

# Greenhouse Monitoring with Biocompatible Humidity Sensor for Smart Farming



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5: Technische Universität Bergakademie Freiberg



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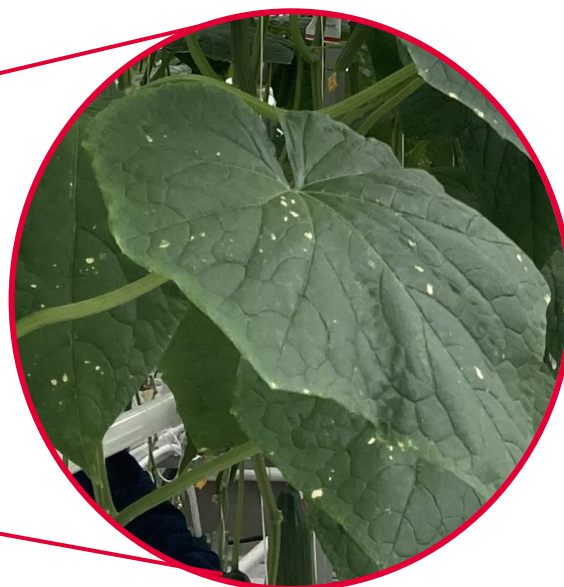
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# What is leaf wetness? Why is it important?



- › Presence of water on the leaf
- › Sources
  - Rain, Fog
  - Dew
  - Overhead irrigation
  - (Guttation)
- › Contribution to disease spread
  - Powdery Mildew
  - Quality loss
  - Crop loss
- › Leaf wetness
  - Indicator for Plant Diseases in Integrated Pest Management (IPM)

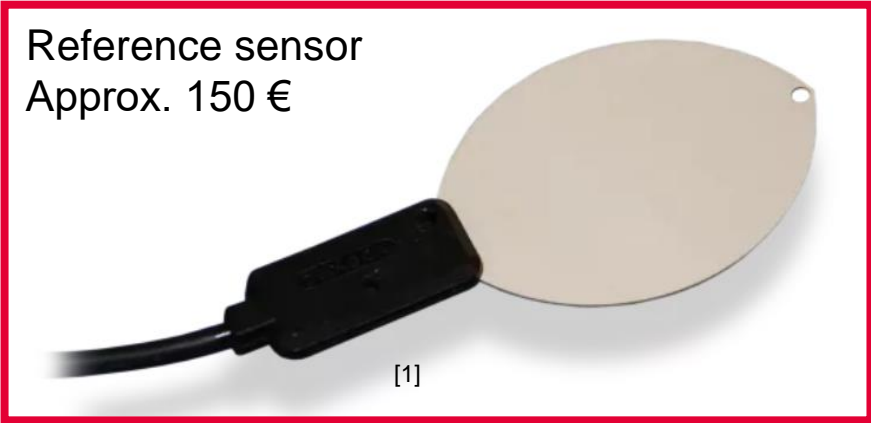
# Why measure leaf wetness in the greenhouse?



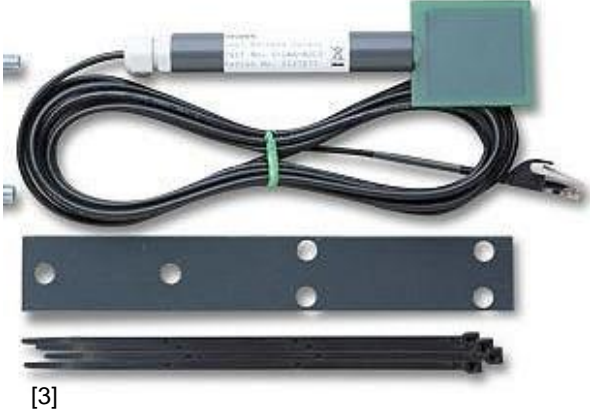
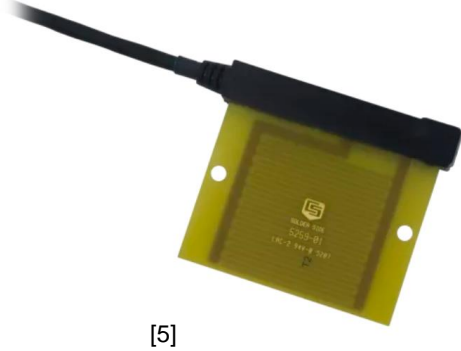
- › Leaf wetness
  - Indicator for Plant Diseases in Integrated Pest Management (IPM)
  
- › Greenhouse
  - Controllable climate
  - High yield crops
  - Investment potential

# State of the Art – Leaf Wetness Sensor

> Capacitive



> Resistive



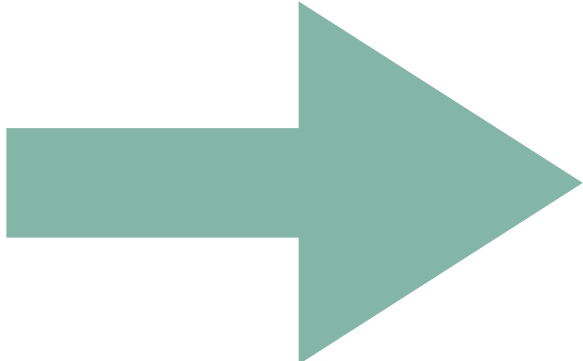
[1] <https://www.metergroup.com/en/meter-environment/products/phytos-31-leaf-wetness-sensor>; [2] <https://www.netsens.it/en/products/sensors-and-portable-instruments-5>; [3] <https://www.onsetcomp.com/products/sensors/s-lwa-m003/>; [4] <https://www.specmeters.com/weather-monitoring/sensors-and-accessories/sensor-options/all-sensors/a-series-leaf-wetness-sensor/>; [5] <https://www.campbellsci.com/237-1>; [6] <https://www.envirodata.com.au/weather-sensors/leaf-wetness-sensor>

# Room for improvement



## State of the Art

- > Big, bulky
- > Costly
- > Mimics leaf properties
  - Thermal properties
  - Orientation to sun



## Innovation

- > Miniaturized
- > Highly integrated
- > Measures leaf properties
  - Low thermal mass
  - Moves with the leaf

# Biocompatible Humidity Sensor

## Biocompatible Materials

- › Parylene C
- › Highest biocompatibility



## Sensing Solution

- › Capacitive Measurement
- › Well-known CMOS Technology
- › Compatible ASIC
- › Highly integrable

## Possible Applications

- › Leaf Wetness Sensing
- › Human Comfort Sensing
- › Medical Sensing

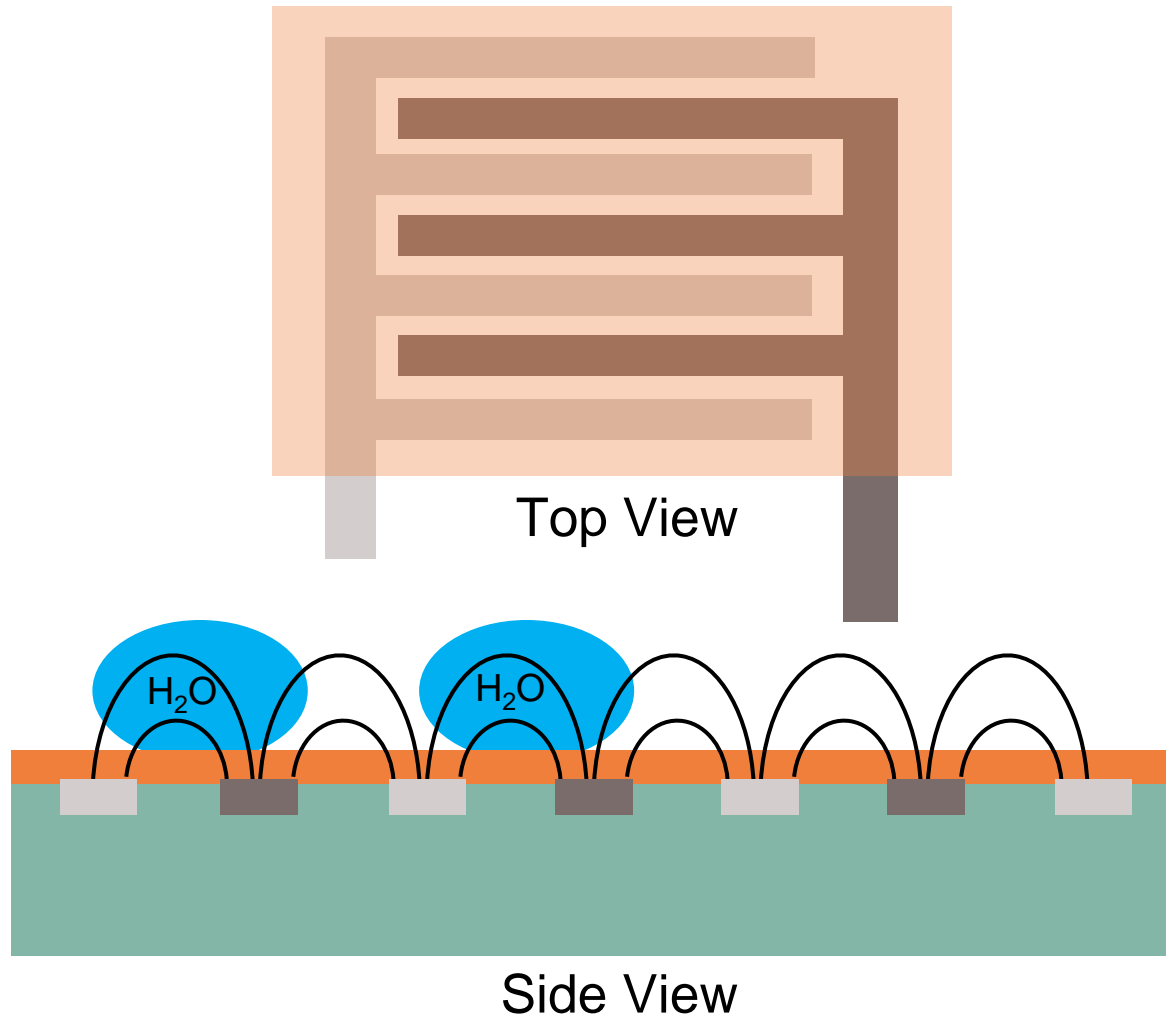


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# Idea – Miniaturized Leaf Wetness Sensor



## Key parameters

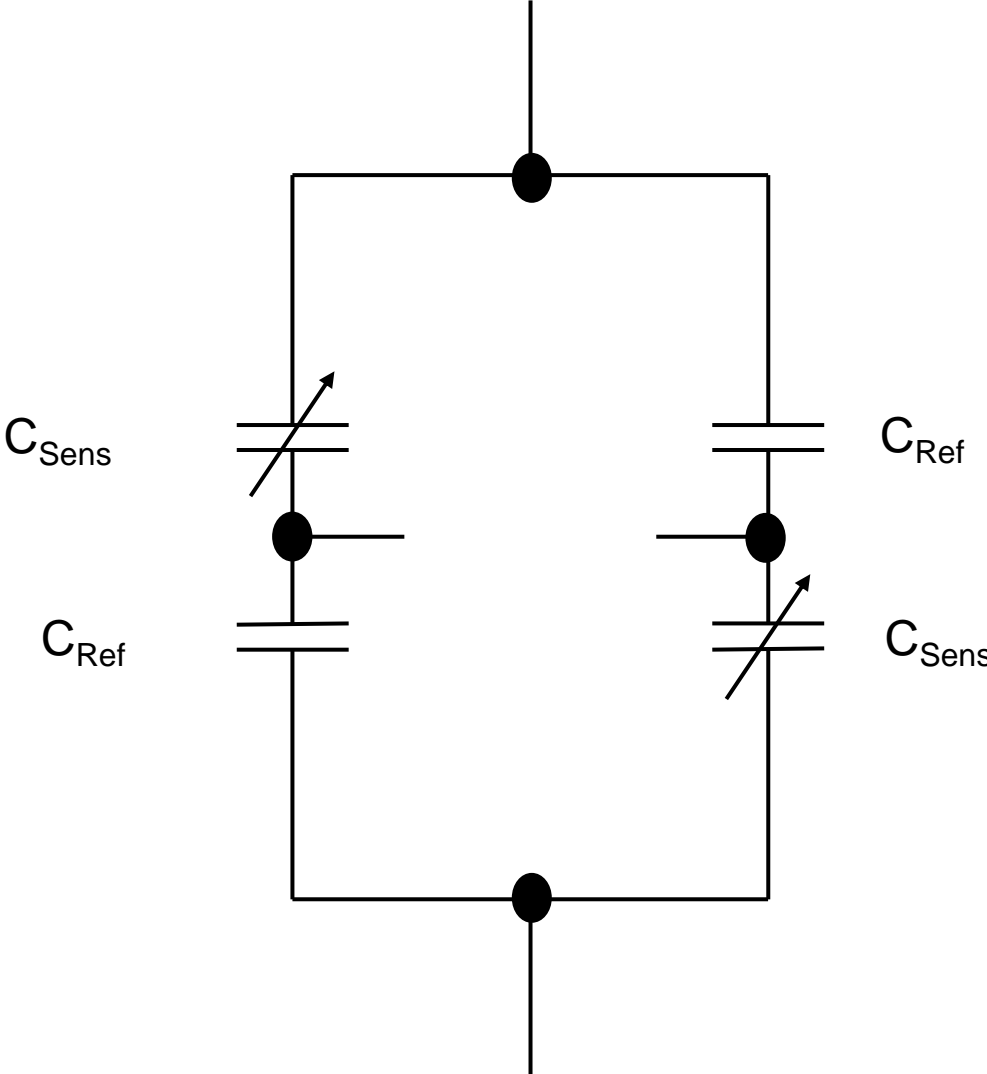
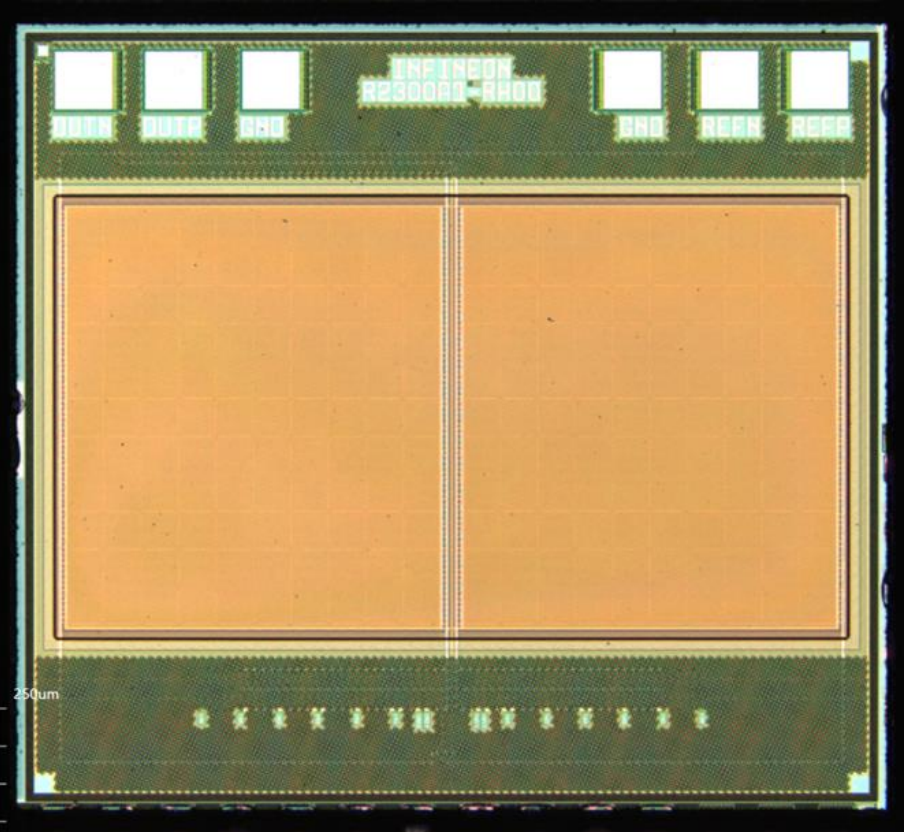
### › Geometry

- Electrode geometry
- Electrode width and gap
- Number of fingers

### › Sensitive material

- Dielectric properties
- Capacitance change in presence of water
- Biocompatibility

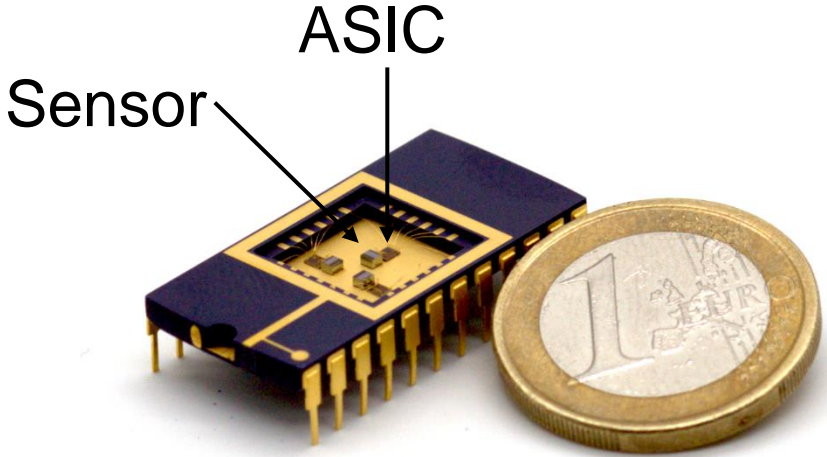
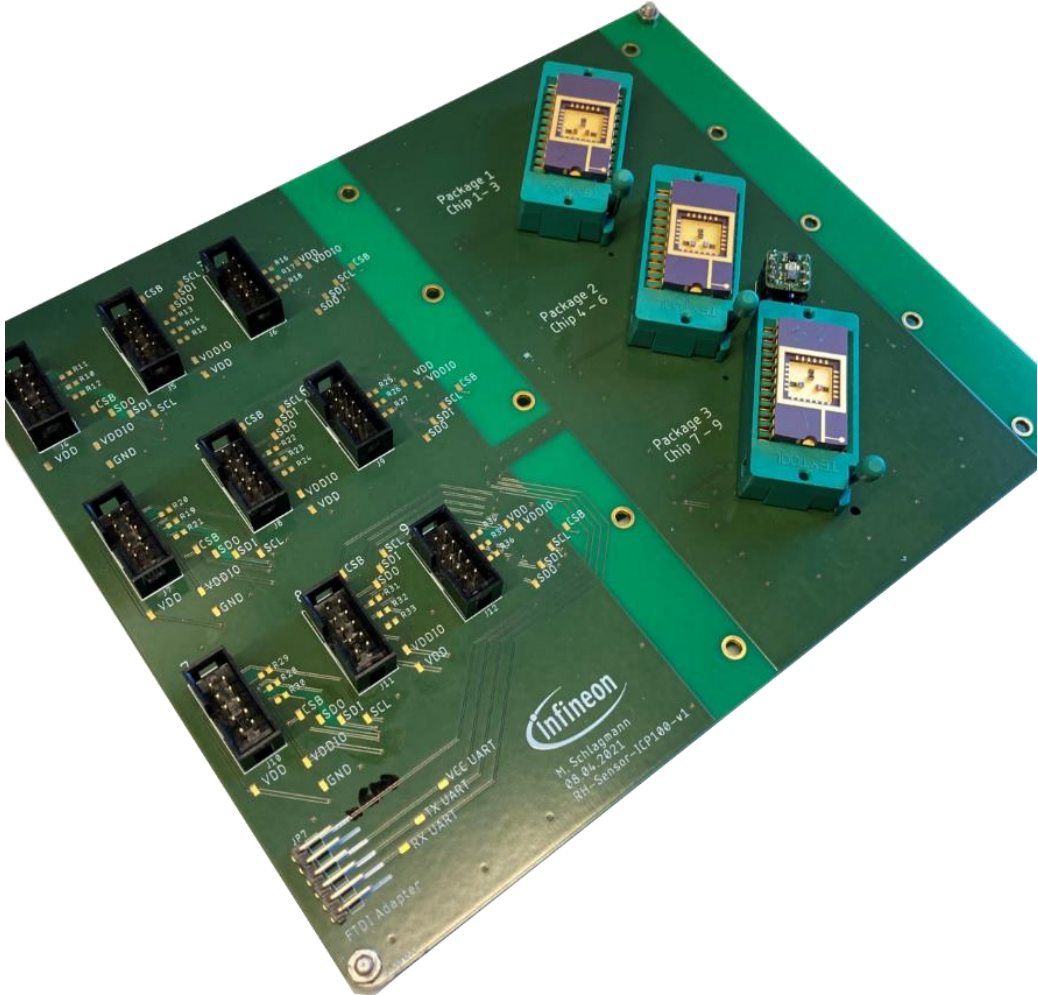
# Structure



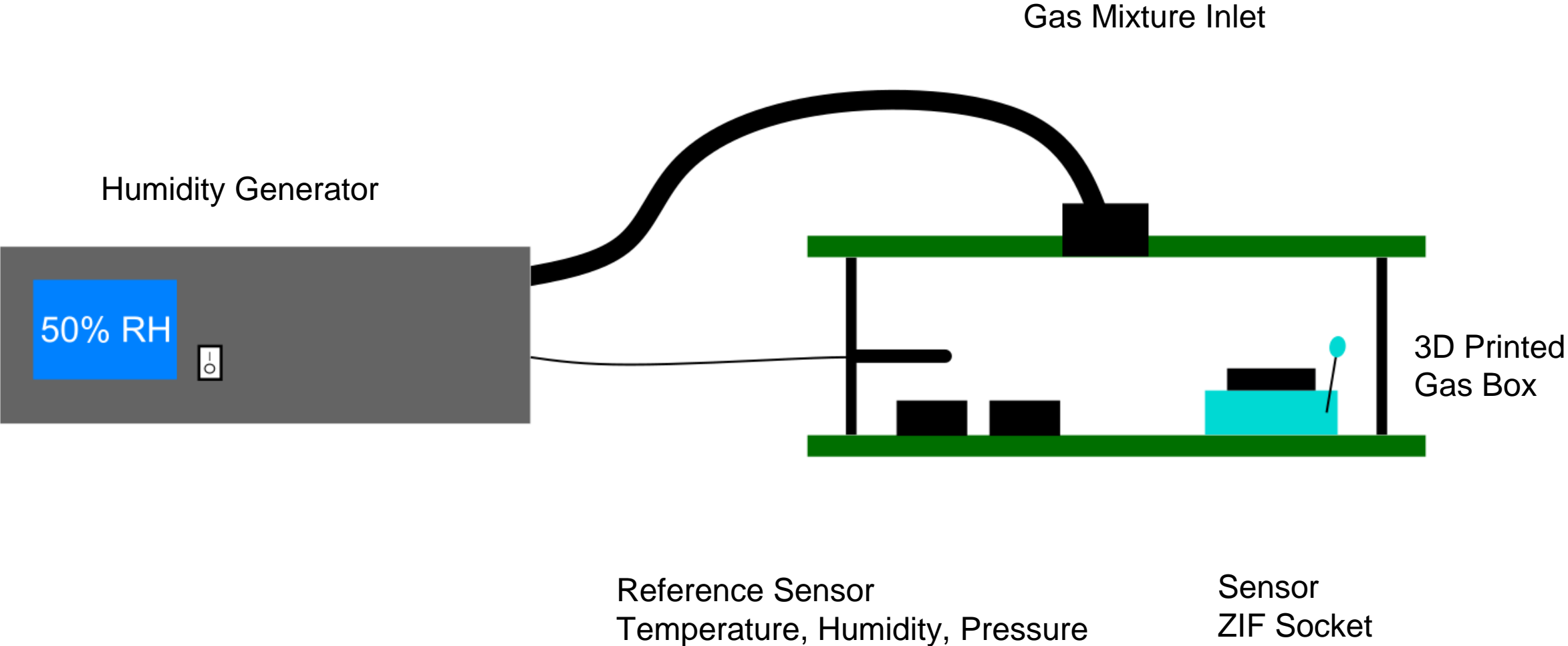
# Samples

> 3 different kind of samples available

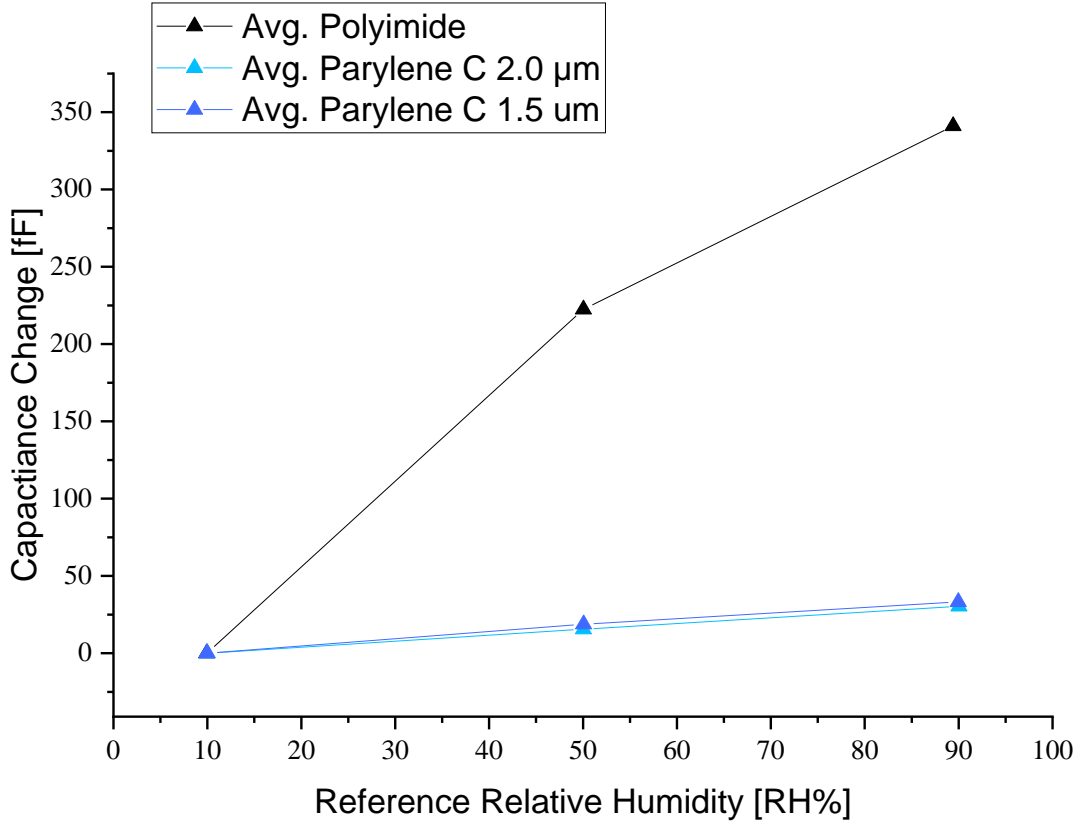
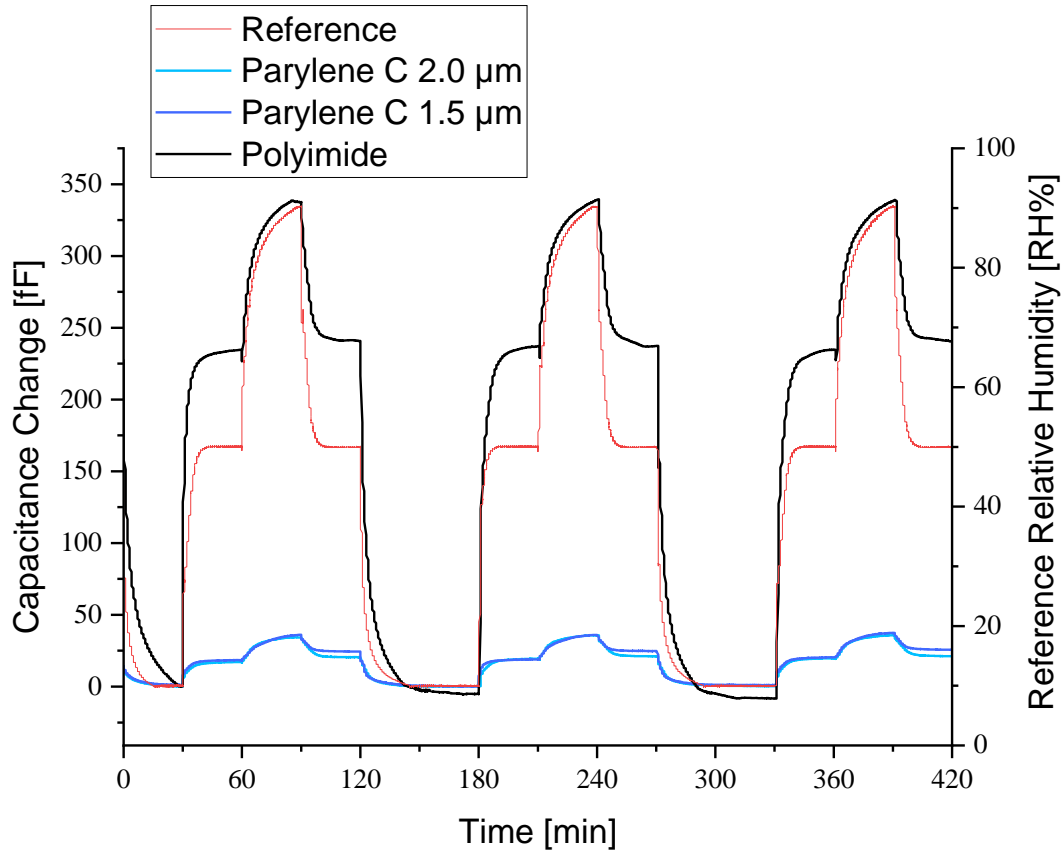
- Parylene C 1.5  $\mu\text{m}$
- Parylene C 2.0  $\mu\text{m}$
- Polyimide



# Measurement system



# Sensitivity



# Sensor adjustments



- › Testing under relevant conditions
  - Sensor on printed circuit board (PCB) attached
  - Parylene C coated
  - Laboratory calibrated
  - 3D printed housing
  - Data and power connected

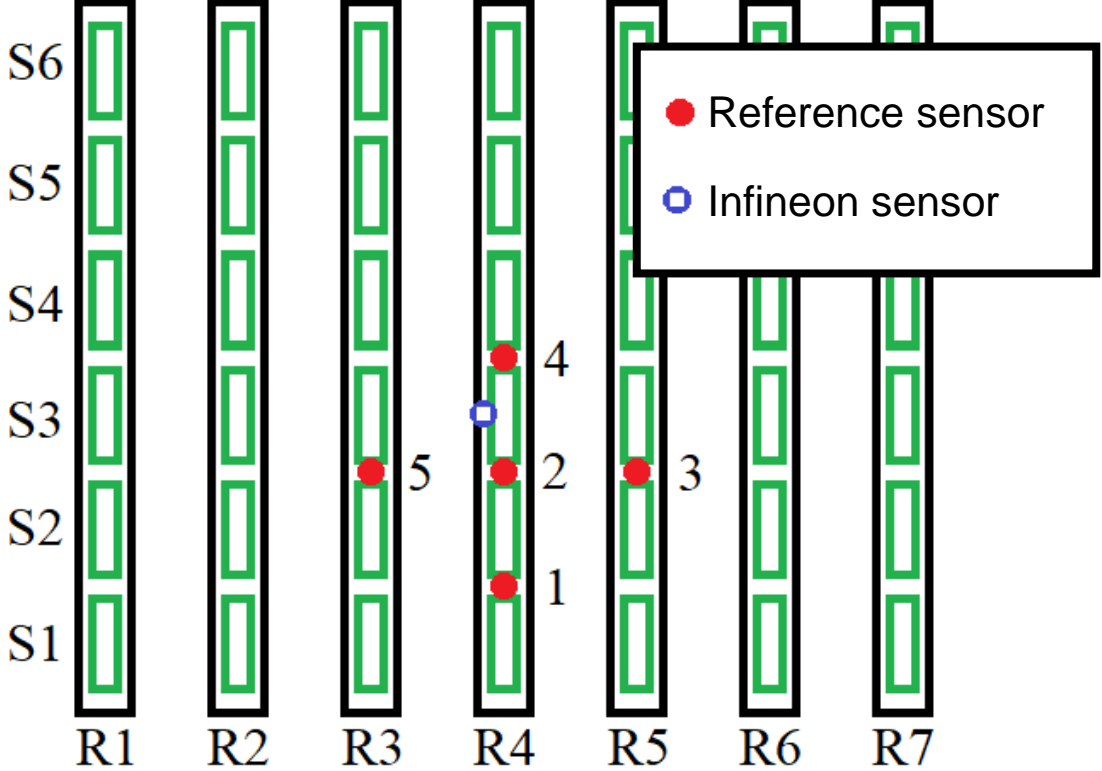
# Greenhouse and reference sensors



- › Venlo-type greenhouse compartment
- › *Nunhems Hi-Power* cucumber cultivar
- › Controlled parameters
  - Window opening
  - Fogging
  - CO<sub>2</sub>
  - Heating (pipe heating at bottom and crop height)



# Reference sensors and greenhouse crop management



- > 5 leaf wetness reference sensors
  - 5 state-of-the-art reference sensors
  - *Phytos 31, Metergroup*
- > Crop management
  - Daily check
  - Weekly crop handling and treatment

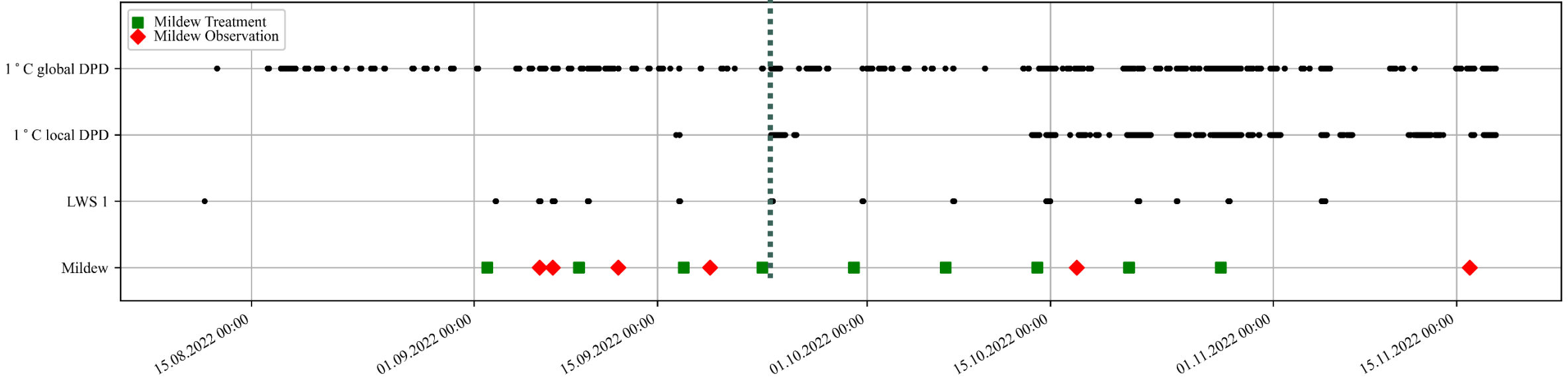
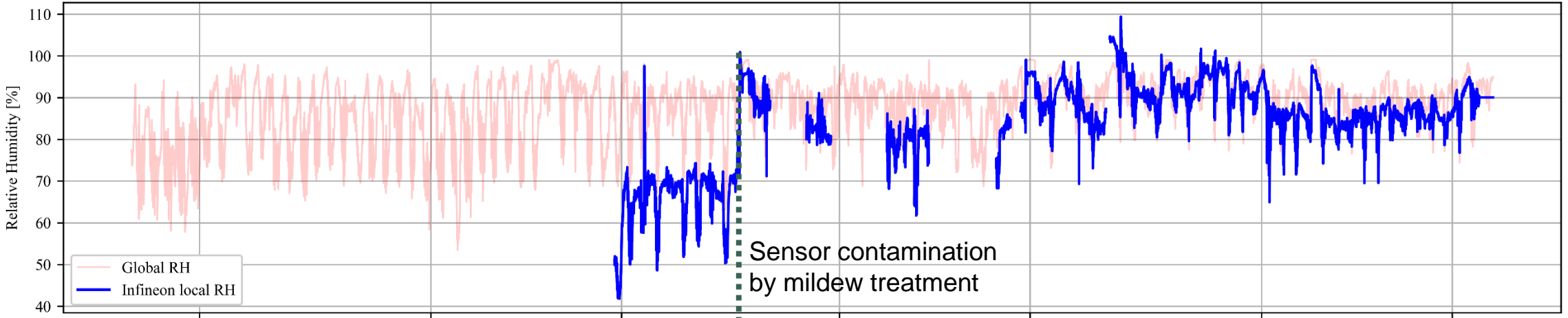
Top view of the greenhouse layout

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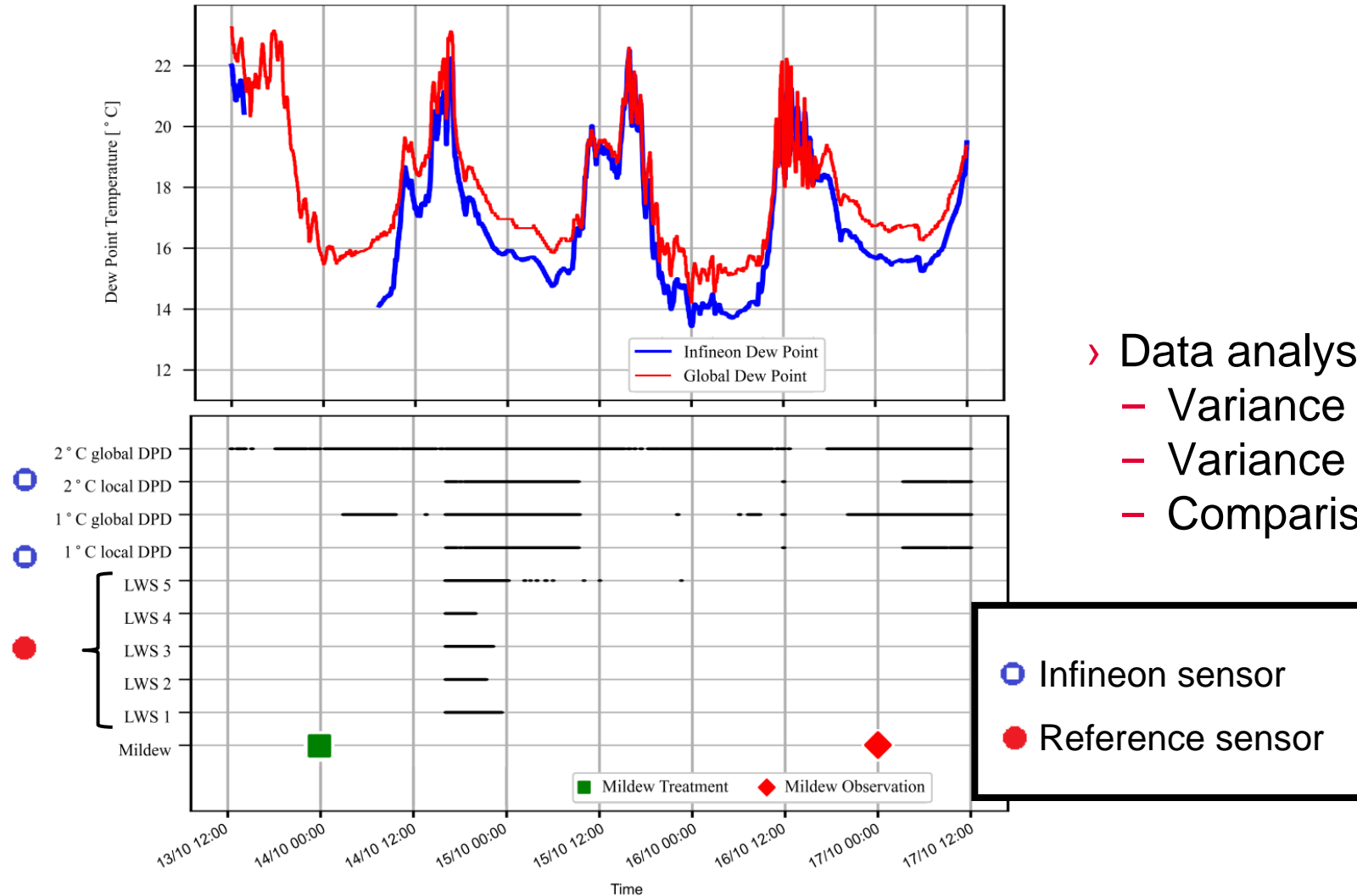
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# Measurement results in the greenhouse



# Example event



- › Data analysis challenging
  - Variance between SoA sensors
  - Variance between local and global DPD
  - Comparison of different DPD thresholds

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## Conclusion and limitations

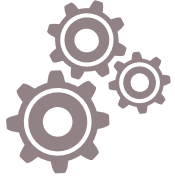
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### **Successful proof of concept under relevant conditions**

- › Relative Humidity / Dew Point can be measured
- › With Dew Point Depression (DPD) leaf wetness duration can be estimated
- › Durability of sensor, with constraints of handling and plant protection product
- › Further investigation towards interaction with powdery mildew for decision making needed

# Outlook



## **Packaging improvements for durability and miniaturization**

- Flexible Parylene C printed circuit board
- Size reduction
- Interconnection improvements



## **Modification of Parylene surface** to enhance sensitivity

- Physical and chemical treatment



## **Next level of application** with several sensors in greenhouse

- Coordinate crop management with sensor validation

# Acknowledgment

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