Duke

Campus Space and Energy

By Shriya, Gabe, Adeildo, and Desmond

Meet the Team

Shriya
CS/BME

Gabe
CS/Econ

Adeildo
CS

Desmond
ME/CS

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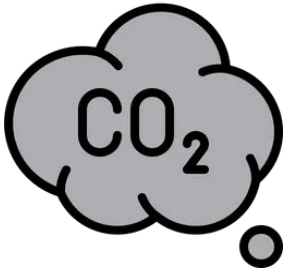
Motivation

- **Duke's Climate Commitment:**
  - Reduce carbon emissions by 50% by 2030
  - Tasked by Duke Facilities (Jeff Bethke & Greg Anspach)

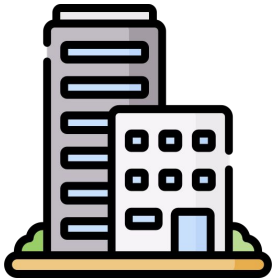
- **Building occupancies** daily/yearly are **unknown**, leads to:

Energy Costs

CO2 Emissions



Poor Space Utilization



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Project Goal

- Create **predictive occupancy models** for Duke Facilities using:

Wi-Fi Data

CO_2 Levels

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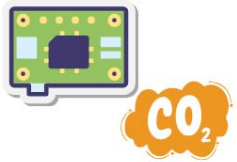
Data used

Wi-Fi APs
Connection logs



Raspberry Pi
CO2 sensor
Atlas Iot™

Physical count of
people in each room

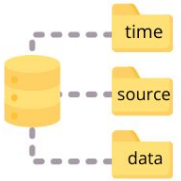
Backend

PostgreSQL

FastAPI

Linux

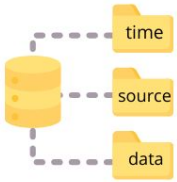
Linux Server



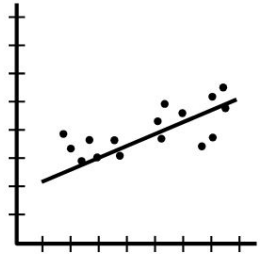
Data repository

Data used | Backend | Product + Front-end

Physical count of people in each room



Data repository



Regression models

Occupancy Models

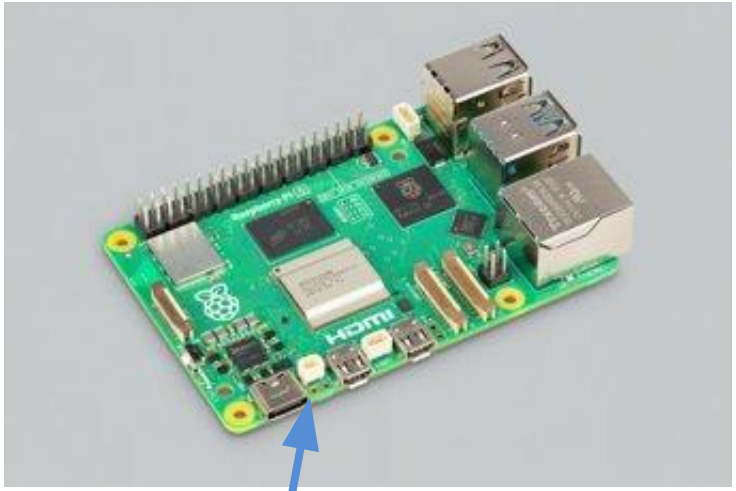
jupyter + voilà

docker

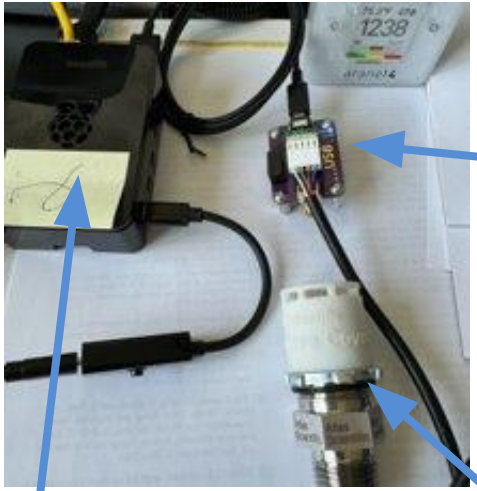
Interactive Dashboard

CO_2: Raspberry Pi

- Live collection of CO_2 levels, timestamp, and room locations



Raspberry Pi Unit



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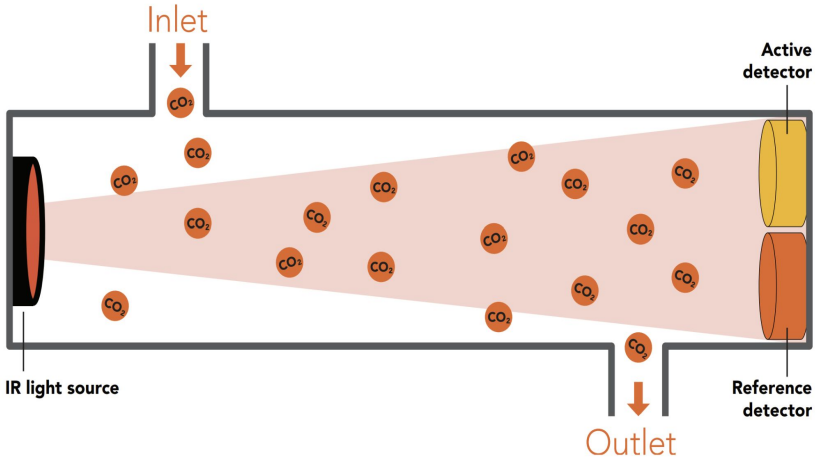
CO_2: Atlas IoT™

1. Pi
2. USB Board
3. CO_2 Sensor
   - **Accuracy** = +/-5%
   - **Range** = 0-10000ppm

CO2 Sensor Mechanism:



Referenced from:
https://files.atlas-scientific.com/EZO_CO2_Datasheet.pdf

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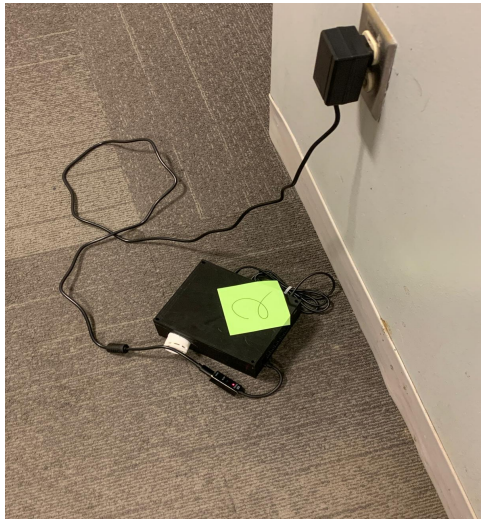
CO_2: Methodology

- Two working Raspberry Pis in 3D print cases
    - Placed in different locations around room

Pi 1 at Location 1

Pi 2 at Location 2



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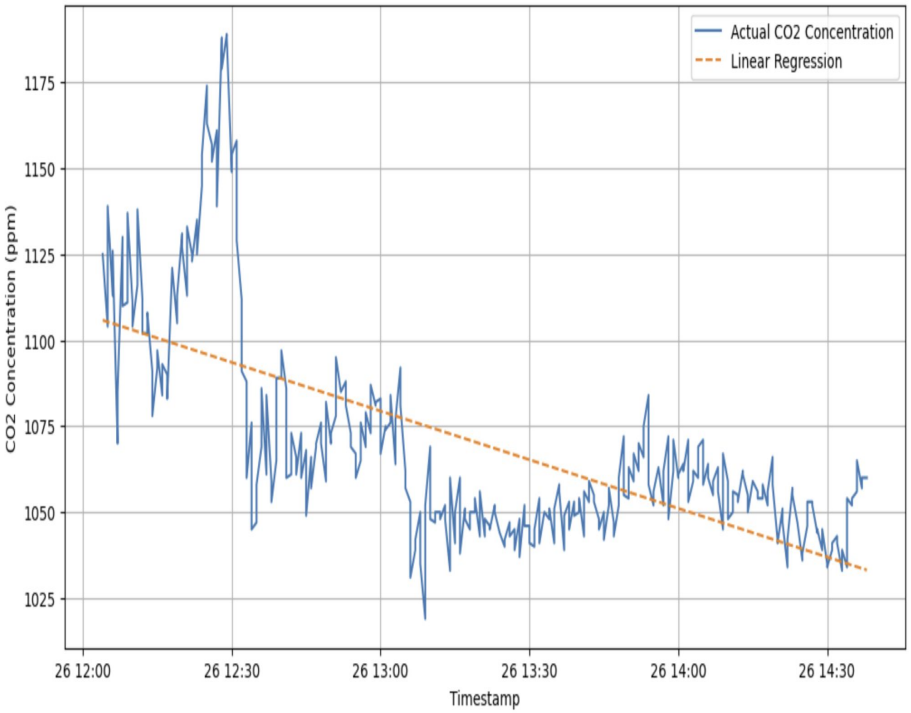
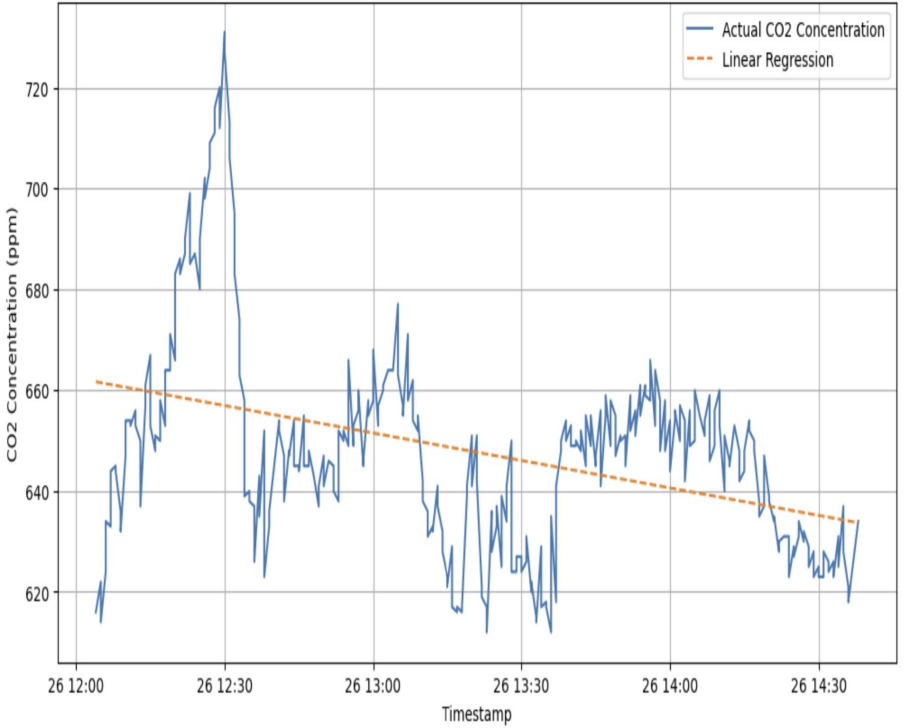
CO_2: Pi Disparities?

Pi 1 on 26th June



Pi 2 on 26th June



CO_2: Data Collection

- **Linux Virtual Machine (VM):**
  - Stores Raspberry Pi data in **dictionaries**

```
codeplus-1@codeplus-1:~/Raspberry-Pi-sample-code $ python3 uartnew.py
Opening serial port now...
Enter command: poll, 30.00
Polling sensor every 30.00 seconds, press ctrl-c to stop polling
Response: 805 at 2024-07-09 09:48:36
Response: 800 at 2024-07-09 09:49:06
Response: 803 at 2024-07-09 09:49:36
Response: 804 at 2024-07-09 09:50:06
Response: 809 at 2024-07-09 09:50:36
Response: 821 at 2024-07-09 09:51:06
```

Response body


```
{
  "timestamp": "2024-5-30 11:34:56 4:00",
  "room_number": "Bostock 15",
  "co2": "1298"
}
```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CO_2: Fast API

```
codeplus-2@codeplus-2:~/Raspberry-Pi-sample-code $ python3 uart16.py
Opening serial port now...
Enter the room you are collecting data in: bostock-prjrm-1
Enter the VCM link: http://vcm-41375.vm.duke.edu:8080/co2_readings/
Enter command: POLL, 2.00
Polling sensor every 2.00 seconds, press Ctrl+C to stop polling
Response from API: {'message': 'CO2 reading added successfully.', 'data': {'timestamp': '2024-07-10T11:13:13', 'room': '
bostock-prjrm-1', 'co2': 518}}
Response: 518 at 2024-07-10 11:13:13
Response from API: {'message': 'CO2 reading added successfully.', 'data': {'timestamp': '2024-07-10T11:13:15', 'room': '
bostock-prjrm-1', 'co2': 521}}
Response: 521 at 2024-07-10 11:13:15
Response from API: {'message': 'CO2 reading added successfully.', 'data': {'timestamp': '2024-07-10T11:13:17', 'room': '
bostock-prjrm-1', 'co2': 522}}
Response: 522 at 2024-07-10 11:13:17
Response from API: {'message': 'CO2 reading added successfully.', 'data': {'timestamp': '2024-07-10T11:13:19', 'room': '
bostock-prjrm-1', 'co2': 523}}
```

```
adeildovieira@MacBook-Air-de-Adeildo-7:~
INFO:     10.194.211.199:38244 - "POST /co2_readings/ HTTP/1.1" 200 OK
INFO:     10.194.211.199:38248 - "POST /co2_readings/ HTTP/1.1" 200 OK
INFO:     10.194.211.199:38260 - "POST /co2_readings/ HTTP/1.1" 200 OK
INFO:     10.194.211.199:35830 - "POST /co2_readings/ HTTP/1.1" 200 OK
INFO:     10.194.211.199:35834 - "POST /co2_readings/ HTTP/1.1" 200 OK
INFO:     10.194.211.199:35844 - "POST /co2_readings/ HTTP/1.1" 200 OK
INFO:     10.194.211.199:35850 - "POST /co2_readings/ HTTP/1.1" 200 OK
INFO:     10.194.211.199:35864 - "POST /co2_readings/ HTTP/1.1" 200 OK
INFO:     10.194.211.199:47664 - "POST /co2_readings/ HTTP/1.1" 200 OK
INFO:     10.194.211.199:47678 - "POST /co2_readings/ HTTP/1.1" 200 OK
INFO:     10.194.211.199:47690 - "POST /co2_readings/ HTTP/1.1" 200 OK
INFO:     10.194.211.199:47696 - "POST /co2_readings/ HTTP/1.1" 200 OK
INFO:     10.194.211.199:47706 - "POST /co2_readings/ HTTP/1.1" 200 OK
INFO:     10.194.211.199:55888 - "POST /co2_readings/ HTTP/1.1" 200 OK
INFO:     10.194.211.199:55896 - "POST /co2_readings/ HTTP/1.1" 200 OK
INFO:     10.194.211.199:55904 - "POST /co2_readings/ HTTP/1.1" 200 OK
INFO:     10.194.211.199:55920 - "POST /co2_readings/ HTTP/1.1" 200 OK
INFO:     10.194.211.199:55932 - "POST /co2_readings/ HTTP/1.1" 200 OK
INFO:     10.194.211.199:34154 - "POST /co2_readings/ HTTP/1.1" 200 OK
INFO:     10.194.211.199:34162 - "POST /co2_readings/ HTTP/1.1" 200 OK
INFO:     10.194.211.199:34176 - "POST /co2_readings/ HTTP/1.1" 200 OK
INFO:     10.194.211.199:34182 - "POST /co2_readings/ HTTP/1.1" 200 OK
INFO:     10.194.211.199:34184 - "POST /co2_readings/ HTTP/1.1" 200 OK
INFO:     10.194.211.199:40342 - "POST /co2_readings/ HTTP/1.1" 200 OK
```

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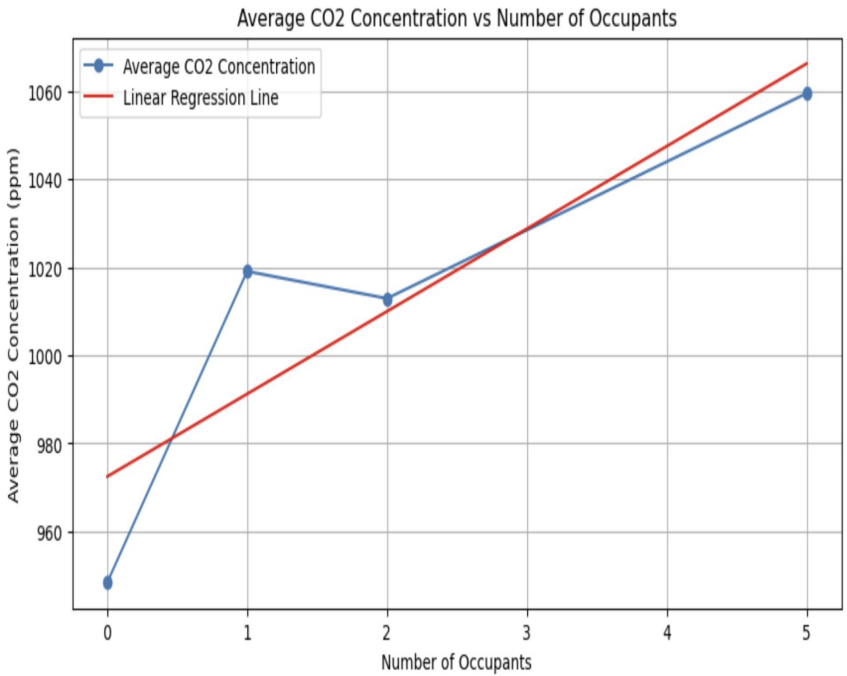
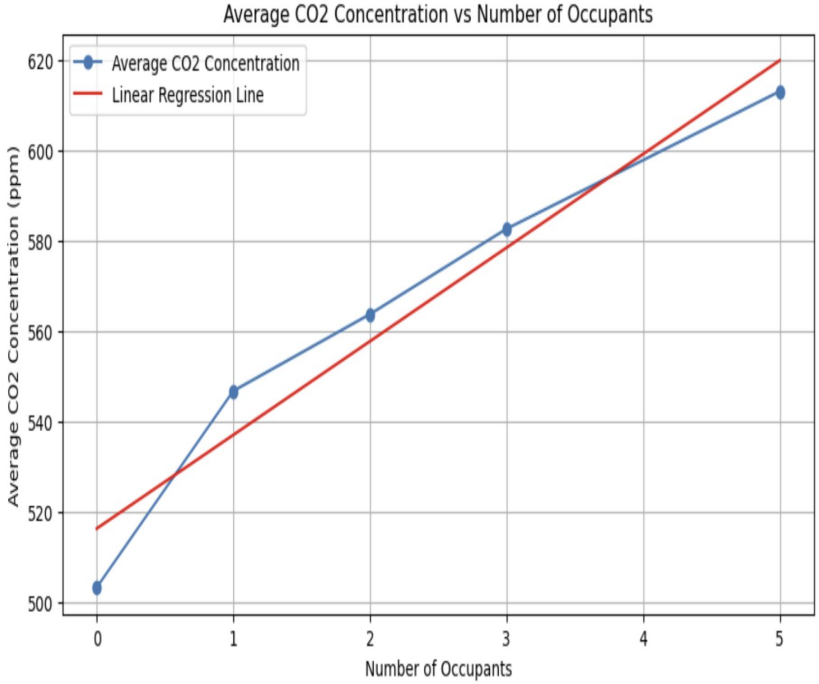
CO_2: Exploring Data

Pi 1: $R^2 = 0.78$



Pi 2: $R^2 = 0.95$



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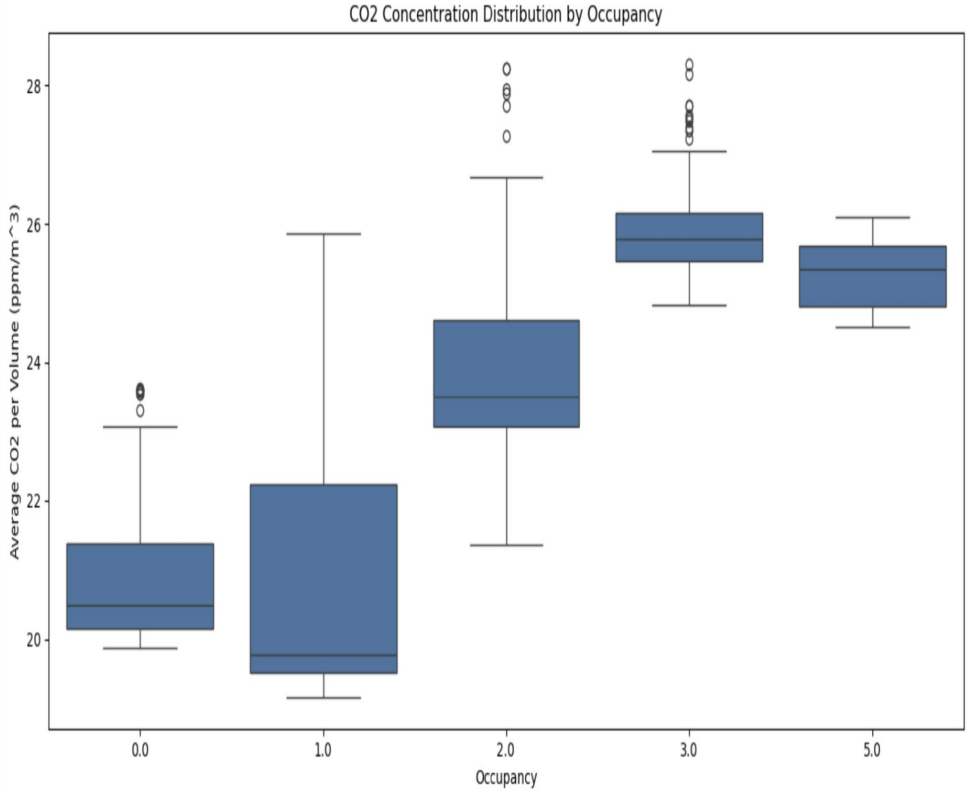
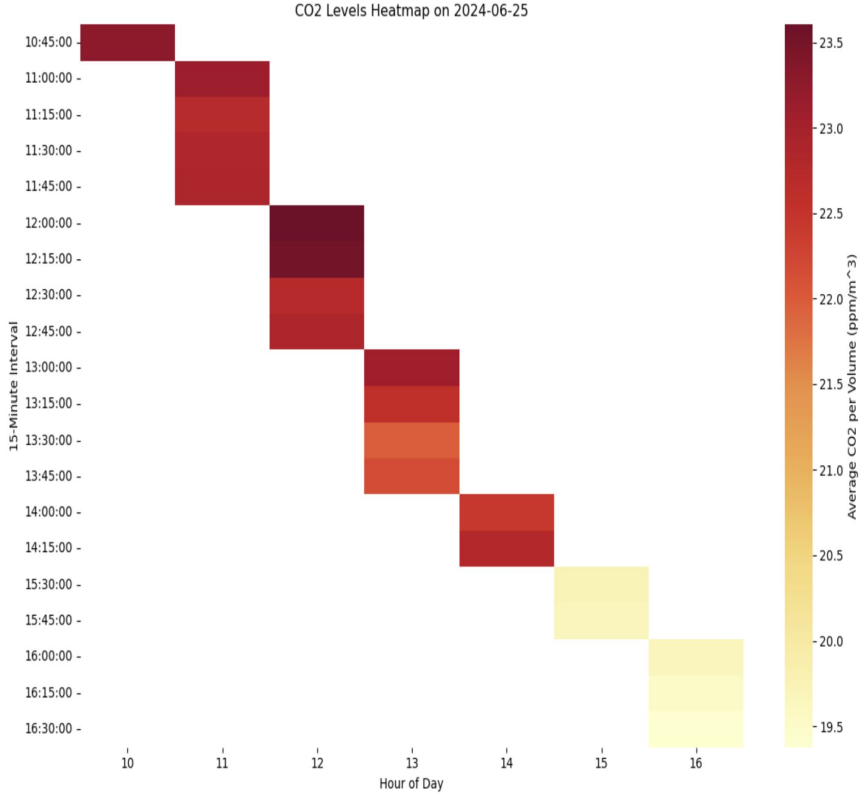
Average CO2/Volume Models





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Wifi: Access Points

- **Access Points (APs)** allow devices to connect wireless networks

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Wifi: AP Data

- Data ranges from June 11 - July 3
- SHA Encryption to preserve privacy

splunk>

	_time	ap_name	netid	ssid	assoc	macaddr
1	2024-04-17 17:19:48-04:00	300fuller-101b-cw9166i-rw-2	4e4cf725bf03	Dukeblue	reassociated	69afa29fa3ad0f43f334186
2	2024-04-17 16:17:07-04:00	300fuller-104-cw9166-hc-1	31fd9f2c56b3	Dukeblue	reassociated	fb051def0509c6b23e64f9
3	2024-04-17 14:16:53-04:00	300fuller-101b-cw9166-rw-1	3cc54fe8c1e	Dukeblue	reassociated	efcd3d30bb4c8f6f144443
4	2024-04-17 20:43:03-04:00	300fuller-101b-cw9166-rw-1	3ab0ef98858	Dukeblue	reassociated	50b34fd7e6224f3eda0bc
5	2024-04-17 19:02:34-04:00	300fuller-104-cw9166-hc-1	28bcf3609bc	DukeOpen	reassociated	19bf2d3760b7afe938bcd
6	2024-04-16 10:09:40-04:00	300fuller-104-cw9166-hc-1	d4c73fb3751	Dukeblue	reassociated	63faccfef0dfb18b0d71bba
7	2024-04-16 09:41:19-04:00	300fuller-104-cw9166-hc-1	d4c73fb3751	Dukeblue	reassociated	34d9793ced3a429cdf5f97

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Wifi: PostgreSQL

- Create a new tablespace
- Copy CSV data into **Postgres**

```
CREATE TABLE IF NOT EXISTS public."june11_june17_
(
    _time date,
    asa_code text COLLATE pg_catalog."default",
    ipaddr text COLLATE pg_catalog."default",
    macaddr text COLLATE pg_catalog."default",
    msgtype text COLLATE pg_catalog."default",
    name text COLLATE pg_catalog."default",
    ssid text COLLATE pg_catalog."default",
    "user" text COLLATE pg_catalog."default"
)
TABLESPACE pg_default;
```

Data Output | Messages | Notifications

	_time date	asa_code text	ipaddr text
1	2024-06-11	APF-3-AUTHENTICATION_TRAP	439b72fb09edf9fbc52ecf7d656eb
2	2024-06-11	APF-3-ASSOC_TRAP	439b72fb09edf9fbc52ecf7d656eb
3	2024-06-11	APF-3-ASSOC_TRAP	439b72fb09edf9fbc52ecf7d656eb
4	2024-06-11	APF-3-AUTHENTICATION_TRAP	f29e377e30393daf486121d3fb57
5	2024-06-11	APF-3-AUTHENTICATION_TRAP	85c1f92a161e26f8563e118129e8
6	2024-06-11	APF-3-AUTHENTICATION_TRAP	f29e377e30393daf486121d3fb57
7	2024-06-11	APF-3-ASSOC_TRAP	f29e377e30393daf486121d3fb57

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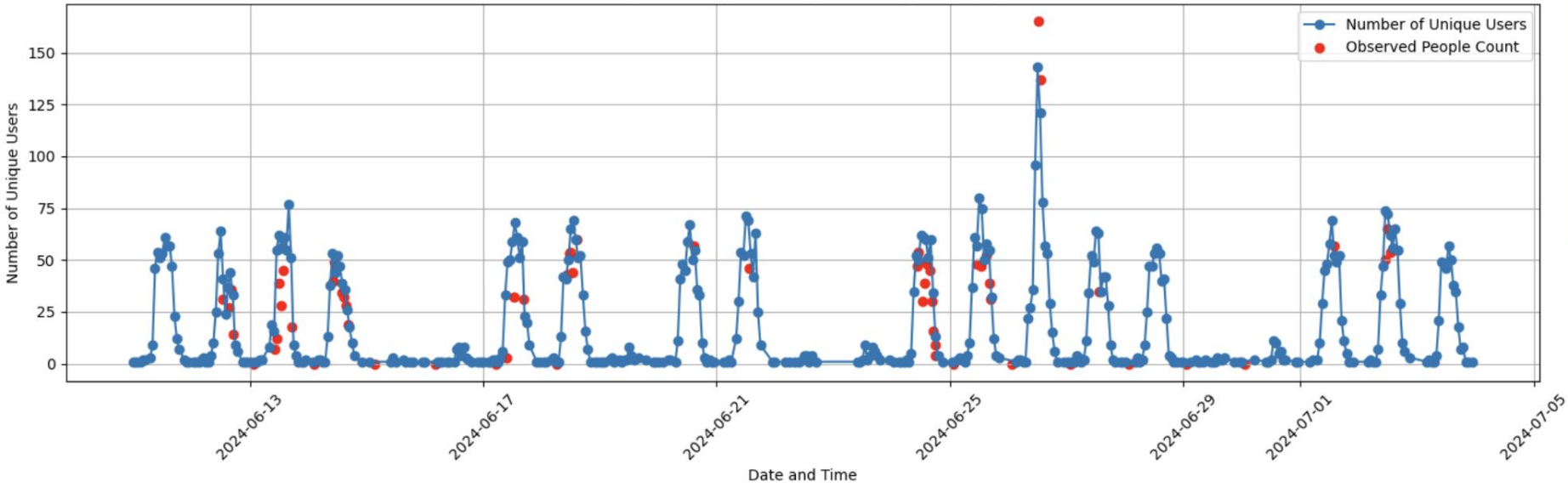
Unique Users per Hour (June 11-July 3)



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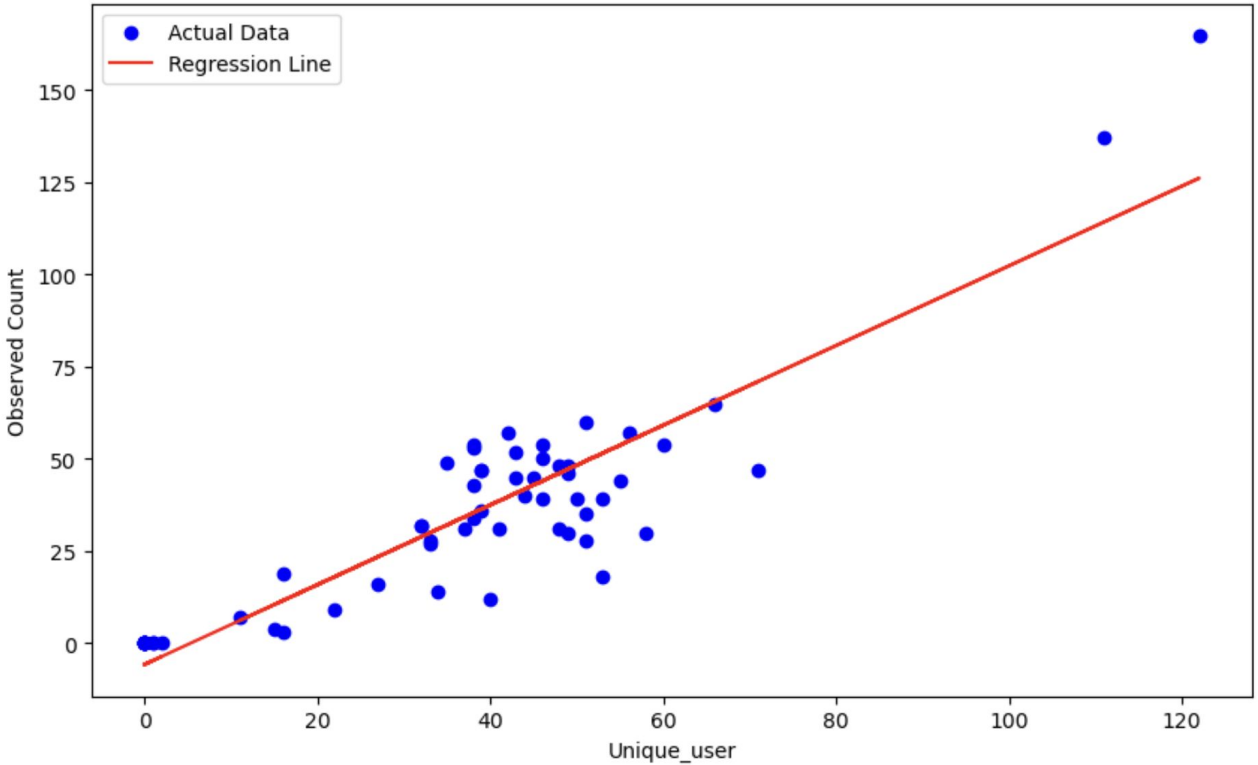
Linear Regression: Observed Count vs Unique Users

R-squared: 0.82
Slope: 1.08
Intercept: -5.75



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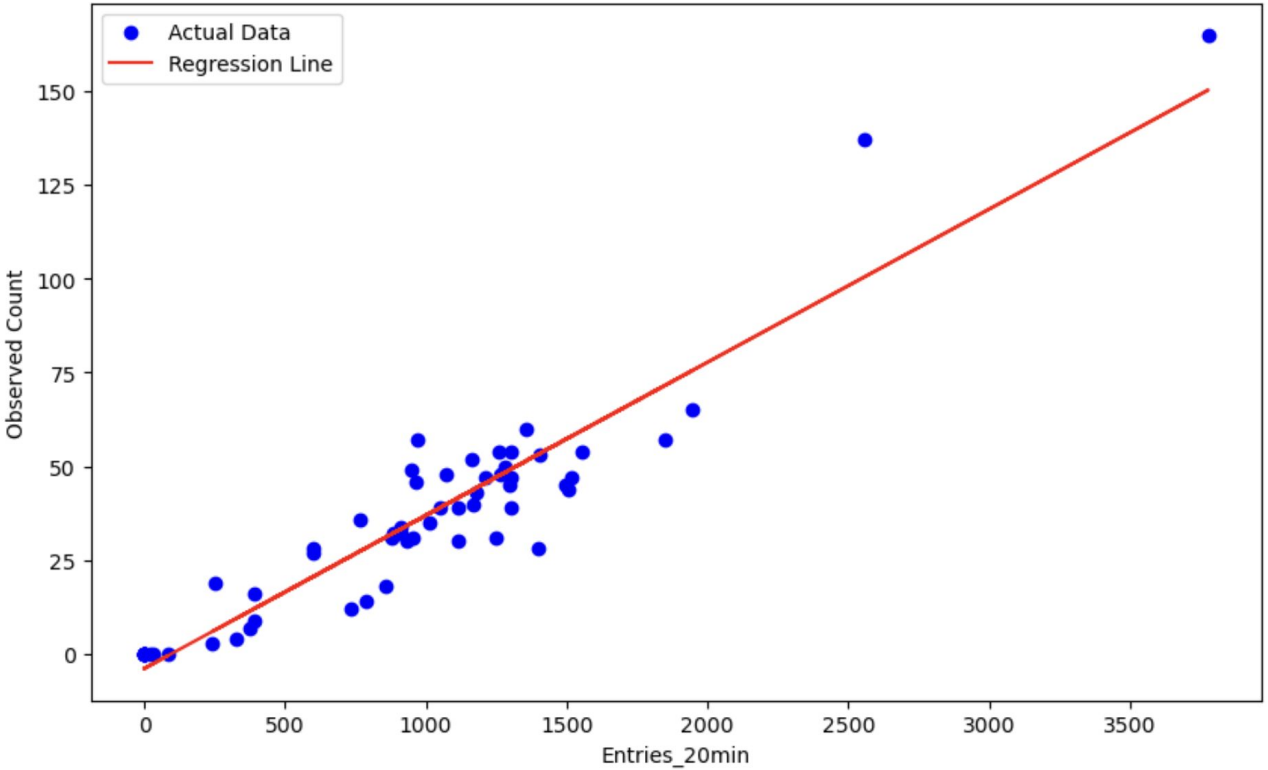
Linear Regression: Observed Count vs Total Entries

R-squared: 0.89

Slope: 0.041

Intercept: -3.81



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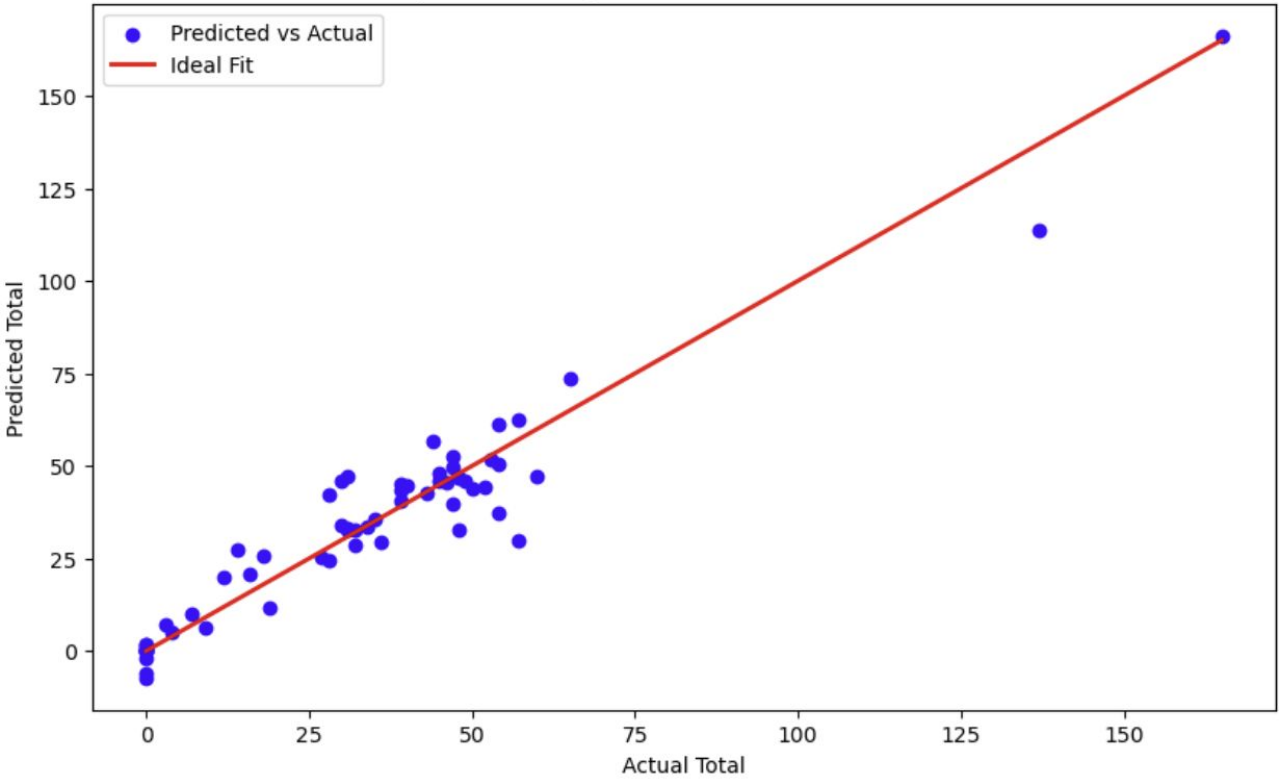
Multiple Linear Regression (with Day of Week)

R-squared: 0.93

Intercept: -0.95



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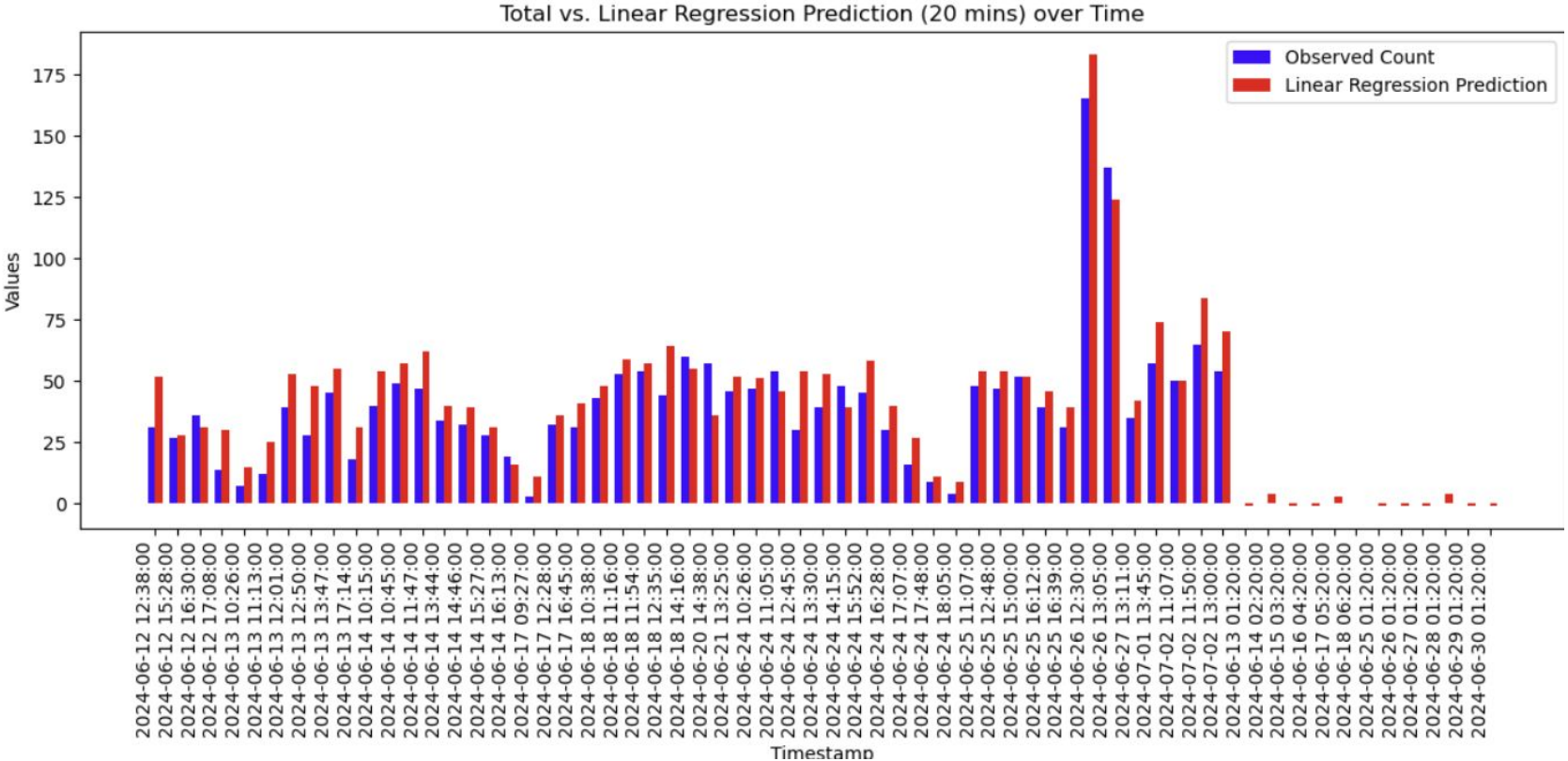
Observed Count vs Linear Regression Prediction



Website Demo

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CO2 and Wifi: Limitations

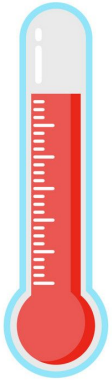
- Confounding variables (ventilation, weather)
- Hardware limitations

- Centered around APs
- Background noise
- No signal strength

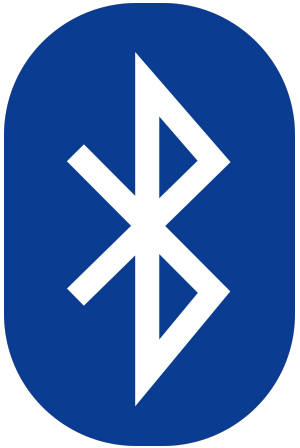
Supplemental Data Sources

Humidity

Temperature



Bluetooth



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Future Steps

1. Refine front-end UI/UX
2. Pull more data to improve model accuracy
3. Update application in production

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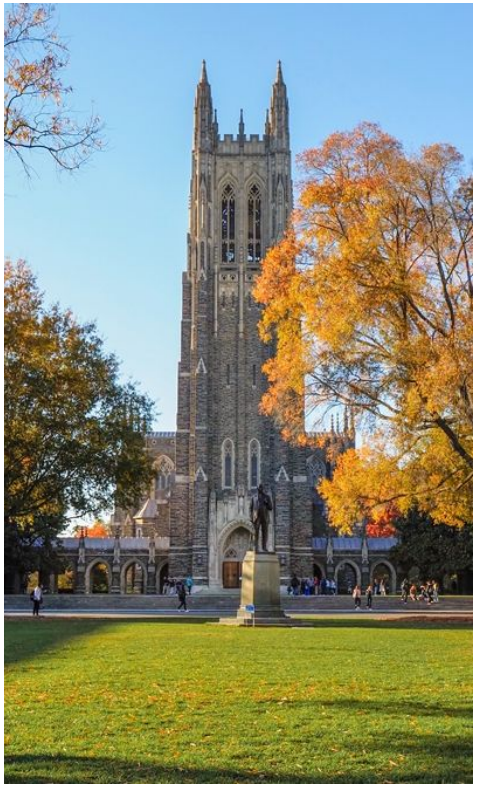
Summary

Key Takeaways:

1. CO_2 Sensor location matters (more research)
2. Strong correlation from Wifi data points
3. Accurate models for Duke Facilities



Acknowledgements:

- **Stakeholders** - Jeff Bethke and Greg Anspach
- **Team Leads** - Mark McCahill and John Haws
- **Code+ Admins** - Isabel Valls and Jen Vizas

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Questions?

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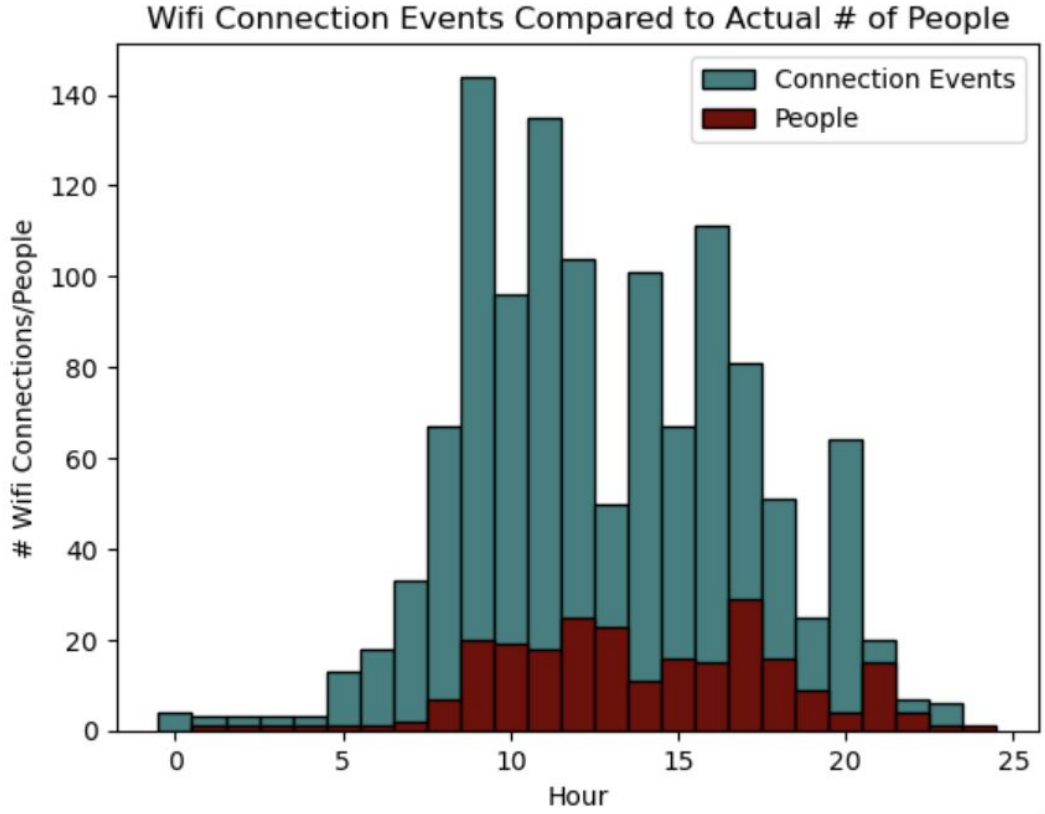
Campus Space
and Energy

Occupancy Models: Wi-Fi



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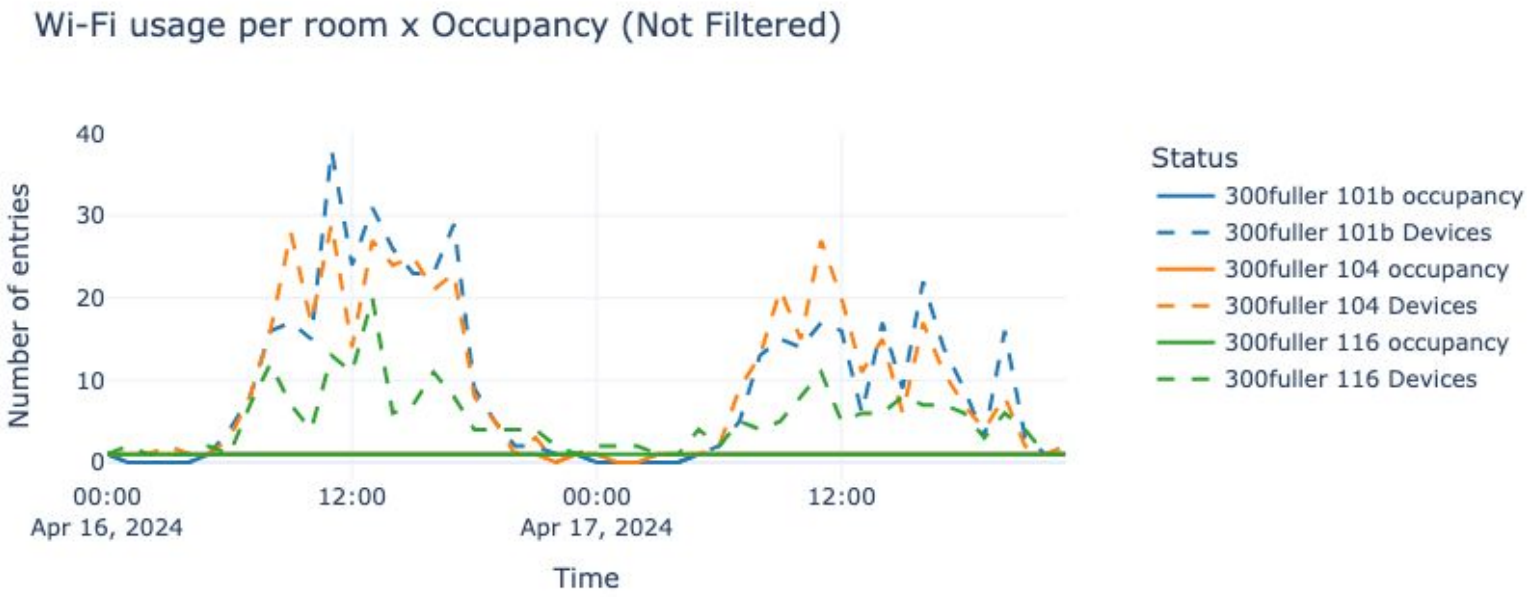
Occupancy Models: Wi-Fi



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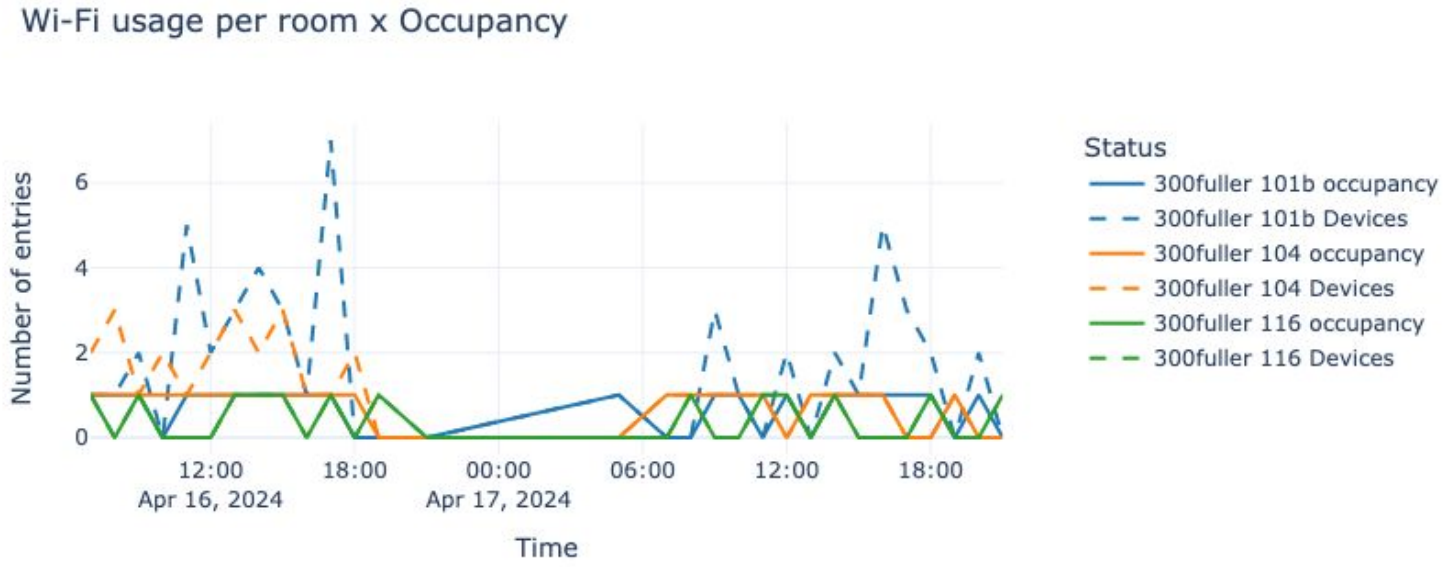
Occupancy Models: Wi-Fi



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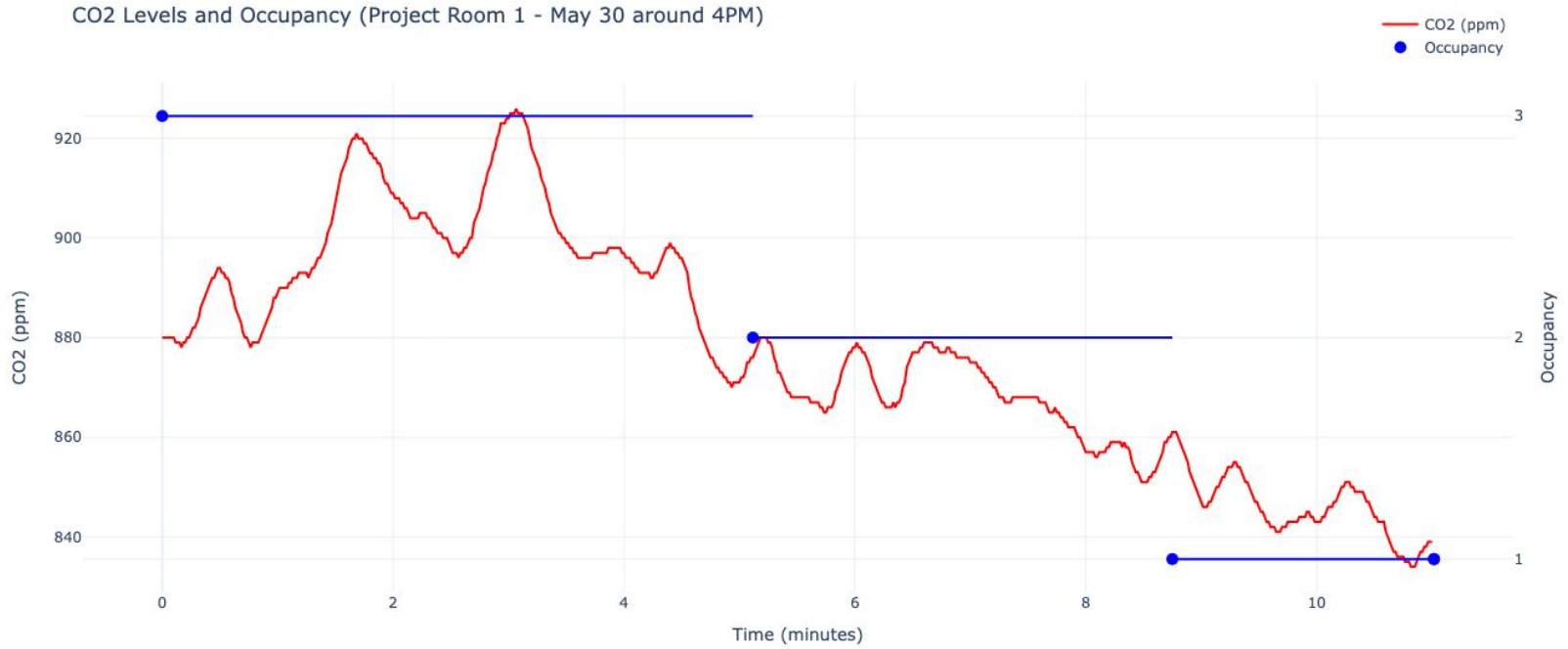
Occupancy Models: CO2



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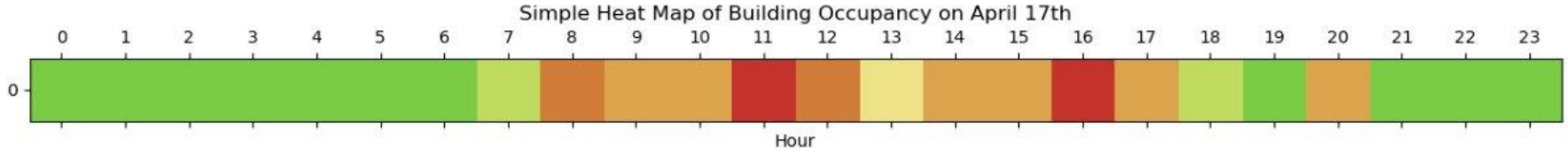
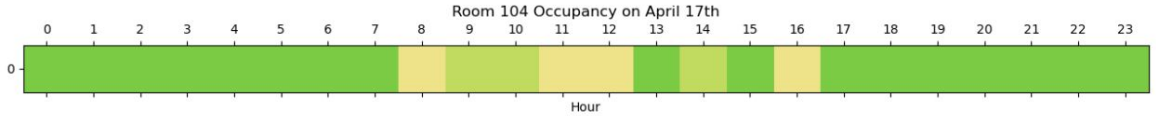
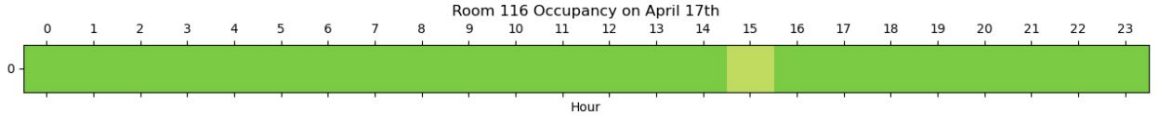
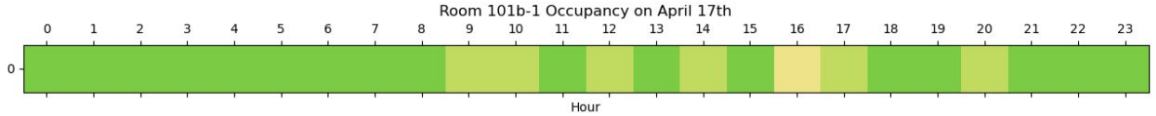
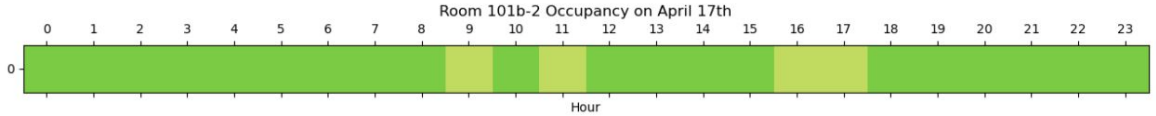
Occupancy Models: Daily Heat Maps











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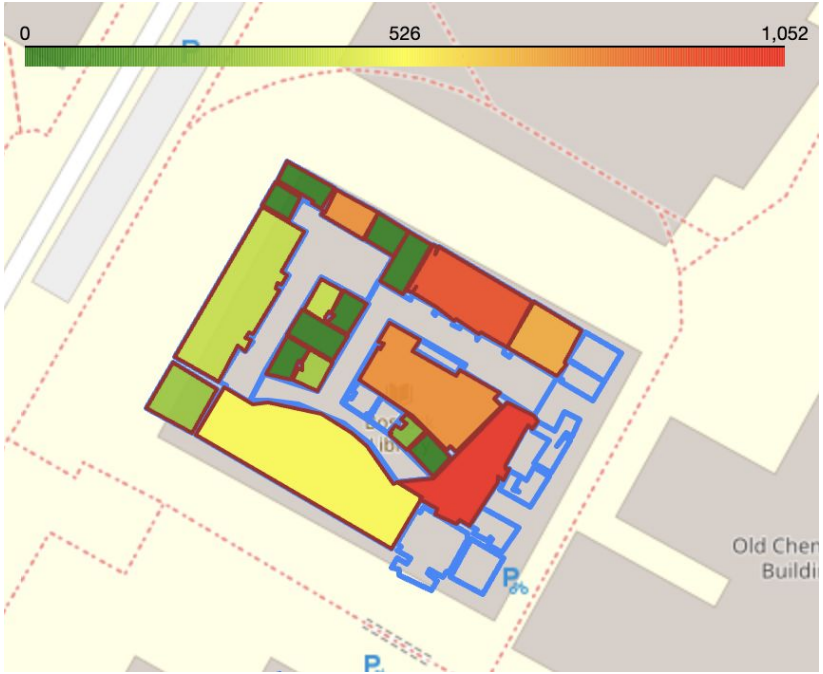
Occupancy Models: Bostock Heat Map



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Demo

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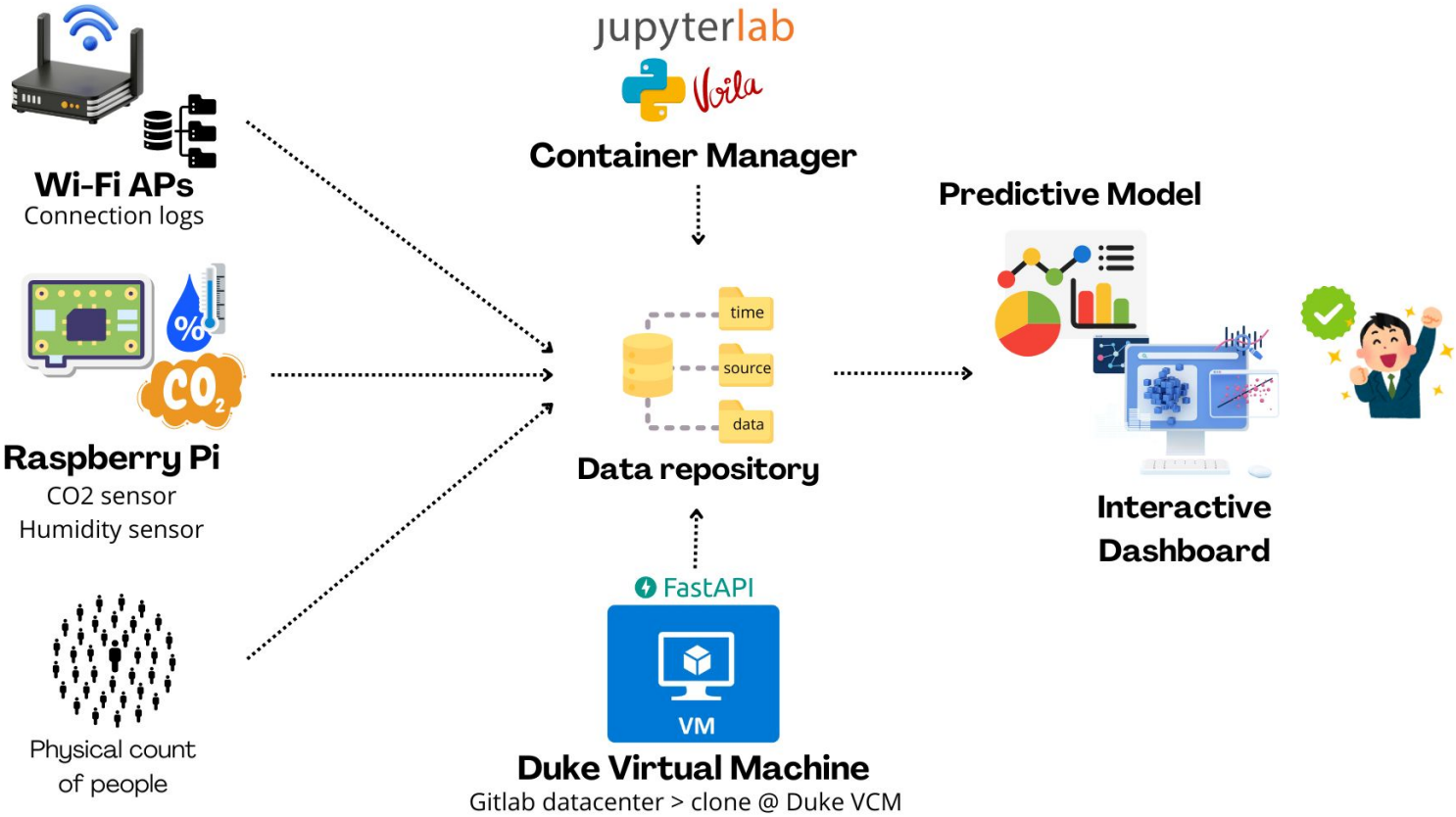
CO2: Postgres

- Access CO2 data using REST web service
    - Create data tables in Postgres


Wi-Fi APs
Connection logs
Raspberry Pi
CO2 sensor
Humidity sensor
Physical count
of people
jupyterlab
Voila
Container Manager
time
source
data
Data repository
FastAPI
VM
Duke Virtual Machine
Gitlab datacenter > clone @ Duke VCM
Predictive Model
Interactive
Dashboard

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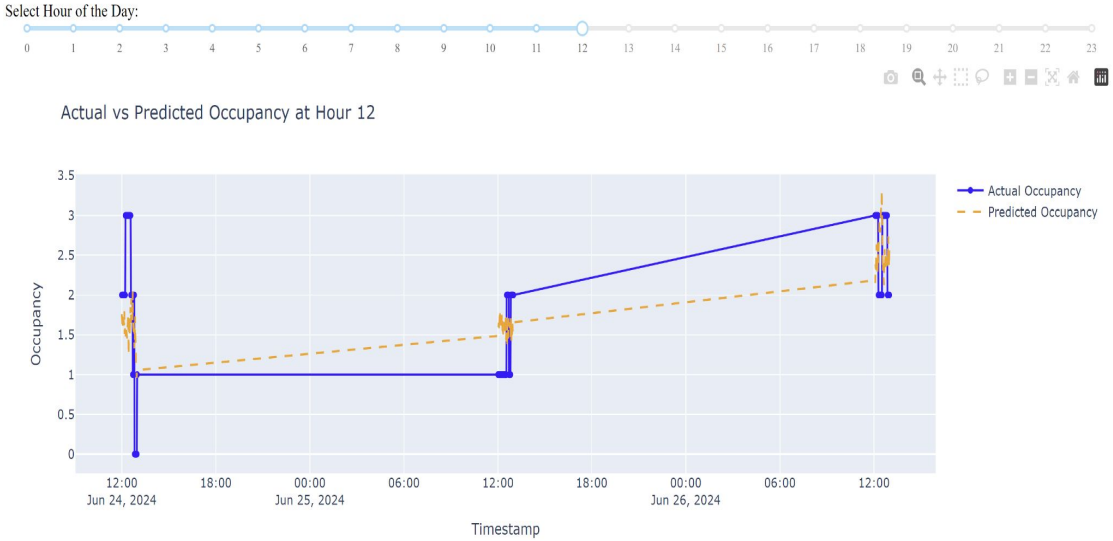
Multivariable Model

- **Uses 2 feature variables:**
  - Average CO_2 concentration between the 2 pis
  - ROC of average CO_2 concentration (ppm/s)



$R^2 = 0.317$

Intercept: -3.33

Coefficients: [0.0089 0.46]

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