# 4CeeD Lecture Series

Lecture #4: SENSELET

March 31st, 2022

## SENSELET: Sensory Network Infrastructure for Scientific Lab Environments

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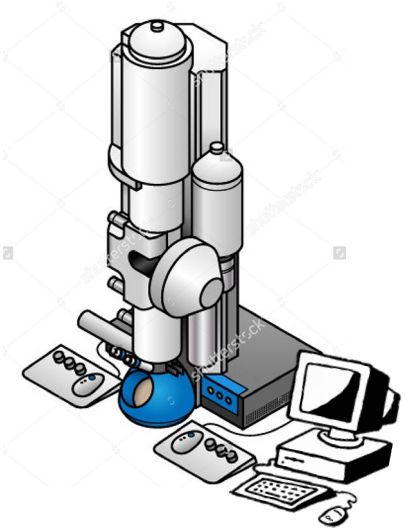
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

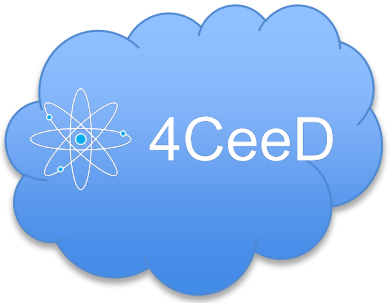
# Lecture Series Learning Objectives

- Lecture 1 (3/22): Overview of 4CeeD
- Lecture 2 (3/24): 4CeeD Demo & Advanced Features
- Lecture 3 (3/29): 4CeeD Backend Services
- **Lecture 4 (3/31): SENSELET**
  - Background & Motivation
  - SENSELET Architecture
  - Components of SENSELET
  - Live Demo of SENSELET Visualization

# Recap of 4CeeD

- Address Scientific Digital Data Acquisition, Curation and Sharing prior to Scientific Publication of Results via Private Cloud Storage Facility






**Instrument**
**(MRL/MNTL)**

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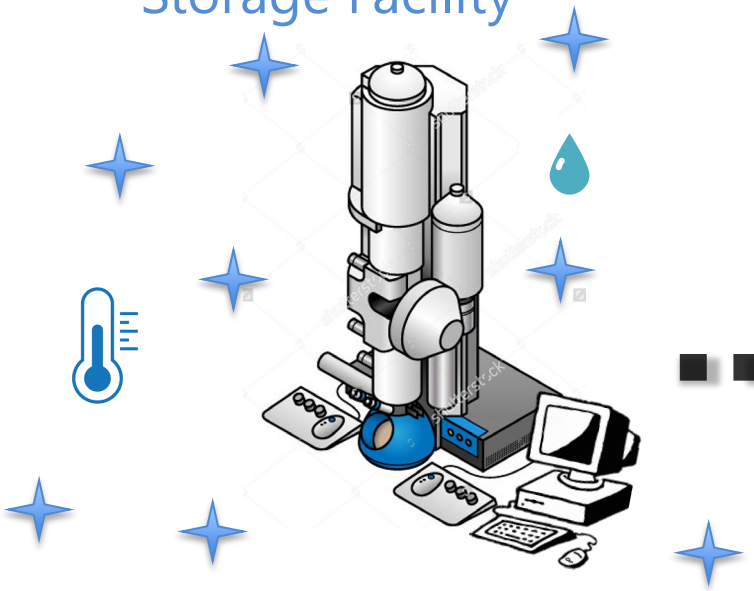

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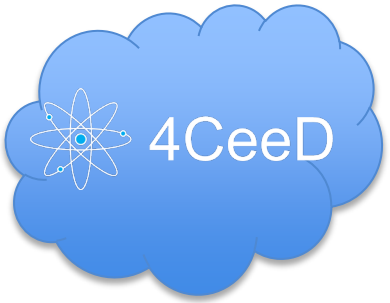

# Outline

- Background & Motivation
- SENSELET Architecture
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# Digitizing the Research Laboratory

- University equipment is utilized well-beyond its expected lifetime
- Many do not offer means for digitalizing feedback data during experiments


30+ year old Plasma Etcher

25+ year old Plasma Deposition

# Consequences of Uncontrolled Environments

- Excess humidity in un-controlled and un-monitored environments can lead to failure modes
  - Photoresist delamination
  - Critical dimension (CD) fluctuation [1]
  - Photoresist thickness variation [1]

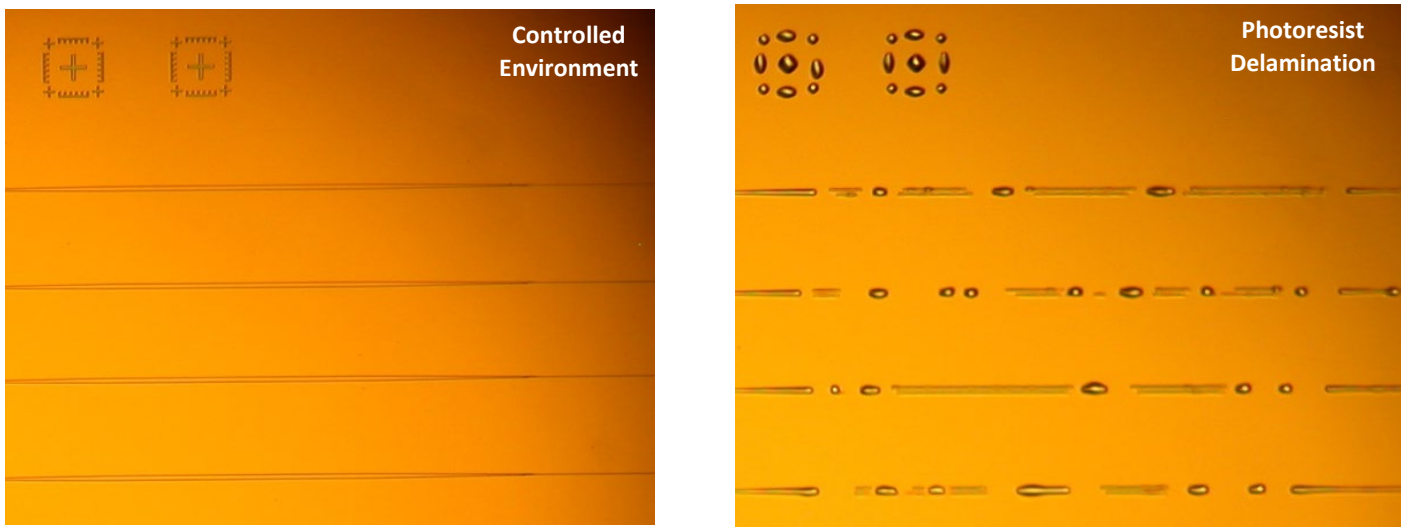
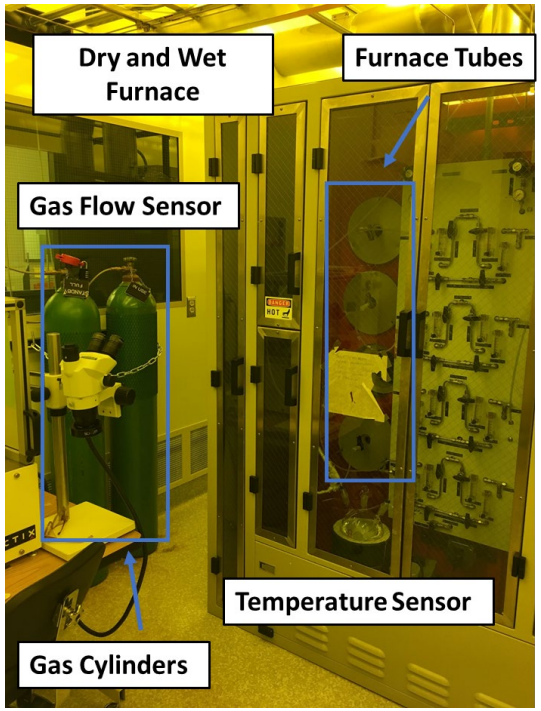



Fig. 1 Comparison between an optical microscope image of developed photoresist that form sharp waveguides (left) and photoresist showing delamination caused by excess humidity of the cleanroom (right).

# Automatic Data Logging of Lab Environments

- Real-time environmental data logging is time-consuming when conducted manually
  - Large-scale commercial sensor networks are expensive
  - Implement variety of sensors on lab equipment (ex. furnaces)




Monitoring of long duration experiments:

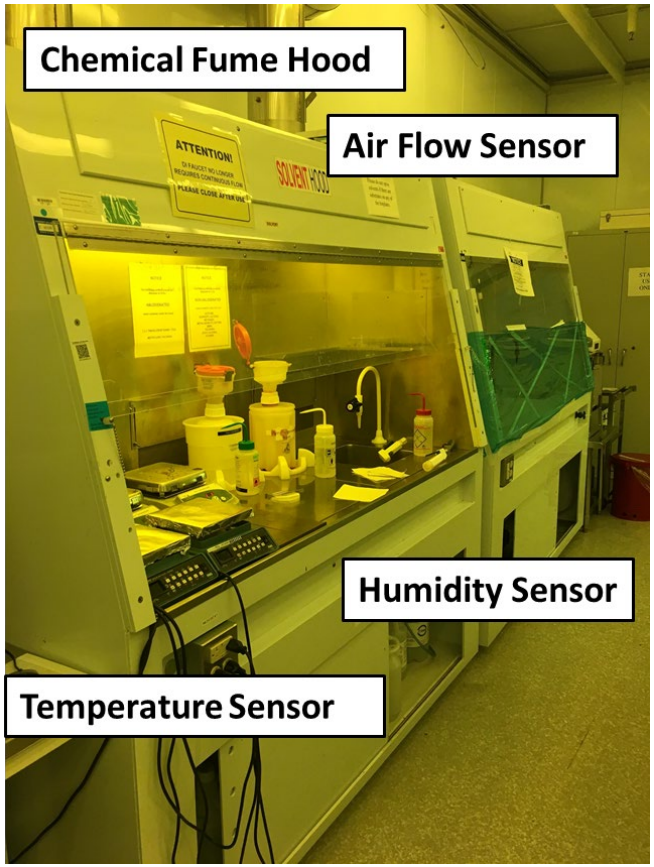
- Diffusion
- Oxidation
- Annealing

Monitoring Sensors:

- Gas flow sensors
- Temperature sensors

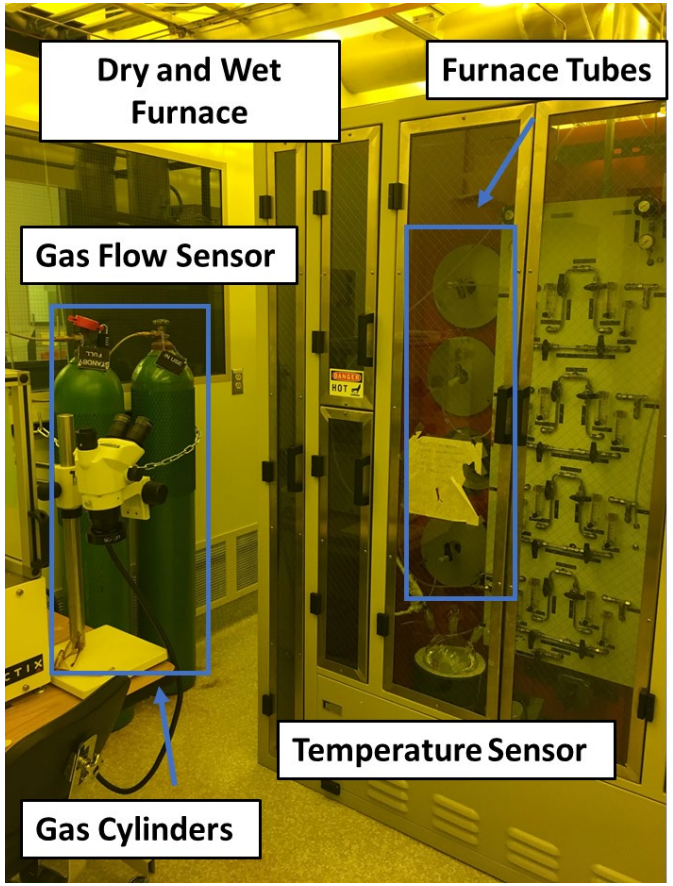
# Environmental Logging: Chemical Fume Hood

- Automatically log/track humidity, temperature, gas flows, and others




- **Temperature/Humidity Sensor:** real-time tracking to ensure optimal performance during lithography processes
- **Air Flow Sensor:** Threshold tracking to notify cleanroom users for out-of-spec performance
  - Eliminates downtime of the fume hood if it doesn't pass safety audit inspection

# Environmental Logging: Furnaces/Gasses




- **Gas Flow Sensor:** real-time tracking of oxidation experiment or determining the remaining amount of gas
- **Temperature Sensor:** real-time tracking of sensitive oxidation, annealing, or diffusion processes
  - Aids in troubleshooting or guaranteeing reliability of long experiments (2-3 hours)

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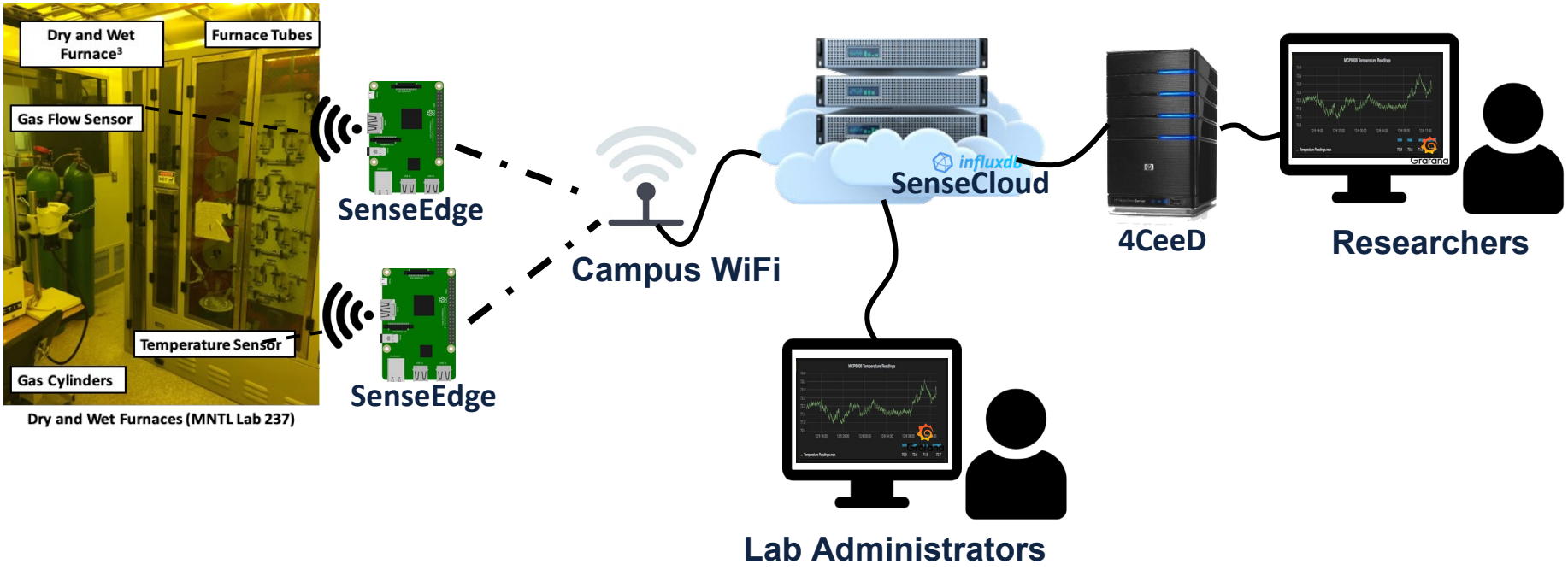
- Live Demo of SENSELET Visualization

# What is SENSELET?

- A system of wireless, automated sensors that monitor the cleanroom environment, together with the central server which manages the sensory data



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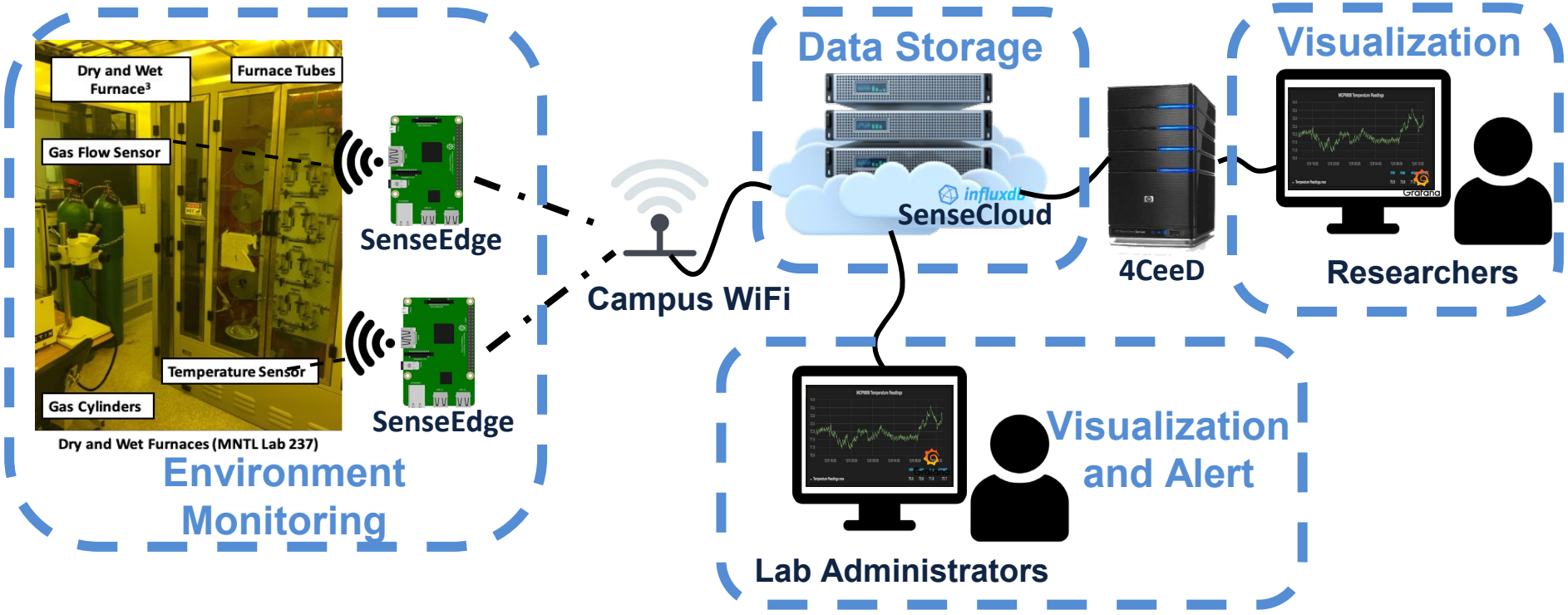

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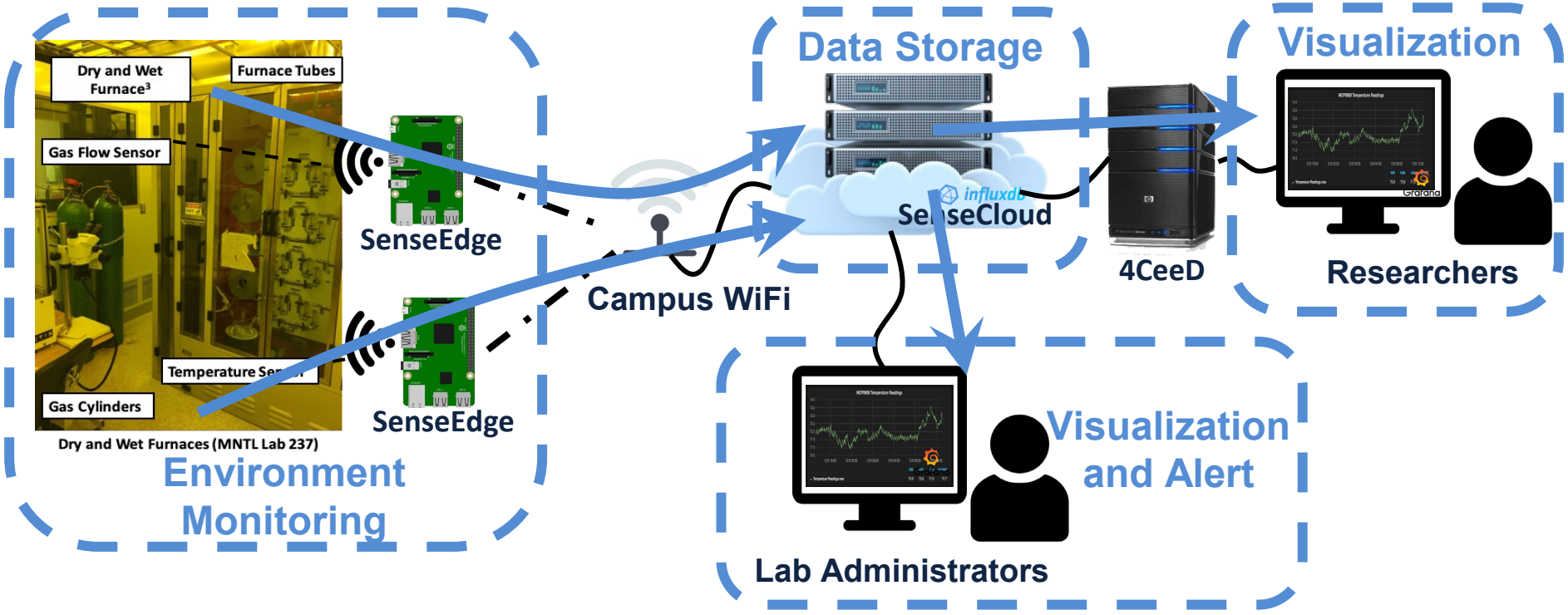
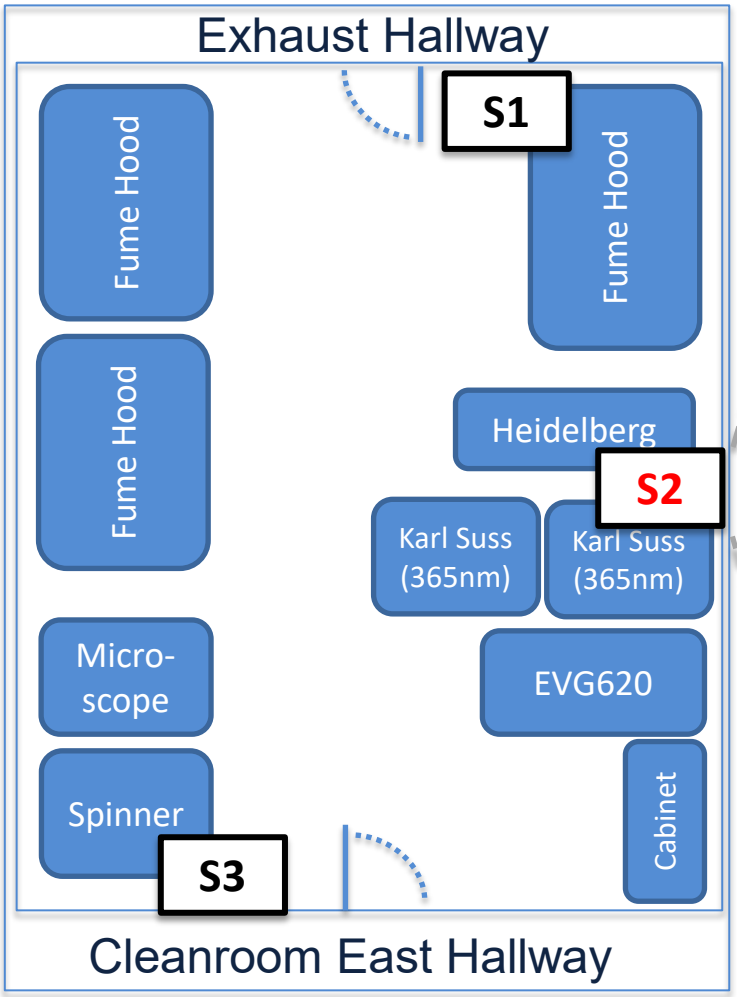
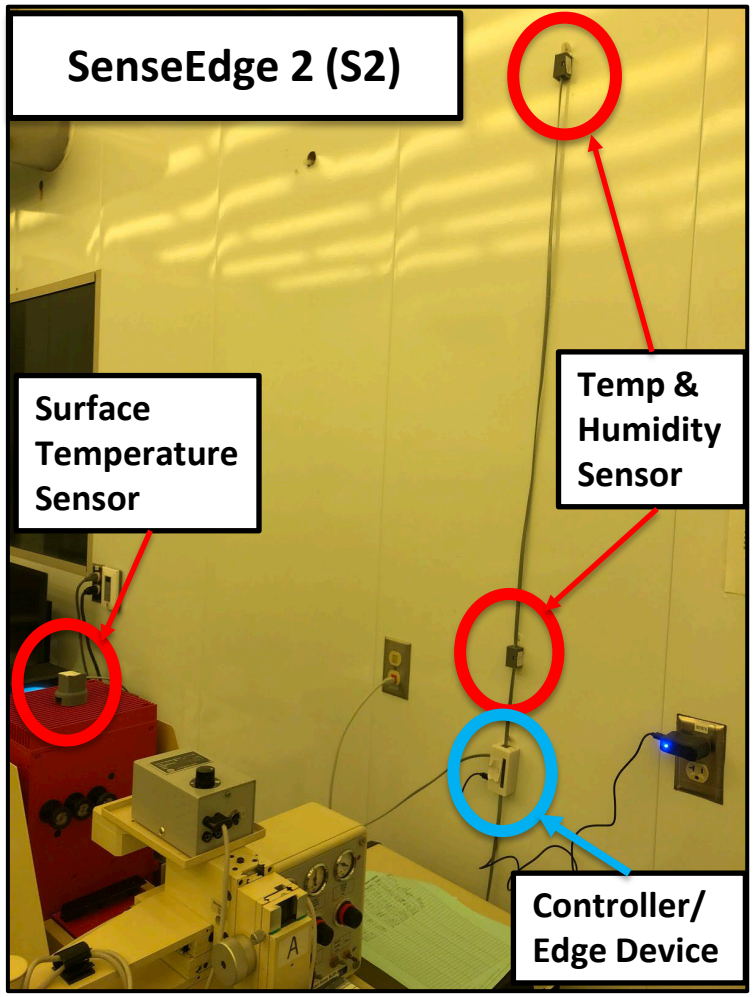


# SENSELET in Lithography Room



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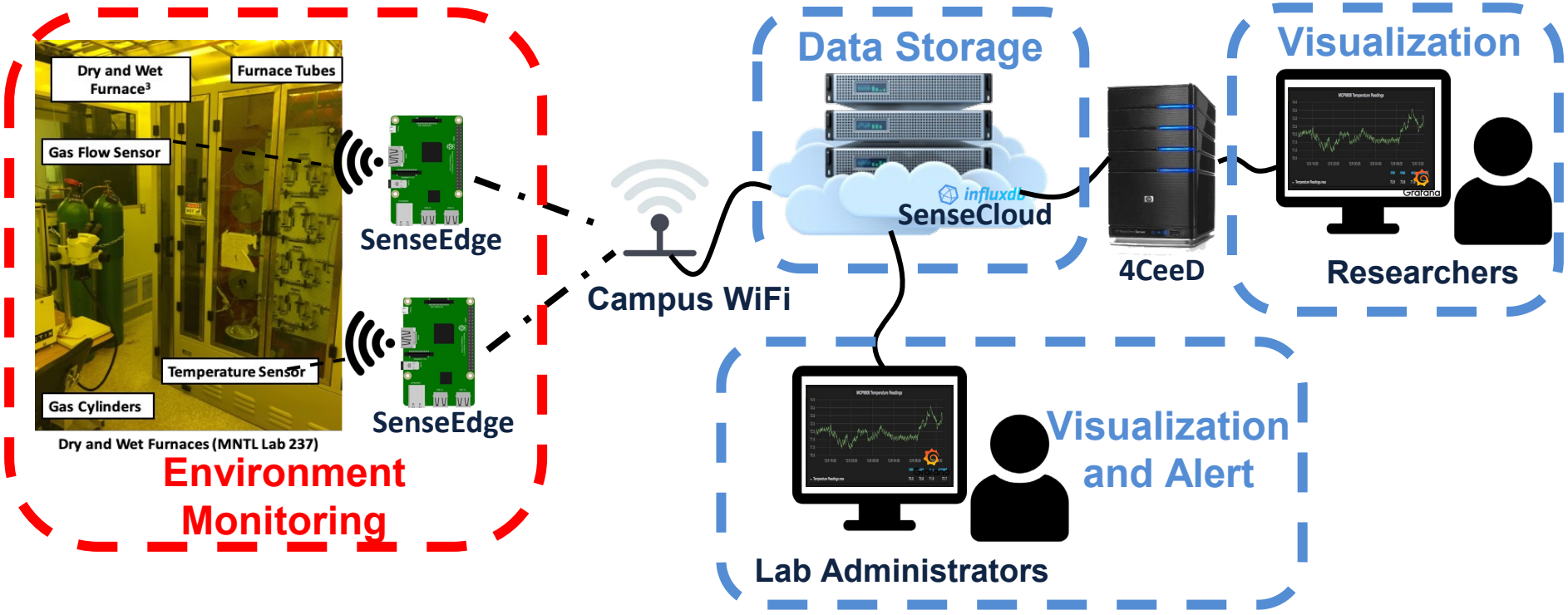
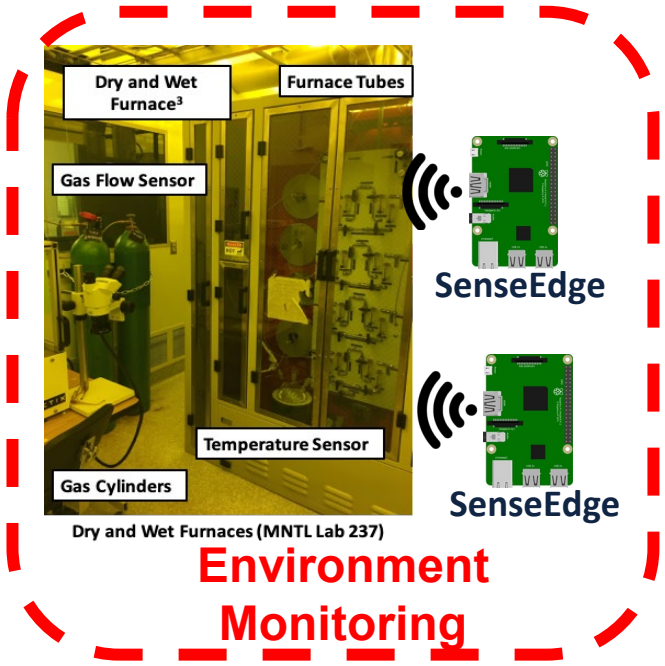


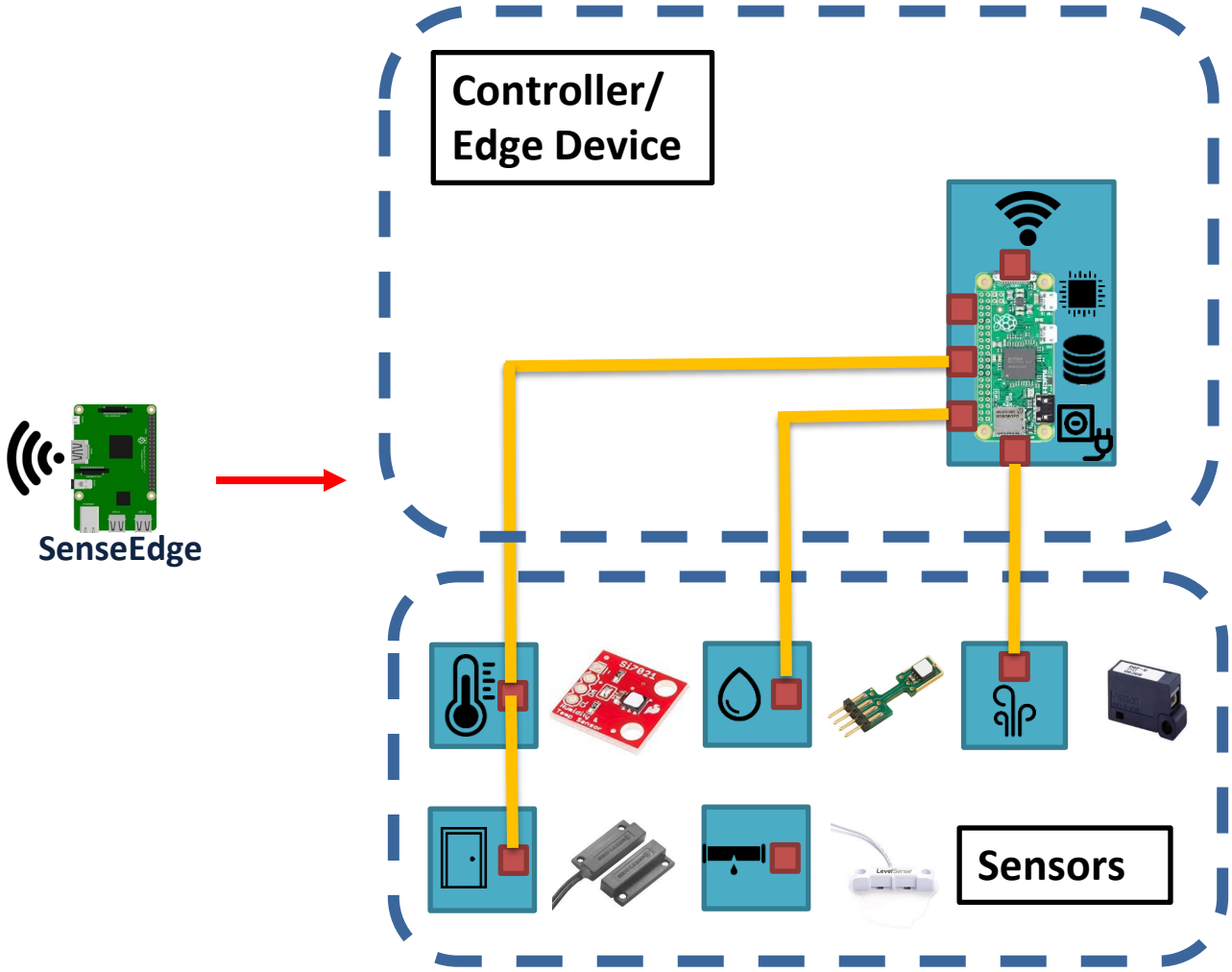
# SenseEdge Functions




Functions of SenseEdge:

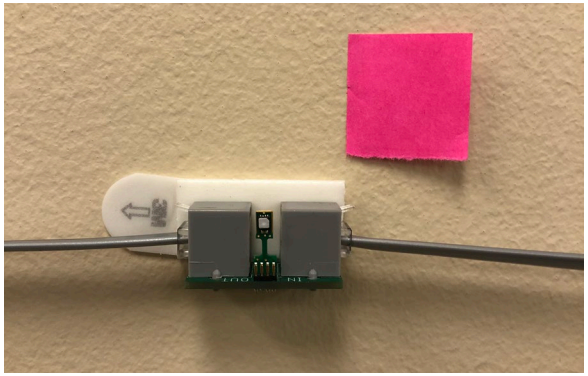
- Track temperature, humidity, (water leakage, air flow, door status etc.)
- Send data to central cloud server
- Recover from failures

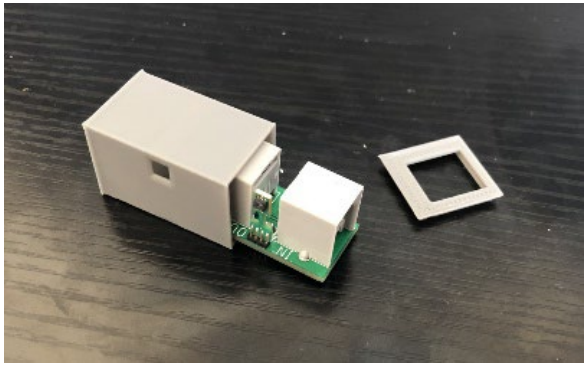
# SenseEdge – Structure



# SenseEdge – Sensors

- Temperature and Humidity Sensor



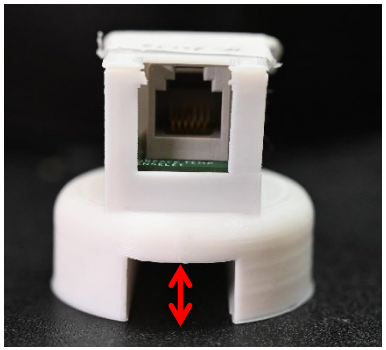


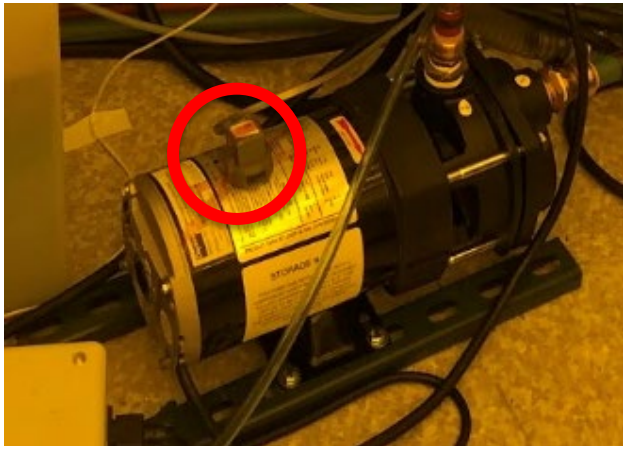
- Humidity Range: 0 … 100% RH
- Humidity Accuracy: ±1.5 %RH

- Temperature Range: -40 … 105 °C
- Temperature Accuracy: ±0.1 °C
  (20 to 50 °C)

# SenseEdge – Sensors

- Infrared Temperature sensor (Pump)

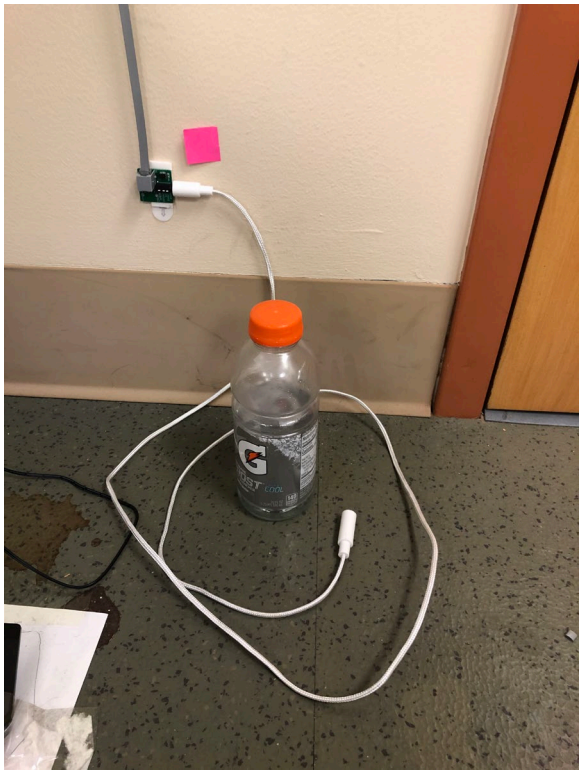




- Temperature Range: -70 … 380 °C
- Temperature Accuracy: ±0.5 °C

# SenseEdge – Sensors

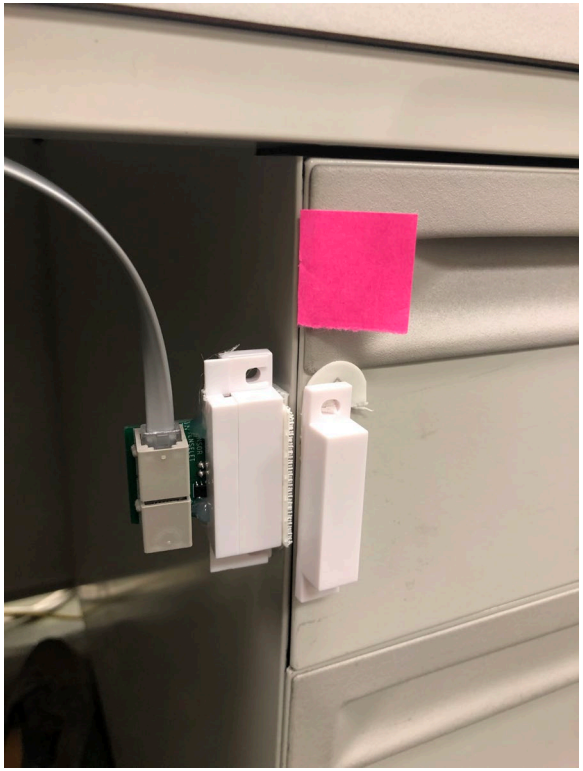
- Water Leakage Sensor Rope



- Water Leakage Sensor Point

# SenseEdge – Sensors

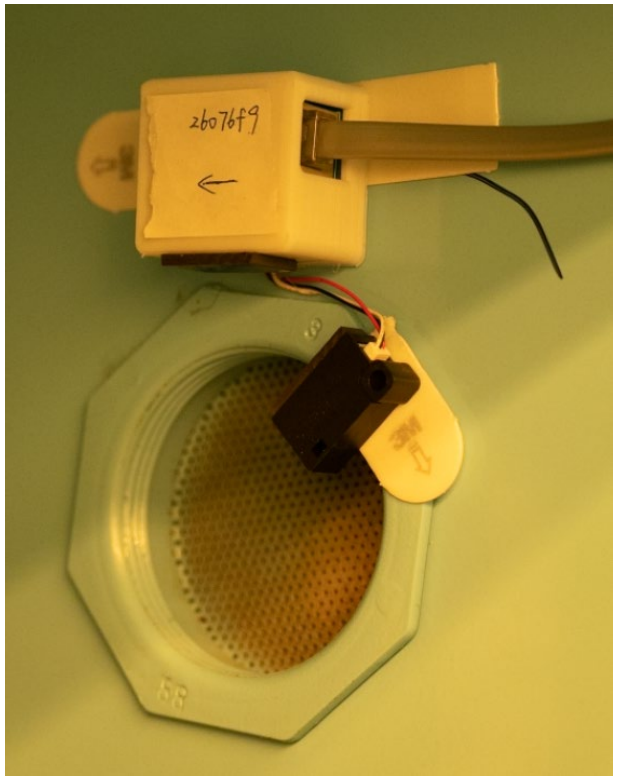
- Magnetic Sensor Large

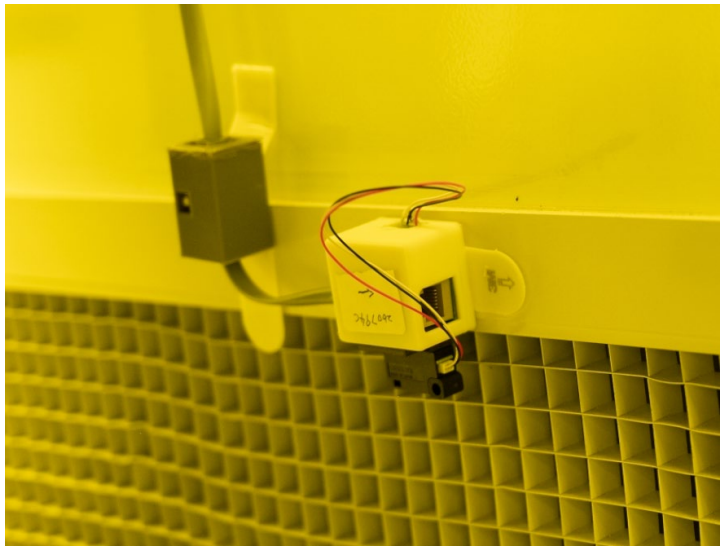


- Magnetic Sensor Small

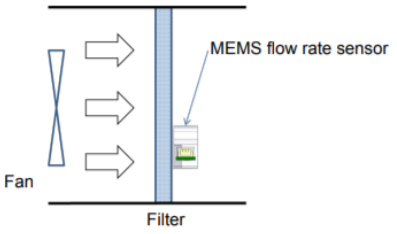
# SenseEdge – Sensors

- Air Flow Sensor

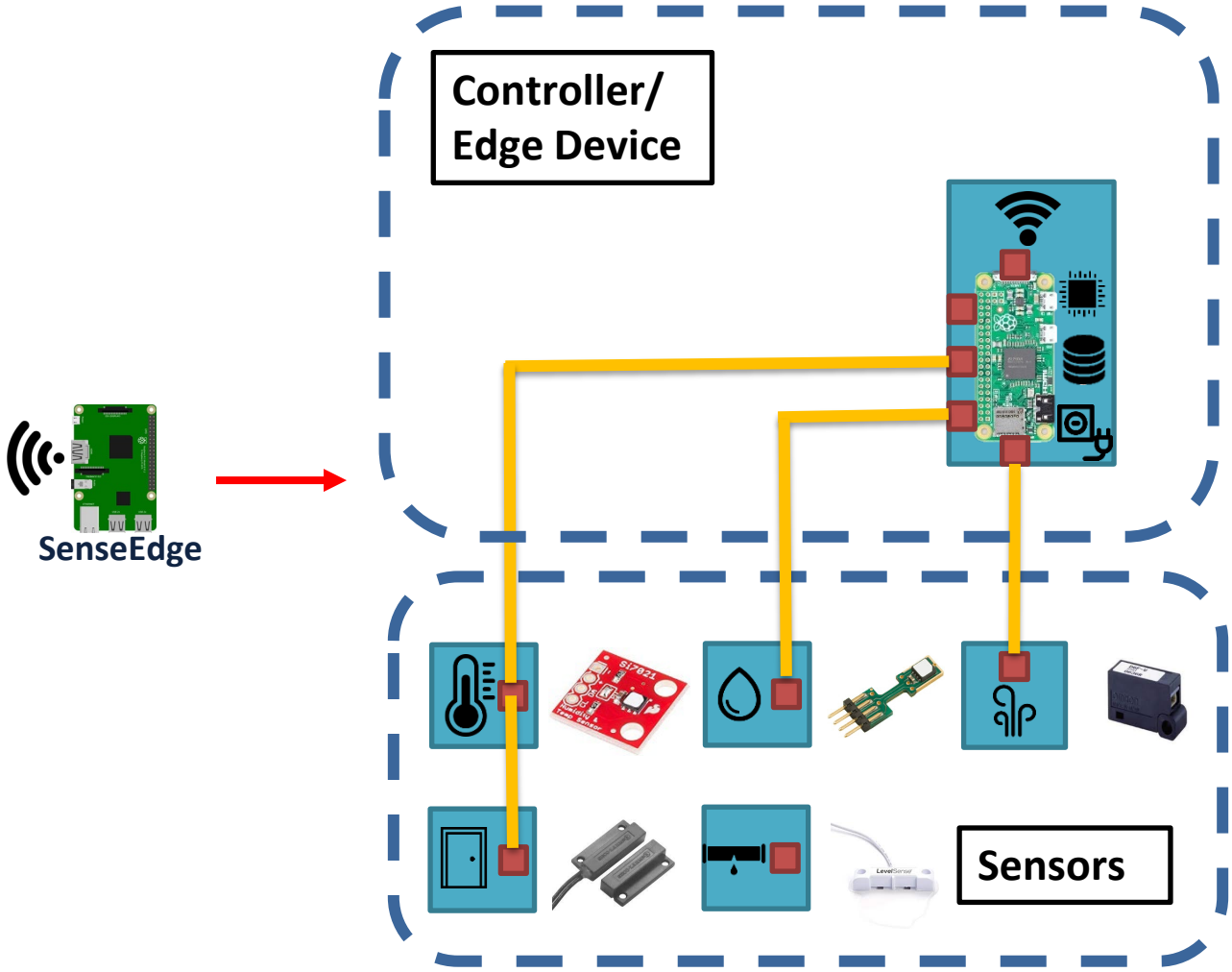


Clogged Filter Detection

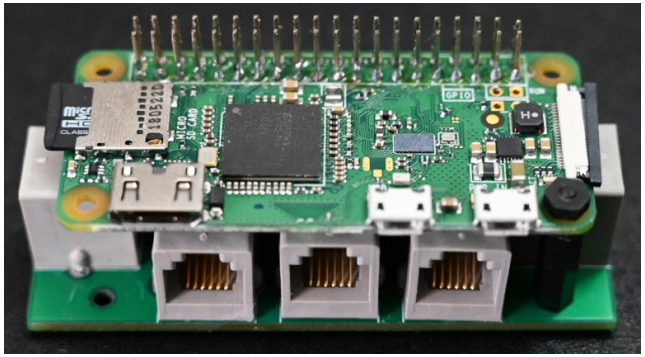


# SenseEdge – Structure



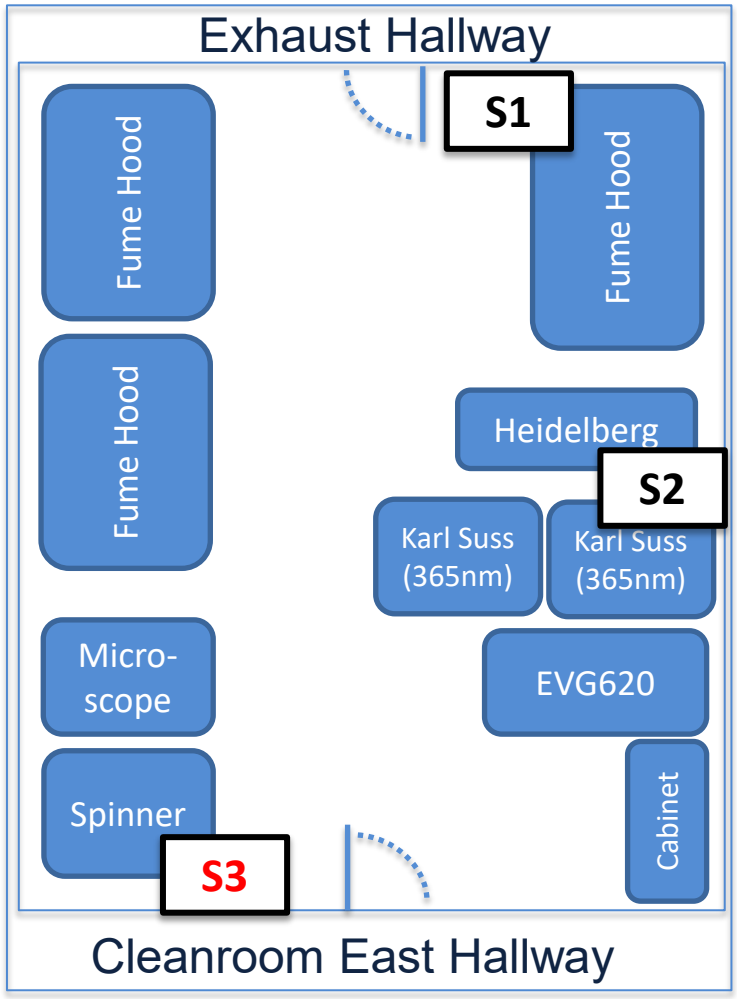
# SenseEdge – Edge Device

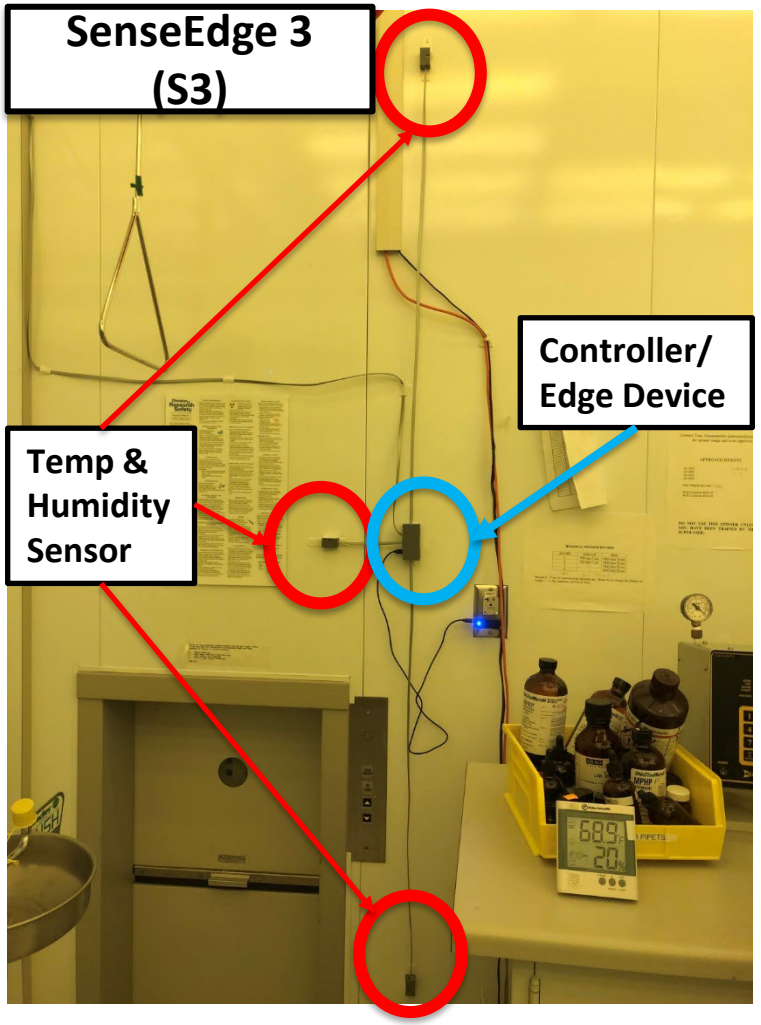
- Edge Device



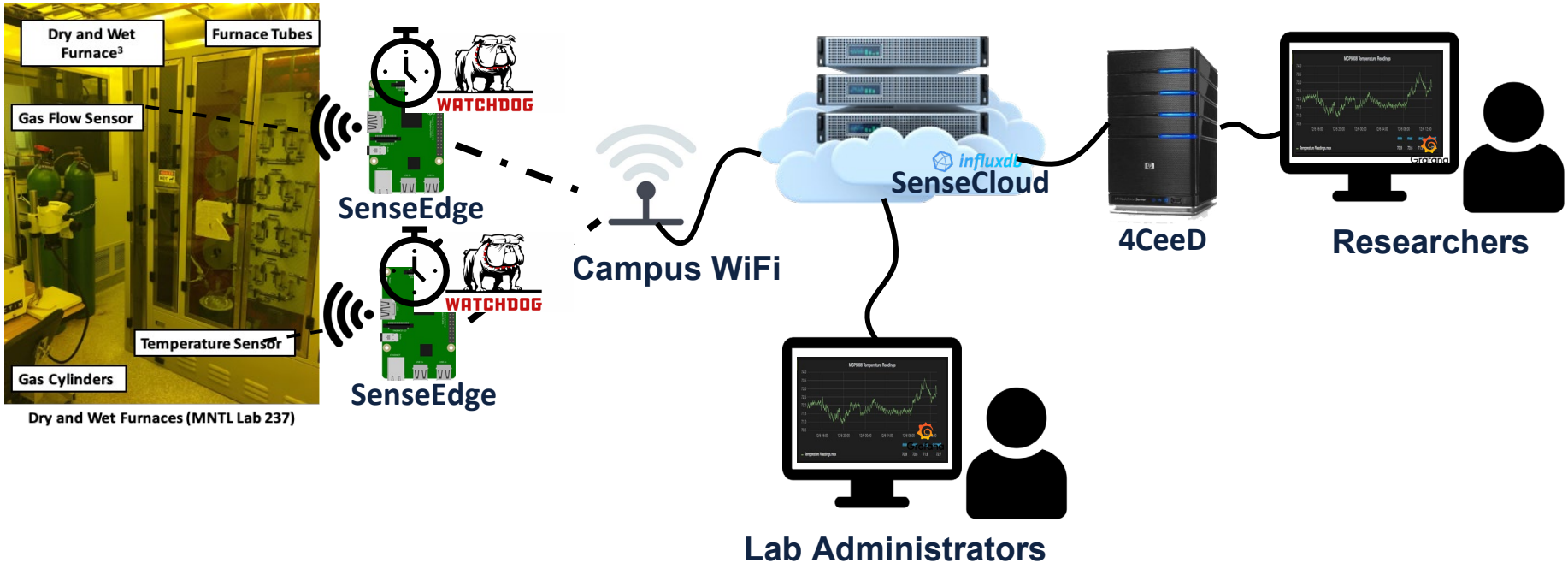
- Raspberry Pi --- “small single-board computers”
- Originally designed to “promote teaching of basic computer science”
- “now widely used even in research projects”
- Wi-Fi, Bluetooth, Ethernet, USB, Micro HDMI, GPIO header pins, CSI interface

# SenseEdge - Deployment



# Reliability of SenseEdge



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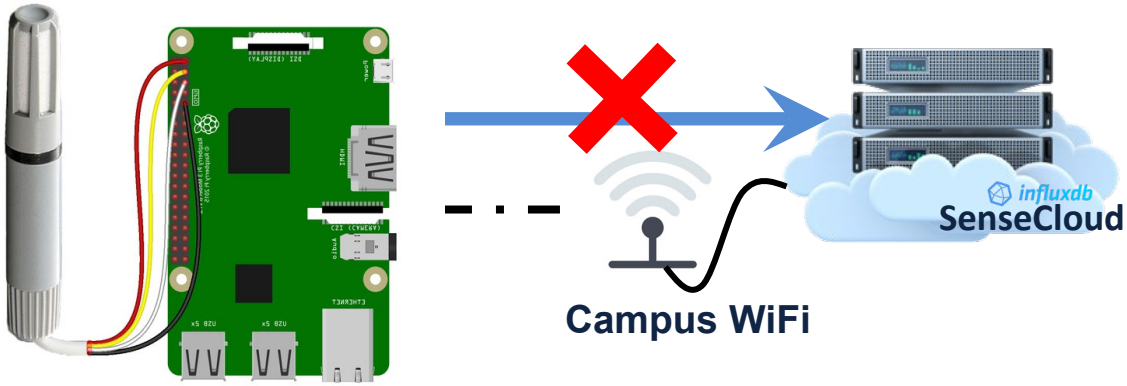

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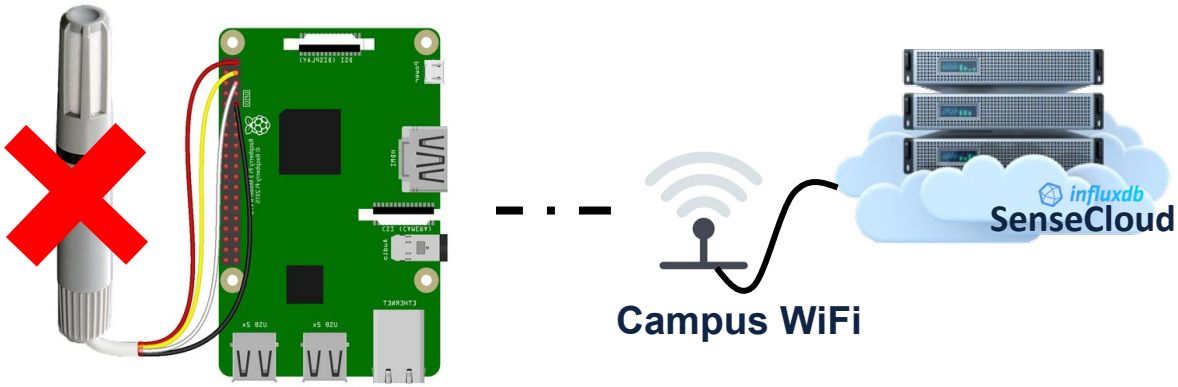

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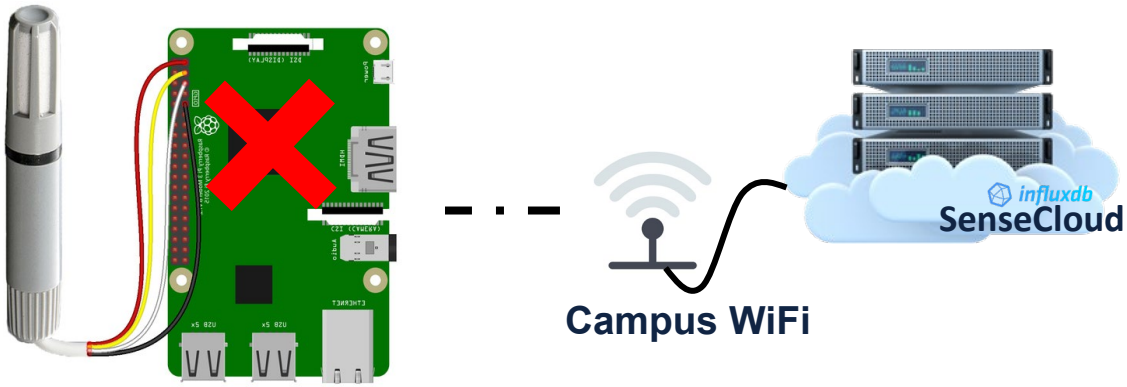

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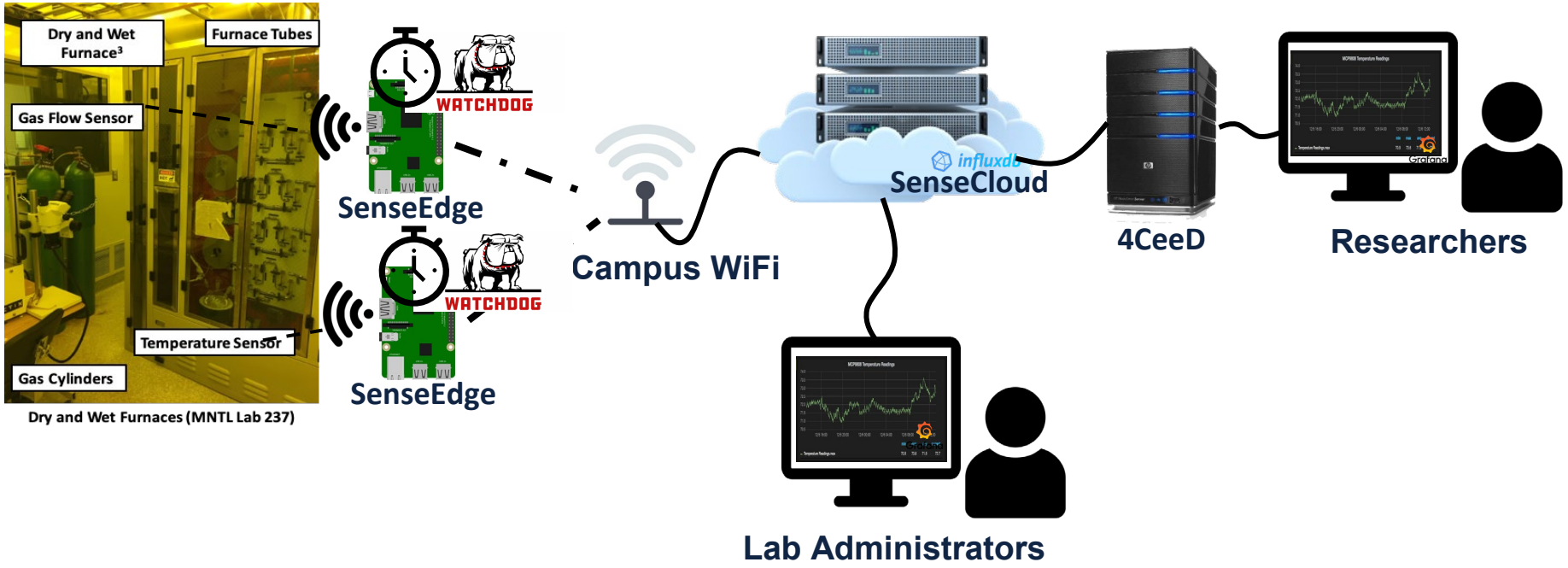

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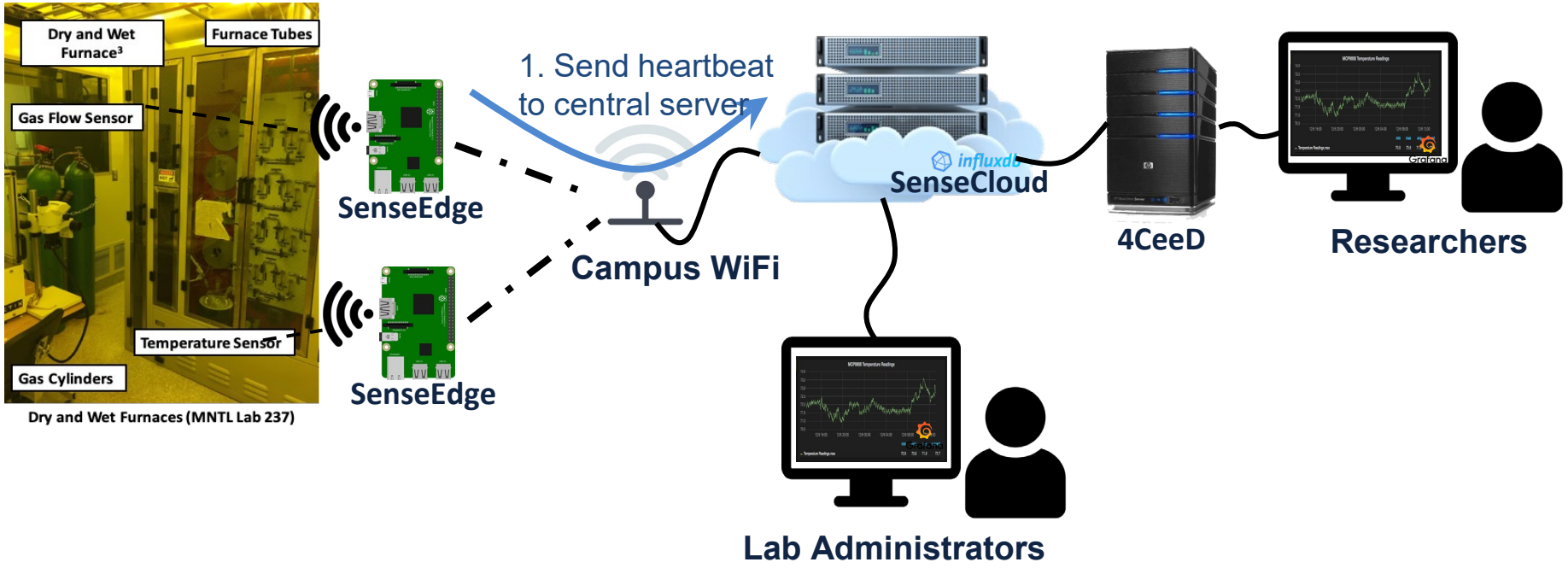

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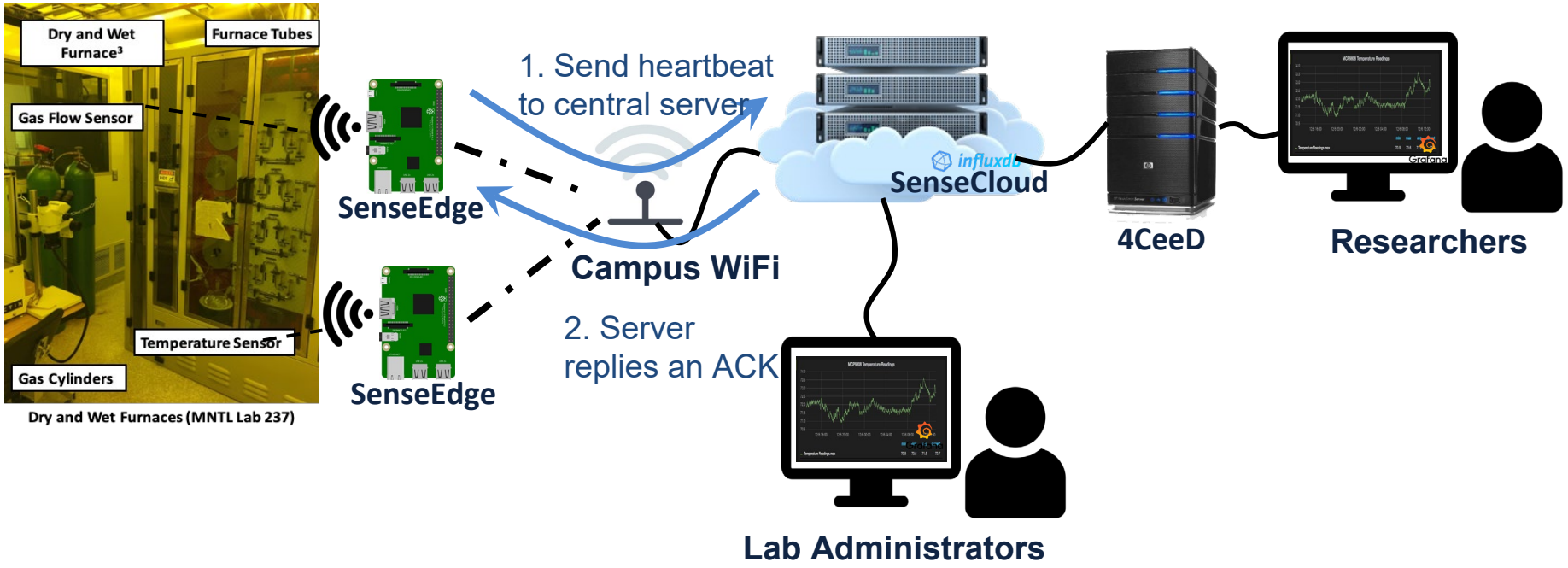

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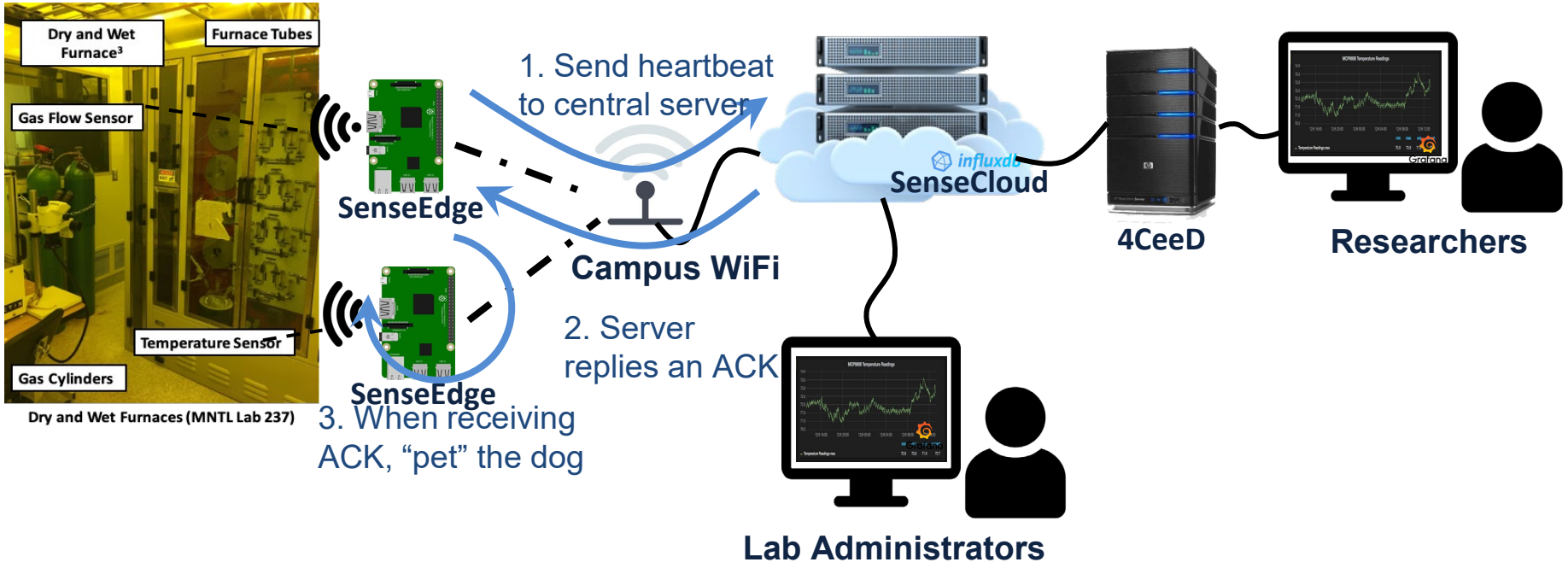
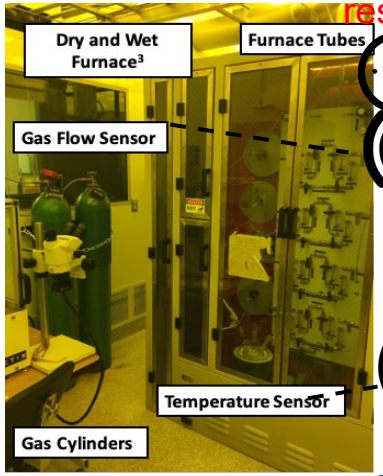


# Reliability of SenseEdge

4. If any step goes wrong and Senselet does not receive ACK for a predefined time interval (eg. 1min), watchdog kicks in and restarts Senselet



Dry and Wet Furnaces (MNTL Lab 237)


SenseEdge

SenseEdge

1. Send heartbeat to central server

Campus WiFi

2. Server replies an ACK

3. When receiving ACK, “pet” the dog


SenseCloud

4CeeD


Researchers

Lab Administrators

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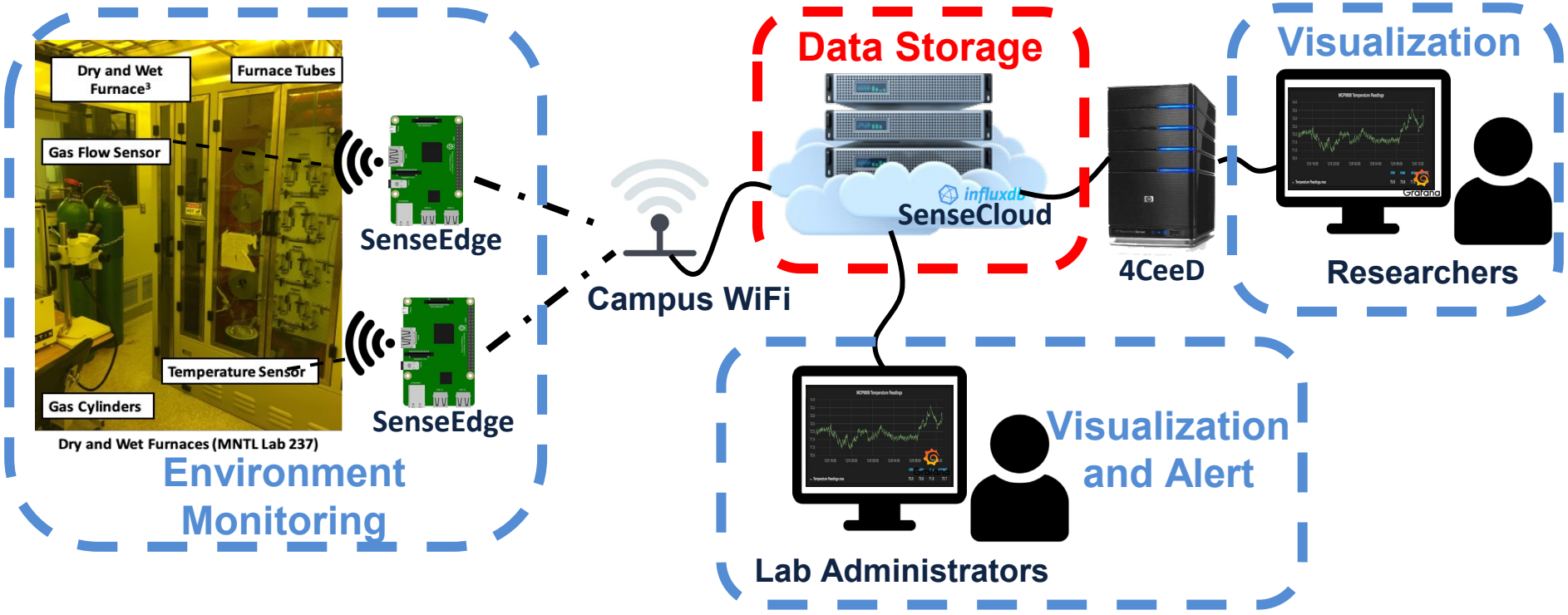


SENSELET

# SENSECLOUD

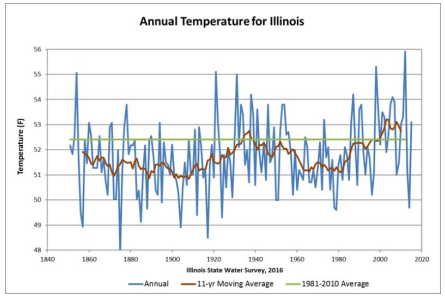

- Time series database

# SENSELET

# SENSECLOUD


- Time series database


FOR



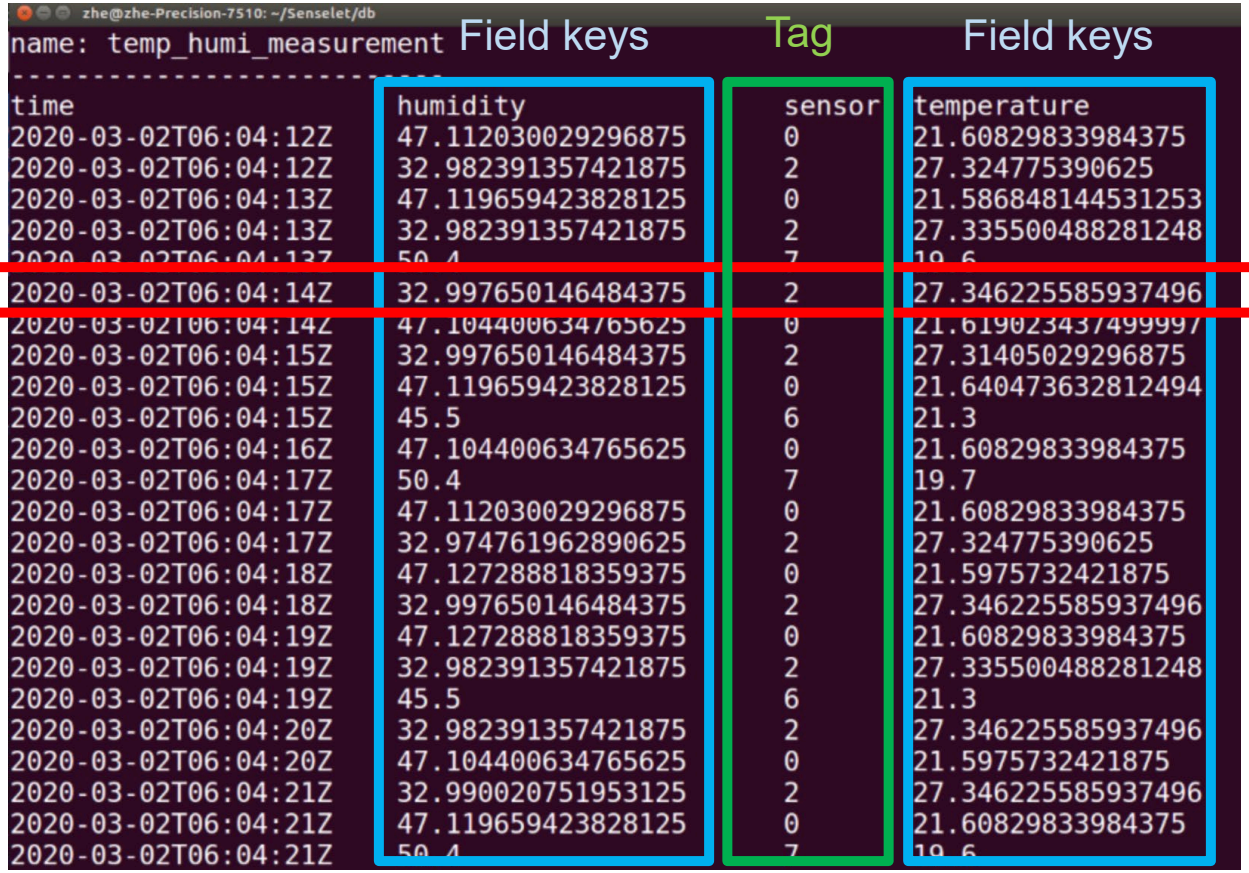
# SENSECLOUD

| Relational Database (MySQL) | Time Series Database (InfluxDB) |
|---|---|
| General purpose | Optimized for time series data (storage, query) |
| Max ingest rate 155k writes/sec (on AWS) | Easily supports ingest rate of 1M writes/sec |
| Keys are usually item IDs | Keys are time stamps |

# SENSECLOUD Database Storage

Timestamp

InfluxDB time series database



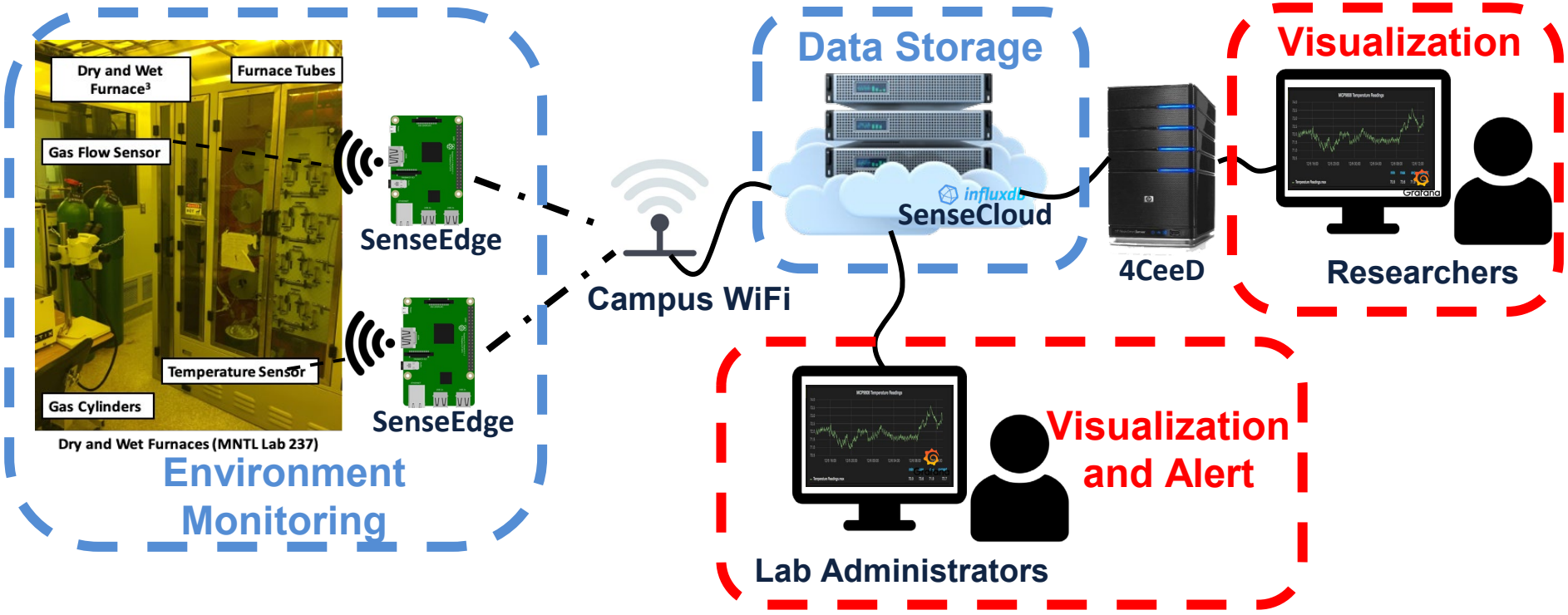
# SENSECLOUD Database Storage

- InfluxDB uses InfluxQL, an SQL-like query language to interact with data in the database.

```
SELECT "humidity"
FROM "temp_humi_measurement"
WHERE ("sensor" = '19-00000003f4ee’)
AND time >= now() - 15m
```

# What is SENSELET?

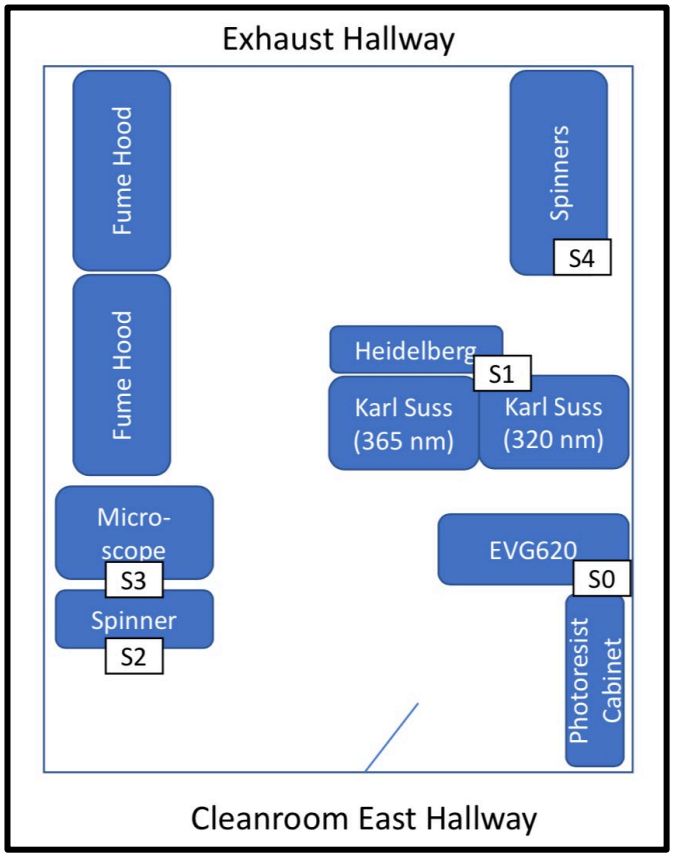
- A system of wireless, automated sensors that monitor the cleanroom environment , together with the central server which manages the sensory data



# SENSELET Visualization & Alert


- Grafana: An open-source visualization tool
- Customize dashboards
- Monitor real-time or historical time series data, do simple analytics
- Can send alerts

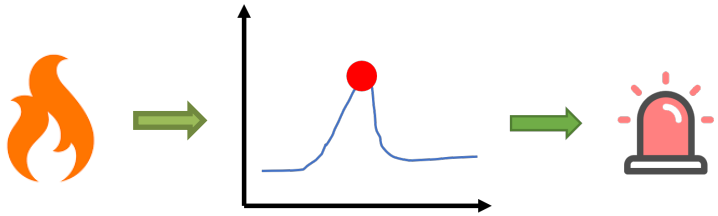
# SENSELET Visualization & Alert



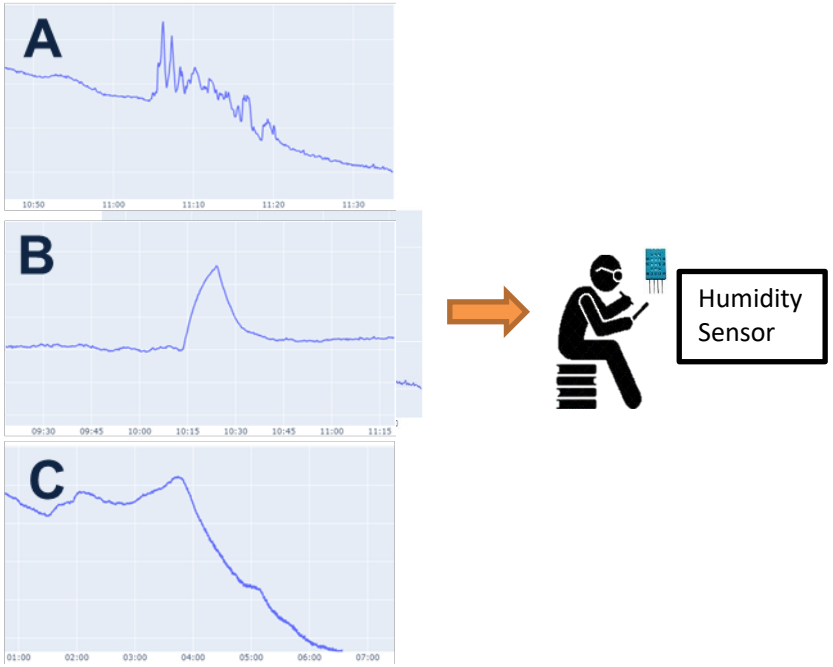

# SENSELET Visualization & Alert

Types of anomaly:

- Critical Anomalies:
  - Fire; Water leakage

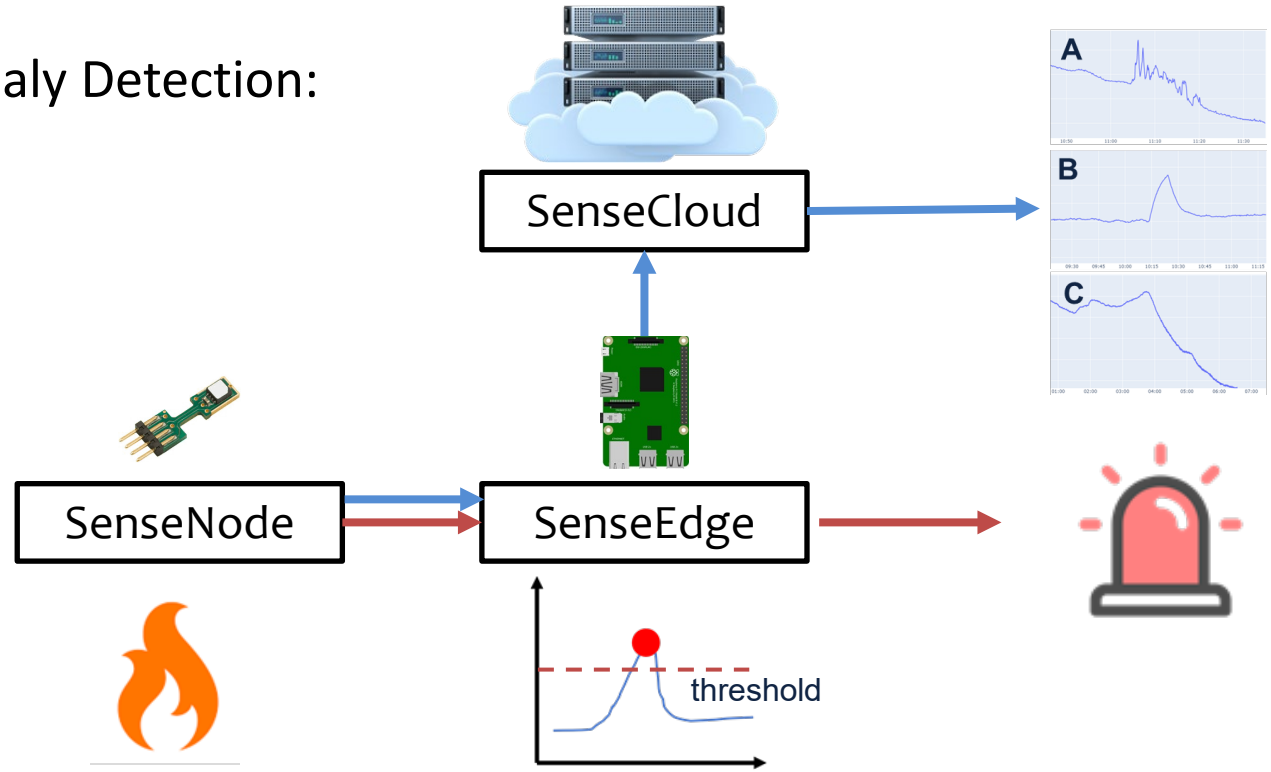


- Non-critical Anomalies:
  - Interesting patterns

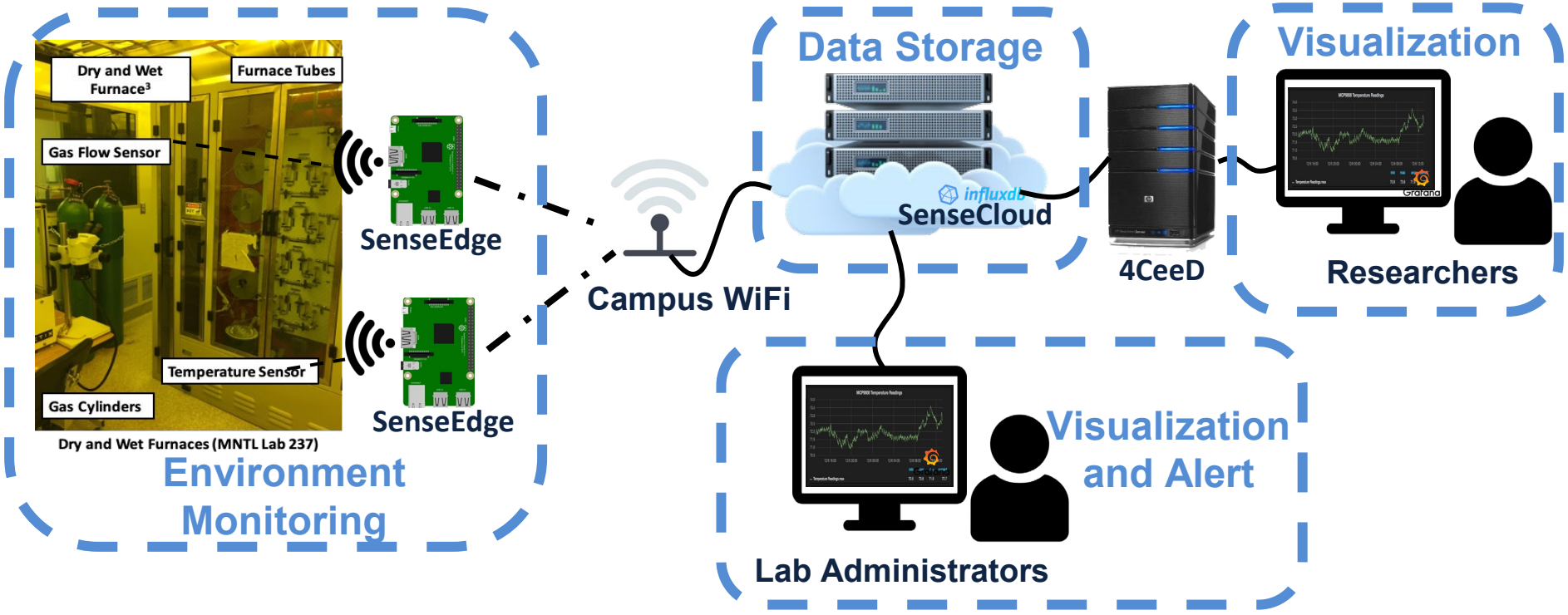


# SENSELET Visualization & Alert

Anomaly Detection:



# Summary


Dry and Wet Furnace³
Furnace Tubes
Gas Flow Sensor
Temperature Sensor
Gas Cylinders
Dry and Wet Furnaces (MNTL Lab 237)
SenseEdge
SenseEdge
Environment Monitoring
Campus WiFi
Data Storage
influxdb
SenseCloud
4CeeD
Visualization
Researchers
Visualization and Alert
Lab Administrators

# Outline

- Background & Motivation
- SENSELET Architecture
- Components of SENSELET
- Live Demo of SENSELET Visualization

# Demo

- Introduction to Grafana web interface
- How to visualize sensory data of specific time range
- How to set an alert (If we have time)
- Try it yourself!