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Key partner in Design Process Innovation

Heat Ventilation and Air Conditioning of a Greenhouse in Antarctica

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The project EDEN ISS

- EDEN ISS (Evolution and Design Environmentally-closed Nutrition-Sources) is an European Commission project funded by Horizon 2020 research and innovation program.
- Mission Objectives:
  - Design of a space analogue mobile test facility for a one year mission in Antarctica to provide a ground demonstration of a bio-regenerative life support system in an highly-isolated environment.
  - Test of key elements for plant cultivation in an ISPR-like system (International Standard Payload Rack) for future tests on the International Space Station (ISS)
  - Demonstration of key technologies and their functionality for safe food production in a Future Exploration Greenhouse (FEG) to prepare for closed-loop bio-regenerative life support systems.

External layout of Mobile Test Facility (Greenhouse)

Neumayer Station III in Antarctica. The MTF will be placed closed to the German AWI Station.

The Air Management System (AMS)

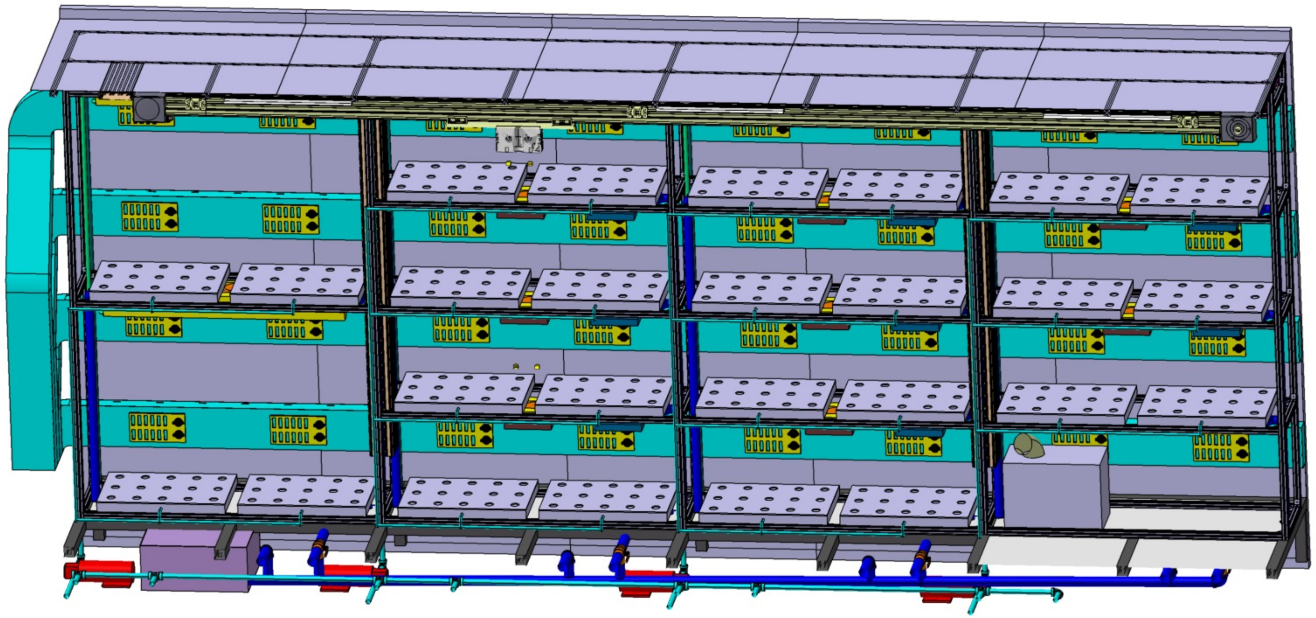
- This part of the project has been developed in close collaboration with the German Aerospace Center (DLR), as EDEN ISS project coordinator, and Aero Sekur responsible of the initial design of the AMS.

- Objective: design of the HVAC and distribution system of this particular greenhouse. The optimization process of the air distribution system has followed the aim to ensure the proper climate conditions for plant growth, with homogeneous temperature, relative humidity and velocity in the growth chamber. CFD analyses are performed to guide the design of the system.

- Motivation: <u>controlled environmental variables allow homogeneous plant growth conditions.</u>

- A particular attention has been paid to the typical problems of Greenhouse conditioning: <u>big volumes which easily lead to stagnation areas and high temperature/RH gradients</u>.

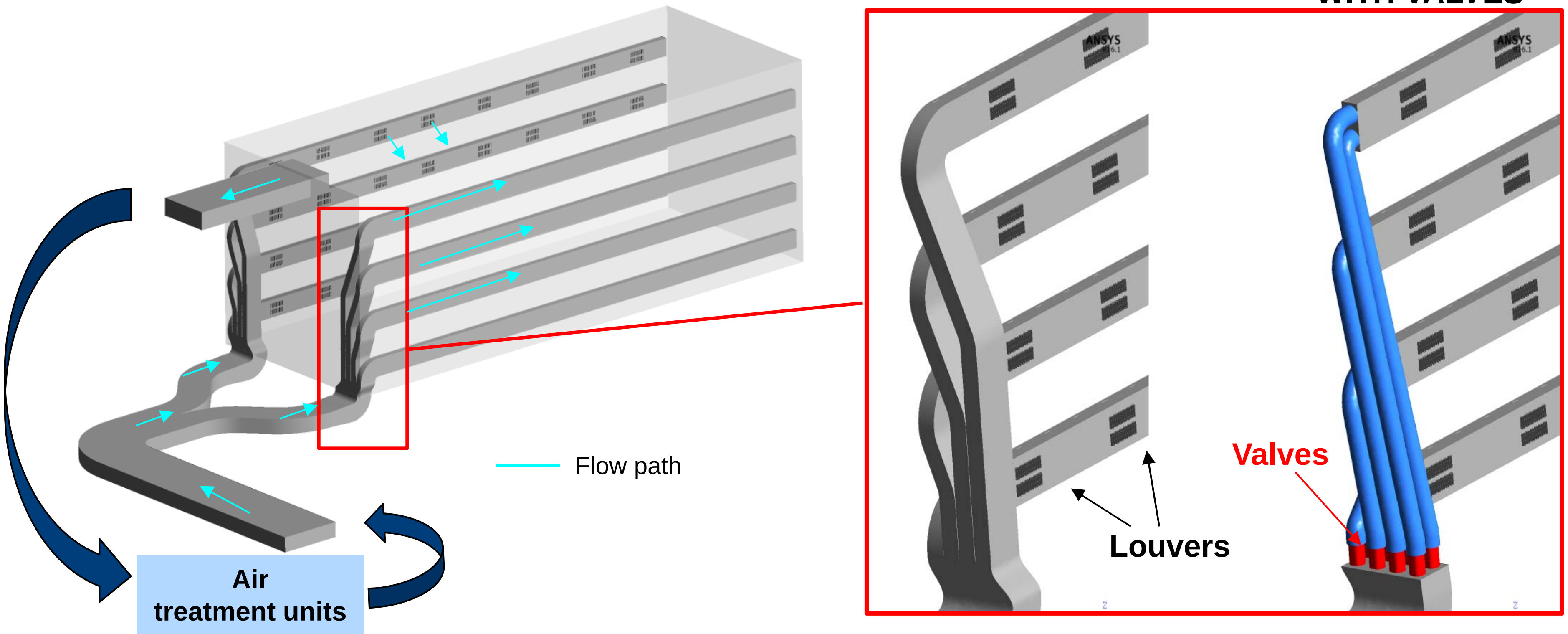
Air Management System (AMS)



Duct shape optimization

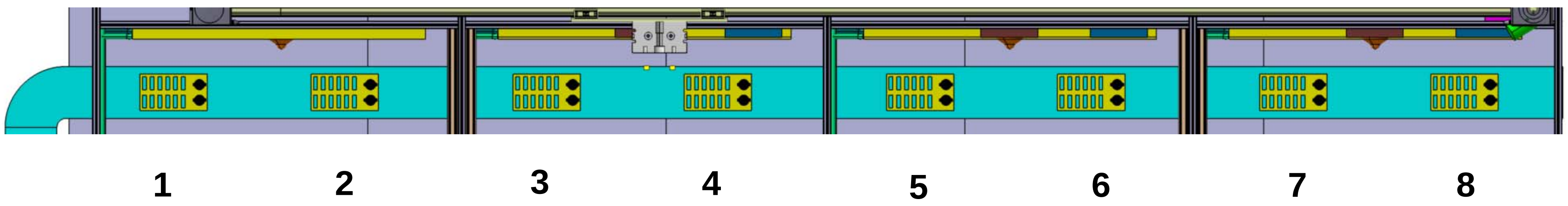
- Starting form the initial geometry, with rigid ducts, the solution with flexible ducts has been selected because it allows:
  - A direct control on the mass flow split among the 8 horizontal ducts
  - With additional pressure drop due to valves is manageable by the AMS fans

AIR MANAGEMENT SYSTEM **RIGID DUCTS** **FLEXIBLE DUCTS WITH VALVES**

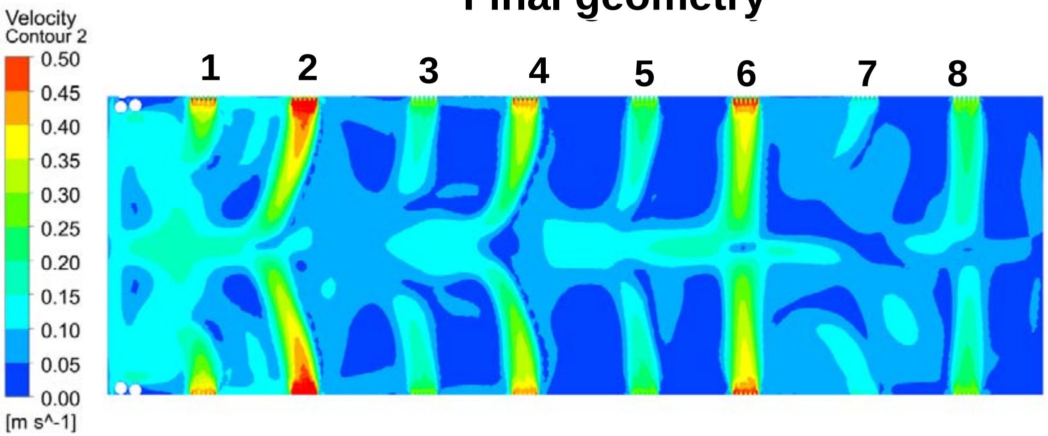


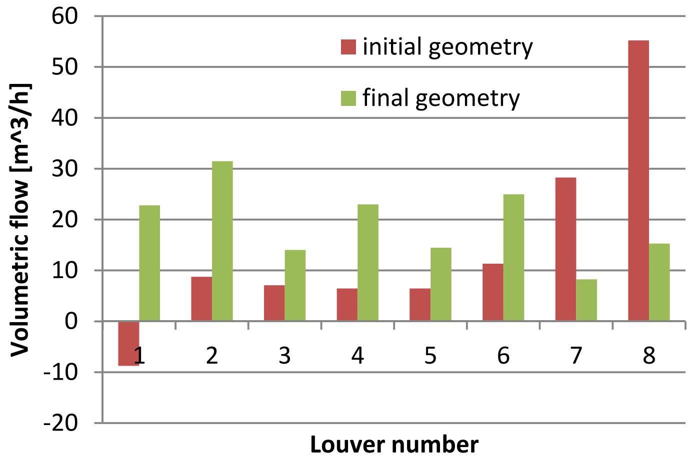
Air distribution along louvers

- The air distribution at louvers level was not balanced for the initial geometry (duct with a constant width)
- The final geometry with a variable width improved the balance of the flow.



Final geometry

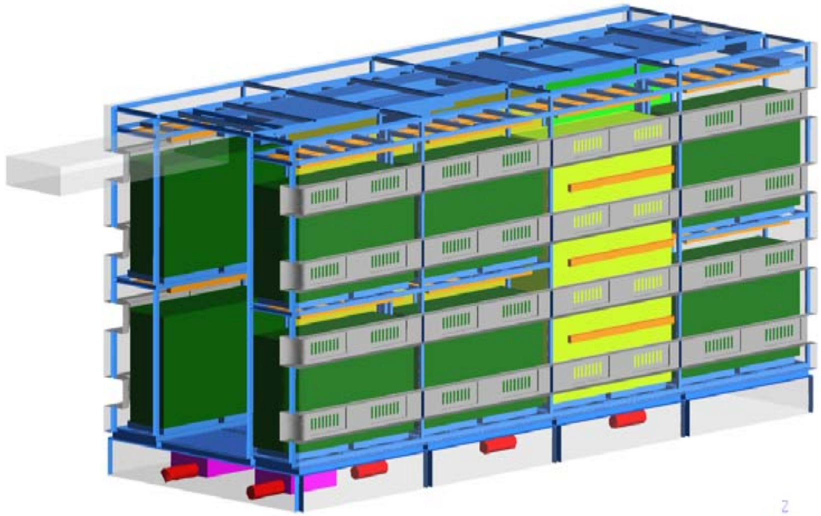




Future Exploration Greenhouse (FEG)

Model of the Greenhouse

CFD model of FEG



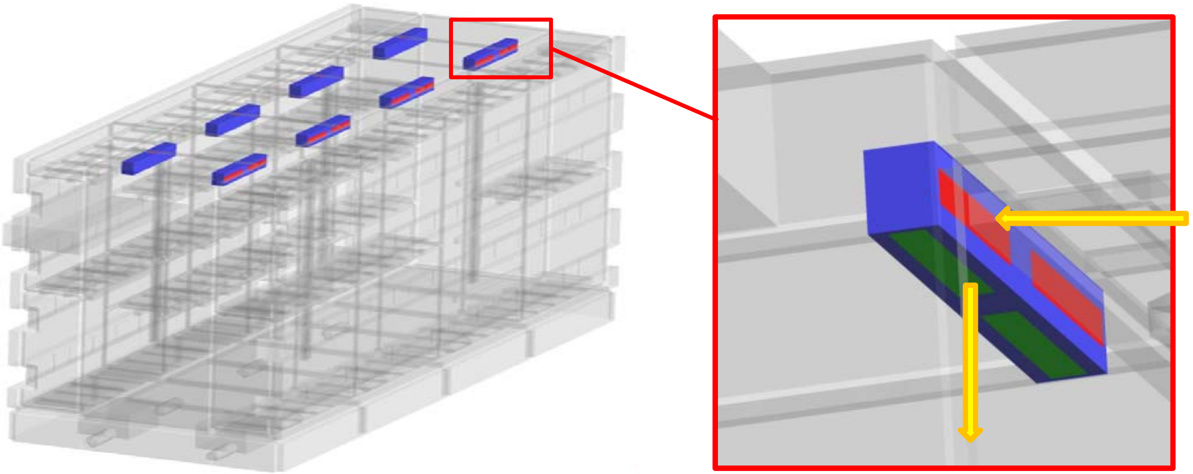
Two solutions have been compared:

- **WITHOUT FANS**: initial geometry
- **WITH 8 MIXING FANS**: final geometry

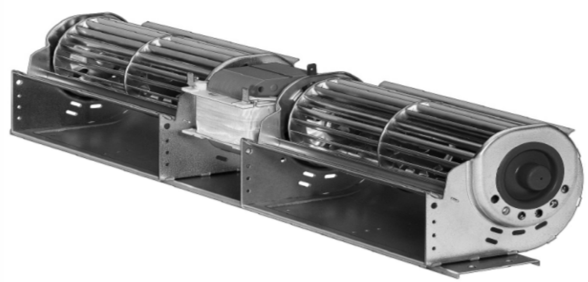
Air conditions at inlet sections:

- Mass flow = 1400 m3/h (One volume/min)
- T = 20°C
- RH = 70 %

8 Additional tangential fans are introduced to improve air mixing



- Hot air is collected from the top-side of FEG and blown downward into the corridor



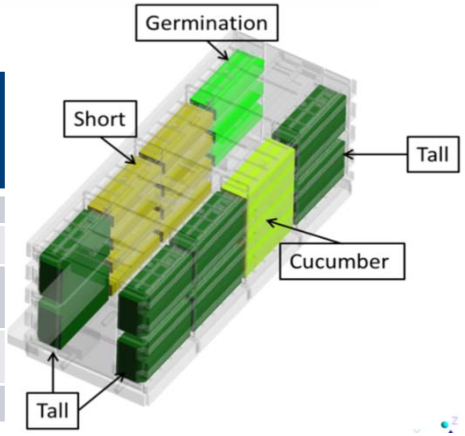
"Summer day" scenario

PLANTS

Plants are modeled as porous media with the following characteristics:

- Divided into tall, short, cucumber and germination, with respectively different volumes of evapotranspiration.
- Maximum level of growth.

Plant type	Number of plants	Total volume [m3]	Energy sink [W]	Max Water Evaporation [g/h]
Short	8	1.21	260.7	383.9
Tall	8	3.72	797.6	1174.6
Germination	3	0.46	97.8	144.0
Cucumber	1	1.10	235.9	347.5
	Total	6.48	**1392**	2050

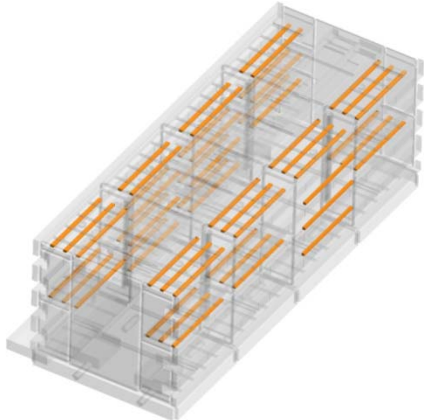


HEAT LOADS

Max heat load with all LED on. The total LED power is split in different parts:

- 50% is dissipated by the water cooling system (not included in the simulation)
- 50 % is applied as radiative heat flux and convective heat flux

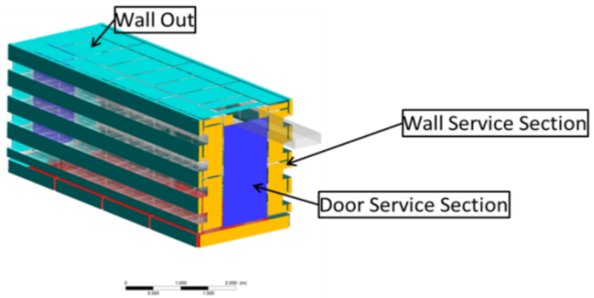
Description	Panel Intensity On Canopy [umol/m2/s]	Power per panel [W]	Number of panels	Total power 100% [W]
Tall crops	600	249	9	2241
Short crops	300	124	8	992
Germination	150	62	3	186
Backlight Cucumber	600	249	1	249
			Total	**3668**



AMBIENT CONDITIONS

The external temperature is 5°C.
The maximal temperature in Antarctica is selected.
The system is practically adiabatic

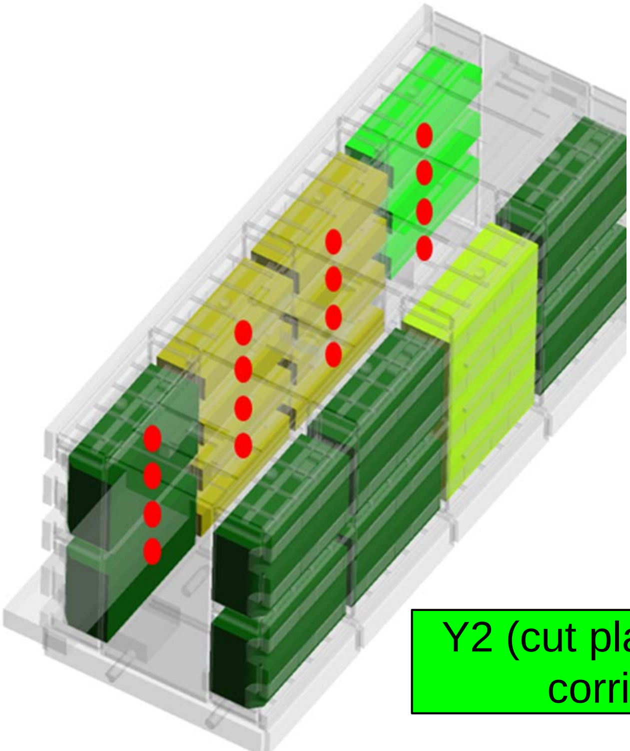
Walls	Main Material	HTC [W/m^2 K]
Floor	Polyuteran Foam	0.21
Lateral	Polyuteran Foam	0.32
Wall FEG-SS	Wood panel	0.74
Door FEG-SS	Wood panel	0.74
Emergency door	Polyuteran Foam	0.21



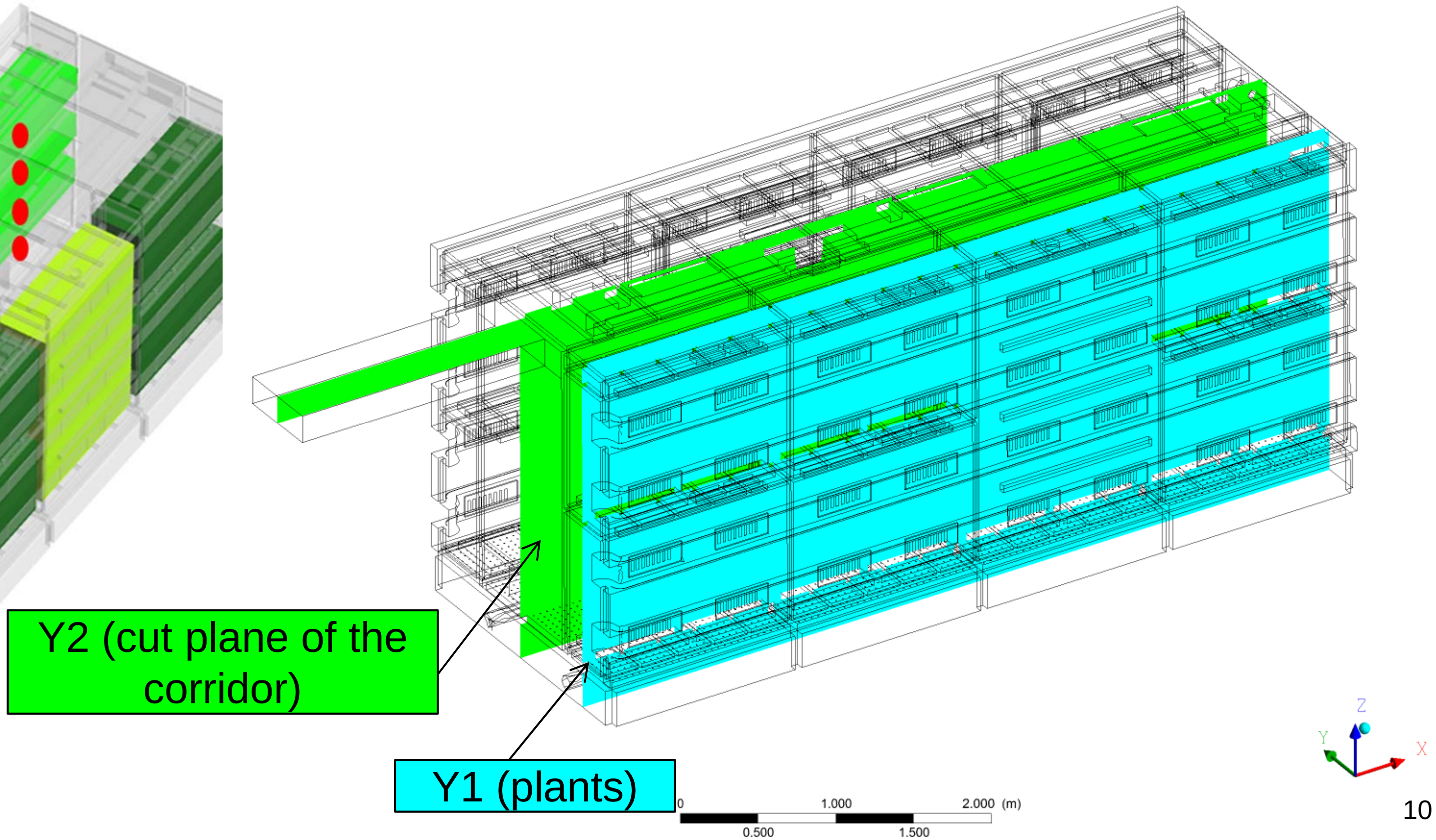
Post-processing / performance criteria

- Cut planes are defined in order to check the velocity, temperature and relative humidity
- Monitor points are placed inside the FEG to check the local values. (Root mean square)

Monitor points



Cut planes for post-processing

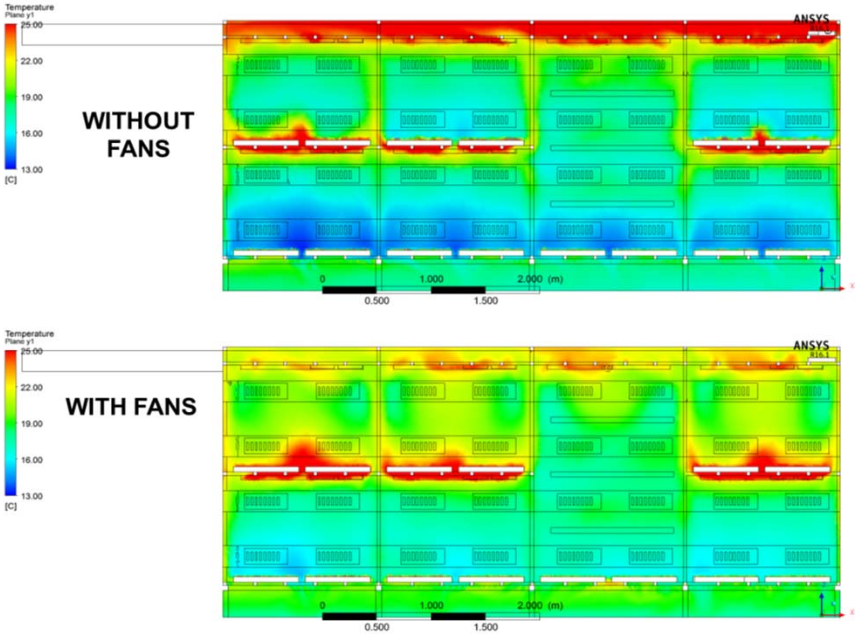


Temperature distribution

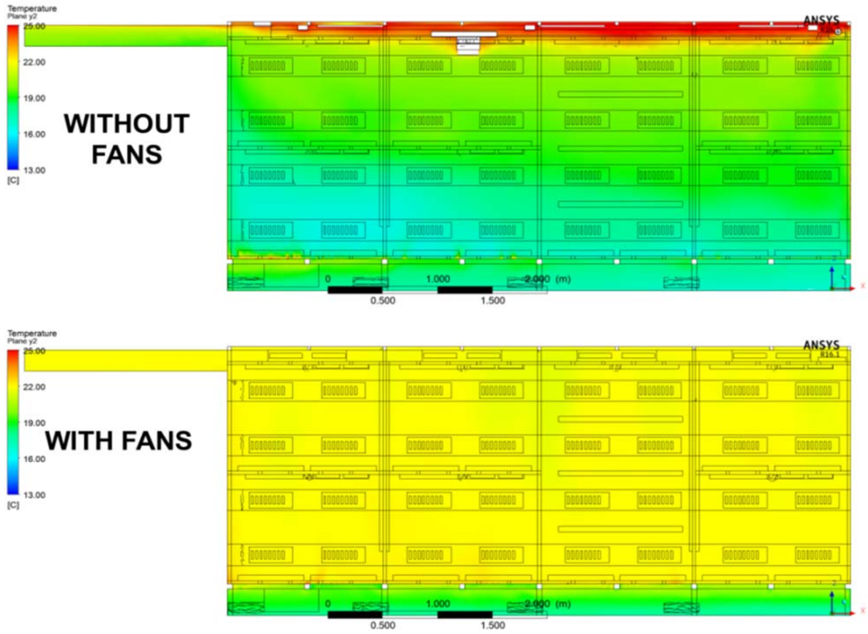
- The effects of natural convection and stratification are dominant in the case without fans.

	WITHOUT FANS	WITH FANS
Global temperature gradient	5.7 [°C]	2.2 [°C]

Temperature at plane y1 (plants)



Temperature at plane y2 (corridor)

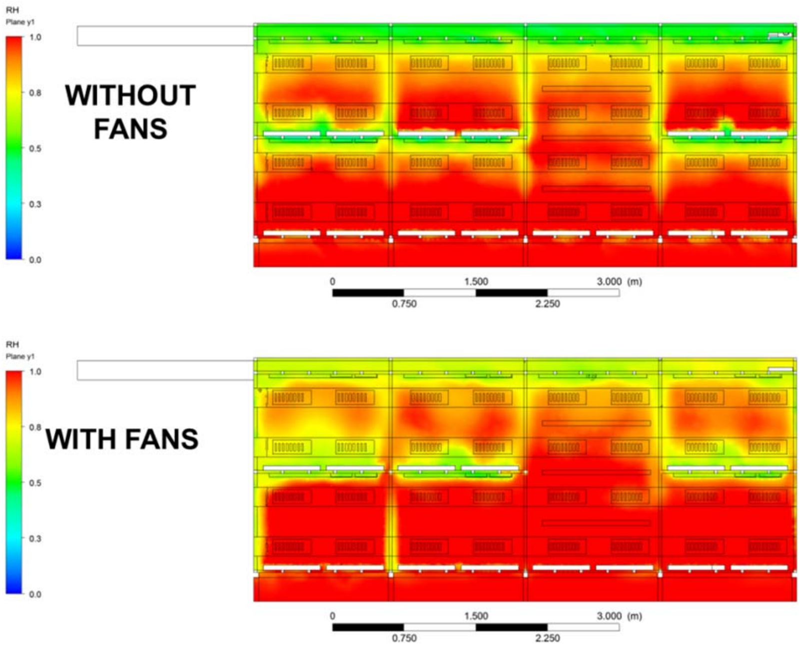


RH distribution

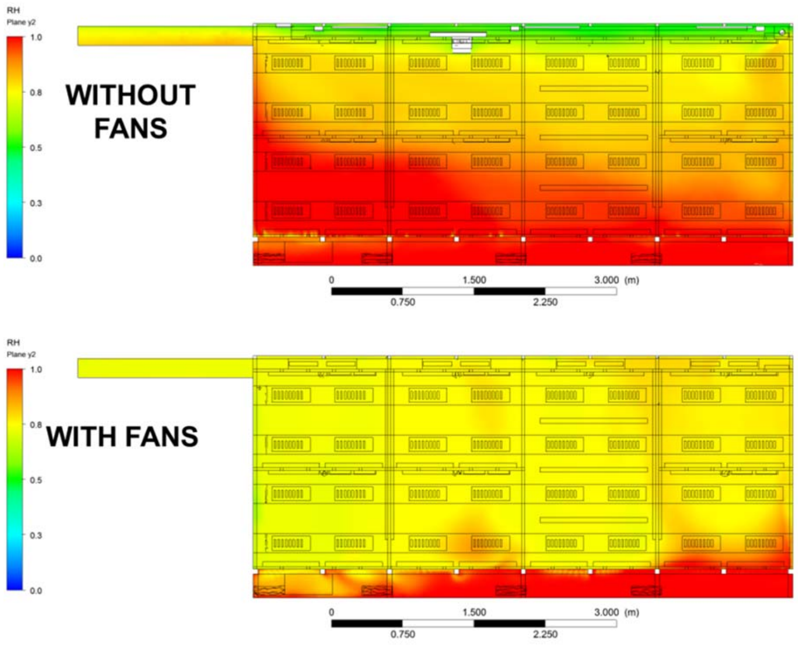
- The introduction of fans reduces RH gradient

	WITHOUT FANS	WITH FANS
Global RH gradient	25%	17%

RH at plane y1 (plants)



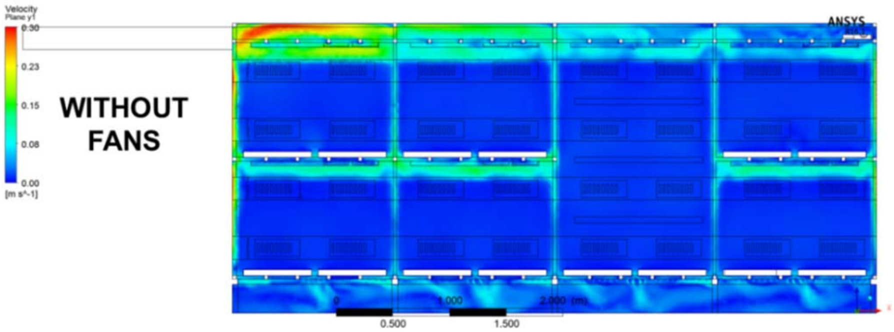
RH at plane y2 (corridor)

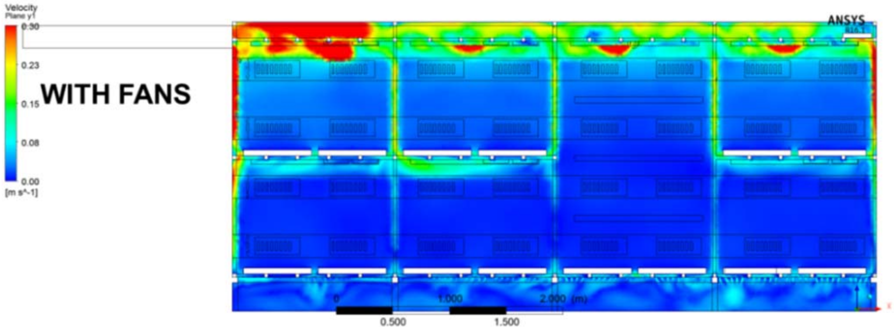


Velocity distribution

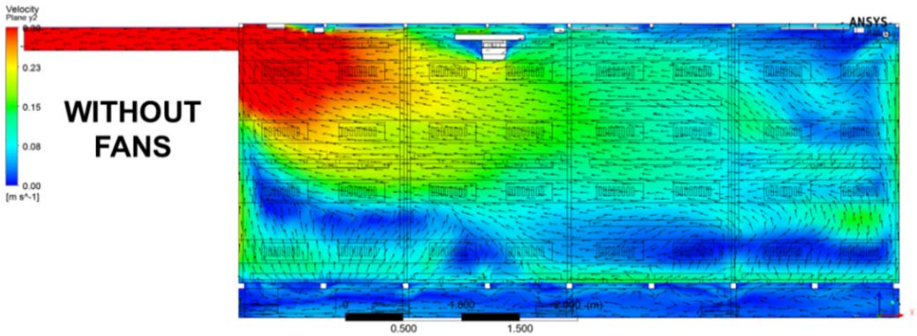
- In the simulation with fans the air has the following behavior:
  - ➢ not forced by the suction effect at outlet section (see cut plane y2) with a general mixing effect due to the fans
  - ➢ the velocity distribution near plants slightly changes. This is due to the plants' porosity.

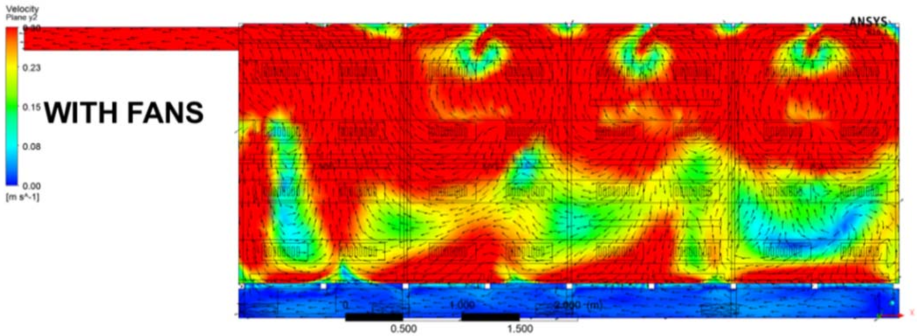
Velocity at plane y1 (plants)





Velocity at plane y2 (corridor)





Conclusions

- AMS (Air Management System) has been designed and optimized with the aid of CFD analysis: proper climate conditions for plant growth, with homogeneous temperature, RH and velocity are assured.

- A predictive and accurate CFD model for the mass and thermal balance of the FEG taking into account of HVAC, LED lights, non adiabatic conditions and plants' evapotranspiration has been built.

- The model allowed prediction for different scenarios:
  - Summer → reported here
  - Winter
  - Transient
  - Functional (no plants)

- CFD model allowed to verify the improvement of the mixing with the additional fans on the FEG's environment.

Thank you for your attention!