Influence of air distribution system on hydroponically-grown lettuce crop performance in the higher plant compartment at MELiSSA Pilot Plant facilities

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ENGINSOFT

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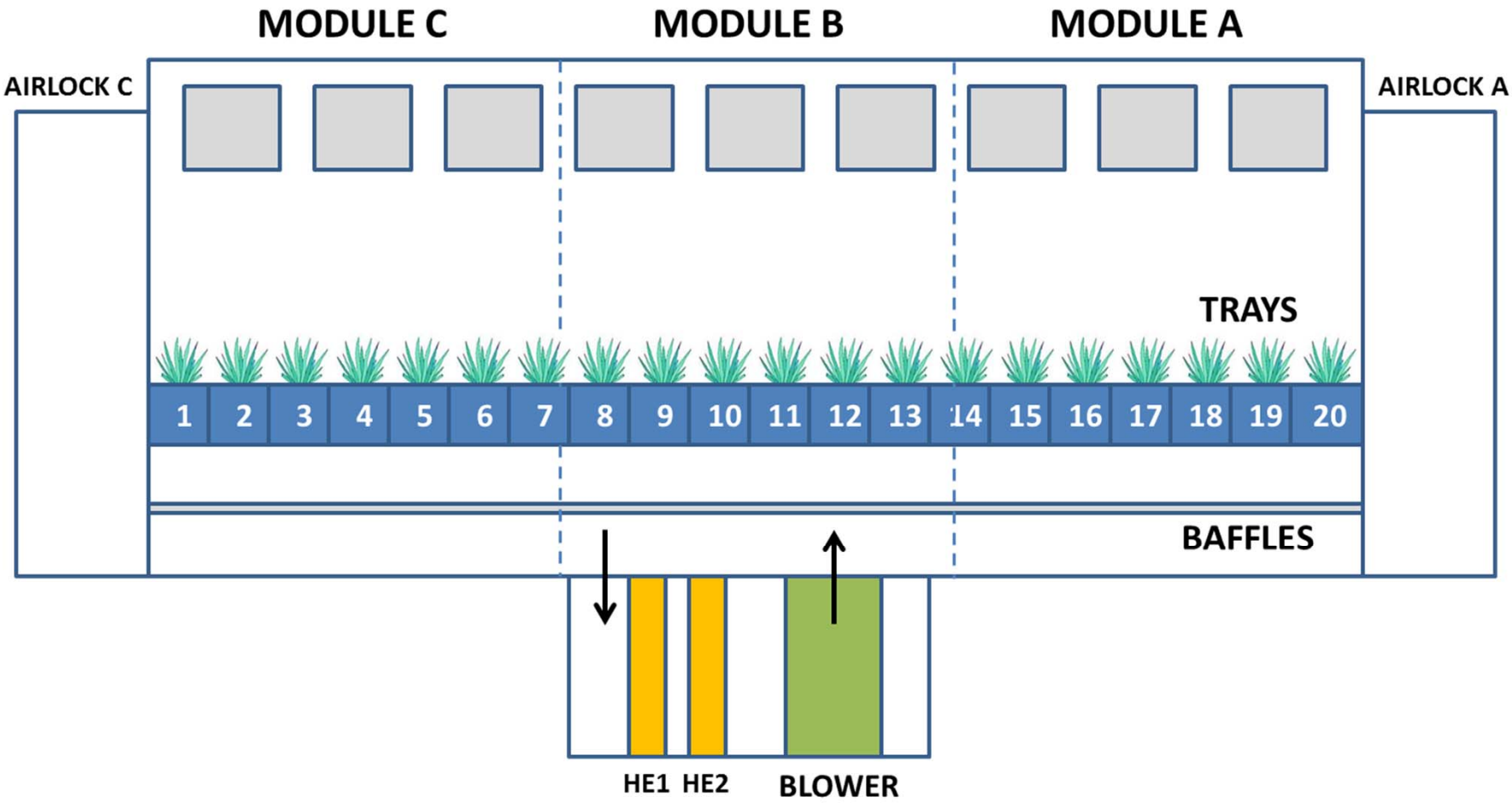
System overview

HPC @ MPP - System description:

- Higher Plant Compartment (HPC) at the Melissa Pilot Plant (MPP), installed in the facilities of Universitat Autònoma de Barcelona, Spain
- Closed plant growth chamber
- Dimensions: L x W x H ≈ 5.0 m x 1.0 m x 1.2 m
- Closed volume ≈ 6000 liters, Chamber growing surface ≈ 5.0 m^2
- 20 trays with 5 lettuce plants each → 100 plants grown
- Closed loop hydroponic system → NFT (Nutrient Film Technique)

Air distribution – Schematic representation

- 3 Modules: A, B, C
- One blower located in the central region

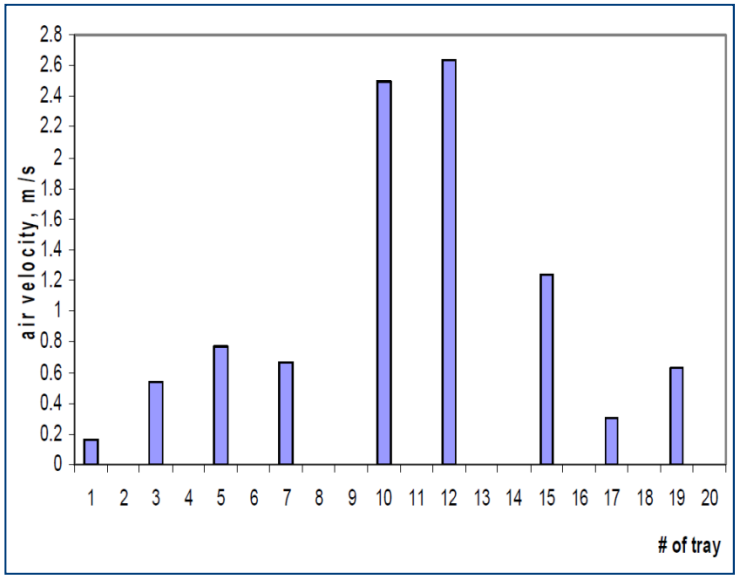


ACSA – Reengineering the air management

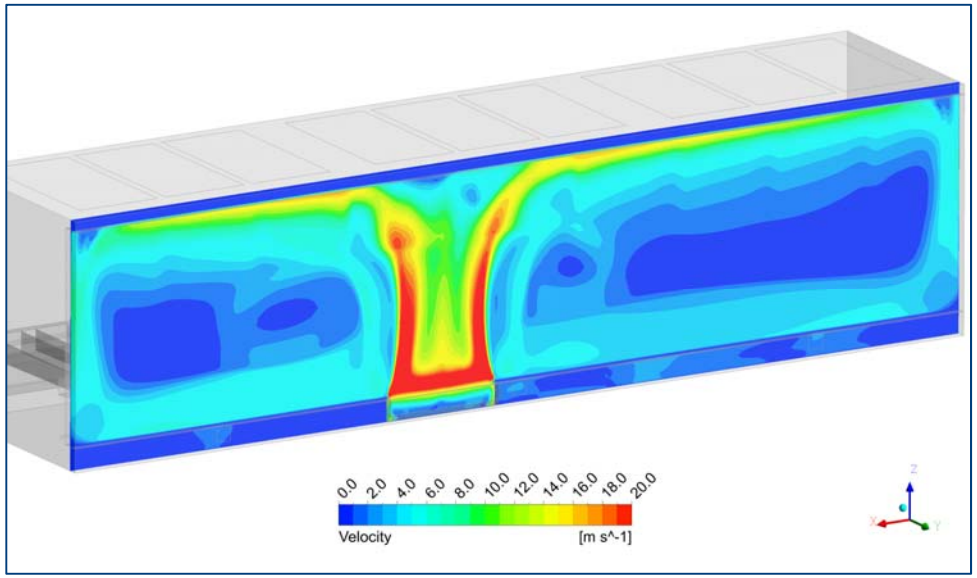
Air management before the ACSA project

The air management system was unable to provide a homogeneous air distribution inside the chamber. The air flow was **partially unbalanced**, mainly directed in the central part.

CFD analyses were performed in order to assess the internal air distribution in detail, accurately matching the experimental results from the laboratory.



Experimental results on air velocity

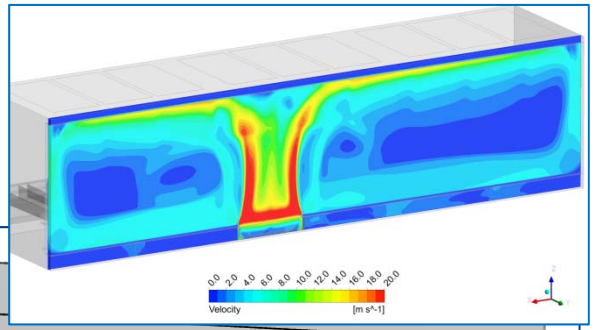


CFD results on air velocity

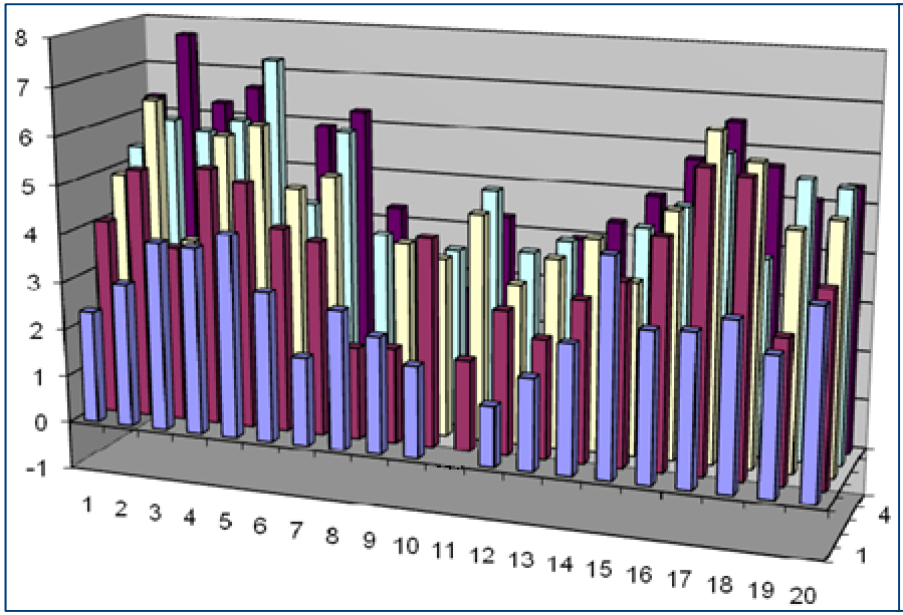
ACSA – Reengineering the air management

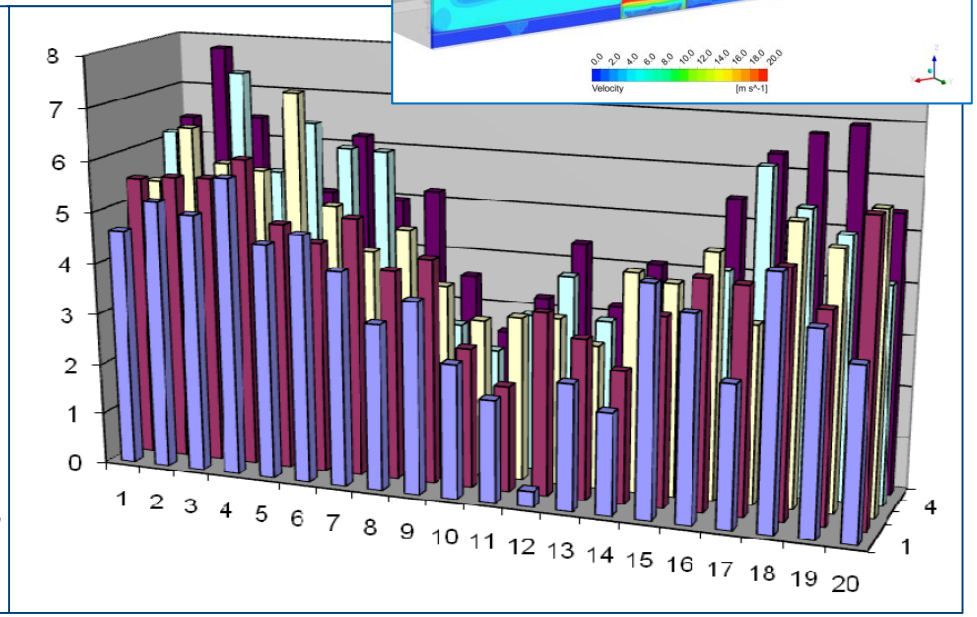
Air management before the ACSA project

The air velocity gradient was considered a possible cause for the unbalanced crop growth within the chamber. Three different crop tests confirmed a reduced plant growth in the central region of the chamber. It is known that high local air velocities may lead to a mechanical stress on the crops.



Two identical crop tests carried out in 2010
Lettuce plant dry weight [g] vs. Crop position





ACSA – Reengineering the air management

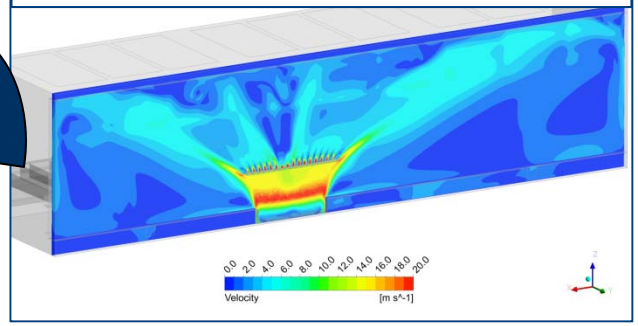
Additional components to modify the system

The redesign of the system to balance the air distribution was performed by means of a detailed 3D CFD study, carried out using state-of-the-art commercial software.

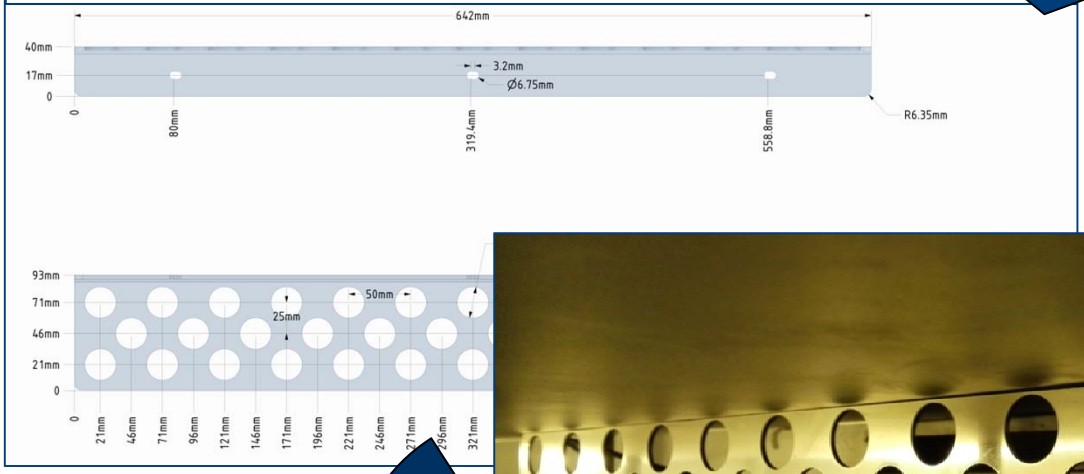
Additional components were inserted based on the CFD optimization.

1. Stainless steel deflector in the plenum region

CFD results with the deflector



CFD-based technical drawing of the deflector



Deflector assembled in the system

ACSA – Reengineering the air management

Additional components to modify the system

The redesign of the system to balance the air distribution was performed by means of a detailed 3D CFD study, carried out using state-of-the-art commercial software.

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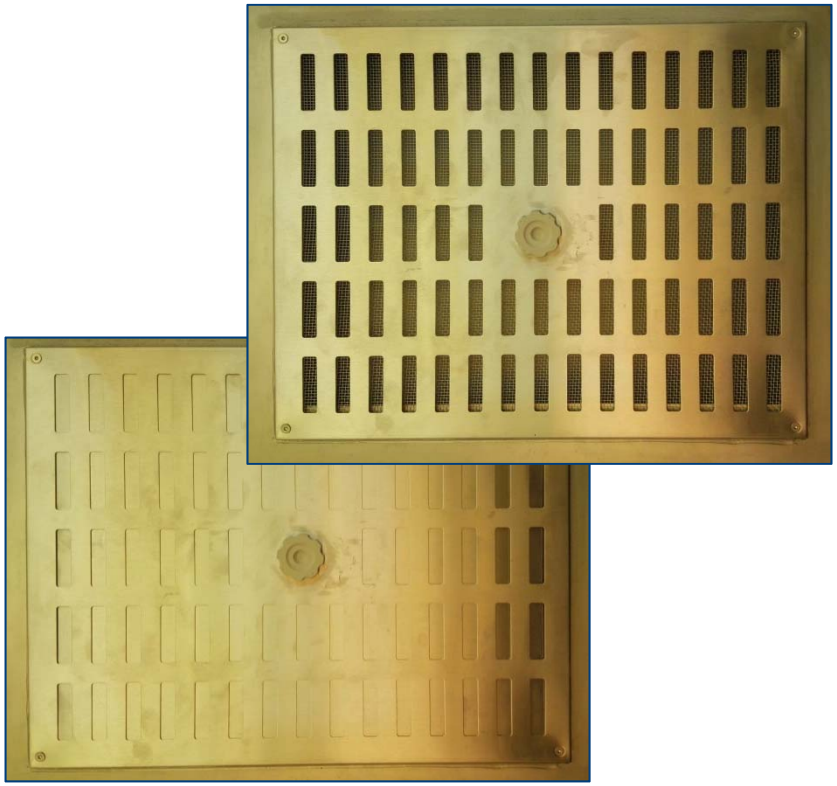
2. Stainless steel adjustable dampers (replacing fixed louvers)



As highlighted by the CFD study, the adjustable dampers were designed and installed in the chamber.

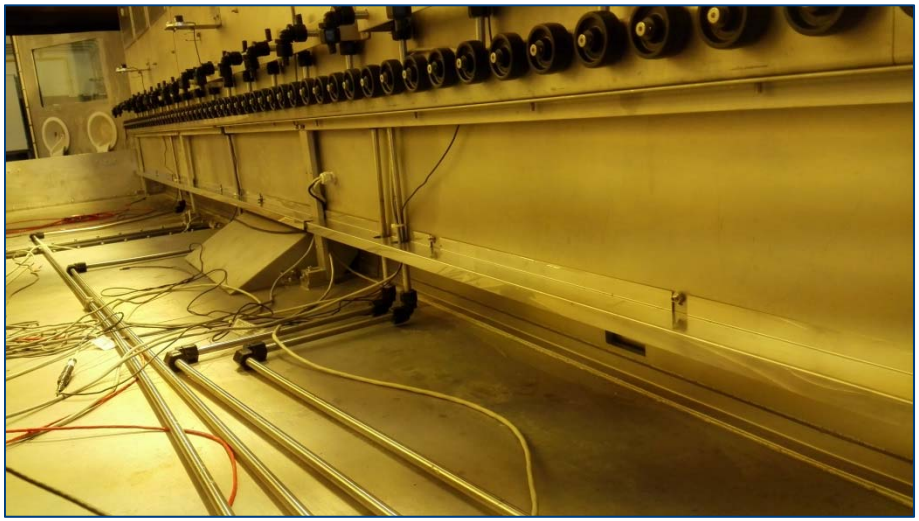
ACSA – Reengineering the air management

Additional components to modify the system

The redesign of the system to balance the air distribution was performed by means of a detailed 3D CFD study, carried out using state-of-the-art commercial software.

Additional components were inserted based on the CFD optimization.

3. Closure of side gaps next to the baffle panels



From the study carried out, a high percentage of air flux was calculated across side gaps. Additional components were designed and installed to close them.

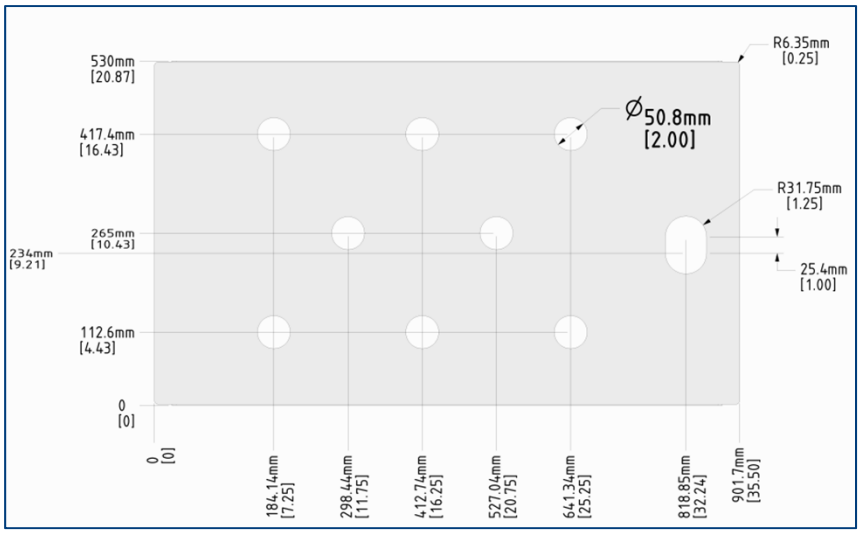
ACSA – Reengineering the air management

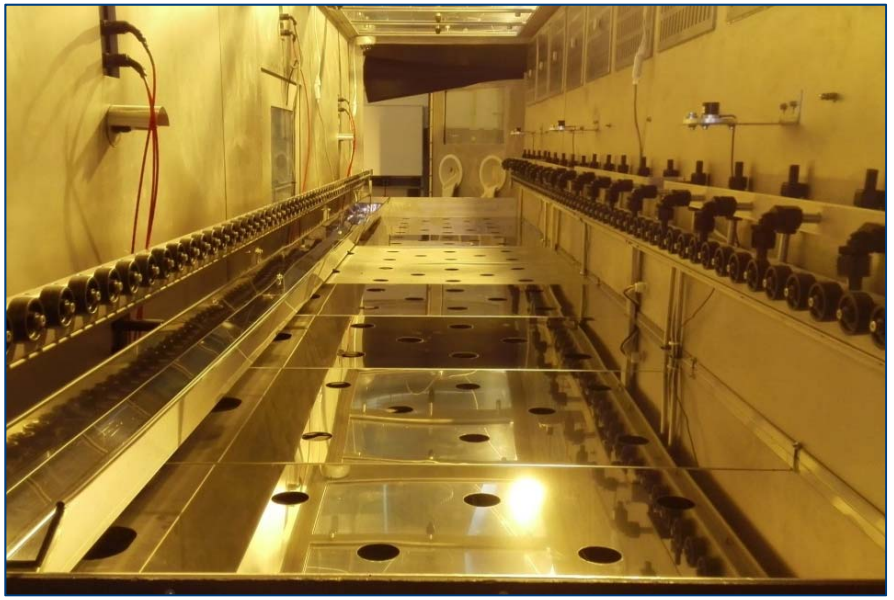
Additional components to modify the system

The redesign of the system to balance the air distribution was performed by means of a detailed 3D CFD study, carried out using state-of-the-art commercial software.

Additional components were inserted based on the CFD optimization.

4. Redesign of the baffle panels





Again, the CFD investigation was used to balance the air flow returning to the HVAC system. New baffle panels were optimized in the CFD study, manufactured and assembled in the plant growth chamber.

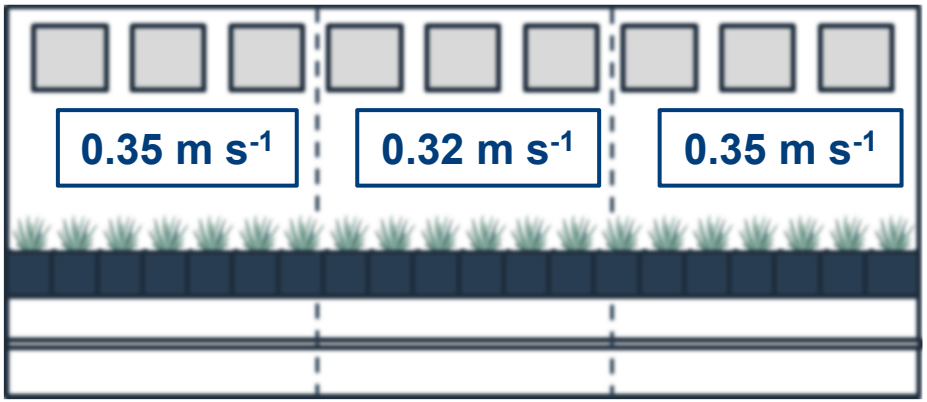
Preparing the crop tests conditions

By means of the air management optimization, the system is now able to obtain a balanced or unbalanced air distribution inside the chamber.

Exploiting this new capability, two different tests were carried out:

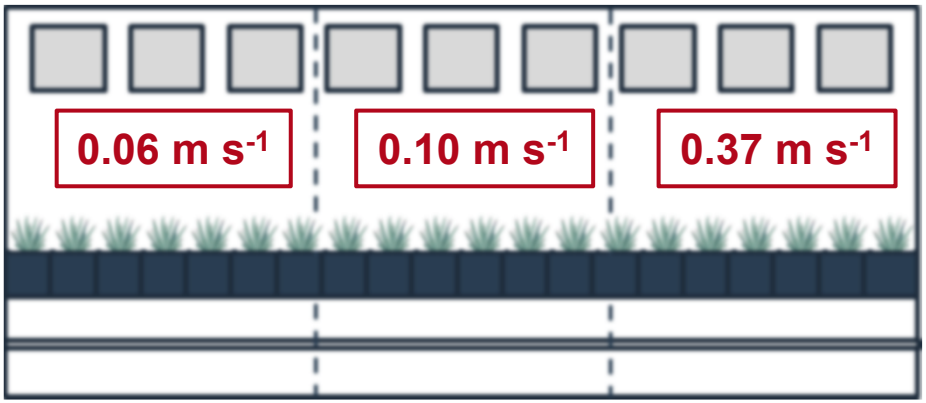
ACSA TEST 1:

BALANCED AIR DISTRIBUTION



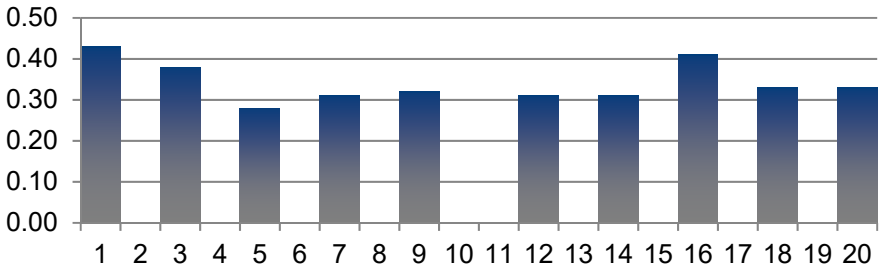
ACSA TEST 2:

UNBALANCED AIR DISTRIBUTION



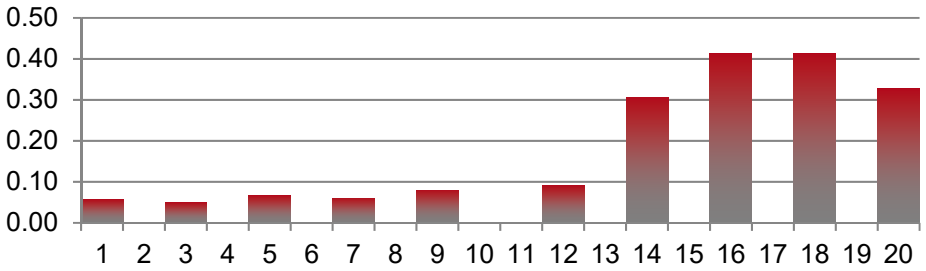
Crop tests conditions – ACSA Tests

ACSA TEST 1 - BALANCED CONDITIONS



Average [m s^{-1}]	0.34
St. Dev. [m s^{-1}]	0.05
St. Dev. [%]	14%

ACSA TEST 2 - UNBALANCED CONDITIONS

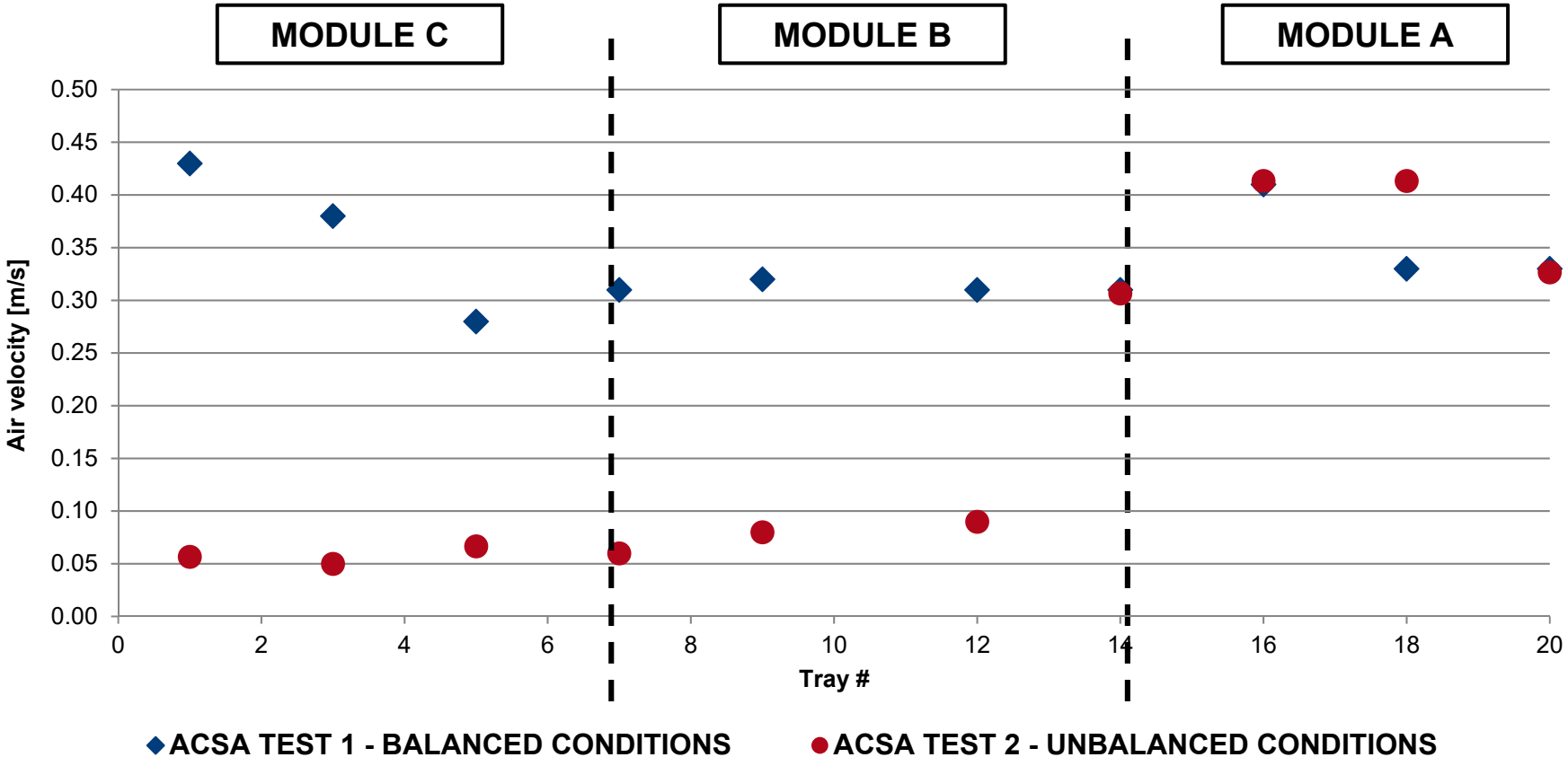


Average [m s^{-1}]	0.19
St. Dev. [m s^{-1}]	0.16
St. Dev. [%]	85%

		MODULE C						MODULE B							MODULE A						
	TRAY NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
TEST 1 BALANCED	AVERAGE LOCAL VELOCITY	0.43		0.38		0.28		0.31		0.32			0.31		0.31		0.41		0.33		0.33
	AIR VELOCITY MAPPING [m/s]	0.35 0.42 0.51		0.52 0.35 0.27		0.24 0.43 0.17		0.26 0.43 0.24		0.27 0.41 0.28			0.35 0.33 0.25		0.28 0.41 0.24		0.33 0.64 0.27		0.29 0.39 0.32		0.32 0.27 0.40
TEST 2 UNBALANCED	AVERAGE LOCAL VELOCITY	0.06		0.05		0.07		0.06		0.08			0.09		0.31		0.41		0.41		0.33
	AIR VELOCITY MAPPING [m/s]	0.03 0.08 0.06		0.03 0.08 0.04		0.04 0.11 0.05		0.05 0.08 0.05		0.07 0.11 0.06			0.08 0.13 0.06		0.39 0.46 0.07		0.39 0.56 0.29		0.20 0.65 0.39		0.26 0.39 0.33

Crop tests conditions – ACSA Tests

Comparison of air velocity at tray height in the chamber



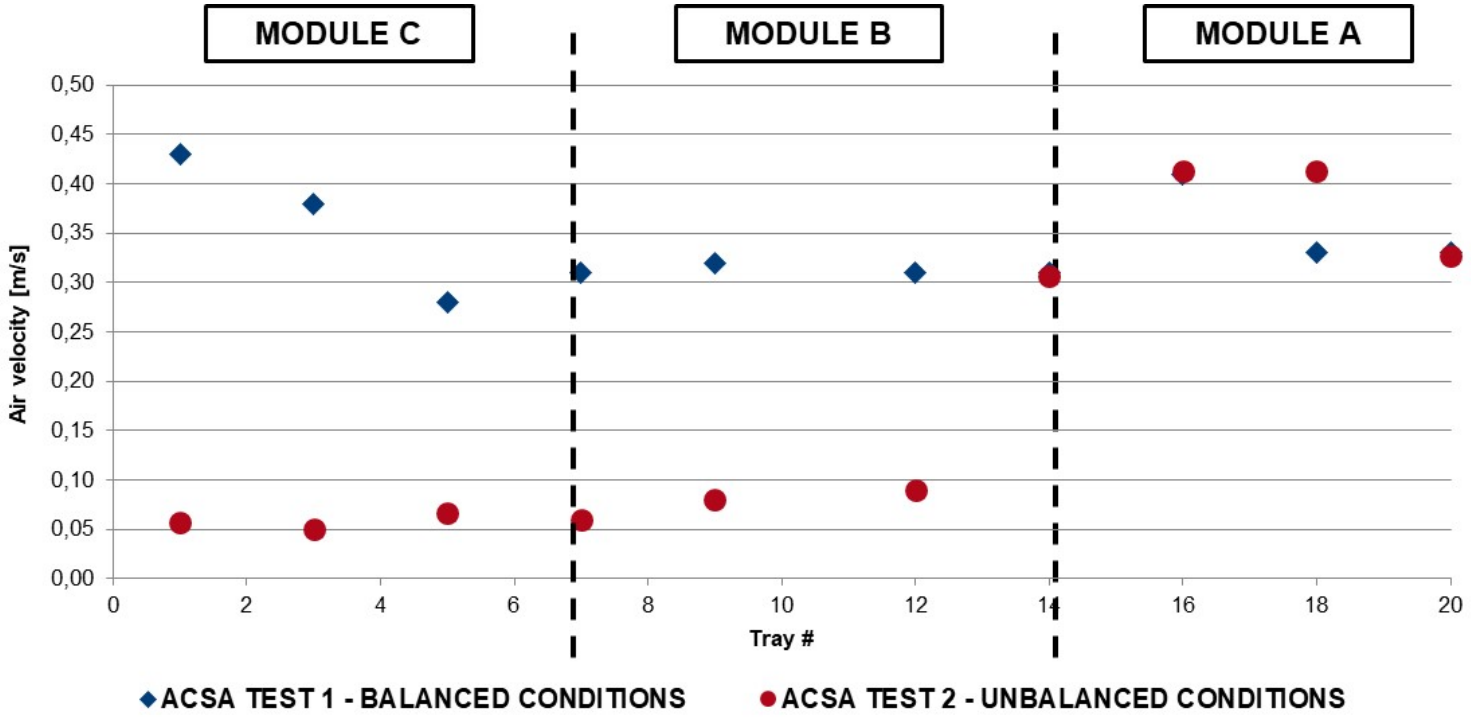
Growing conditions

- **Chamber growing surface:** 5 m^2
- **Plant material:** 100 9-day old seedlings of (*Lactuca sativa L.*) cv. *'Grand Rapids'*
- **Plant density:** 20 plants m^{-2}
- **Temperature and Relative Humidity:** 26/20°C and 50/70% (day/night)
- **Lighting system:** MH and HPS lamps ratio 1:2 PPFD 450 µmol m^{-2} s^{-1} **light cycle** 16hrs:8hrs (day:night)
- **Hydroponic system:** Nutrient Film Technique - 20 trays with 5 plants each
- **Nutrient solution:** modified Hoagland, pH 5.9 – EC 1.9 dS m^{-1} at 25°C
- **CO_2 concentration:** 1000 ppm
- **Growth cycle:** 28 days (plants harvested 37 Days After Sowing, DAS)

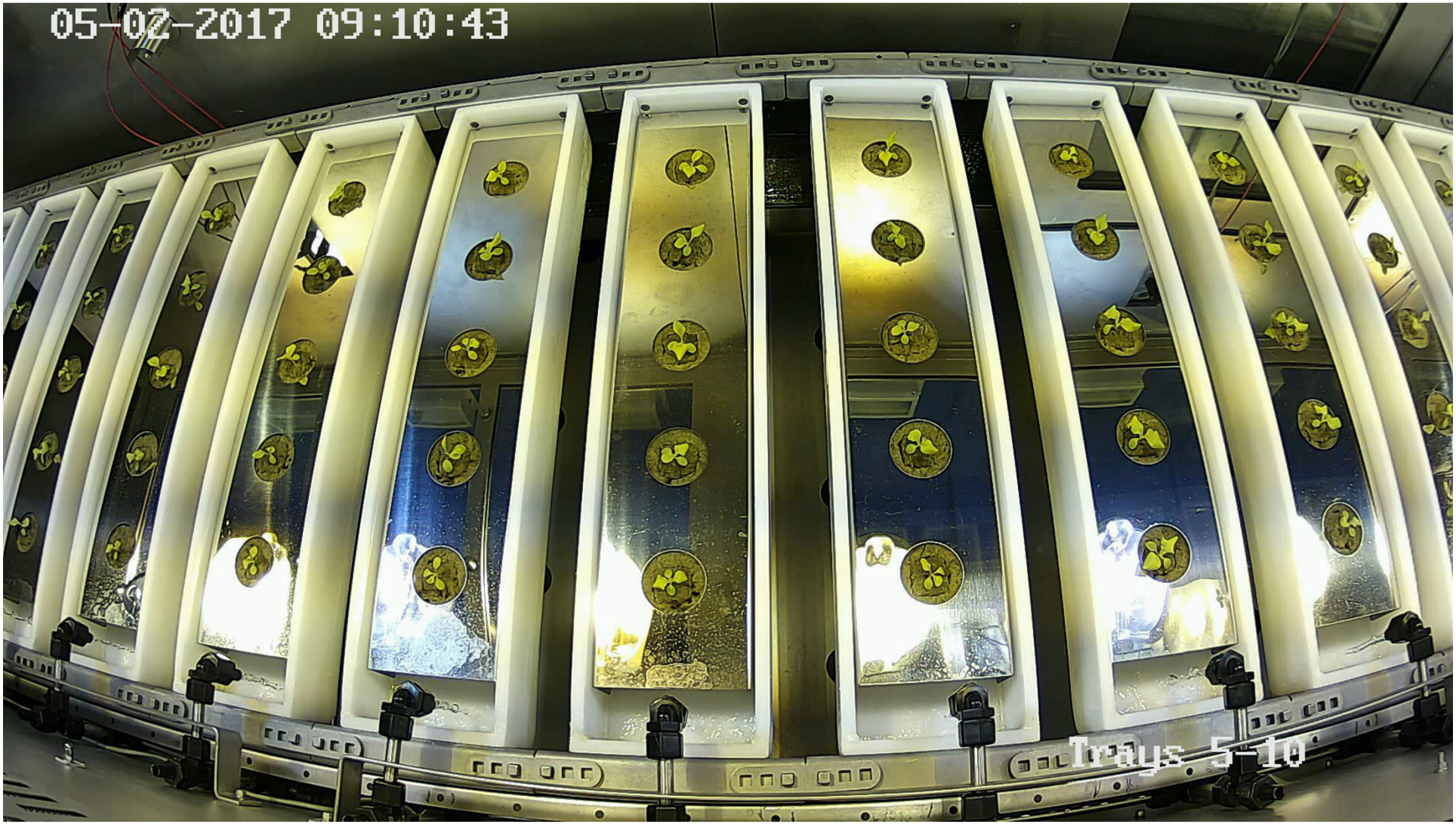
Experimental design

Two experiments:

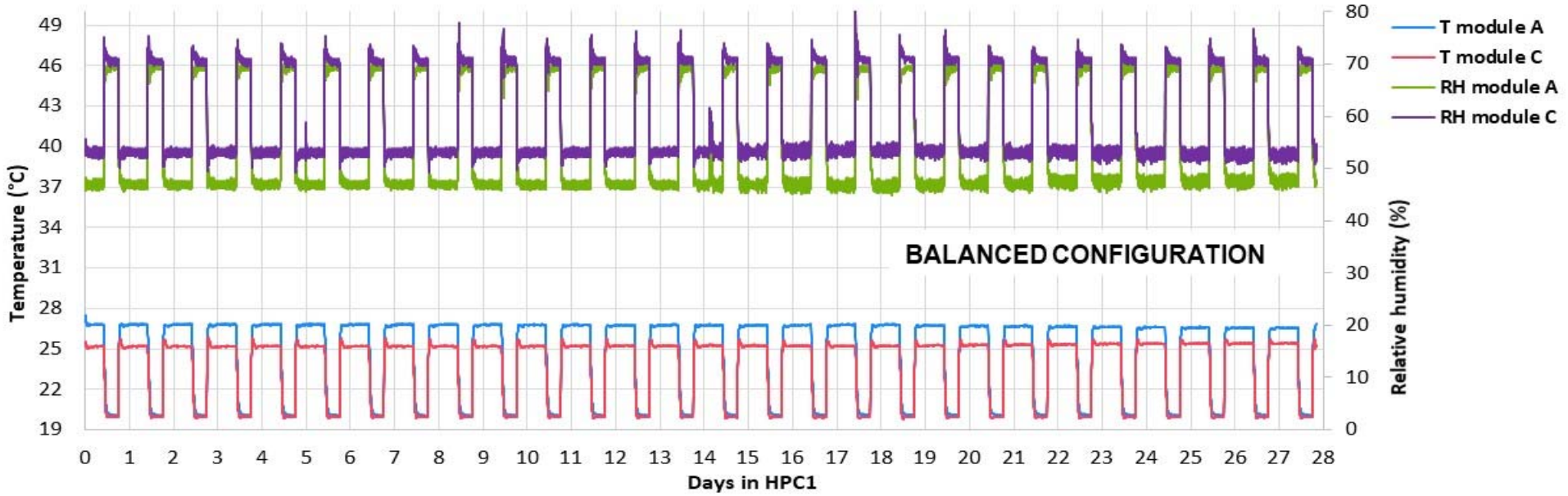
- ACSA Test 1: optimal air flow conditions with homogeneous air velocity in Module A, B and C (0.35 m s^{-1})
- ACSA Test 2: non-homogeneous air flow conditions obtained by closing 5 of 9 side inlet-vents (Module A = 0.35 m s^{-1}, Module B = gradient from 0.35 to 0.05 m s^{-1} and Module C = 0.05 m s^{-1})

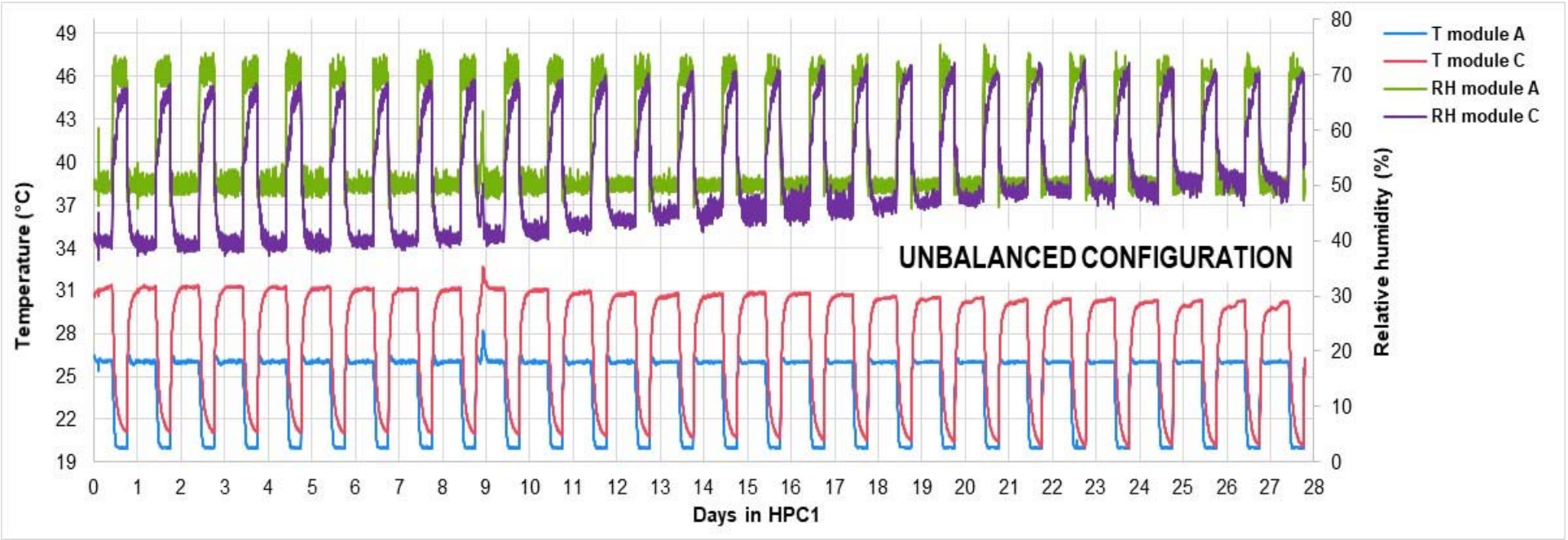


Lettuce growth cycle in HPC1



Comparison of T and RH between Test 1 and Test 2





Harvest of plants (28 DAT)

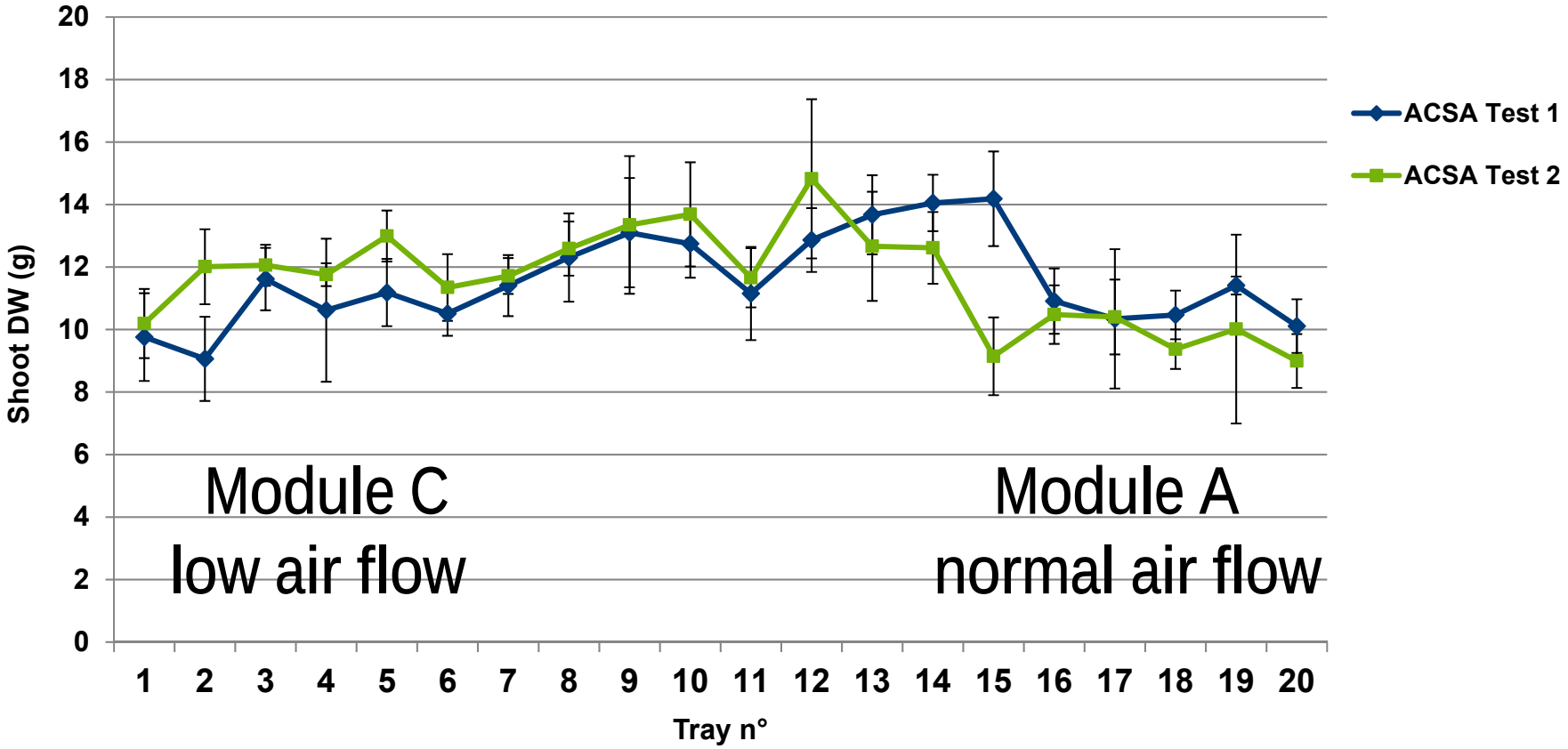
View from airlock C

HPC1 performance comparison

Harvest Date	Lettuce Test (28 DAT)	Dry mass yield	Fresh yield	Shoot Dry Weight	Root Dry Weight	Harvest Index
		(g DW)	(g FW)	(g DW/plant)	(g DW/plant)	
02/03/2017	Test 1 - Balanced Configuration	1264 a	27861 a	11.63 a	1.01 b	0.92 a
25/05/2017	Test 2 - Unbalanced Configuration	1323 a	28490 a	11.59 a	1.64 a	0.88 b

Shoot dry biomass homogeneity

Lettuce Test (28 DAT)	Shoot Dry Weight (g DW/plant)	Standard deviation (g DW/plant)	Standard deviation %
Test 1 Balanced Configuration	11.63	1.46	12.63
Test 2 Unbalanced Configuration	11.59	1.60	13.76



Pictures from the cameras after 3 weeks in HPC1

Test 1 (module A)

Test 2 (module A)

Test 1 (module C)

Test 2 (module C)

Destructive analysis of fresh shoots

ACSA Test 2 - Unbalanced configuration

Plants in module A

Plants in module C

Bolting effect and rotten leaves

Lateral shoots

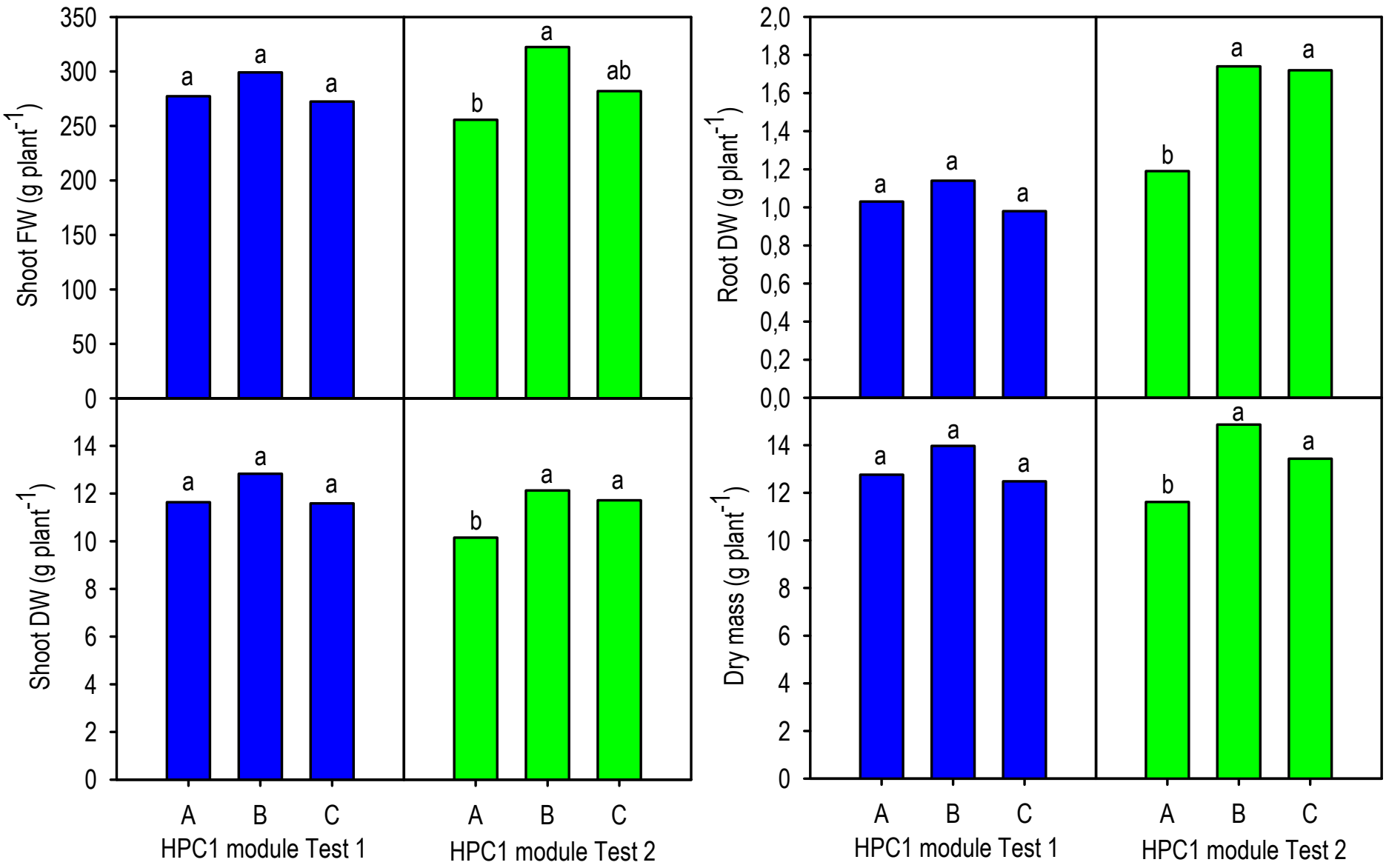
Destructive analysis of fresh shoots

ACSA Test 2 - Unbalanced configuration

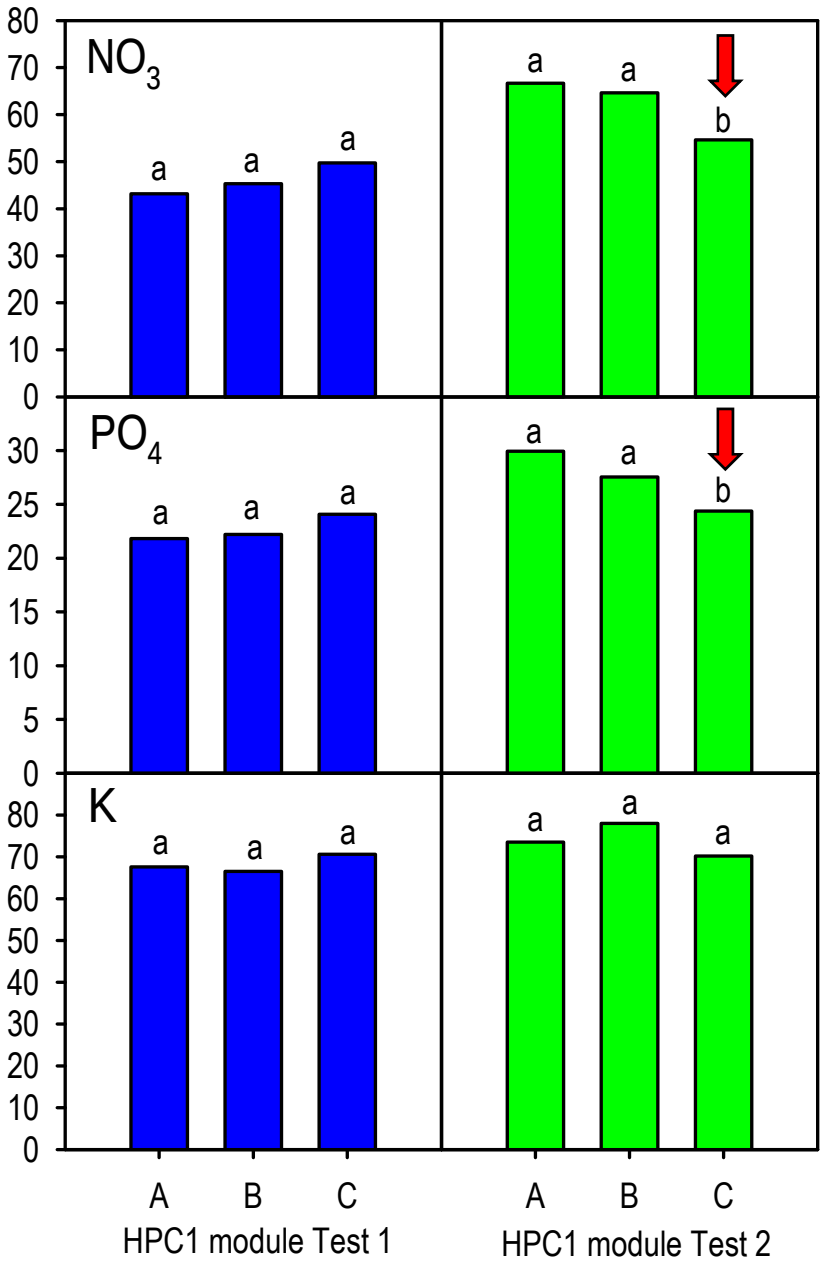
Module	Presence of bolting	Presence of rotten leaves
	(% of plants)	(% of plants)
A (normal)	0.00 b	14.3 b
B	40.0 a	100.0 a
C (low)	57.1 a	100.0 a

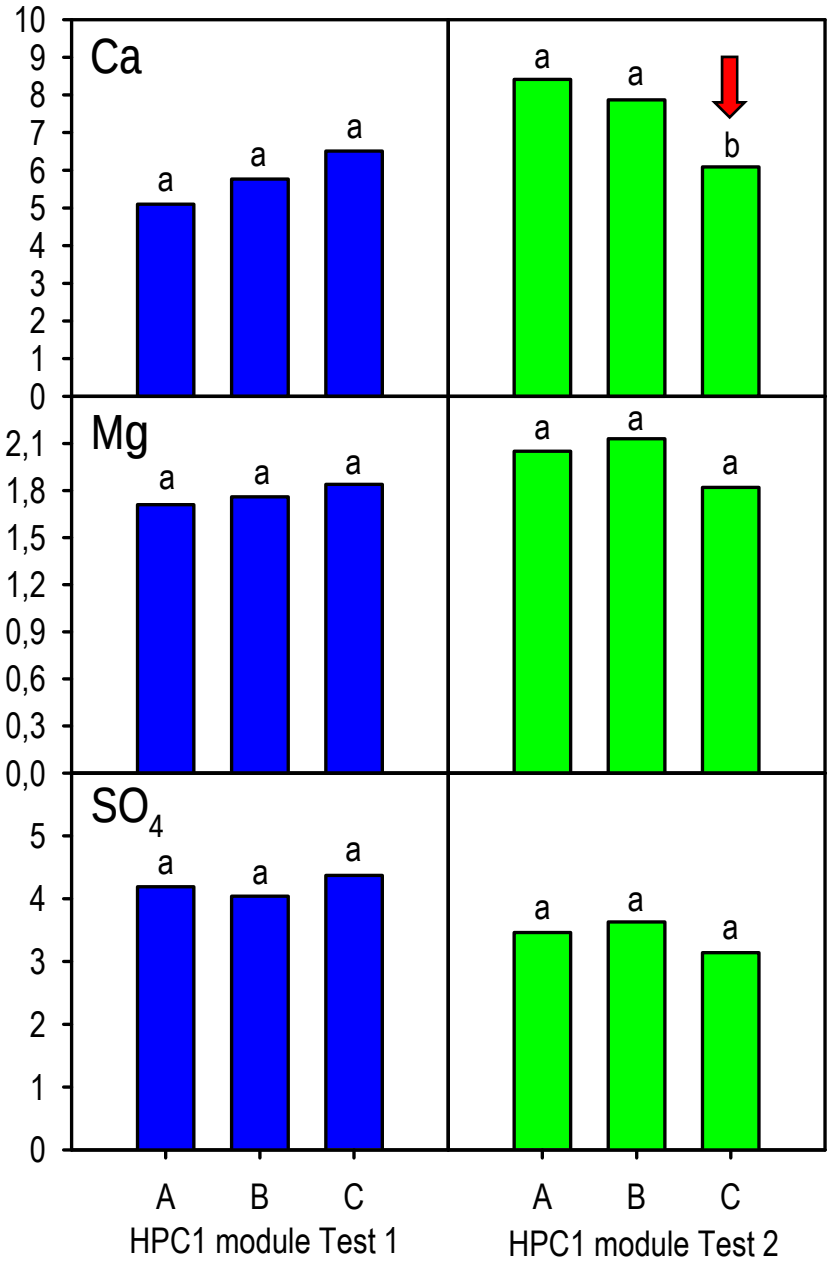
Module	Leaves of main stem	Leaves of lateral shoots	Total leaves
	(N plant^{-1})	(N plant^{-1})	(N plant^{-1})
A (normal)	20.9 a	0.0 b	20.9 b
C (low)	12.9 b	15.6 a	28.5 a

Biometric data

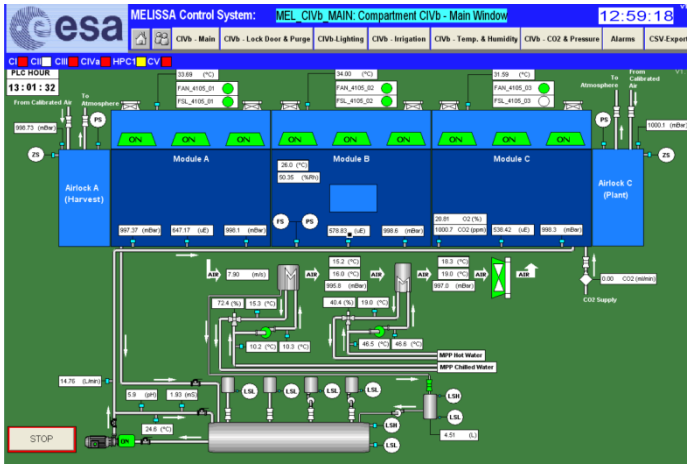


Shoot mineral analysis data (g kg DW^{-1})



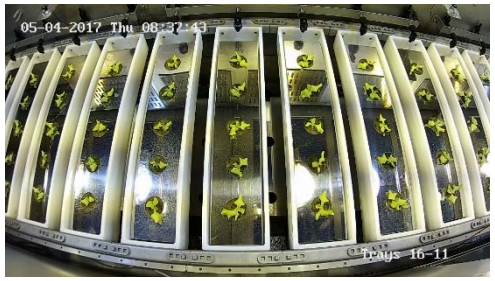


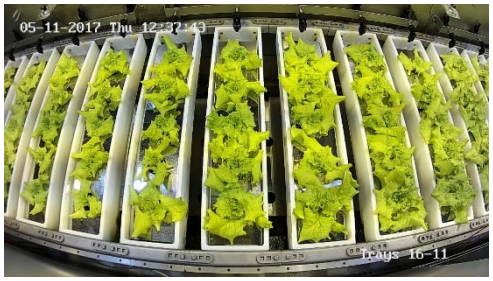
Nutrient solution analysis



NS sampling (DAT)	Lettuce Test	P (mg l^{-1})	K (mg l^{-1})	Ca (mg l^{-1})	Mg (mg l^{-1})	S (mg l^{-1})
0	Test 1 Balanced Configuration	39.78	174.48	105.74	21.79	56.79
7		42.31	201.77	121.63	25.99	64.14
14		39.84	207.36	133.49	23.17	58.90
21		28.47	208.69	187.34	33.04	82.80
28		11.68	22.42	285.44	44.39	126.16
0	Test 2 Unbalanced Configuration	38.22	180.88	104.04	22.02	57.08
7		33.85	282.11	141.94	22.27	55.11
14		37.05	199.05	144.23	21.72	56.49
21		22.47	192.71	202.70	29.17	77.65
28		4.14	21.55	300.89	38.24	118.95

Conclusions





- The HPC1 at the MPP was proved to be reliable and able to sustain a batch crop test campaign.
- Tests on lettuce, by using balanced or unbalanced air distribution, confirmed that significant differences in plant growth and mineral composition can be determined by different air flow velocity and homogeneity in the cultivation environment.
- Improved air flow homogeneity resulted in more uniform plant biomass distribution within the chamber and higher produce quality.
- The lowest air flow did not affect the total biomass production but reduced the edible biomass (by inducing bolting and leaf rot).

Conclusions

Thank you for your attention!