump	NM-III	1	Yes

13.4 *Scientific outputs*

Positive aspects - LED use – UV light for antioxidant

There is increasing interest on plant growth in fully controlled environment not only for space dedicated activities, but also for technically advanced horticulture and in general for the expansion and the increase of efficiency of controlled environment agriculture systems. The activities on quality of produce when the environment is so tightly controlled are in comparison much less that for quantity of products. With this respect we have the possibility to add new scientific knowledge in the area of quality and nutraceutical food quality control with controlled environment, particularly taking into account the use of LED which is the real breakthrough in technology with respect to past times. Focus on QDA would be of great benefit with this respect.

Negative aspects

Due to stringent limitation on the energy, space, complexity, and time availability during the mission in Antarctica, the span of environmental parameter variation is quite limited. Particularly relevant is the limitation of the light intensity and quality modulation available for normal growth and for stress induction. Similarly the FEG can only stand one temperature regime for all S/C growing at the same time and this limits again the selection of an optimal environment for species differing in temperature optimum, and the possibility to use temperature as stress inducible response related to quality.

Finally no proper scientific protocols can be established until all other aspect of the facilities and procedures are properly set and defined.

Solutions

A relevant set of activities are planned in relation to quality, safety and long term storage of products as preparatory activities for the Antarctica mission. CNR and LIT, in tight collaboration with DLR, DLO and all other participant should take advantage of these activities to increase the scientific output of the EDEN ISS project overcoming with more space, time, and span in environmental parameters settings the limits of the FEG unit. Furthermore a close coordination among the FEG and ISPR activities in terms of quality and safety conditions can increase the scientific outputs of the project.

Proper scientific protocols should be defined for pre-Antarctica and Antarctica activities in order to increase the scientific output of EDEN ISS.

13.5 *Practical value of the MTF activities*

Analytical data may be compromised by available storage and shipping methods to be utilised in relocating plant tissue to home laboratories. Lack of available scientifically trained crew may also impact on the simple analysis needed to be carried out on plant tissue at NM-III, where sensitivity to the cold is an issue. These physical limits will play a major role in the final outputs from the compositional, nutraceutical and sensory investigations.

13.6 *Open questions for Further Consideration*

1) Growth analysis and production data? Determinant of S/C selection.

2) Organoleptic composition and effects on panel testing?

3) NDS to be used in home labs activities – current systems are non aeroponics based. Can we use our hydroponic setup?

14 Microbial Investigations

14.1 *Classical sampling for microbial monitoring of FEG, SS, ISPR*

Measurements can/shall be combined with E-Nose measurements

Sampling tool: Swab

Frequency: 1x per month

Sampling locations: 10 locations in FEG (2 swabs from each location*)
6 locations in the SM (2 swabs from each location*) **tbc**
4 locations in the ISPR (2 swabs from each location*) **tbc**
2 blanks (2 swabs*)

→ 42 Swabs per month
462 Swabs in 11 months

Material: 462 Swabs (+ spares)
231 (+ spares) sterile 15 ml Flacon tubes filled with 2.5 ml water/PBS tbc
≥ 4 pair of (sterile) gloves per measurement event = 44 (+ spares) pair of gloves (more would be better)
marker, protocol sheet, freezer for sample storage

* 1 swab for analysis by cultivation, 1 swab for molecular analysis, molecular analysis is not part of the EDEN ISS project

14.2 *Classical microbial measurements for monitoring of plants*

Measurements can/shall be combined with E-Nose measurements

Sampling tool: Swab **tbc, pretests necessary**

Frequency: 1x per month **tbc**

Samples from: 10 plants (2 samples of each plant*) **tbc**
2 blanks (2 swabs*)

→ 22 Swabs per month
242 Swabs in 11 months

Material: 242 Swabs (+ spares)
121 (+ spares) sterile 15 ml Flacon tubes filled with 2.5 ml water/PBS tbc
≥ 4 pair of (sterile) gloves per measurement event = 44 (+ spares) pair of gloves (more would be better)
marker, protocol sheet, freezer for sample storage

* 1 swab for analysis by cultivation, 1 swab for molecular analysis, molecular analysis is not part of the EDEN ISS project

Table 14-1 and Table 14-2 summarize the overall consumables and sample return requirements of the proposed microbial investigations.

Table 14-1: Estimate of consumables required for the microbial investigations during the Antarctic deployment phase.

Item	Packing Unit	Qty	Total number	Mass [kg]	Dimension [cm]
Aluminum Case	1	1	1	15.000	80 x 50 x 60
15 ml centrifuge tube + 2,5 ml water/PBS	50	8	400	3.800	
2 ml tube + 1 ml water	1	800	800	1.600	
Lab Booklet	1	1	1	0.570	
Plastic Bag small	20	1	20	0.098	
Marker	1	3	3	0.026	
Plastic Bag big	20	1	20	0.848	
FLOQSwab	100	8	800	4.144	
50 ml centrifuge tube + wipe	1	30	30	1.500	
50 ml centrifuge tube	1	30	30	0.750	
Sterile gloves	30	4	120	2.800	
			Total	**31.136**	

Table 14-2: Estimate of the microbial investigation sample return requirements of the Antarctic deployment phase.

Item	Packing Unit	Qty	Total number	Mass [kg]	Dimension [cm]
15 ml centrifuge tube + 2,5 ml water/PBS + swabhead			400	4.000	
FLOQSwab			400	2.072	
50 ml centrifuge tube + wipe			30	1.500	
50 ml centrifuge tube			30	0.750	
			Total	**8.32**	

15 Bio-Detection and Decontamination

During the CE Study bio-detection and decontamination was discussed with the involved disciplines (Food Quality; Plant Health Monitoring; Microbial Investigations) regarding the different requirements / limitations given by the plants.

15.1 *Baseline Design*

15.1.1 Bio Detection

For the bio-detection of the biological load on the plants but also on several surfaces the commercial E-Nose (in Figure 15-1 the ISS Model can be seen) will be used. But it first had to be checked if the available sample taking unit is sufficient for the required measurements.

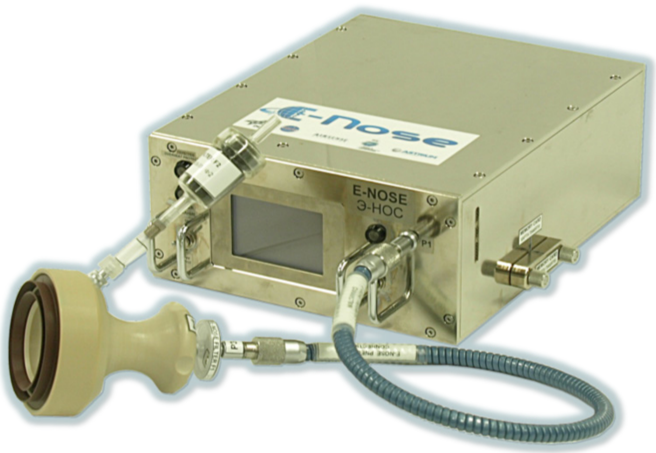


Figure 15-1: E-Nose.

Since the plants do not have flat surfaces, the following options have been considered:

<u>Breaking off a leafs and measurement of the leaf with the available sampler</u> (as it can be seen in Figure 15-2 below; in this case the target is the leaf or the piece of plant).

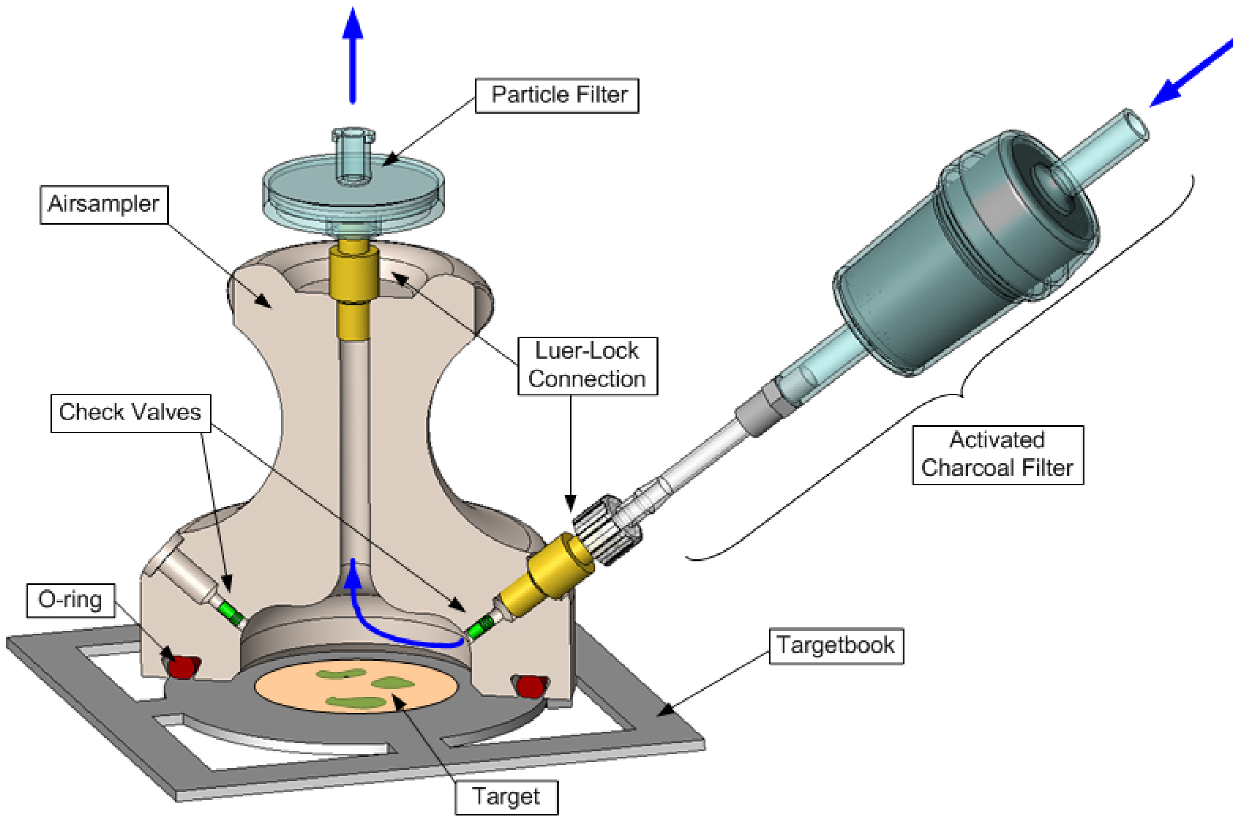


Figure 15-2: Sample Taking Unit

Due to the information of the plant health monitoring domain, if the plant is injured (e.g. by cutting off leaves or pieces) it immediately starts to produce different compounds to close the "wound". These organic compounds are very volatile and would strongly affect the measurements. So the cutting out of samples of the plant has not been selected for sample taking.

Sample taking directly on leaves: The sample taking directly on a leaf (as it can be seen in Figure 15-3 below) is only applicable for a couple of the chosen plants. This kind of sample taking does not allow measurements on e.g. the plant stem. Although with this sampler the plants cannot be monitored directly, it can be used for the measurements of the inner surfaces of the habitat (is discussed in this chapter below).

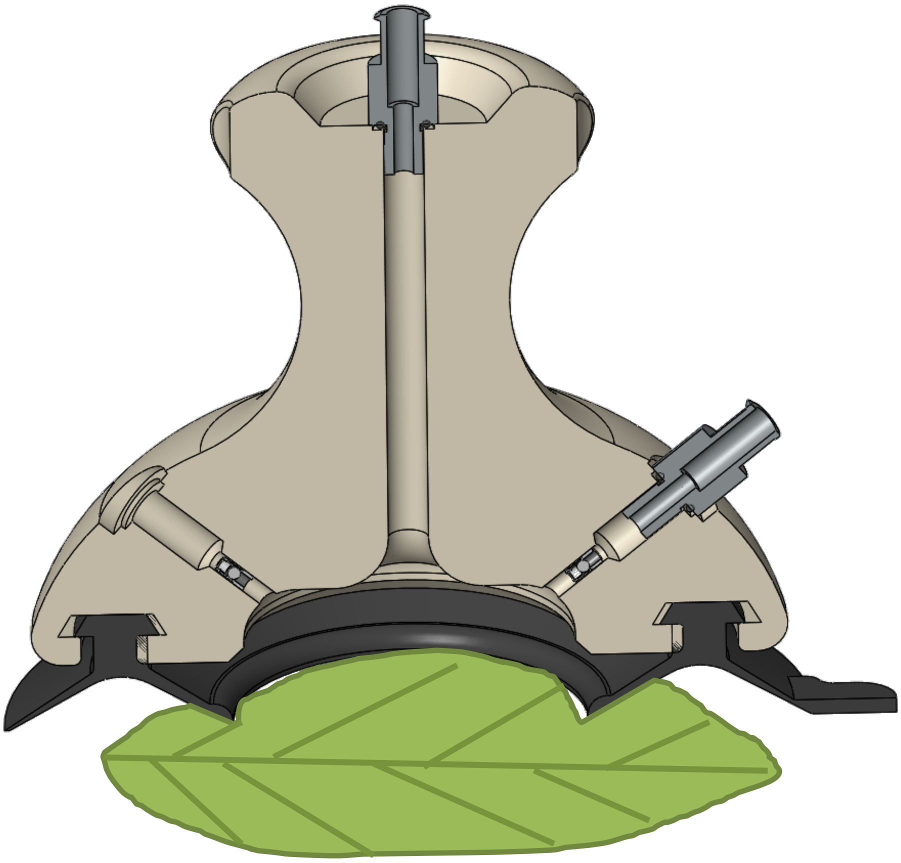


Figure 15-3: Sample Taking on a Leaf.

Also the sample taking with a sample taking unit which has a smaller sampling area (see Figure 15-4) does not allow the whole range of measurements on the plants.

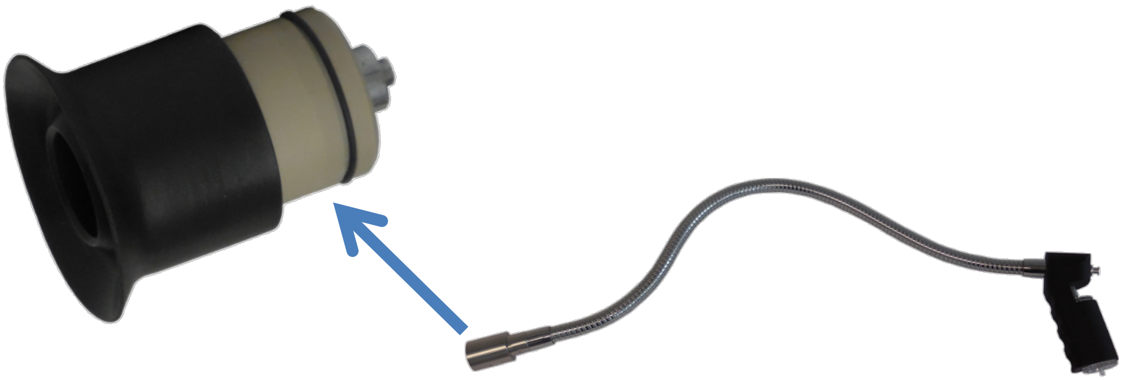
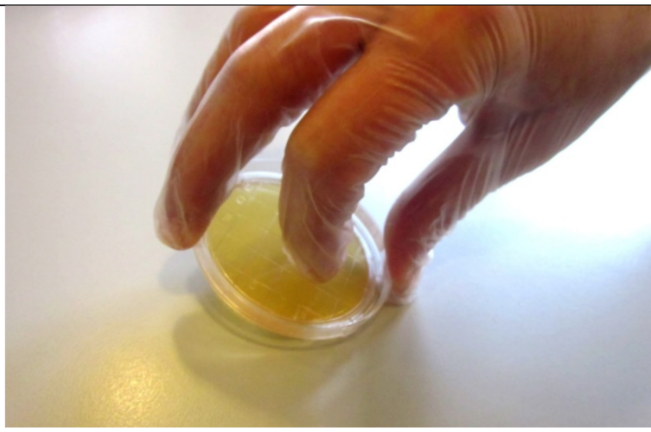
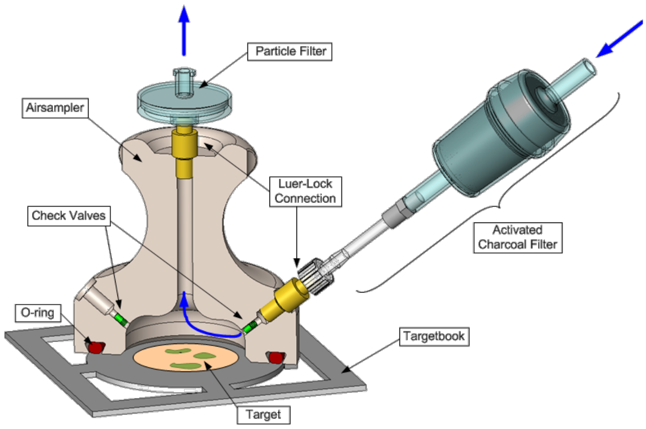


Figure 15-4: Sample Taking for Small Areas.

Indirect Sample Taking on Plants: With regards to the requirements of the plant and the microbial investigation domain an indirect sample taking process was developed for bio-detection (see Table 15-1).

Table 15-1: Indirect Sample Taking Process.

<table>
<tr><td>Step 1: Contact plate is attached to the plant or surface. So a collection of the contamination on a defined area can be guaranteed</td><td></td></tr>
<tr><td>Step 2: The contact plate (target) is now placed under the air sampler</td><td>
</td></tr>
<tr><td>Step 3: The contamination on the contact plate is now measured with the E-Nose</td><td></td></tr>
<tr><td>Optional Step 4: Additionally the contact plate can be incubated for the classical counting of the CFUs (Colony Forming Units).

Remark: Antarctica protection issue has to be checked</td><td></td></tr>
</table>

15.1.2 Training of the E-Nose

For the detection of the contamination the E-Nose needs dedicated training. Therefore a strain is cultivated, measured with the E-Nose and the measurement data is included in the Training-Database.

In the ISS E-Nose project, some strains have been trained already. First of all, it had to be checked if already trained strains are relevant for the EDEN ISS project. The following cultures have been trained before:

- *Bacillus subtilis*
- *Staphylococcus warneri*
- *Aspergillus versicolor*
- *Penicillium expansum*
- *Pseudomonas geniculata*
- *Micrococcus luteus*

In Figure 15-5 below the so-called PCA (principal component analysis) of the E-Nose training with 4 different strains can be seen. If an additional strain will be trained, it will be included in the database in the same manner.

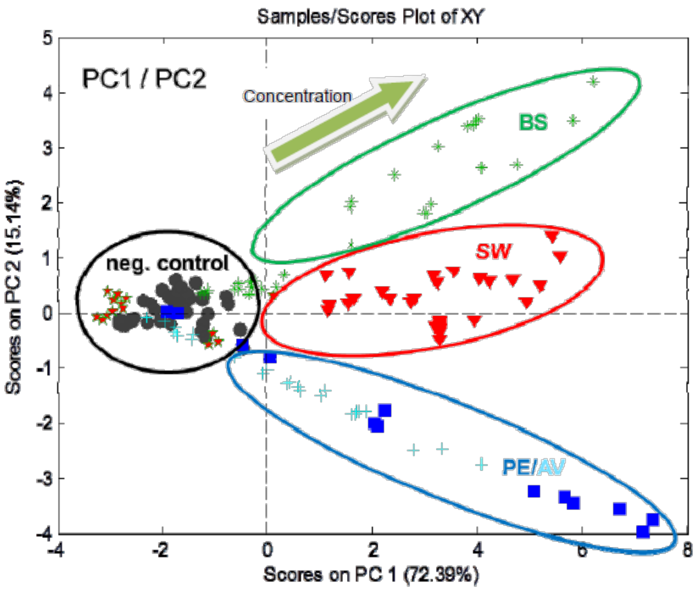


Figure 15-5: PCA of an E-Nose Training Including 4 Strains.

After research and discussion with the dedicated disciplines regarding the relevant strains for the EDEN ISS project, the following could be concluded:

- Only pathogenic strains to be detected
- The most important strains regarding food safety are:
  - *E. coli*
  - *Salmonella spp.*
- If strains to be trained regarding plant health is still open and will be confirmed by DLO

15.1.3 Expression of the Results

For the expression of the results gained with the E-Nose, the thresholds for the maximum allowable concentration of biological contamination on the plants has to be considered. Since there is no expertise regarding regulations given by authorities, the requirements regarding the microbiological load are planned to be combined with the inputs given in the document shown in Figure 15-6 below.

COMMISSION REGULATION (EC) No 2073/2005

of 15 November 2005

on microbiological criteria for foodstuffs

(Text with EEA relevance)

Figure 15-6: Regulation Documentation.

This document includes thresholds for the control of foodstuff contaminations which are not applicable to the EDEN ISS project. By the microbial investigations domain the requirement is given to express the amount of contamination in CFUs (Colony Forming Units). In the document mentioned above there is only a requirement that in 25 g of the fruit the dedicated contaminants have to be absent (the thresholds are still to be clarified by the different disciplines). One also common requirement in the EU regulations is the ALARA - as low as reasonably achievable. For that reason a new view for the expression of measurement data was introduced and agreed by the dedicated parties (see Figure 15-7 below).

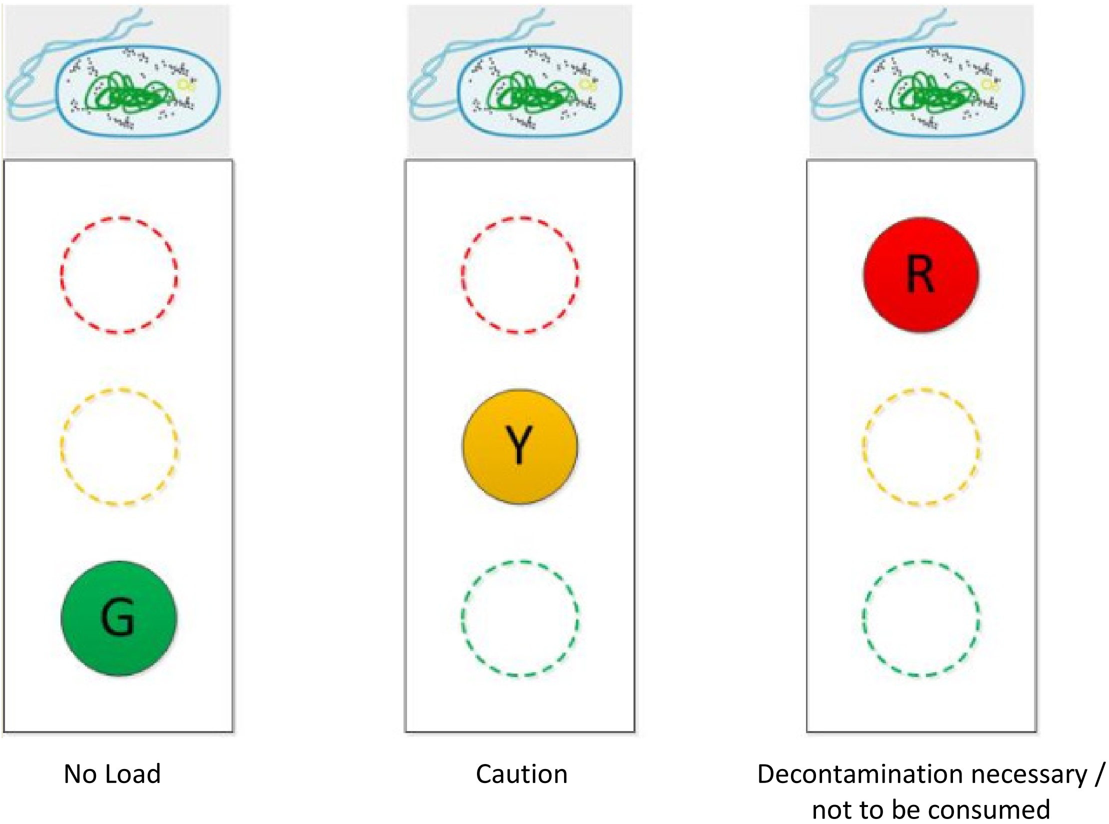


Figure 15-7: Expression of the Measurement Data.

- No Load: If either no contamination is detected or is below the requirement given by the regulation above or below the LOD (Limit of Detection), the measurement can be seen as without contamination
- Caution: If a contamination can be measured (e. g. in a range of 10e5 - 10e8 CFU tbc) it has to be checked if the plants have to be further processed (cleaning, etc.).

- Decontamination necessary / not to be consumed: If a contamination above the maximum allowable limit (TBD) is measured (e. g. higher than 10e8 CFU tbc), the plants are not to be consumed or even the whole greenhouse must be decontaminated.

Remark: It is recommended to perform the measurements of the dedicated plants right before harvest (e.g. one day before). Also if the 4th optional step in Table 15-1 will be applied (culturing), the time between sample taking for the classical analysis and harvest is sufficient to get reliable results on the load of the plants.

15.1.4 Measurement Locations

Since the E-Nose measurements will be compared with the classical analysis the measurement locations for both methods have to be agreed.

The classical microbial investigation method is performed by swabbing of the dedicated surfaces or plants with a FLOQSwab™ (see Figure 15-8 below).

Figure 15-8: Sample Taking of a Surface.

For that reason on the chosen surfaces and plants samples are taken with the FLOQSwab™ (see Figure 15-9) monthly on a predefined area (≤ 25 cm^2). The swab has a Nylon flocked head and is moistened with sterile pure H_2O.

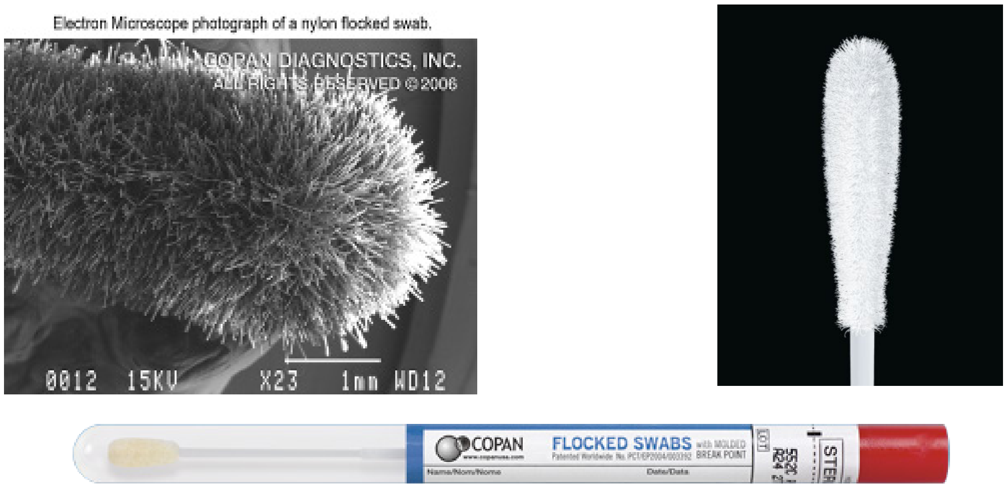


Figure 15-9: FLOQSwab™ for Classical Microbial Investigation.

A draft selection of the surfaces to be measured with the E-Nose and via the classical microbiological method can be seen in Figure 15-10. As it can be seen, there are some surfaces which are monitored during the whole exploitation time of the greenhouse (microbial growth monitoring) but also surfaces of exchanged hardware (e. g. tray) to monitor the effectiveness of the cleaning procedures.

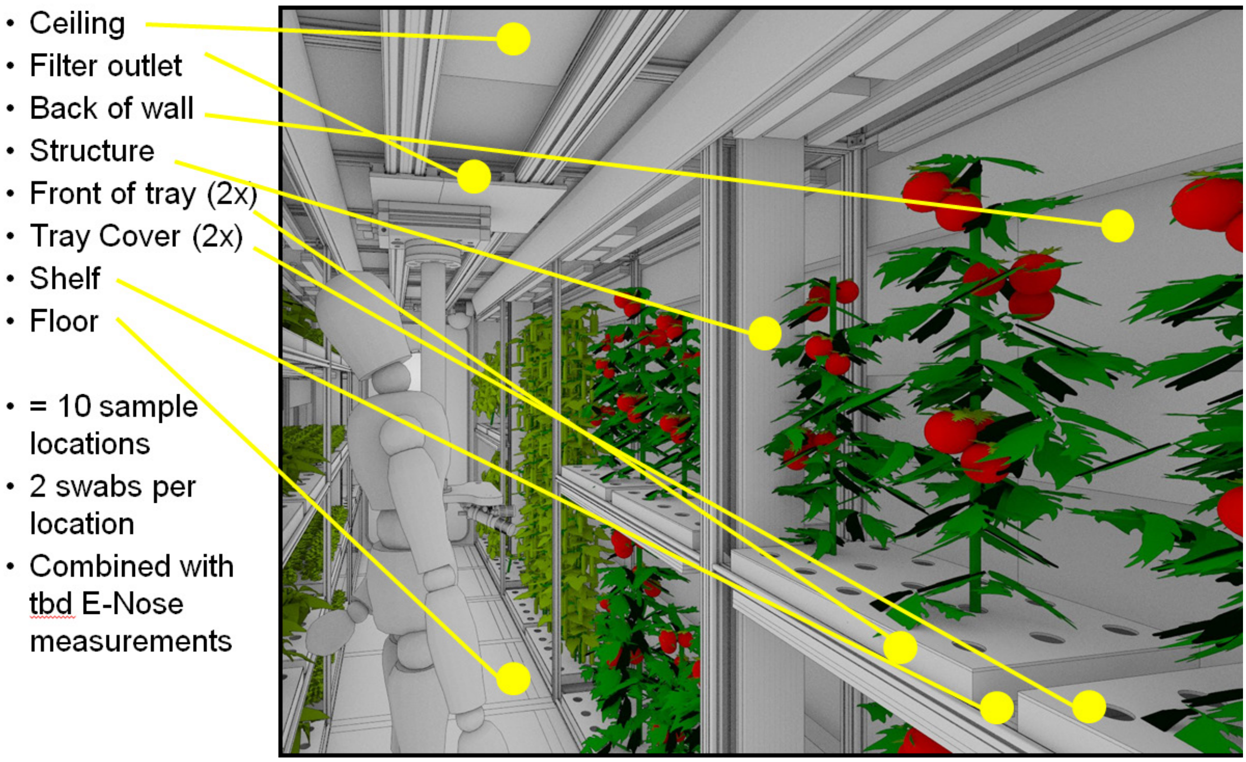
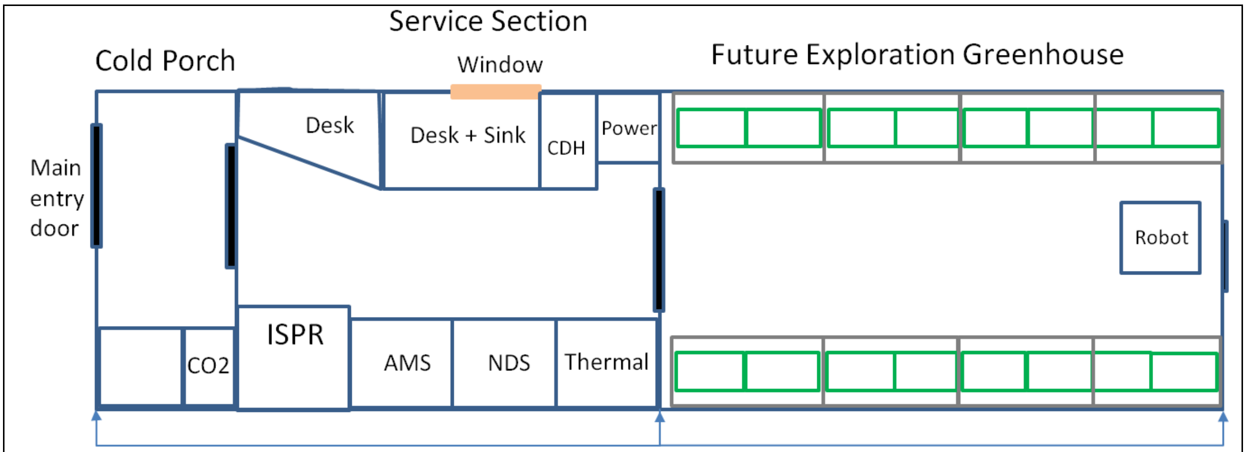


Figure 15-10: Selected Measurement Surfaces.

It was agreed to perform microbial investigation (also with the E-Nose) in the Service Section as well as in the FEG. In Figure 15-11 below the draft distribution of the sample surfaces can be seen. It is planned to perform the classical method and the E-Nose measurements monthly.



Surfaces to be observed: • ISPR - 4 locations • SS - 6 locations	Surfaces to be observed: • FEG - 10 locations Plants to be observed: • FEG - 10 plants

Figure 15-11: Surfaces to be Observed.

15.1.5 Decontamination

If "dangerous" contamination could be found with the microbial investigations mentioned above, it is planned to perform a decontamination.

The already available decontamination system (TransMADDS, see Figure 15-12 below) was judged as too sizable for the purpose of use within the greenhouse. But also other requirements do not allow the decontamination as it was planned before (e.g. decontamination with bacteriophages). The reasons can be found below in this chapter.

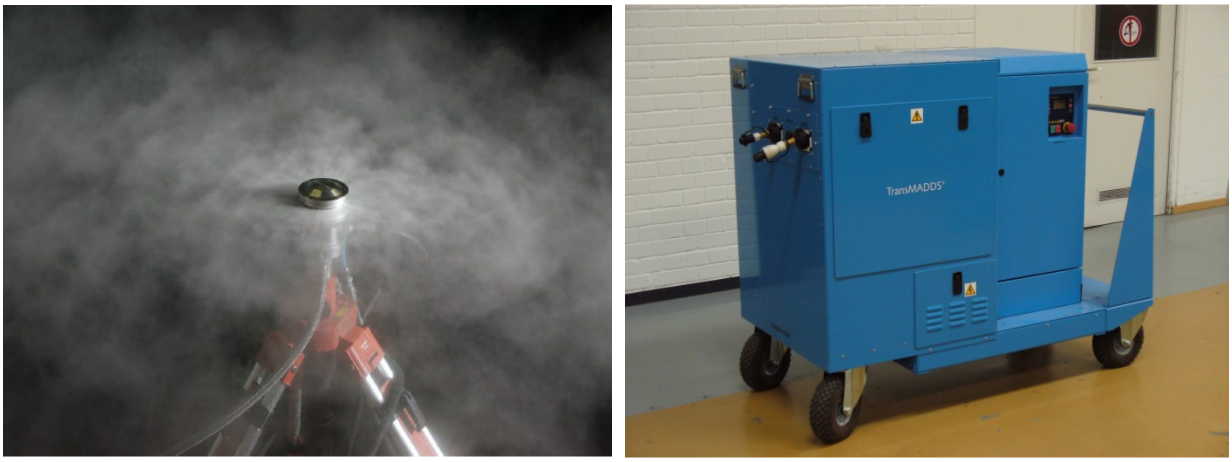


Figure 15-12: The current TransMADDS Decontamination System.

First off, the question was raised if the decontamination system will be stationary installed within the FEG (as it can be seen in Figure 15-13 below).

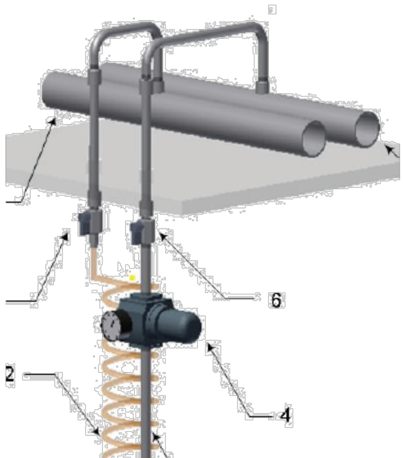


Figure 15-13: Stationary Installed Decontamination System.

Since it is not assumed that the decontamination of the whole FEG will be necessary during the exploitation period, it was decided not to install the decontamination system stationary within the FEG. The system will be stored within the Neumayer Station and brought to the FEG if necessary.

For that reason, a smaller, portable system was chosen for the decontamination of the FEG (an example can be seen in Figure 15-14 below).

Nozzle Compressor

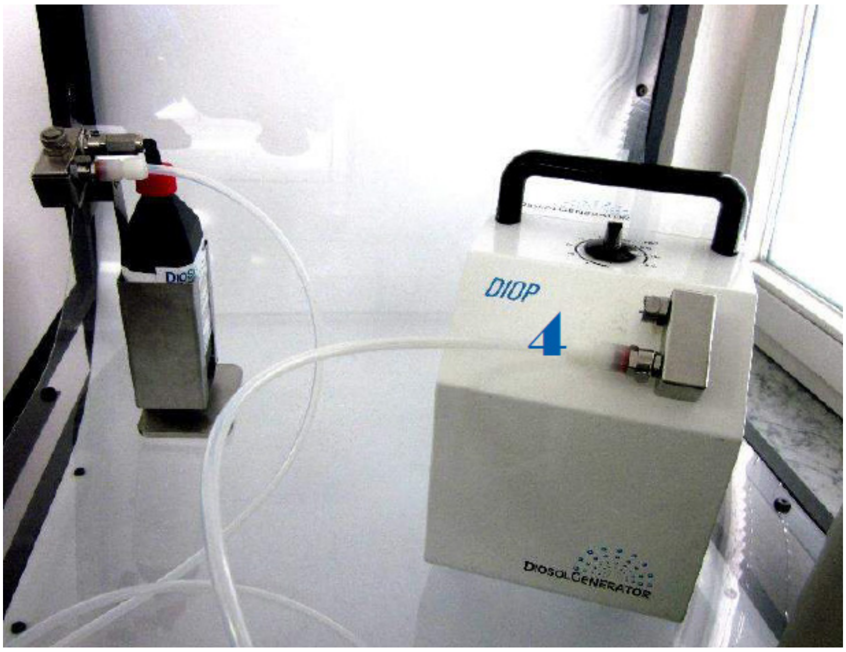


Figure 15-14: Possible Decontamination System.

Also the decontamination agent was discussed with the dedicated disciplines. For the decontamination agent the following requirements could be found:

- Material compatibility (if the agent is destructive to material)
- Plant compatibility (if the agent has an effect on the plants)
- Human compatibility (if the agent is dangerous for human beings)
- Antarctic compatibility (if the agent is harmful to Antarctica)

For that reason the following decision matrix (Table 15-2) has been developed. The following four agents have been compared:

- Peptide (since the effects of decontamination with peptides are not clearly known, peptides have been judged as doubtful)
- Bacteriophages (since bacteriophages are viruses, the dedicated decontamination would not pass the Safety Review Team with regards to Antarctic protection)
- Ethanol (if ethanol is vaporized to a droplet size of up to 1 µm, an explosive gas mixture could be produced)
- Hydrogen peroxide (H_2O_2 was chosen for decontamination since it has no effect on the most involved systems)

Table 15-2: Decision Matrix of Decontamination Agents.

Agent / Effect on	Peptide	Bacterio-Phage	Ethanol	Hydrogenperoxide
Material	OK	OK	OK	OK
Plant	???	OK	?	OK tbc
Human	???	?	OK	OK
Antarctica	???	NO	OK	OK
	Doubtful	Doubtful	EXPLOSIVE	

It still has to be verified if there is an influence of H_2O_2 on the plants (regarding the droplet-size / stomata) and which concentration can be brought out within the FEG.

To show the functionality of the decontamination system (even if there will be no need to decontaminate the FEG) a positive control experiment is planned to be performed with the MTF at DLR Bremen.

15.2 *List of Equipment - Key Values*

Table 15-3: Key values of the Bio-Detection and Decontamination subsystem.

	Mass	Peak power	Power day - nominal mode	Power night - nominal mode
Mobile Test Facility	10 kg	2030 W	0.3 W	0 W
Neumayer Station III	55 kg	0	0 W	0 W
Spares, consumables, tools	TBD	0	N/A	N/A
TOTAL	**TBD**	**2030 W**	**0.3 W**	**0 W**

Fast-Track Pathways for ISS - *Draft*

In the course of the technical analysis over the last months, the project leading team at DLR has analysed and elaborated different options for early developments that may be suitable for direct testing on board the ISS in the scope of this project. The following abstract shall highlight these considerations.

Nevertheless, it shall be stated at this point in time that these considerations are only preliminary and additional analysis and evaluation needs to be conducted in order to confirm such fast-track pathways towards ISS. A common observation is that the EDEN ISS research objectives do not allow big parallel developments within the project. This does not mean that concurrent pathways could not be opened-up, directly targeting a flight opportunity in the coming (near-term) years. Here, the created knowledge, gathered during the EDEN ISS project can be used for these development pathways. A separate development solution would be preferable by the consortium, since it does not put additional development pressure on the EDEN project team. The following options are a first analysis of possible experiments on board the ISS, which will be iterated with the consortium over the next months until a final statement can be made at the CDR in March 2016:

- **ISPR Developments:**

  With respect to system testing on board ISS, most chances can be seen within the ISPR developments, but additional funding is necessary for these options. Three areas were investigated:

  - Full Rack System:

    The cultivation system was conceptualized as a modular approach, which allows investigations and thus flight possibilities even on subsystem level. Two major cultivation systems were designed; one for small growing plants (e.g. lettuce) and one system for taller plants (e.g. dwarf tomato). The development strategy was linked to the EDRII developments, currently being built for ISS deployment under TAS-I project lead. The design team decided to split the cultivation system in half, meaning that on each side of the EDR II, one cultivation system can be mounted.

    The two growth chambers are built-up in the same fashion with respect to illumination- and air management system. The NDS is centralized and serves both chambers. The same accounts for the control and data handling system.

    Putting the full system, or at least one growth chamber, on a fast-track towards ISS would be possible, but requires the following actions:

    - Redirecting the project scope for the ISPR within EDEN ISS.
    - Additional funding for space-ready hardware for some components within the growth system (the foreseen hardware for the analogue mission already follows a flight design, but the components are not flight-certificated so that dedicated hardware needs to be purchased).
    - Additional funding for engineering the adaptation towards a full space deployment.
    - Space readiness testing could be conducted or assisted by ESA (at their own expense)

    Summarizing, the conclusion can be made that, in principle, a full or part rack system capable of an ISS deployment can be made, but a substantial increase in funding needs to take place for such an undertaking. A dedicated program would be advisable for this option. Therefore, the potential for this fast-track option has to be seen as unlikely within the limited budget scope of the EDEN ISS project.

Nevertheless, the developments steps that will take place in the next months will highly contribute to a potential flight readiness of a full EDR II cultivation system. This contribution shall be seen also in conjunction with the Food Complement Unit (FCU) project of ESA (MELiSSA group) with TAS-I as project lead. Significant synergies should be investigated in the coming months on this subject.

Likelihood: low; Budget increase: substantial

- Nutrient Delivery System:

  Looking on the subsystem level within the ISPR, the NDS has the highest likelihood to be put on a fast-track path. Here, possible NDS deployments could be envisioned in collaboration with the US VEGGIE system from ORBITEC, which is currently on board the ISS. The VEGGIE unit does not have an active NDS and here the EDEN ISS system could function in conjunction with the VEGGIE unit as an integrated system. Doing so, would require collaboration willingness of the American/European side of course. Although, the design of the NDS follows already a strict flight development pathway, the purchase of flight ready components is not yet foreseen in the NDS work package and would need to be funded separately.

  Likelihood: low/medium; Budget increase: medium (but not yet defined)

- Root Module:

  A scaled-down deployment option with respect to the NDS could be to only test the root compartment with integrated sensors. This would again be integrated into the VEGGIE unit, but also a possible integration into the European Modular Cultivation System (EMCS) may be feasible. Here a premixed irrigation solution would be used for irrigation of the root zone. Humidity patterns and salt accumulation could be investigated for this type of ISS experiment.

  Likelihood: medium; Budget increase: medium/low (but not yet defined)

- **LED fixtures**

  Plant growth LED fixtures being tested as part of the EDEN ISS project, in both the FEG and ISPR, could be put on a fast-track path for flight. Such hardware could be integrated into a number of different on orbit facilities but some addition analysis and adjustment to the hardware would be required depending on the decided upon on orbit implementation (e.g. water cooled, desired light levels).

  Likelihood: medium; Budget increase: medium/low

- **TransMADDS**

  Originally, the TransMADDS system was considered for a fast-track path, but after deeper analysis and considering the hardware budget for this system as well as the strict safety regulations for ISS testing (with respect to the cleaning agent), this option was ruled out.

  Likelihood: very low; Budget increase: substantial

- **E-Nose (pathogen extension pack)**

  The E-Nose system already has a flight-ready status, since it was previously tested on board the ISS. The new aspect that could be tested would be the new pathogen species catalogue, established by the scope of the EDEN ISS project and dedicated to plant cultivation processes. Possible testing on board the ISS could envision the examination of the microbial environment within different growth chambers (e.g. VEGGIE, EMCS).

  Likelihood: high; Budget increase: none (when E-Nose will be tested on ISS anyway)

- **Food safety measurement procedures**

  Within this domain a set of different procedures dealing with plant health-, food safety-, and food quality procedures were worked out during the EDEN ISS CE study. A variety of different handling procedures were worked out, incorporating a set of handheld devices for quick tests (e.g. nitrate meter, colorimeter) of the food safety- and quality status of the harvested biomass.

  Here again, existing ISS plant growth chambers need to be integrated into the experiment plan, since they need to provide the edible biomass products for on-board testing.

  Likelihood: high; Budget increase: low (depending on ISS safety regulations with respect to handheld devices)

Preliminary conclusion:

As of now, the project team only sees concurrent pathways for the last two options (E-Nose and food quality) without major additional funding possibilities. For the full rack system option and its sub options, additional funding is required (medium to high), which cannot be covered by the project itself. Nevertheless, all possibilities will be revisited again in the next few months and even new options may be considered. A final conclusion can be made during the CDR in March 2016.

References

Amundson, S. et al., 2012. Optimizing plant density and production systems to maximize yield of greenhouse-grown 'Trust' Tomatoes. *HortTechnology,* Volume 22, pp. 44-48.

ASCE, 2003. *ASCE Standard - Minimum design loads for buildings and other structures - SEI/ASCE 7-02,* s.l.: American Society of Civil Engineers.

Audimute, 2015. *Eco-C-Tex & Acousticolor acoustic material tiles.* [Online]
Available at: http://www.audimutesoundproofing.com/acoustic-material.aspx
[Accessed 09 2015].

AWI, 2006. Technische Spezifikation für zwei 20' Container als Spurenstoffobservatorium (NM-III Air Chemistry Oberservatory Specifications).

BD Index, 2015. *Building Design - Better decisions for better environments.* [Online]
Available at: http://www.buildingdesignindex.co.uk/
[Accessed 09 2015].

Bilco, 2015. *Bilco - The worldwide source for specialty access products.* [Online]
Available at: http://www.bilco.com/
[Accessed 09 2015].

CEL Components, 2015. *Honeycomb Panel - COMPOCEL AL Floor.* [Online]
Available at: http://www.honeycombpanels.eu/index.php?IDcod=119&lang=uk
[Accessed 09 2015].

Engineering Edge, 2015. *Structural beam deflection equations and stress formula and beam deflection calculators.* [Online]
Available at: http://www.engineersedge.com/beam_calc_menu.shtml
[Accessed 09 2015].

GK Marine, 2015. GK-Packsysteme - Packing Systems - Catalogue.

Grainger, 2015. *Green Gas Cylinder Cabinet.* [Online]
Available at: http://www.grainger.com/product/SECURALL-GreenGas-Cylinder-Cabinet-38V829
[Accessed 09 2015].

Linde, 2008. *Produktendatenblatt: Kohlendioxid.* [Online]
Available at: http://produkte.linde-gase.de/db_neu/kohlendioxid.pdf
[Accessed 09 2015].

NASA, 1999. International Space Station Flight Crew Integration Standard - NASA-STD-3000/T.

Refco, 2015. *Condensate Pumps - Karoo.* [Online]
Available at: http://www.refco.ch/en/products/condensate-pumps.php
[Accessed 09 2015].

Stanghellini, C., 1987. Transpiration of greenhouse crops. An aid to climate management - PhD Thesis - Wageningen.

The Engineering ToolBox, 2015. *Modulus of Elasticity or Young's Modulus.* [Online]
Available at: http://www.engineeringtoolbox.com/young-modulus-d_417.html
[Accessed 09 2015].

TYFOROP Chemie GmbH, 2015. *Tyfocor.* [Online]
Available at: http://www.tyfo.de/
[Accessed 09 2015].

Zwart, H., 1996. Analyzing energy-saving options in greenhouse cultivation using a simulation model - PhD Thesis - Wageningen.