MELiSSA

TECHNICAL NOTE 96.9

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TECHNICAL NOTE 96.9

HPC1 mapping protocols and procedures

Prepared by/Préparé par	EnginSoft/UAB
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ACRONYMS

CESRF	Controlled Environment Systems Research Facility
CFD	Computational Fluid Dynamics
HPC	Higher Plant Chamber
HVAC	Heating Ventilation Air Conditioning
MSDS	Material Safety Data Sheet
PAR	Photosynthetically Active Radiation
PP	Polypropylene
PPF	Photosynthetic Photon Flux
RH	Relative Humidity
UAB	Universitat Autònoma de Barcelona
UoG	University of Guelph

1.Scope

The present document specifies the protocols to be followed for the mapping activities to be carried out on HPC1 as per the requirements expressed in AD5 and for the following parameters : pressure, temperature, humidity, light and air velocity.

2.Reference and applicable documents

2.1.Applicable documents

AD1	19071/05/NL/CP	Frame Contract between ESA and UAB AD2
AD2	MPP-OFR-08-0001(3)	Proposal for Call Off Order 6 – HPC1 installation and start-up in the MPP
AD3	MPP-QA-07-0001	MPP Quality Manual
AD4	MPP-QA-07-0003	MPP rules for good lab practices
AD5	TN96.8	HPC1 mapping requirements

2.2.Reference documents

RD1	TN85.71	HPC1 User Manual
RD2	TN95.1	HPC1 control requirements and software description

3.Acronyms/Definitions

HPC1	Higher Plant Compartment 1
MPP	MELiSSA Pilot Plant
UAB	Universitat Autònoma de Barcelona
MELiSSA	Micro Ecological Life Support System Alternative
CFD	Computational fluid dynamics
PLC	Programmable logical computer
RH	Relative humidity
HPS	High Pressure Sodium
MH	Metal Halide

HVAC	Heating Ventilation Air Conditioning
SES	Sensor for Electromagnetic Spectrum

4.Test items

4.1.Description (PID, technical drawings, user manual)

- Higher Plants Compartment (HPC1) is described in document RD1
- PID and Sherpa control are described in documents RD2

4.2.Hazards induced by test item and safety measures to be taken

- Mechanical hazard (pump, blower)
  - The protection against these hazard is ensured by the panels preventing access to these equipments
- Pressure hazard (compressed gases mixtures in K-size tanks at 200barg, and N_2 and O_2 building supplies at 6 bars)
  - The presence of gas pressure regulators on the gas cylinders and building supply tubing reduces the delivery pressure down to 2 barg
- Intense light hazard is present for the light mapping activity ; the operator have to wear the adequate sunglasses to avoid blinding effects of the lights

4.3.Instructions for operation

- See user manuals RD1 and RD2

4.4.Instructions for maintenance

- See user manual RD1

5.Protocols

5.1.General guide-lines

Following are the guide lines recommended for the mapping measurements:

- The chamber should be closed (air lock and curtains) and the shutter should be placed on the central side glass
- The plants should not be placed inside the chamber
- The sensors should be placed in the specified positions
- The lamp sequence should not be changed during the measurement activity
- The blower should work in stable condition (no rpm or flow rate changes)
- The 20 trays should be all placed inside the chamber
- The trays should be equally spaced (mid position of the tray spacer)
- The trays spacing should not be modified during the measurement activity
- If the chamber were to be opened for operating on probes, the following measurement should be taken in the same operating conditions as before (based on the chamber sensors T and RH) (10 to 15 min)
- If curtains only were to be opened, as before, the stabilization time should be a few minutes

5.2.Light measurement under the glass panel

These measurements have to be taken separately under one MH lamp and then under one HPS lamp.

The W/m^2 distribution will be monitored right below the tempered glass (approximately 5cm distance) which divides the chamber from the lighting system for the two different lamps. The objective is to evaluate the spatial distribution of the light intensity and to characterize the spectrum of the lamps. To this end, the light measurement points should be placed as shown in **¡Error! No se encuentra el origen de la referencia.¡Error! No se encuentra el origen de la referencia.**.

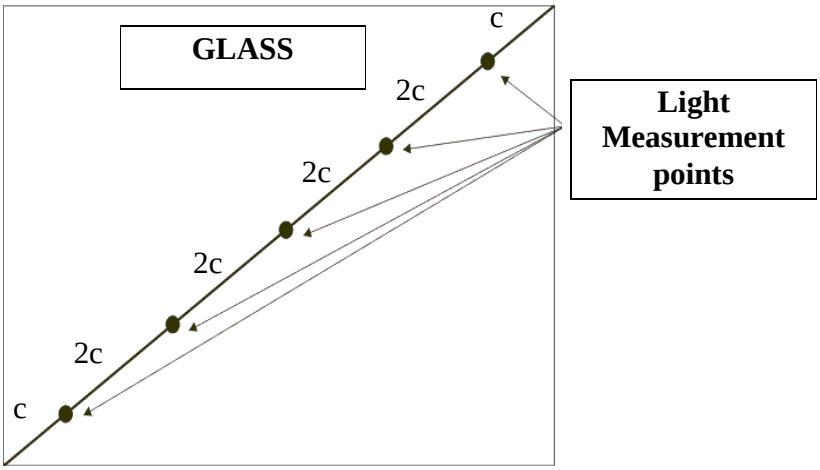


Figure 1 Light measurement points

5.2.1.Environmental requirements:

T, RH and P conditions can be chosen freely.

5.2.2.Operating conditions:

The lamp under measurement should be switched on ; the other lamps can be switched off, or be kept on.

5.2.3.Variables to be recorded:

Position of the measurement point, with respect to glass and to the lamp (for the lamp the overall dimensions and position of the center of the filament should be taken);

Light intensity spectrum in the spectral range of each sensor (as a digital curve)

5.2.4.Test Procedure:

Step #	Description	Required	Remarks
1	Install hardware for performing the measurement under the selected lamp	y	
2	Switch on the lamp under measurement and wait 15 minutes for stabilization	y	The lamp should not be switched off until measurement termination, assure lamp compartment ventilation is on
3	Measure the lamp power consumption	Possibly yes	
4	Mark each point of measurement with a distinctive label	Y	Should be different for the two lamps, take a picture of the hardware frame or a sketch
5	Take spectrum for each point and each spectral band available, take light intensity (depending on hardware could be taken at same time or in two different steps)	y	UV should be negligible
6	Take the position (xyz) of the point of measurement.	y	
7	Repeat 5,6 for each of the 5 measurements under each lamp		
8	Repeat 1-7 for the other lamp		

5.3.Light measurement at tray level

The light intensity will be measured in proximity of the trays with the TRISTAN 5 sensor or equivalent for electromagnetic spectrum, adequate for the spectral characterization (see appendix 1 for the datasheet).
The required measurement points are shown in the following figures. As the measurements do not need to be performed all at the same time, the SES sensor will be moved from one measurement point to another in order to cover all the specified positions.

The SES sensor type TRISTAN 5 is regarded as adequate for the spectral characterization, but any other equivalent is acceptable.

There will be three different positions (planes) for this test, and for each of these planes (in a cross section of the chamber, see Figure 2), three points of measurement.

The three cross sections selected are as shown on Figure 3:

1. Section 1 : under an MH lamp (on the middle plane of the lamp), just the lamp under consideration switched on
2. Section 5 : under an HPS lamp (on the middle plane of the lamp), just the lamp under consideration switched on
3. Section 7 : in between the chosen MH and HPS lamps, with both lamps switched on

A = 20 cm
Distance between
- Probe
- Wall

B = 20 cm
Distance between
- Probe
- Top of the tray

SES = Sensor able to detect the Electromagnetic Spectrum

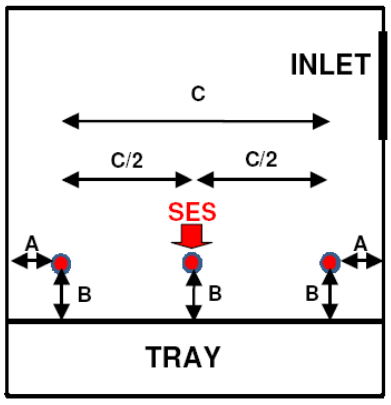


Figure 2 Measurement points in the cross section

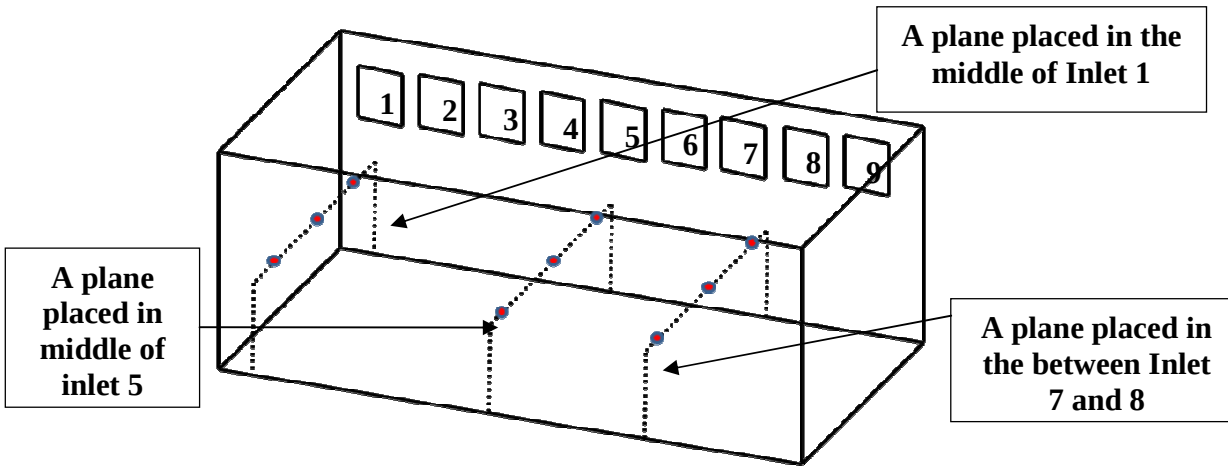


Figure 3 Measurement points along the axis and location wrt the air inlets

5.3.1.Environmental requirements:

No special requirement for T, RH and P conditions.

Curtains are left open.

5.3.2.Operating conditions:

All lamps are witched on for positions 1, 5 and 7.

5.3.3.Variables to be recorded:

Point of measurement position, with respect to inside of the chamber;

Light intensity spectrum in the spectral range of each sensor

5.3.4.Test Procedure:

Step #	Description	Required	Remarks
1	Install hardware for performing the measurement in section 1	y	Verify correct positioning of the sensor
2	Switch on the lamp under measurement and wait 10 minutes for stabilization (one or two depending on cross section)	y	The lamp should not be switched off until measurement termination, assure lamp compartment ventilation is on
3	Measure the lamp power consumption	n	Already done previous step
4	Mark each point of measurement with a distinctive label	Y	Should be different for the two lamps, take a picture of the hardware frame or a sketch

5	Acquire spectrum for each point and each spectral band available, measure light intensity for the A position	y	
6	Note the position (xyz) of the point of measurement for the A position	y	The reference should be taken from the chamber walls and the lamps
7	Repeat 5,6 for positions B and C		
8	Repeat 1-7 for section 5 and section 7		

5.4.Light measurement Verifications

There will be two other points for verifications that should be taken into account:

1. a measurement at half way between the glass and the tray, just to verify the distribution on the height. This measurement should follow the same protocol as on trays, but taken at a height of 50cm above the trays. This can be done indifferently on the MH or HPS lamp.
2. A reflection measurement: The reflection measurement should be taken on the first lamp near the curtains, putting a white paper at 20 cm on trays and measuring the reflection on the paper from the highest position available inside the chamber; the same protocol as above is applicable.
3. A light intensity measurement will be made above the glass panel for one MH lamp and for one HPS lamp.

5.5.Pressure mapping

5.5.1.Definition of the sensors

Five pressure probes are required in total. They will be PTX 7500 with the characteristics detailed in appendix 3.

5.5.2.Location of the sensors

The two first probes P1 and P2 are placed in the plenum of the chamber (see Figure 4), to check the balanced pressurization of the air plenum distribution system.

The P3 probe is placed in proximity of the HVAC return entrance below the air balancing panels and above the chamber floor (see Figure 5), to evaluate the pressure drop before the HVAC system thermally processes the air.

The P4 probe is placed between the cooler and heater (see **¡Error! No se encuentra el origen de la referencia.**) to validate with P3 the pressure drop of the cooler.

The last probe P5 is placed in the lower right of the HVAC system (see **¡Error! No se encuentra el origen de la referencia.**),to validate with P4 the pressure drop of the heater and with P1 and P2 the pressure rise of the blower.

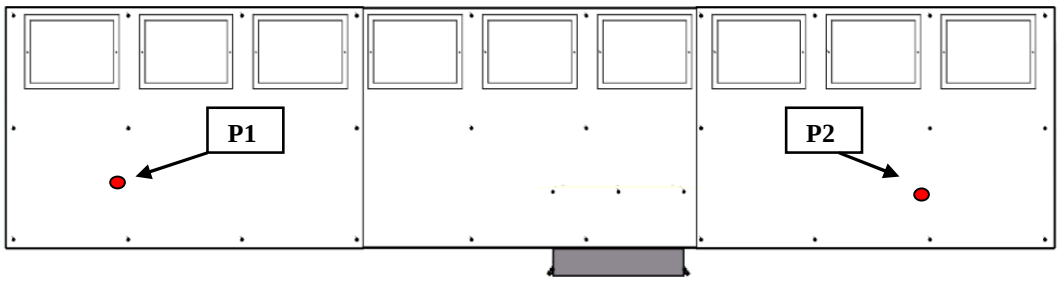


Figure 4 Pressure probes in the plenum of the chamber

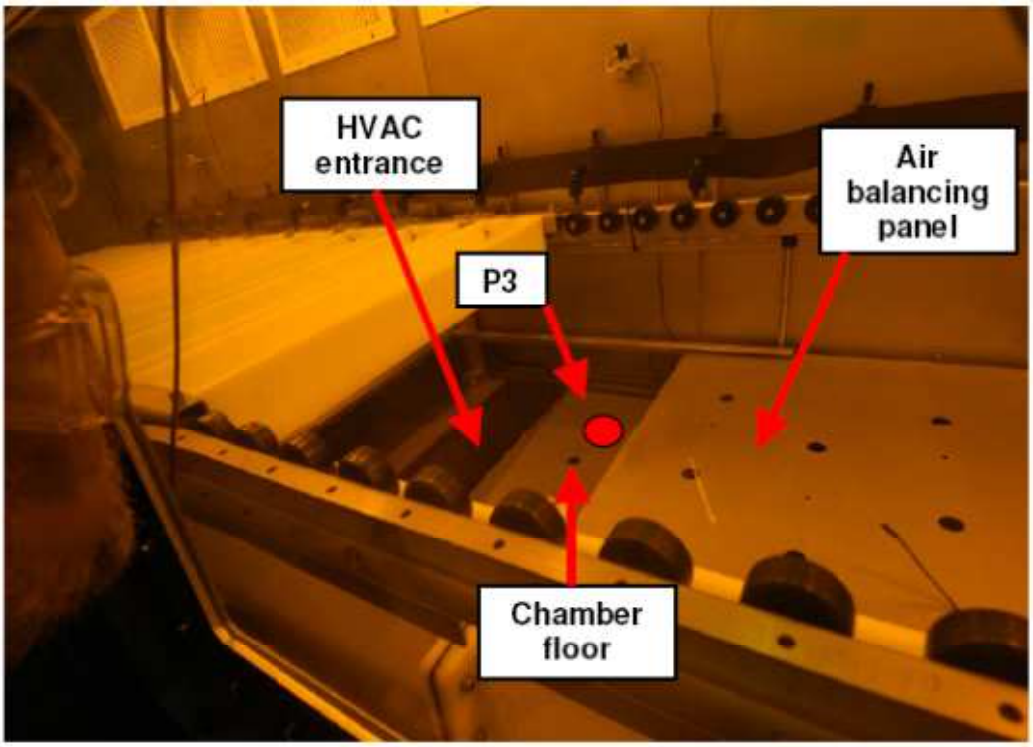


Figure 5 Pressure probe in proximity of the HVAC entrance

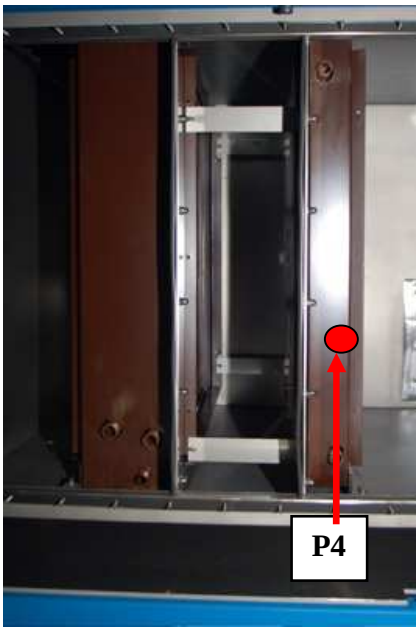


Figure 6 Pressure probe between the heater and the cooler

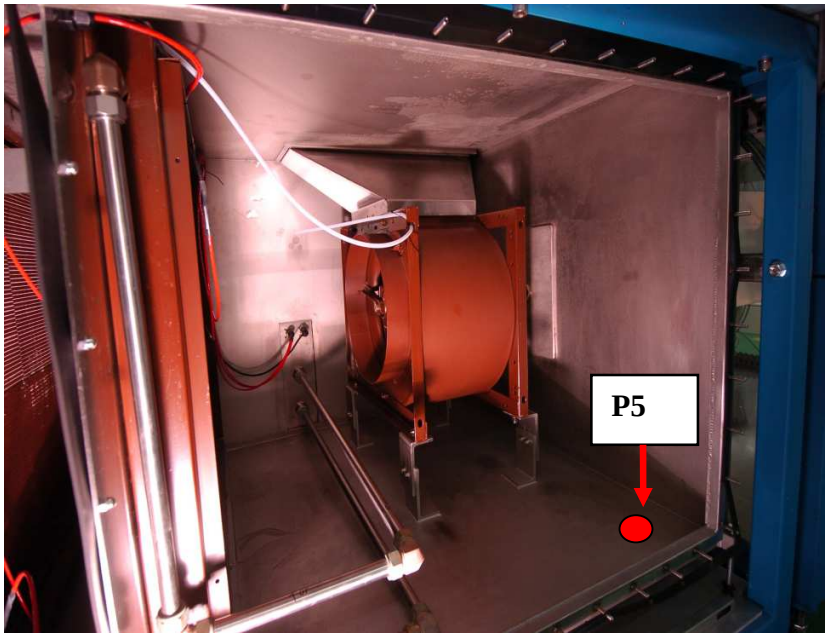


Figure 7 Pressure probe in the HVAC

5.5.3.Test Procedure :

See par 5.6

5.6.HVAC mapping

5.6.1.Location of the sensors

The cross section of the chamber with the trays in place measures about 75*90 cm^2 (b*h). On this section the measurement points are placed as shown in Figure 8:

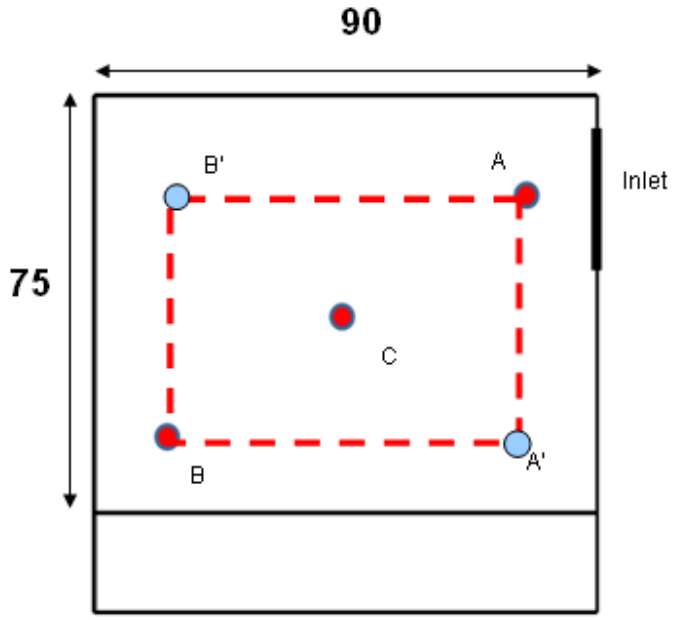


Figure 8 Cross section

- Point A centered on the air inlet at 7-8 cm distance from it.
- Point B positioned 7-8 cm distance from the wall and 7-8 cm distance from the top of the tray
- Point C placed in the middle of the diagonal between point A and B
- Points A' and B' are specular and measurements could be taken during the way back of the movement of the trays, changing the connecting poles.

As the air velocity field changes a lot with the height, the measurement ranges differ on the basis of the measurement point:

1. Point A: range 0.5 – 10 [m/s]
2. Point B and C (B' A'): range 0.1 – 2 [m/s]

The probes could be different in order to accommodate the different velocity ranges.

On the longitudinal direction the measurements should be scanned as shown in Figure 9.

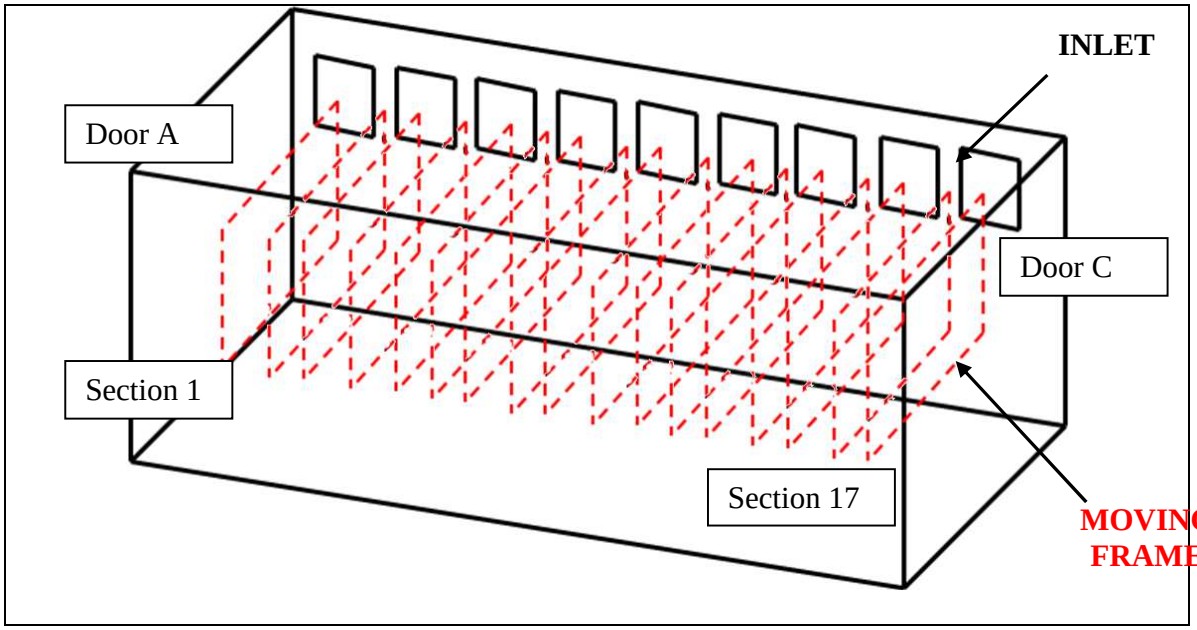


Figure 9 Measurements on the longitudinal direction

The position of the sensors are determined by marks placed in the chamber with reflecting tape that could be aligned with a mark placed on the tray. The tray will be moved by displacing the trays through the chamber. It can be needed to open, remove the tray and insert new trays while moving the sensors.
This can force to wait to recover the test conditions before performing a new measurement. In principle, a stabilization time of 10min is expected between two positions on the chamber longitudinal axis.

The total number of sensors is 3 temperature probes, 3 RH sensors and 3 air velocity sensors. In principle RH and temperature sensor are usually implemented in a unique device capable of performing both measurements. Velocity sensors include one sensor in the range of 0.15 - 1 m/s for very low air flows and two sensors in the range of 0.5 to 10 m/s.

See appendix 2 for the exact geometry of the support and location of sensors

5.6.2.Variables to be recorded:

- Point of measurement position, with respect to inside of the chamber;

- Temperature, relative humidity and air velocity
- All other environmental parameters of HPC1 including the P1, P2, P3, P4, P5 probes for the additional pressure measurements explained in 5.5.

5.6.3.Sensors accuracies

The accuracy of the air velocity probes should be 0.08 [m/s] measured at 0.5 [m/s] for the magnitude of the velocity.
The temperature and Relative Humidity probes have the following accuracies:

- 0,1deg C for T
- 3% for RH

5.6.4.Environmental requirements and operating conditions:

The test consists in acquiring a set of data (30 seconds) displacing the setup by 25 cm for each acquisition, with a total of 17 positions (the chamber is 5 meters long). In addition, the test must be performed with a controlled temperature and humidity, around 22 ºC, and repeated for 2 different RH, and with the lights on and off, resulting in 4 different runs.

The conditions for each run are summarized in the following table:

Run name	Lighting	Temperature setpoint	Humidity setpoint	Configuration of sensors	Sense
Scan 1	100% ON	26ºC	50%	Long sensor support at plenum's side, short support at window side.	17 to 1
Scan 2	100% OFF	20ºC	60% to 70%	Long sensor support at plenum's side, short support at window side.	1 to 17
Scan 3	100% OFF	20ºC	60% to 70%	Short sensor support at plenum's side, long support at window side.	17 to 1
Scan 4	100% ON	26ºC	50%	Short sensor support at plenum's side, long support at window side	1 to 17

5.6.1.Test procedure :

Step #	Description
1	The sensor's harness is placed at one end of the HPC and as many trays as possible (6 or 7) are placed between the curtain and the door, at the side where the sensors are. The gap between the door and the curtain at the other side is kept empty
2	The HPC is closed and the test conditions are introduced as control loop set points.
3	An initial stabilization time is left so that the set-point values are reached and HPC is steady. This time should be at least 10 minutes.
4	When HPC is steady, a 90sec data acquisition is performed on temperature, humidity, and air flow velocity. Sampling time is 1 second for these sensors. For all the other HPC1 sensors, the chamber parameters are also acquired but at a sampling frequency of 5 sec.
5	Trays are shifted without opening the HPC doors by extracting one tray at the end where the measurement tray is supposed to move and inserting a new tray at the opposite end (whenever possible). HPC stabilization after such a manipulation is awaited for at least 30 sec.
6	Steps 4 and 5 are repeated as long as there are available trays stored between the curtain and the door.
7	When this condition is not true any more, HPC doors are opened (without opening the curtains) and trays accumulated at one side of the compartment are removed and brought to the other. Stabilization time after this manipulation is established as 10 minutes. Ideally, the HPC1 is opened three times for each scan
8	Repeat 1 to 8 for the following scan

During measurements all PLC reference values on the HPC1 existing sensors should be available to be sure of the operating conditions inside the chamber.

5.6.2.Data acquisition conditions

During the mapping tests, the PLC (control system) will perform the mapping measurements of T, RH and Air-flow on all available points at the same instants.

6.Conclusions

The table below summarizes the equipment required for the proposed new measurements.

Sensor	Number	Position	Remarks and Reminders
Pressure	5	Fixed	Used to check the static pressure drops of the air flow across the locations pointed out in paragraph **¡Error! No se encuentra el origen de la referencia.**
Velocity	3	Moving on rail/frame	Only magnitude probes are requested in the range 0.1-5 m/s or larger with required accuracy
Temperature	3	Moving on rail/frame	Required range 0-40 deg C
Relative Humidity	3	Moving on rail/frame	
Light Intensity	1	Moving	The light intensity distribution is evaluated by moving the SES sensor in the specified position below the tempered glass and above the trays.

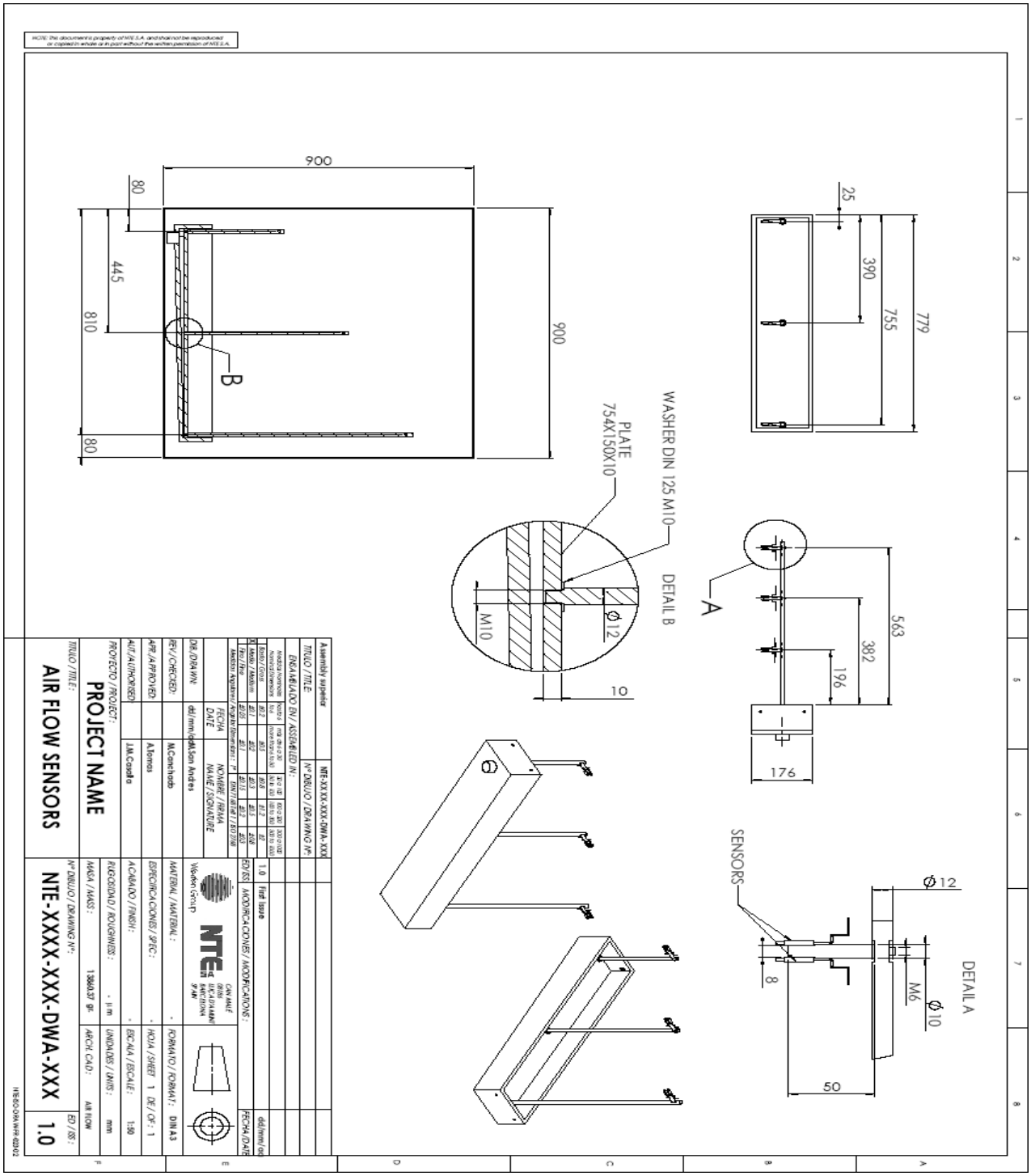
Table 1 Equipment summary

The proposed new measurements are necessary and sufficient for the characterization of the plant growth chamber.

The moving frame for T RH and V measurement could be equipped with at least 3 probes and swapped at the extremity to monitor a total of 5 points for each section.

To limit the number of probes and cut costs, just one light intensity probe could be used. As mentioned in paragraph **¡Error! No se encuentra el origen de la referencia.**, the light measurement are not supposed to be performed all at the same time thus the light intensity probe could be moved from one measurement point to another in order to cover all the specified positions (10 points below the glass and 9 points above the trays).

7.Appendix 1 -Test harness for the HVAC mapping.



8.Appendix 2 - SPECTROMETER TRISTAN-5 (200-800 nm) data sheet

PHOTO RESEARCH®, Inc.

The PR®-655 SpectraScan® Colorimeter

Unique Design

For nearly 15 years, the PR-650 SpectraScan has been the most widely used spectroradiometer in the world - the workhorse of the industry. The new PR-655 replaces the world renowned PR-650 with a plethora of enhancements. This unique, portable battery powered instrument utilizes a fast-scanning 128 detector element spectrometer with a spectral resolution of 3.12 nm per pixel and is supplied with an automated measure shutter. A 1º measuring field is standard equipment with the PR-655 - a 1/2º aperture can be ordered as an option. Other hardware features include AutoSync® for automatically synchronizing to the source refresh rate insuring the utmost accuracy, an external trigger port allowing remote measurement activation from either a push button or perpherial device, a Secure Digital (SD) port for measurement storage, and a long lasting rechargeable Lithium-ion (Li) battery.

PR-655 SpectraScan Colorimeter

Easy to Use

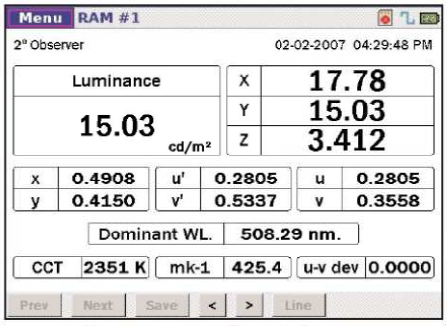
The PR-655 menus are accessed via the on-board, 2.25" x 3" high resolution, full color touch screen LCD display and 5-way navigation keypad. Following a measurement, the PR-655 displays data *and* color spectral graphs on the system display. The PR-655 design provides stand alone operation - no PC required. The PR-655 can be also controlled via the world famous SpectraWin software over the USB or Bluetooth interface or using text based commands (Remote Mode).

Flexibility

The unique design of the PR-655 makes tasks such as spectrally based photometric and colorimetric measurements, source spectral power distribution, dominant wavelenth and correlated color temperature quick and simple.

The PR-655 can be supplied with up to 15 filter based remote heads connected to the instrument in a 'daisy chain' configuration to make simultaneous illuminance or luminance measurements - an ideal tool for tasks such as projector uniformity. Select heads for luminance, illuminance or chromaticity.

For applications other than radiance or luminance the PR-655 can be supplied with optical accessories such as a cosine receptor for irradiance / illuminance, LR-127 LED Analyzer for testing LED's to CIE 127, fiber probe for remote non-line-of-sight luminance testing, and a series of magnification lens for small spot size analysis. In fact, all of the accessories available for the PR-650 SpectraScan can be used on the PR-655. An RGB option is available that provides an interactive method for display white point calibration based on spectral measurements.



Measurement Result Screen

Connectivity

It's easy for the PR-655 to talk to the outside world - it comes equipped with USB and (optional) Bluetooth® wireless interfaces. It is supplied with text based, Remote Mode syntax and a driver that emulates an RS232 interface (COM: port) making it a simple task to generate custom programming to perform specific tasks or for inclusion in an ATE environment. If you want, we can optionally add a traditional RS232 I/F.

Applications

Display luminance and color	Medical / dental color testing
Contrast	Reflectance / transmittance
Screen brightness	Quality control
LED testing	Human factors
Paper, ink and textile testing	Dominant wavelength

Features	*Benefits*
Full Color Touch Screen Display	Easy-to-use menu based software
Wide Dynamic Range	Address almost any display measurement requirement
USB Interface	Connects to virtually any PC
Bluetooth ready (optional)	Wireless, remote data transfer
Long lasting rechargeable Li battery	Excellent for field use.
SD Memory	Save thousands of measurements

PR-655 Specifications

Detector	128 detector array
Spectroradiometer Wavelength Range	380 to 780 nm
Optics	Pritchard viewing and measuring system.
Digital Resolution	16 bits
Spectral Resolution	3.12 nm / pixel
Spectral bandwidth	8 nm (5 nm optional)
Spectral Accuracy	± 1 nm
Liminance accuracy (Against NIST luminance standard)	± 2%
Luminance repeatability	≤ 1% at 3 cd/m^2
Color Accuracy (for Illuminant A)	±0.0015 in CIE 1931 x,y
Measurement Capabilities	Luminance, Illuminance, luminous intensity, chromaticity, correlated color temperature, dominant wavelength.
Measurement Time	6 ms to 6 secs.
Battery	Rechargeable Lithium-ion. (≥ 12 hours continuous operation)
Weight	3.75 lbs (1.7 kg)
Operating Temperature	34° to 95° F (1° to 35° C)

Notes:

1. Sensitivities are for 100:1 signal to RMS noise against an Illuminant A based NIST traceable luminance standard
2. All specifications are subject to change without notice.

Measurement Spot Size

		Aperture	
Accessory	Working Distance	1°	1/2°
MS-75 (355 mm to infinity)	355 mm 305 m	5.25 mm 5.32 m	2.63 mm 2.66 m
SL-0.5X	94.1 mm to 137 mm	1.5 mm to 2.54 mm	0.75 mm to 1.27 mm
SL-1X	46 mm to 66 mm	0.890 mm to 1.32 mm	0.445 mm to 0.660 mm
MS-2.5X	46 mm	0.51 mm	0.225 mm
MS-5X	28 mm	0.289 mm	0.145 mm
MS-7.5	100 mm 3.05 m	17.5 mm 53 cm	4.38 mm 13.3 cm
LA-600	Contact	13.2 mm	13.2 mm
FP-600	Contact	3.17 mm	3.17 mm

Luminance Range (cd/m^2)

	Aperture	
Access.	1°	1/2°
MS-75	3.4 to 17,000	13.6 to 68,000
SL-0.5X	3.4 to 17,000	13.6 to 68,000
SL-1X	3.4 to 17,000	13.6 to 68,000
MS-2.5X	10.3 to 51,400	41.2 to 205,600
MS-5X	13.7 to 51,400	54,800 to 205,600
MS-7.5	3.4 to 17,000	13.6 to 68,000
LA-600	3.4 to 17,000	13.6 to 68,000
FP-600	8.6 to 43,000	34.4 to 172,000
CR-600	21.5 to 107,700 lux	86 to 430,800 lux

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9.Appendix 3 - PRESSURE SENSOR PTX 7500 Series data sheet

GE
Sensing

PTX 7500 Specifications

Pressure Measurement

Operating Pressure Ranges
Any zero based full scale (FS) from 1.5 to 1000 psi (100 mbar to 70 bar) gauge or absolute
Any zero based FS above 1000 psi (70 bar) up to 10000 psi (700 bar) sealed gauge or absolute
Barometric 11.5 to 17.4 psi (800 to 1200 mbar) absolute

For other barometric, elevated zero (e.g. 15 to 60 psi (1 to 4bar)) and compound ranges (e.g. -15 to +15 psi (-1 to +1 bar)) Refer to GE Druck for further information

Pressure Units
psi, mbar, bar, hPa, kPa, MPa, mmH_2O, torr, kgf/cm^2 cmH_2O, mH_2O, inH_2O, ftH_2O, mmHg, inHg, kg/cm^2

Over Pressure
The operating FS pressure range can be exceeded by the following multiples with negligible effect on calibration:
- 8 x for ranges up to 2.5 psi (160 mbar)
- 6 x for ranges above 2.5 to 7.5 psi (160 up to 500 mbar)
- 4 x for ranges above 7.5 to 30 psi (500 mbar up to 2 bar)
- 3 x for ranges above 30 up to 2030 psi (2 up to 140 bar) (2900 psi (200 bar) max)
- 2 x for ranges above 2030 up to 10000 psi (140 up to 700 bar) (14500 psi (1000 bar) max.)

Pressure Containment
The operating FS pressure range may be exceeded by the following multiples without a loss of mechanical containment:-

Gauge ranges:
- 12 x for ranges up to 2.5 psi (160 mbar)
- 8 x for ranges above 2.5 to 7.5 psi (160 up to 500 mbar)
- 6 x for ranges above 7.5 to 30 psi (500 mbar up to 2 bar)
- 4 x for ranges above 30 to 1015 psi (2 up to 70 bar) (2900 psi (200 bar) max)

Sealed gauge and absolute ranges:
- 3625 psi (250 bar) for ranges 1.5 to 2030 psi (100 mbar to 140 bar)
- 14500 psi (1000 bar) for ranges above 2030 up to 10155 psi (140 up to 700 bar)

Pressure Equipment Directive (PED) 97/23/EC approved (Category 1 - Pressure Accessory)

Pressure Media
Fluids compatible with 316L stainless steel and Hastelloy C276 (NACE compatible grades)
Supply Voltage
9 to 30 V at PTX terminals (28 V maximum for Intrinsically Safe option)

Start -Up Time
Recommended minimum power on time before output sample is taken is 500 msec

Output Signal
4 to 20 mA (2 wire) proportional to the zero to FS pressure range

Performance

Accuracy
Combined effects of non-linearity, hysteresis and repeatability
±0.1% FS Best Straight Line (BSL) typical (±0.2% FS BSL max)
0.15% Terminal Straight Line (TSL) typical (0.3% TSL max.)

Zero Offset and Span Setting
Supplied with ±5% zero and span noninteractive site adjustable potentiometers (excludes 7533 model)

Long Term Stability
±0.1% FS per year

Operating Temperature Range
-40 to 212°F (-40 to 100°C) ambient (176°F (80°C) max for 7511/7533/7534 models)
-40 to 248°F (-40 to 120°C) process media

Temperature Effects
Output will not deviate from room temperature (RTE) by more than:
- 0.7% FS typical (1% FS max) over 14 to 122°F (-10 to 50°C)
- 1.5% FS typical (2% FS max) over -4 to 176°F (-20 to 80°C)

For ranges below 500 bar, these values will multiply on a pro rata basis.

Shock
- 1000g, half sine pulse, duration 1 msec
- 100g, peak half sine wave duration 11 msec
- 2000g, half sine pulse, duration 0.5 msec

All in each of 3 mutually respendicular axis will not effect calibration.

Vibration
Conforms to MIL-STD 810C method 514.2 figure 514.2-2 curve L

Pressure Response
1kHz band width (63% response to step change in pressure).