# Digital Twins in Infection Risk Modelling

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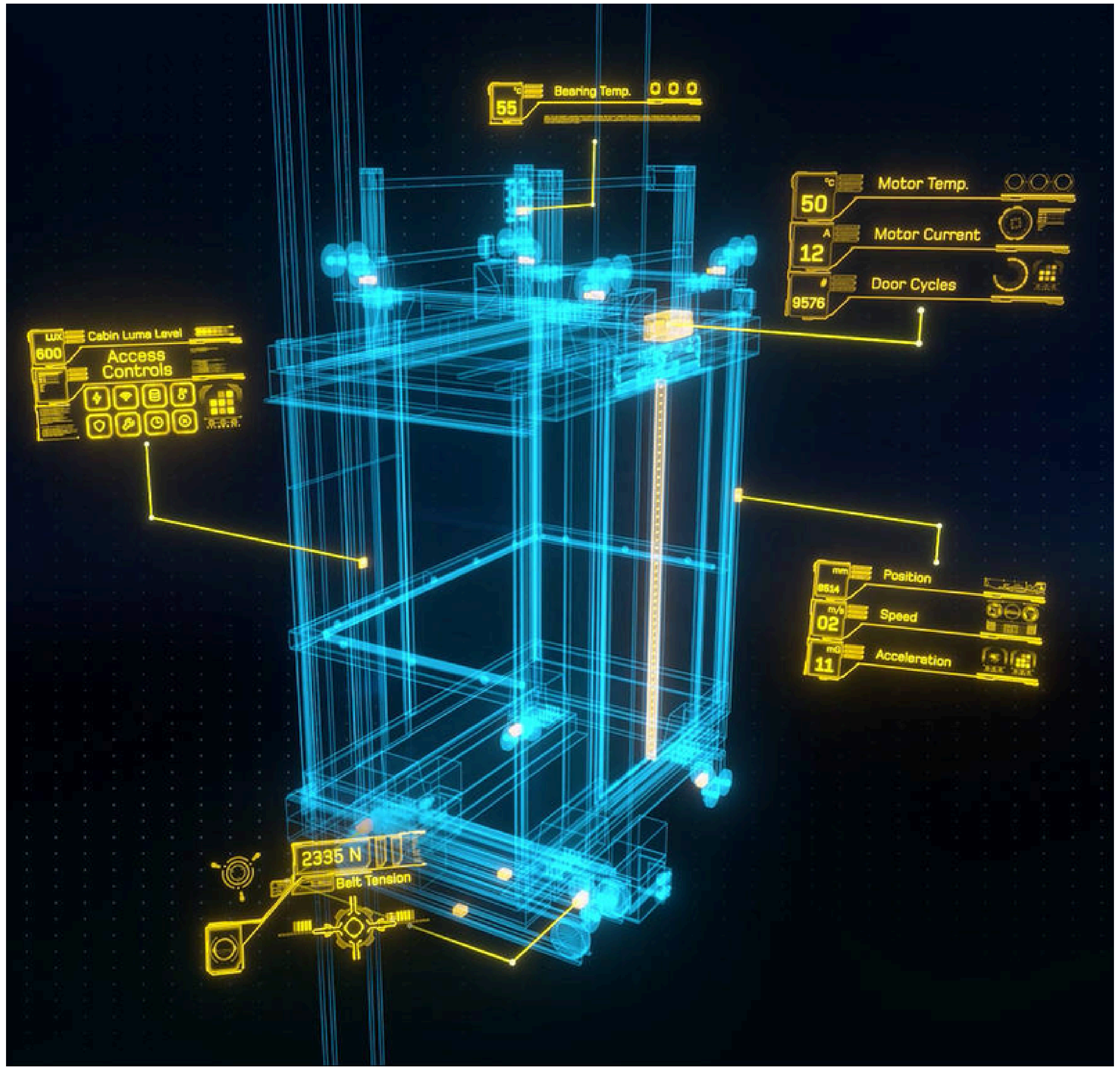

# Background & Motivation

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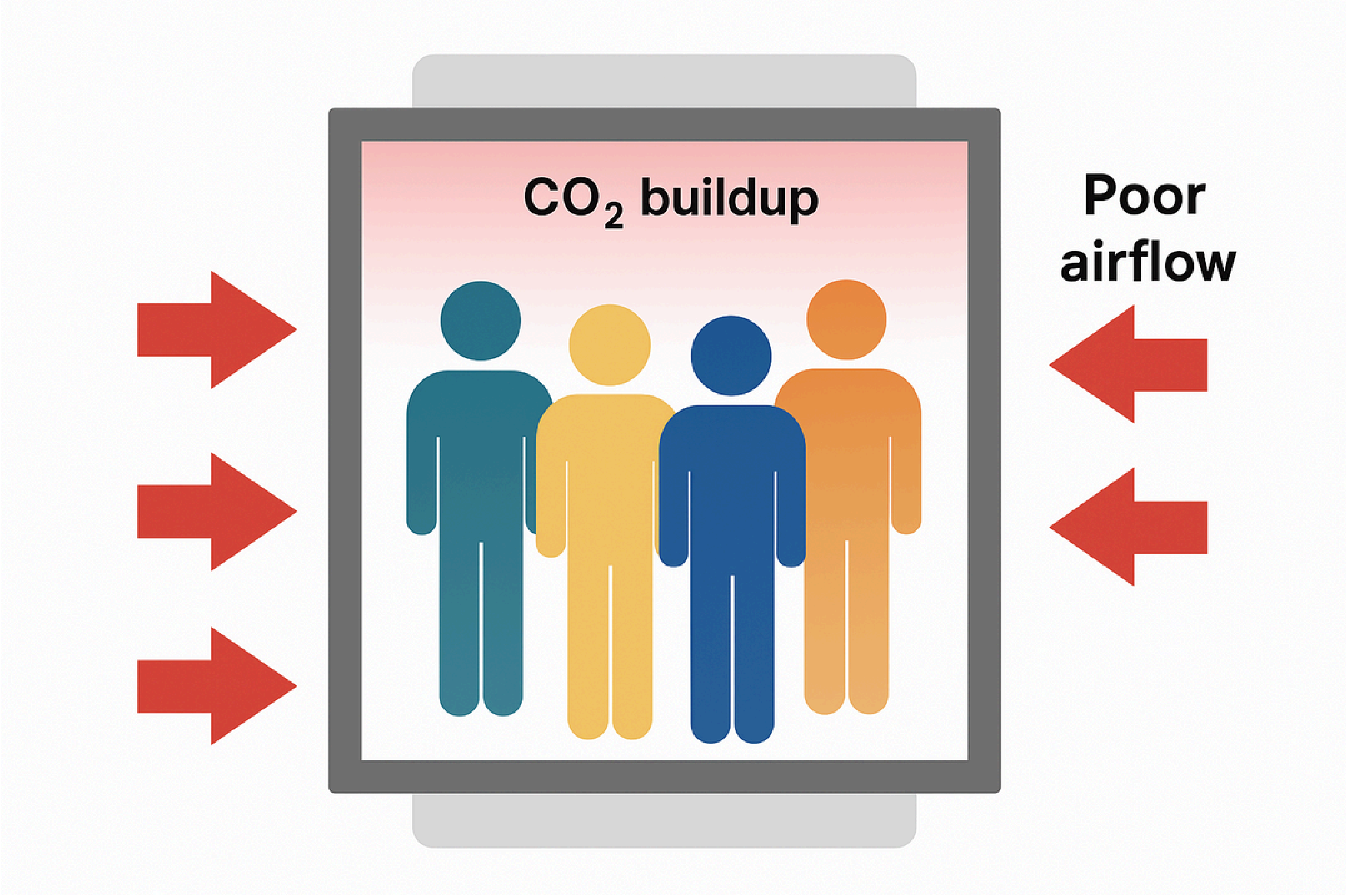
## Lifts: High-Risk Zones for Airborne Transmission

**Confined Volume:** Enclosed cabin space typically ranges from 3–5 m³, leaving limited room for air dilution.

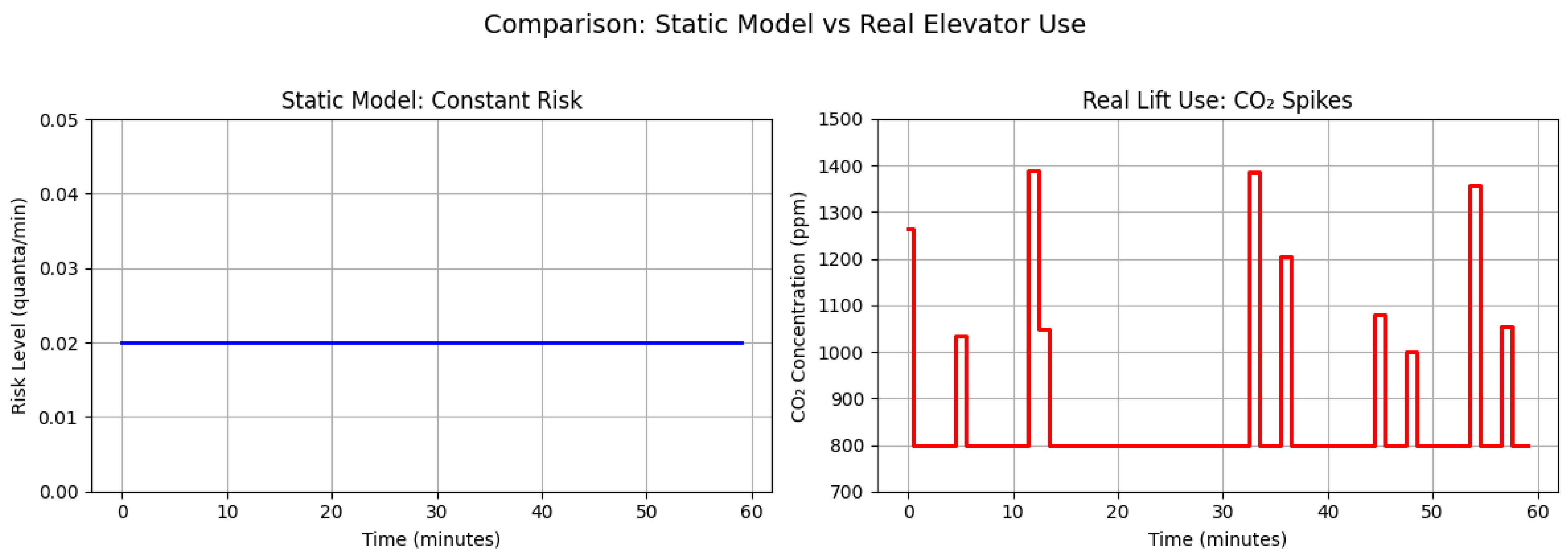
**Frequent Use:** Elevators experience high occupancy turnover, often used dozens of times per hour by different individuals.

**Poor Ventilation**: Ventilation is usually passive or shaft-dependent, leading to limited fresh air exchange.

**Short but Intense Exposure**: While trips are brief, passengers are nearby, and $CO_2$ and aerosol buildup can spike rapidly between rides.



# Static Models Fall Short




*The graphs use **simulated data** to conceptually illustrate differences between static models and real elevator use. They do not reflect actual sensor readings.

## Limitations of Traditional Risk Models

**Assume Average Conditions:** Uses fixed occupancy and ventilation values.

**Miss Short-Term Spikes:** Fails to detect short-term risk surges (e.g., post-lecture crowds).

**Delayed Risk Detection:** Delays in identifying high-risk moments.

**Pathogen-Agnostic Assumptions:** Doesn't adapt to different disease transmission rates.

# Bridging the Gap: Real-Time, Affordable Risk Detection

## Real-Time Data

Continuously monitor $CO_2$, temperature, and humidity to reflect real-time environmental conditions inside lifts.

## Disease-aware modelling

Dynamically update infection risk based on changing occupancy and ventilation levels.

## Alerts

Scale effortlessly across multiple lifts and buildings without heavy infrastructure.

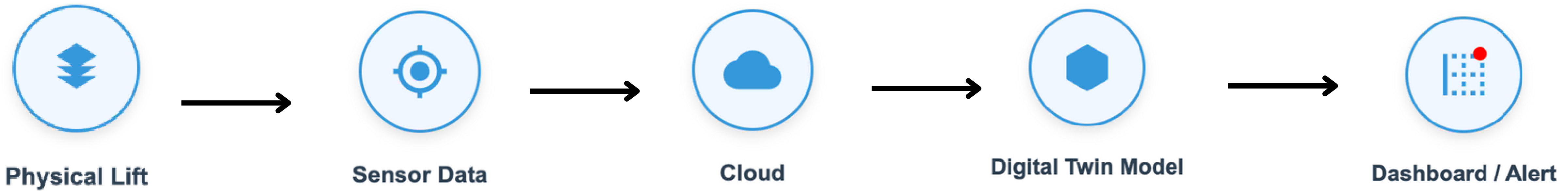
## Low-Cost

Operate on low-cost hardware, avoiding reliance on expensive or proprietary IoT ecosystems.

# The Digital Twin Solution

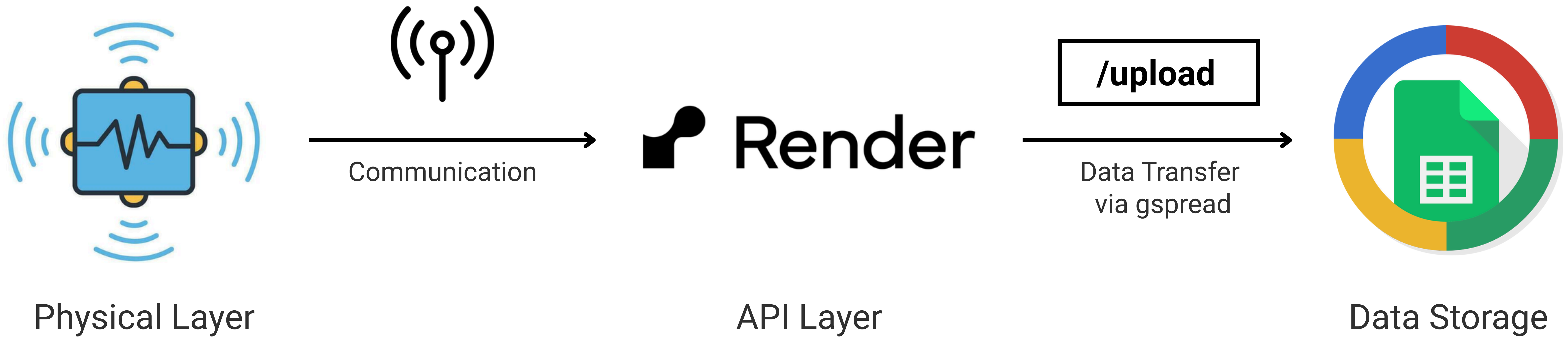
"A digital twin is a virtual representation of a connected physical asset and encompasses its entire product lifecycle."

*-Digital Twin: Definition & Value – An AIAA and AIA Position Paper*



# Design of the Digital Twins System

# Designing the Digital Twin Architecture




*This is my setup for the digital twins in the lift.

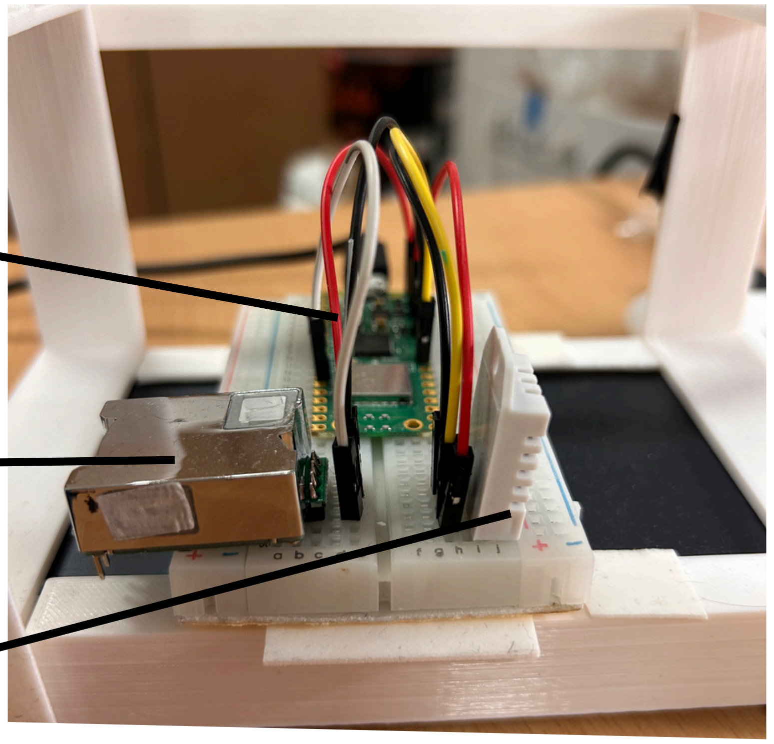
# Deploying the System in a Real Lift

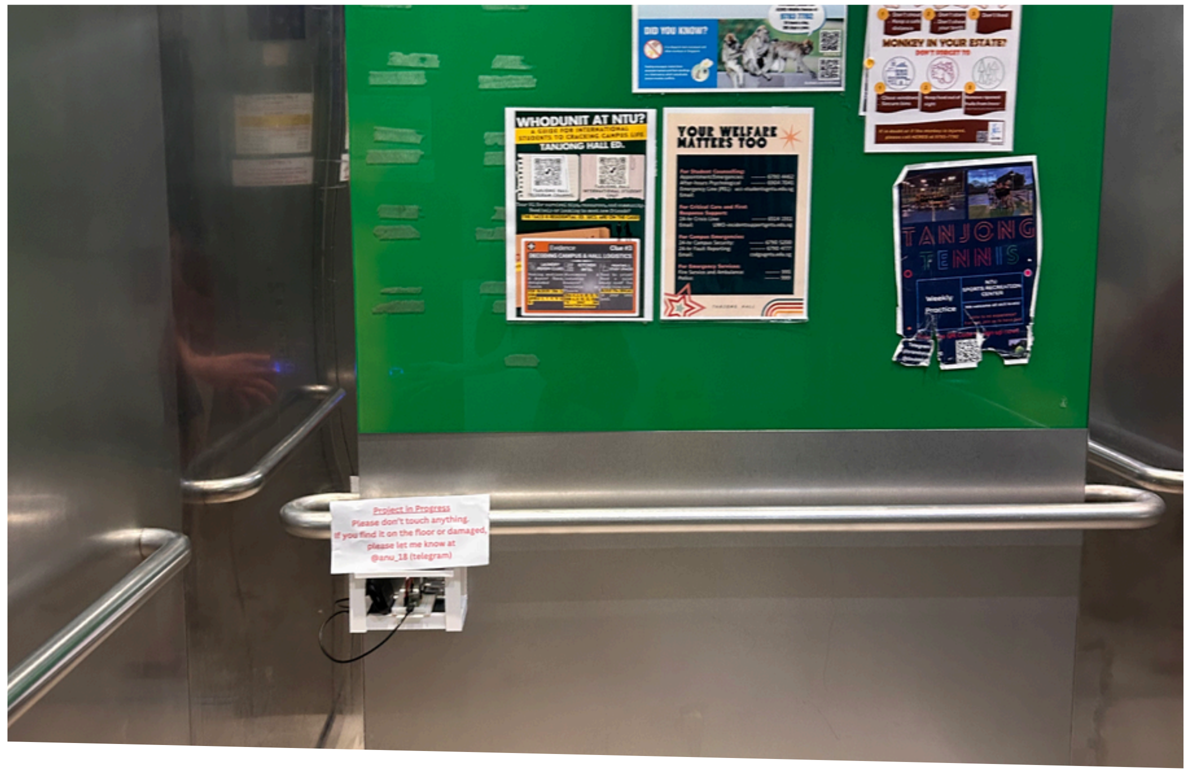
Raspberry Pi Pico W
(Microcontroller)

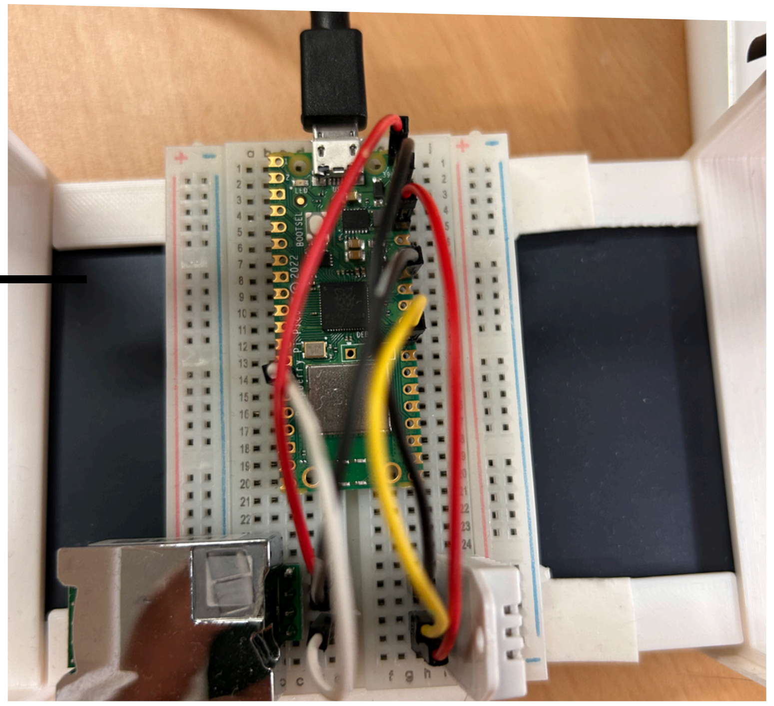
V4 C8 CO2
(Co2 sensor)

DHT22
(Temp & Humdity sensor)

Power Bank
(Xiaomi Portable
10,000mAh )







# Infection
# Risk
# Modelling

# Epidemiology Meets Engineering

**Wells-Riley Equation**

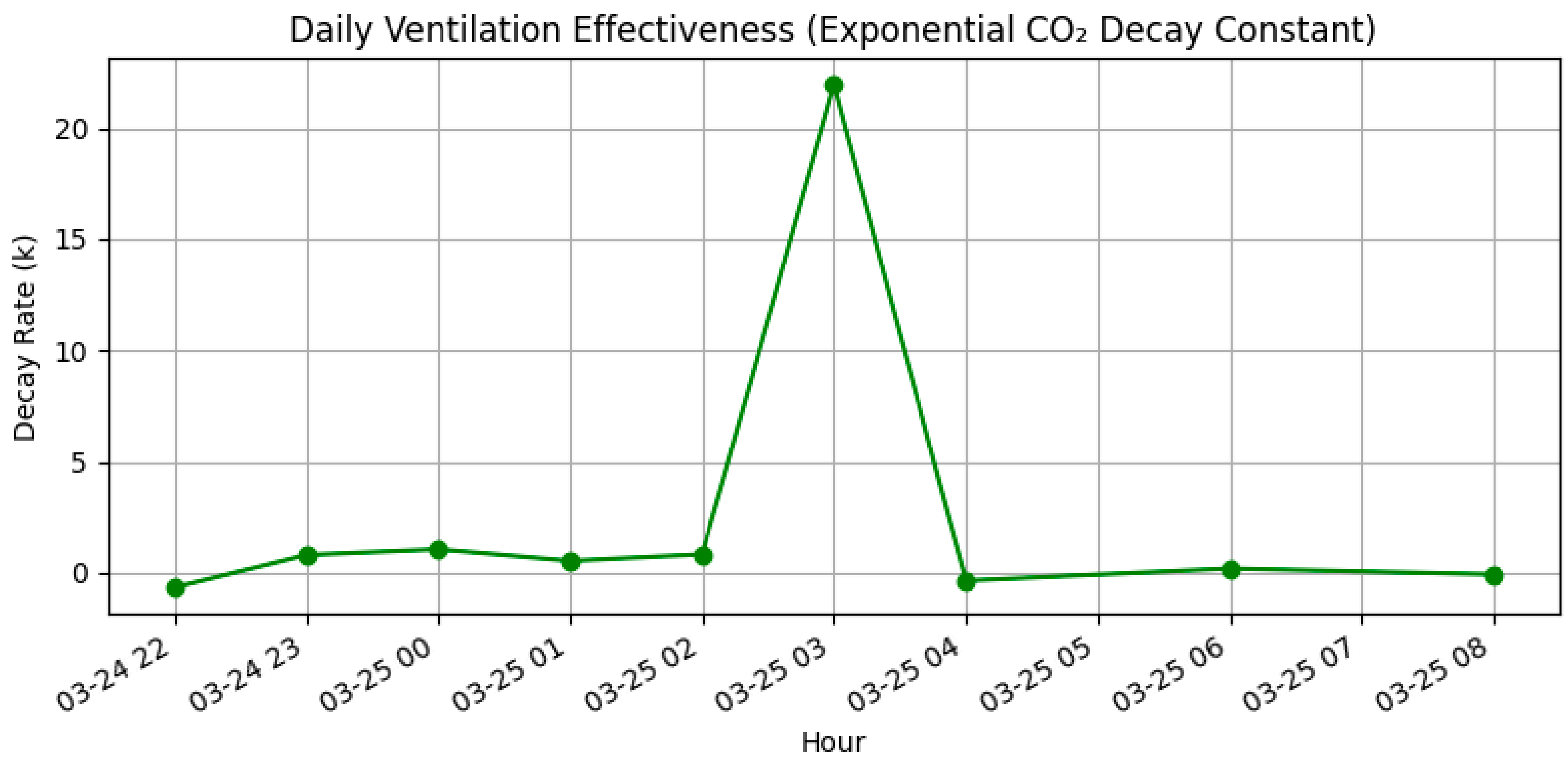
$$P = 1 - e^{\left(\frac{-Ipqt}{Q}\right)}$$

$I$ : Number of infectious individuals
$q$: Quanta generation rate (disease-dependent)
$p$: Breathing rate of susceptible individuals
$t$: Exposure duration
$Q$: Room ventilation rate (in volume/time)

Assumption:

**$I$ = 1:** Assumes at least one infected individual is present in the lift.
**q (Quanta Generation Rate):** Values taken from peer-reviewed research for COVID-19, Measles, and TB.
**p (Pulmonary Ventilation Rate):** Based on average breathing rate of a resting adult.
**t (Exposure Time):** Calculated from sensor logs; an average duration per lift ride was used.

# From $CO_2$ Decay to Ventilation Rate: How Q is Calculated




CO2 decays exponentially post occupancy

Fitted using:

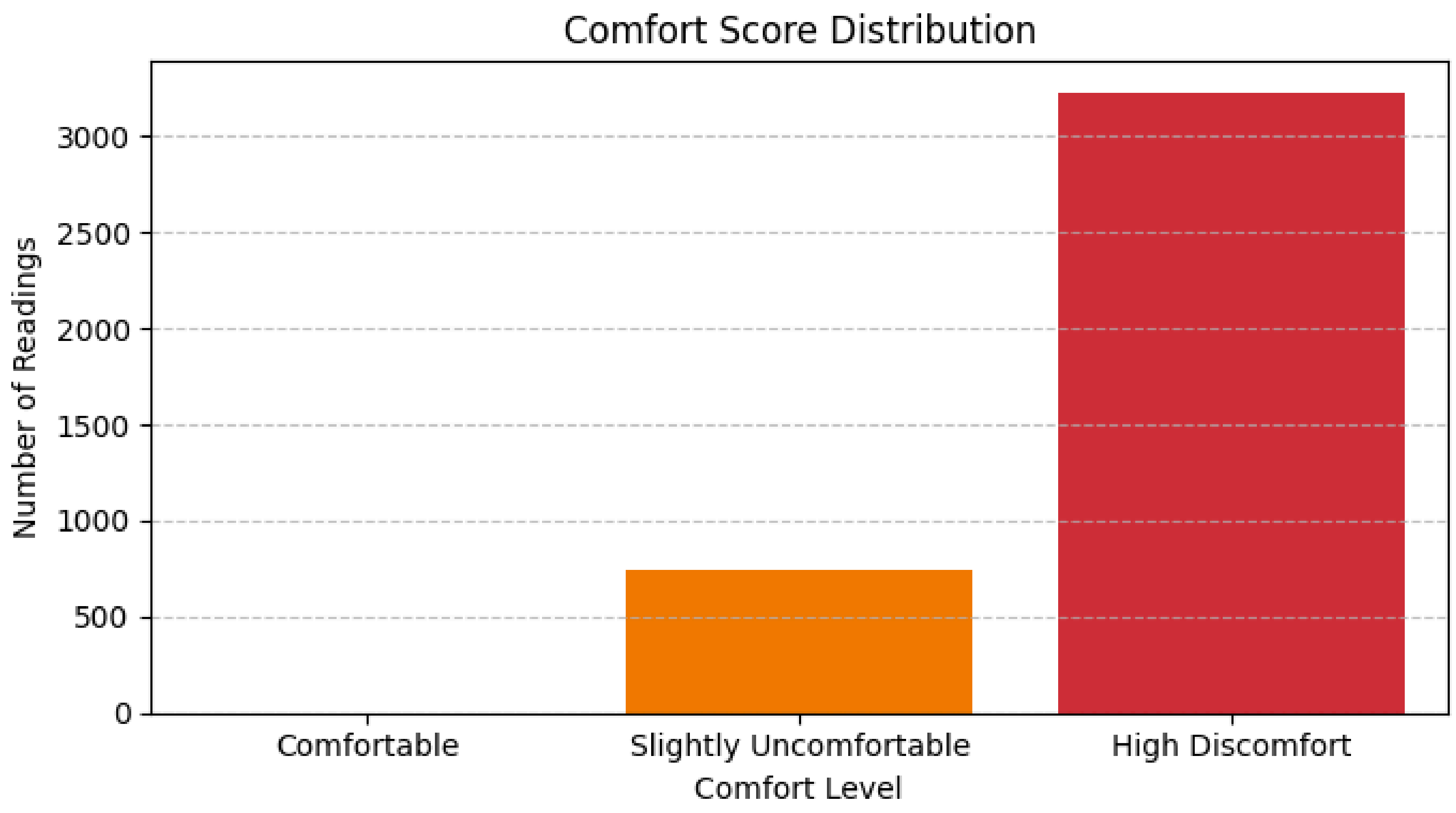
$$C\left(t\right) = C_0 \times e^{(-k \times t)} + C_t$$

Air changes per hour (ACH) derived from k

Enables real-time estimation of Q, no airflow sensor required

Good fit = fast decay → better ventilation

# Balancing Safety and Comfort: VESS and ASHRAE Scoring

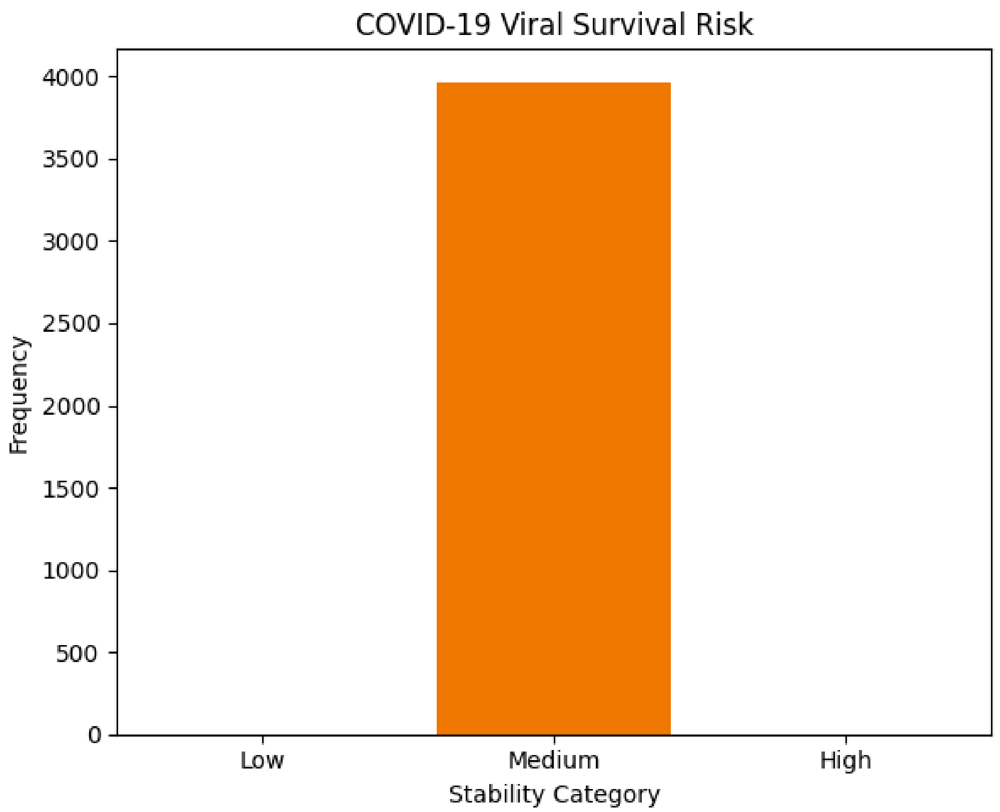


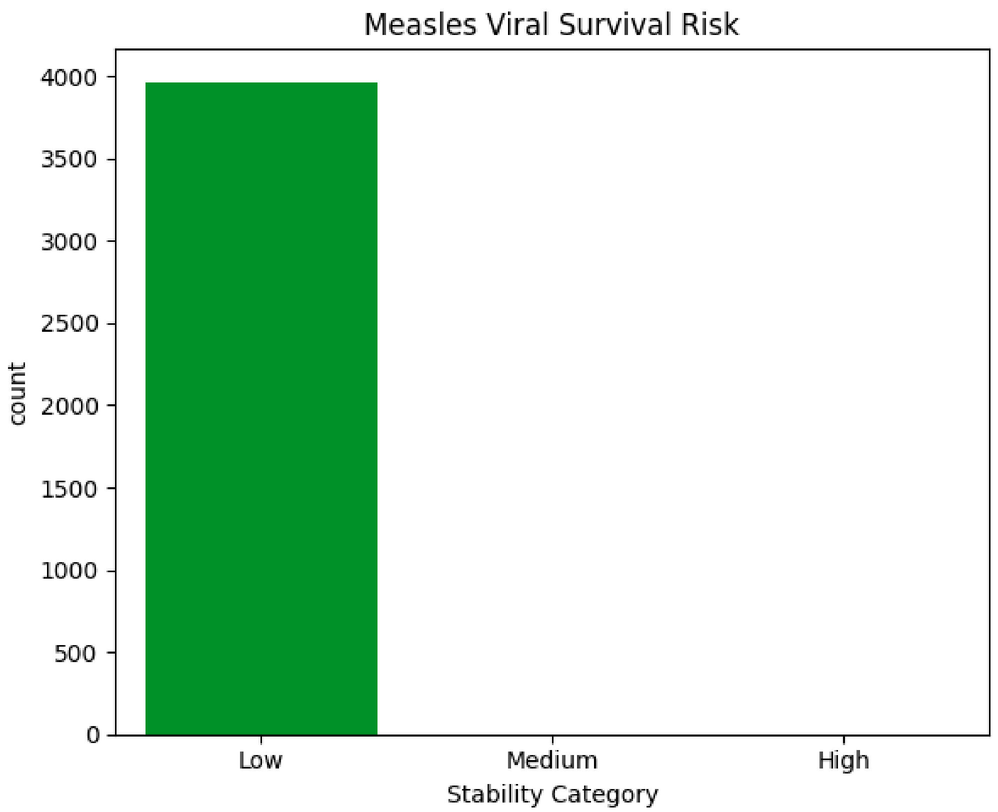

**0** — Comfortable
22°C ≤ Temp ≤ 26°C and 30% ≤ RH ≤ 70%

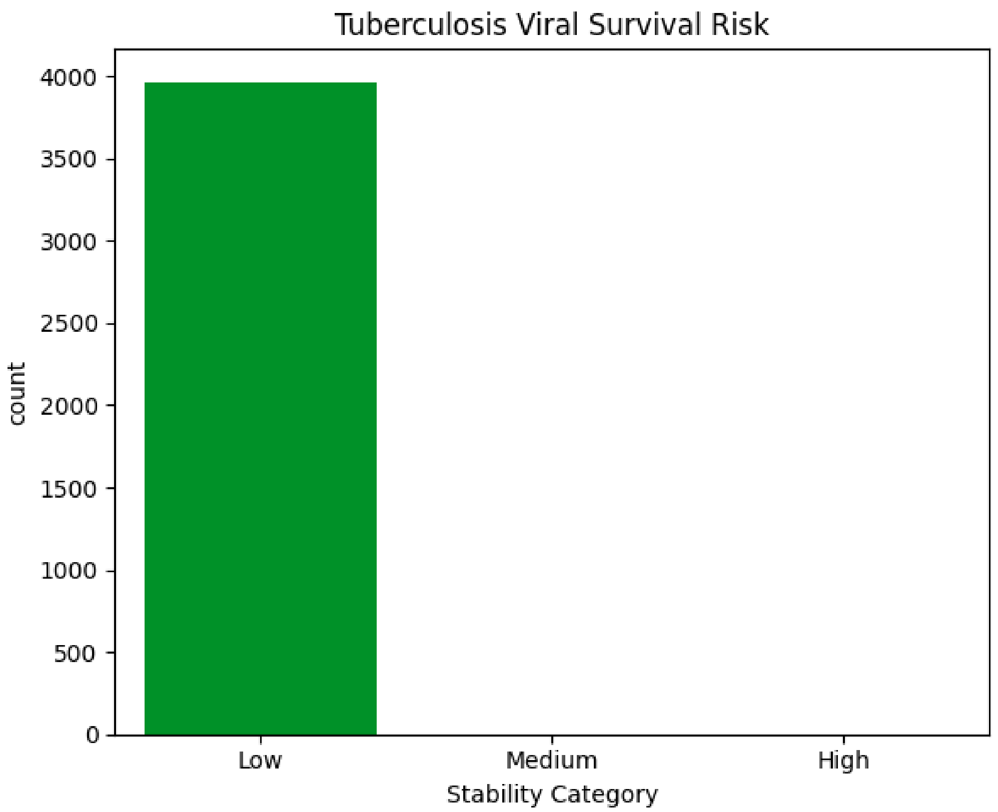
**1** — Slightly Comfortable
(24°C ≤ Temp < 26°C or 26°C < Temp ≤ 29°C) and 20% ≤ RH ≤ 80%

**2** — High Discomfort
All other conditions outside the above ranges

# Balancing Safety and Comfort: VESS and ASHRAE Scoring



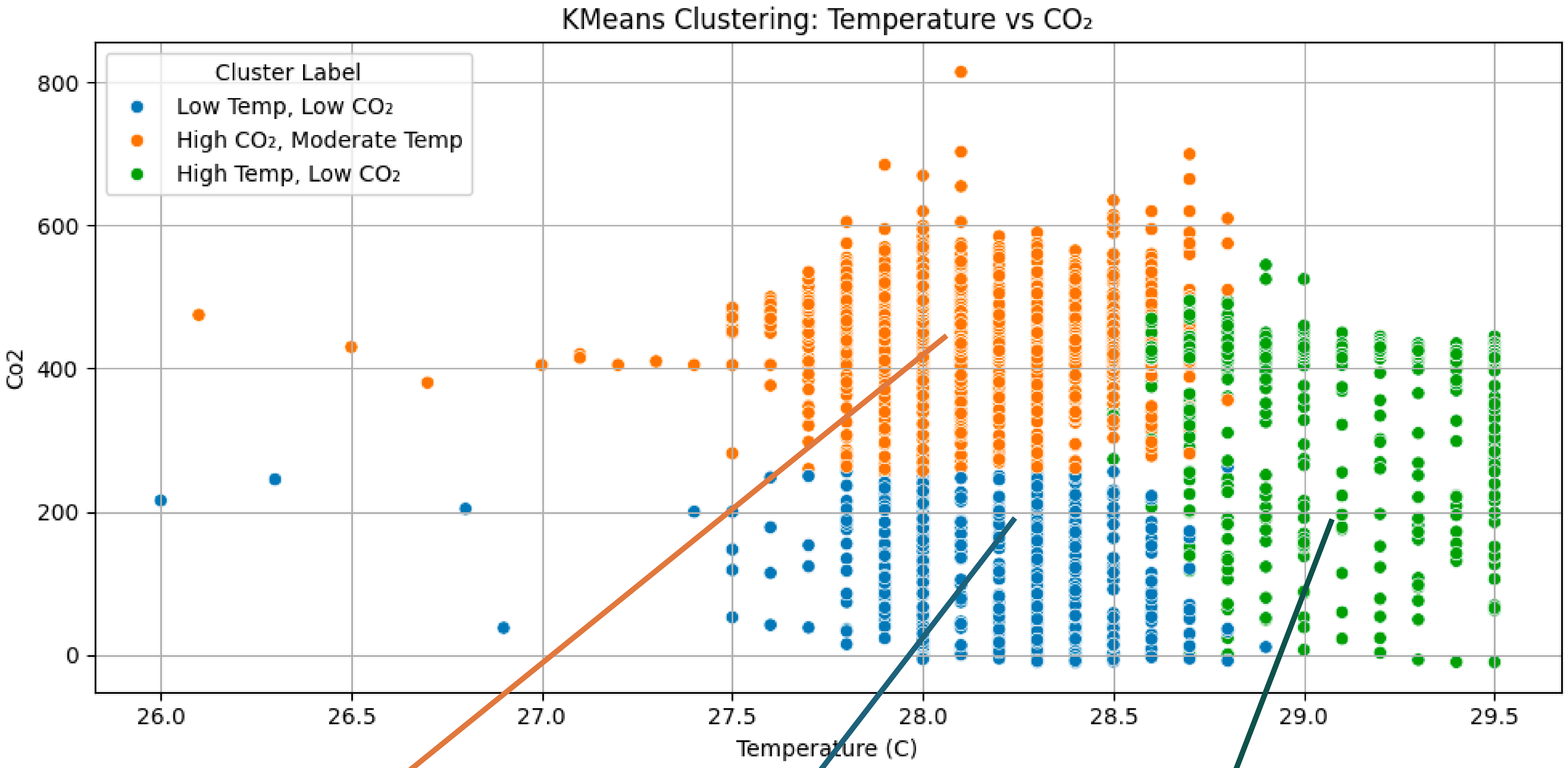

| | | | |
|---|---|---|---|
| Low | Temp ≥ 20°C and 40% ≤ RH ≤ 60% | **Temp ≥ 21°C and RH ≥ 50%** | **Temp ≥ 25°C and RH ≥ 50%** |
| Med | **Temp < 20°C or RH < 40% or > 60%** | Temp < 21°C or RH < 50% | Temp < 25°C or RH < 50% |
| High | Temp < 21°C and RH < 50% | Temp < 21°C and RH < 50% | Temp < 25°C and RH < 50% |

# Machine Learning & their Roles

# Profiling Lift Environments Using K-Means Clustering

## Dominant Drivers of Risk

Temperature and $CO_2$ were found to be the most direct indicators of ventilation quality and occupancy load—key factors in infection risk. Humidity had lower variance and less discriminative power.




**Caution Zone**

High $CO_2$, Moderate Temp
Crowded but within tolerable thermal range

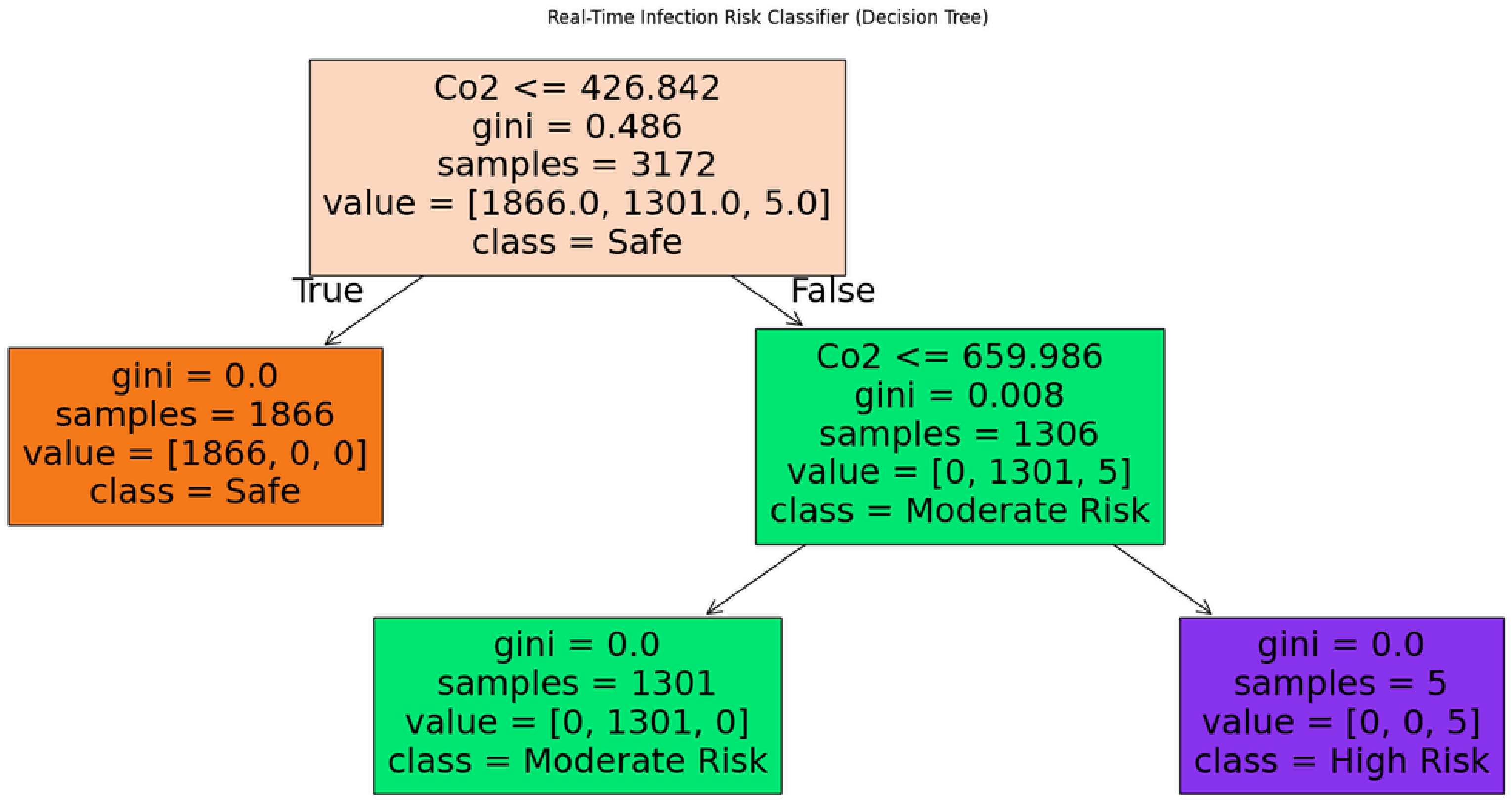
**Optimal Zone**

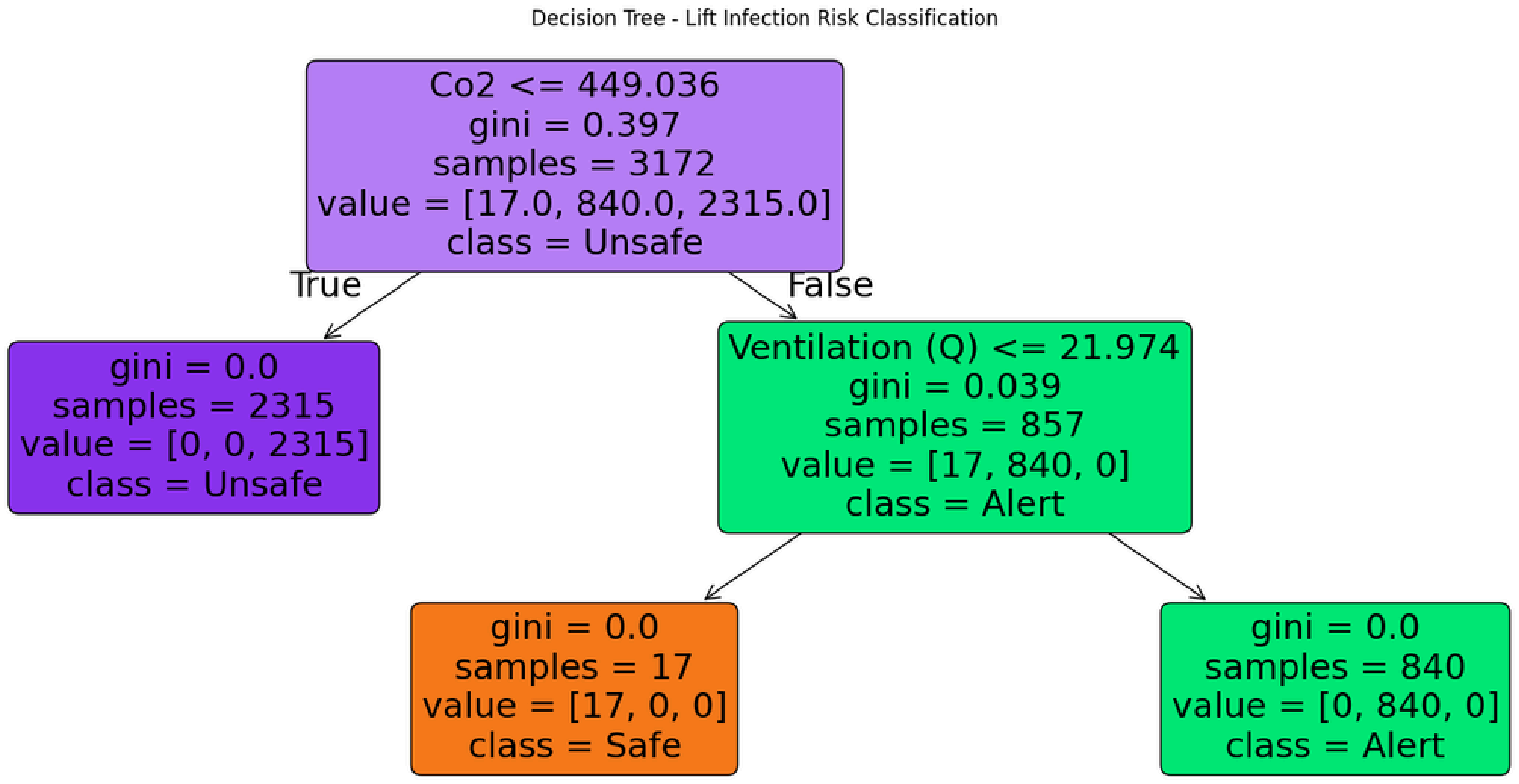
Low $CO_2$, Low Temp
Well-ventilated, thermally comfortable

**Red Zone**

High $CO_2$, High Temp
Poor ventilation and thermal discomfort — high-risk environment

# Classifying Lift Conditions: From Sensor Data to Safety Labels




## Tree 1: CO2 - Only Classifer

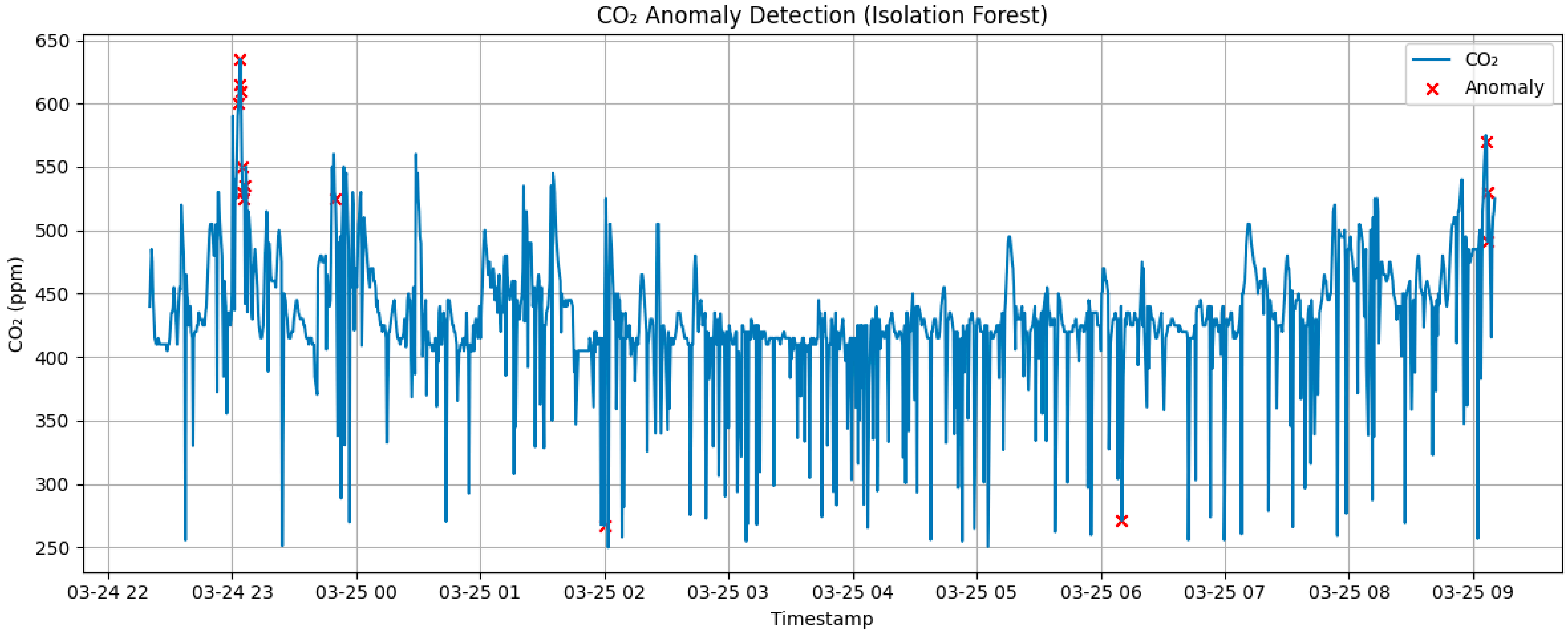
- Risk increases as $CO_2$ concentration rises.
- Thresholds like 426 ppm and 660 ppm are used to segment risk into safe, moderate, and high.

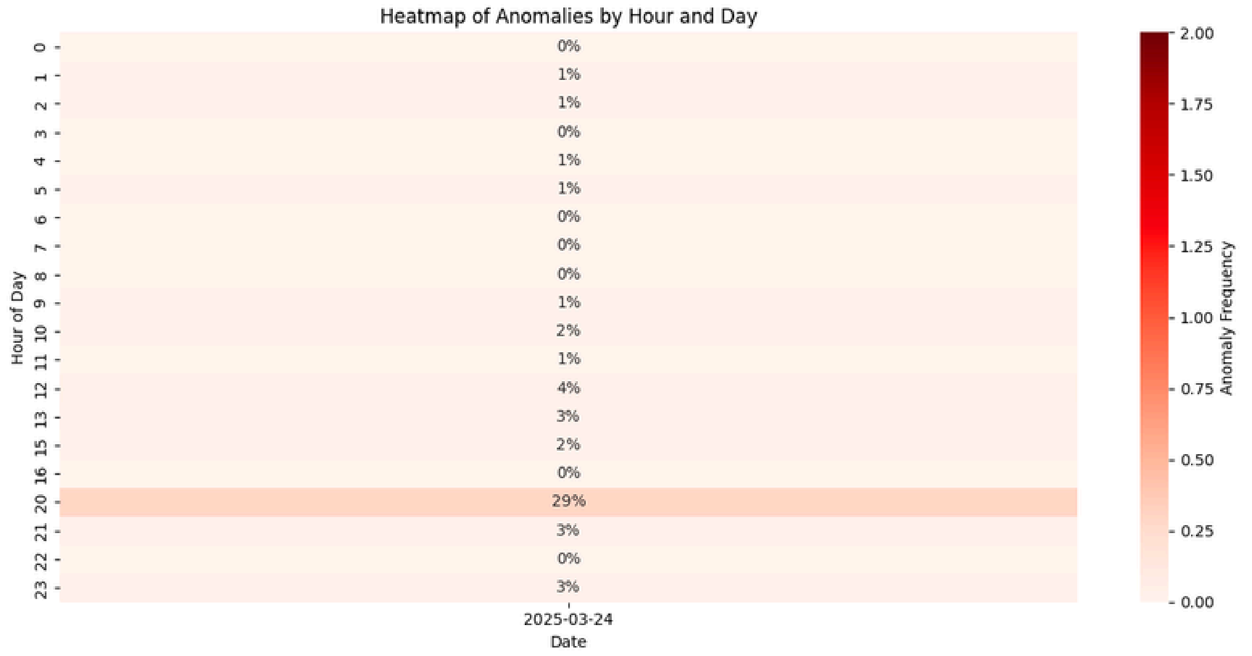
**Higher $CO_2$ → higher likelihood of shared air → higher risk.**

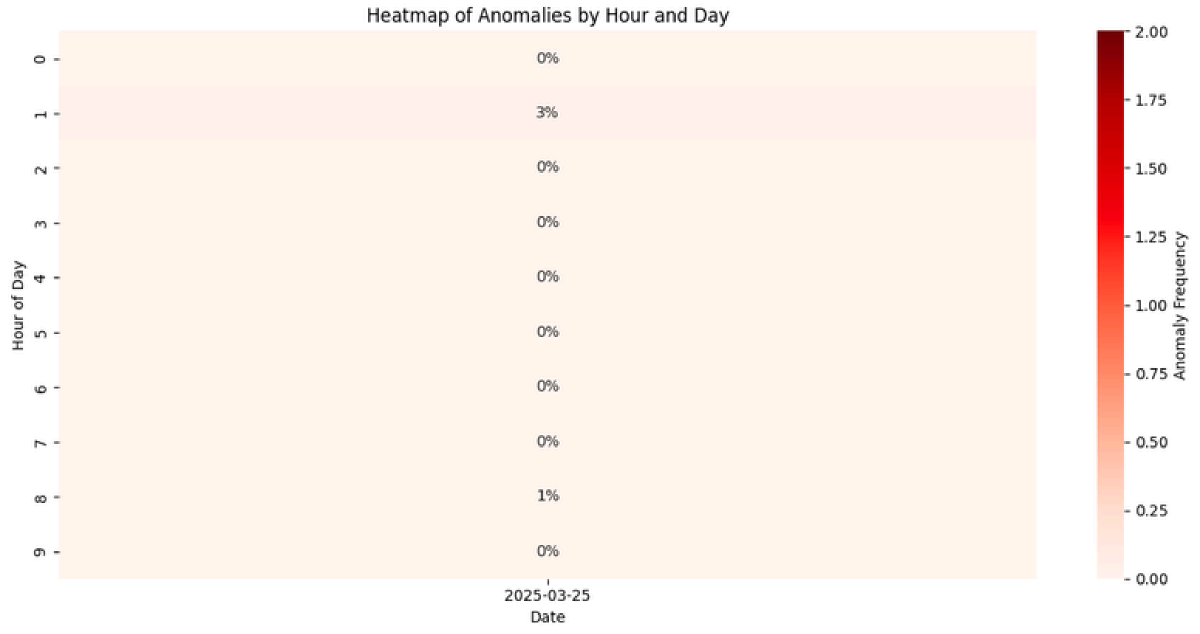
## Tree 2: Multi-Parameter Risk Classifier

- Low $CO_2$ doesn't always mean safe — poor ventilation can still allow infectious aerosols to linger.
- The model reveals hidden risk by classifying conditions as unsafe when ventilation (Q) is critically low, even if $CO_2$ appears acceptable.

# Anomaly Detection: Spotting What Doesn’t Belong




Flag anomalies like:

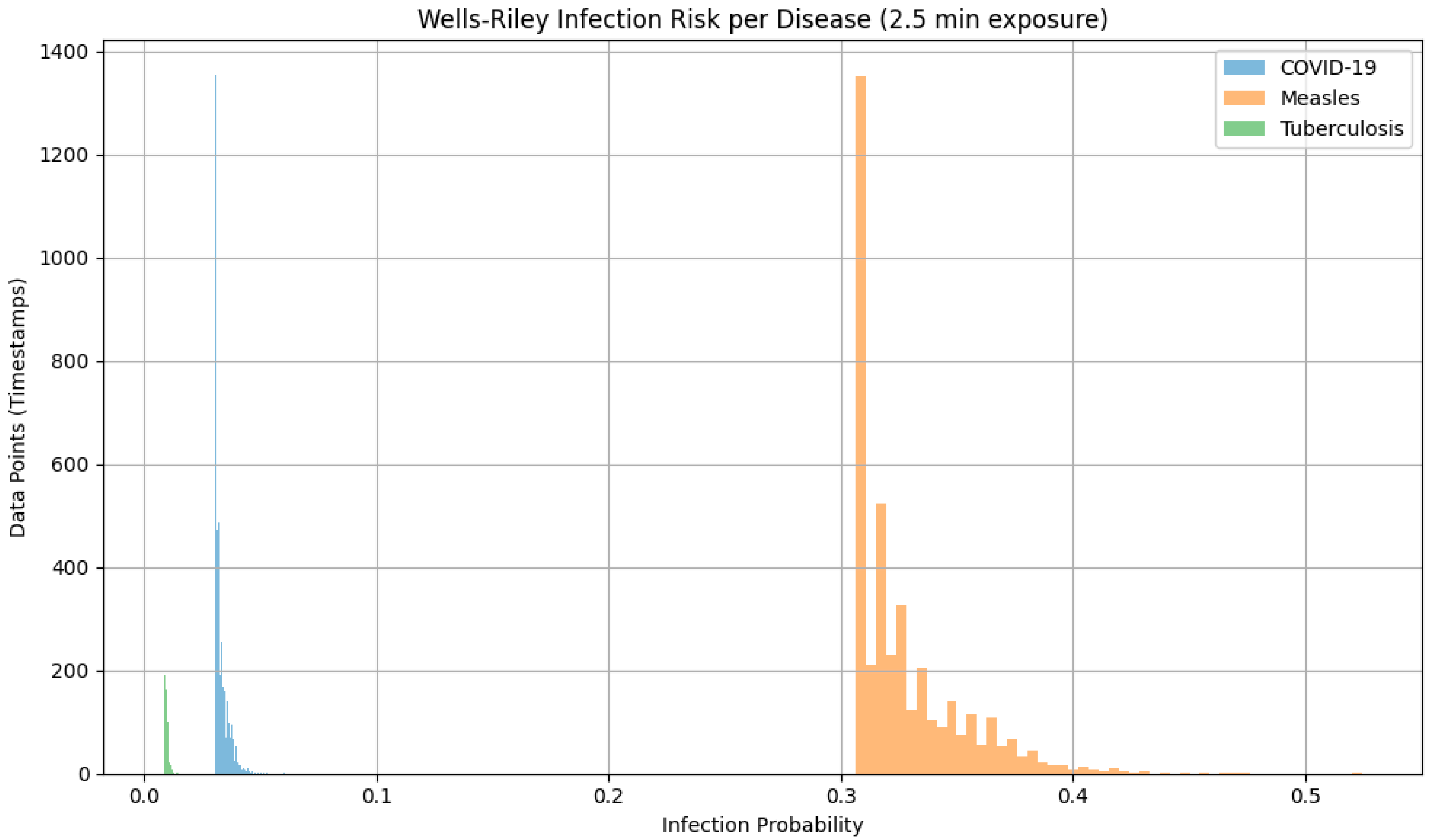
- Sensor Dropout
- Unexpected $CO_2$ surges
- Ventilation failure

**14 total anomalies were found.**

# Bringing It All Together: Real-Time Analytics at the Edge

# Key Results
# &
# Insights

# Wells-Riley's Prediction

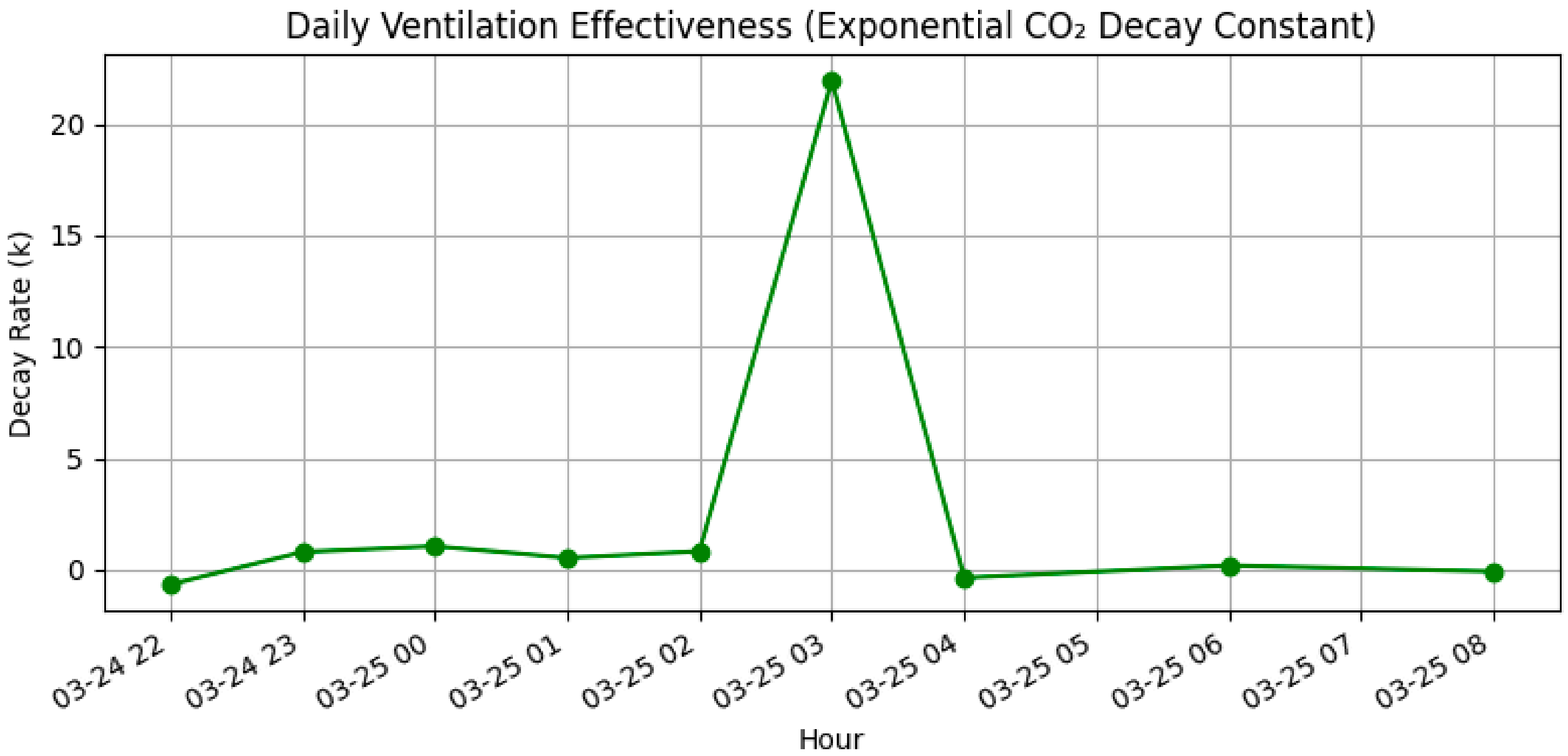


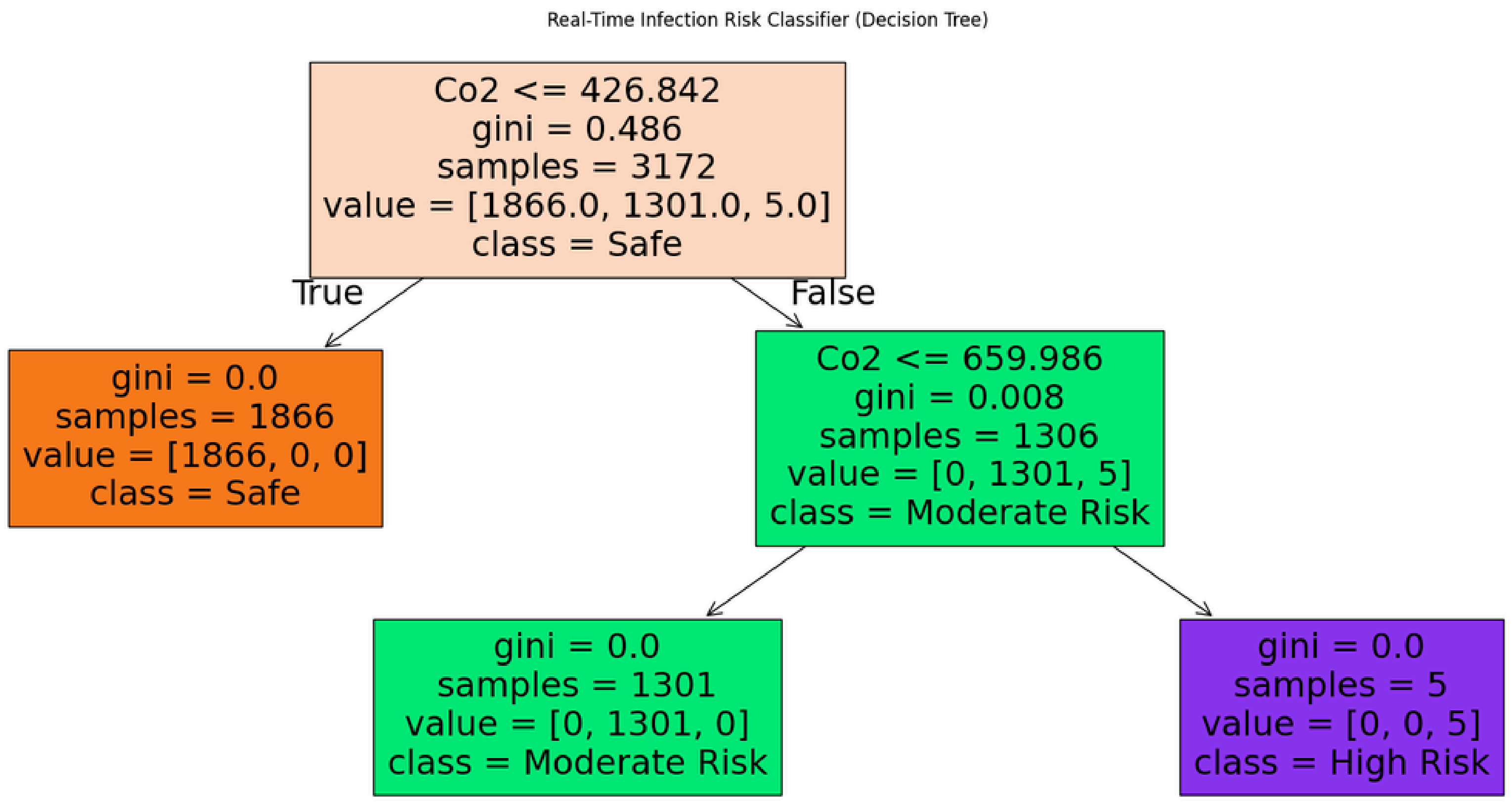

**Covid-19** Infection Rate: 2.38%
Moderate transmission

**Meales** Infection Rate: 32.68%
Extremely high risk

**TB** Infection Rate: 0.90%
Lower airborne quanta

# What the Twin Revealed: Risk Hidden in Plain Sight




## Ventilation Reality Check

- $CO_2$ decay constants near zero in most sessions
- Air wasn't being exchanged, indicating poor ventilation even if conditions felt "normal"

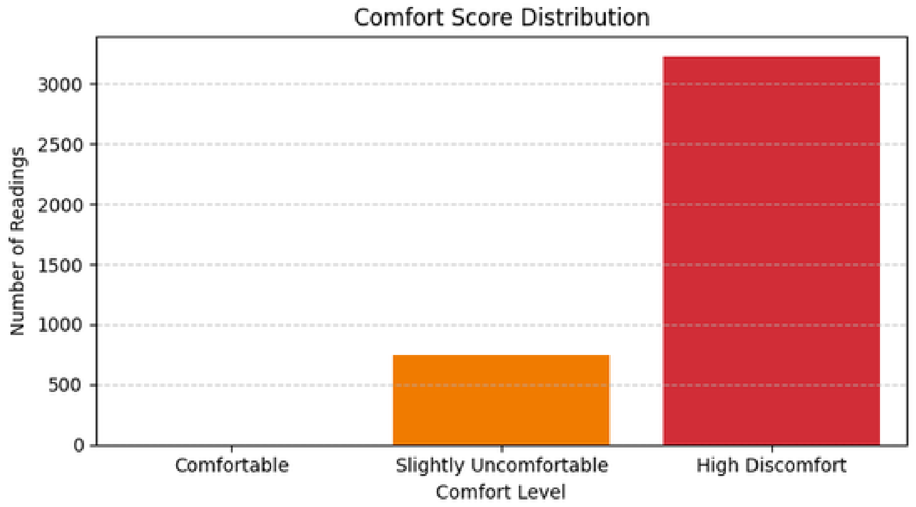
## $CO_2$ Threshold Logic

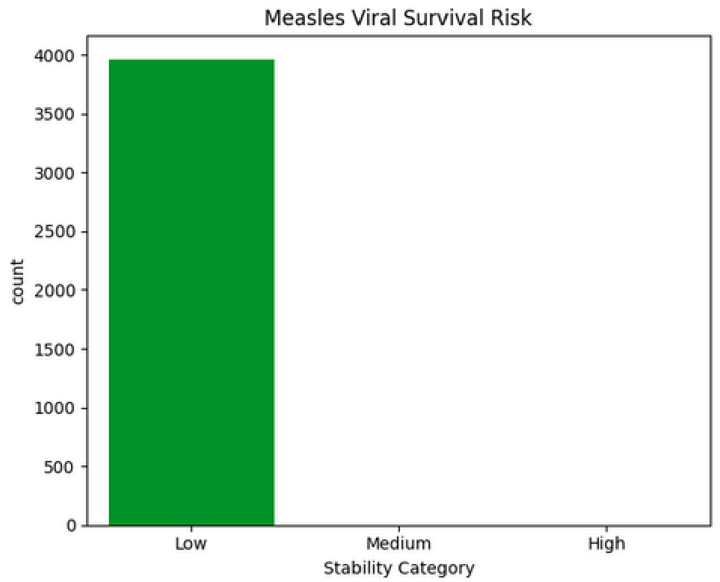
- When $CO_2$ > 660 ppm, risk sharply increases
- This threshold aligned with anomaly spikes and infection probability

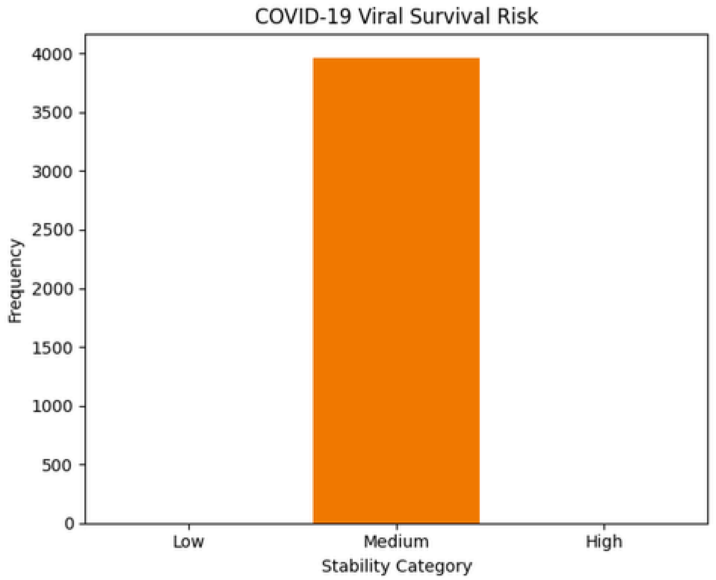
# What the Twin Revealed: Risk Hidden in Plain Sight

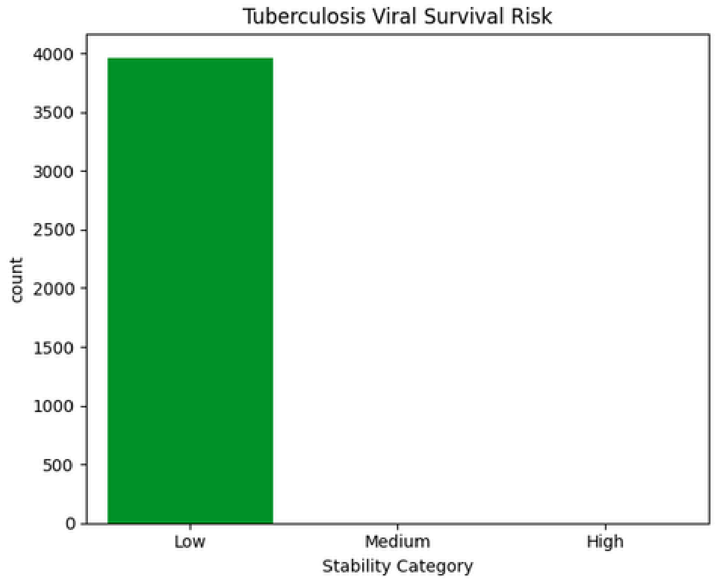
## Insights: VESS & Comfort Score

- **Measles & TB → Low VESS:** Warm, humid lift conditions limited virus survival for both pathogens.
- **COVID-19 → Medium VESS:** Environmental conditions allowed moderate persistence—still a concern for transmission.
- **High Discomfort Dominates:** Over 80% of readings were "Slightly or Highly Uncomfortable", highlighting thermal stress and its impact on lift usability.
- **Inverse Relationship:** Conditions that reduced virus viability (high humidity) also led to poor thermal comfort—a tradeoff between health risk and occupant experience.



# Conclusion & Future Works

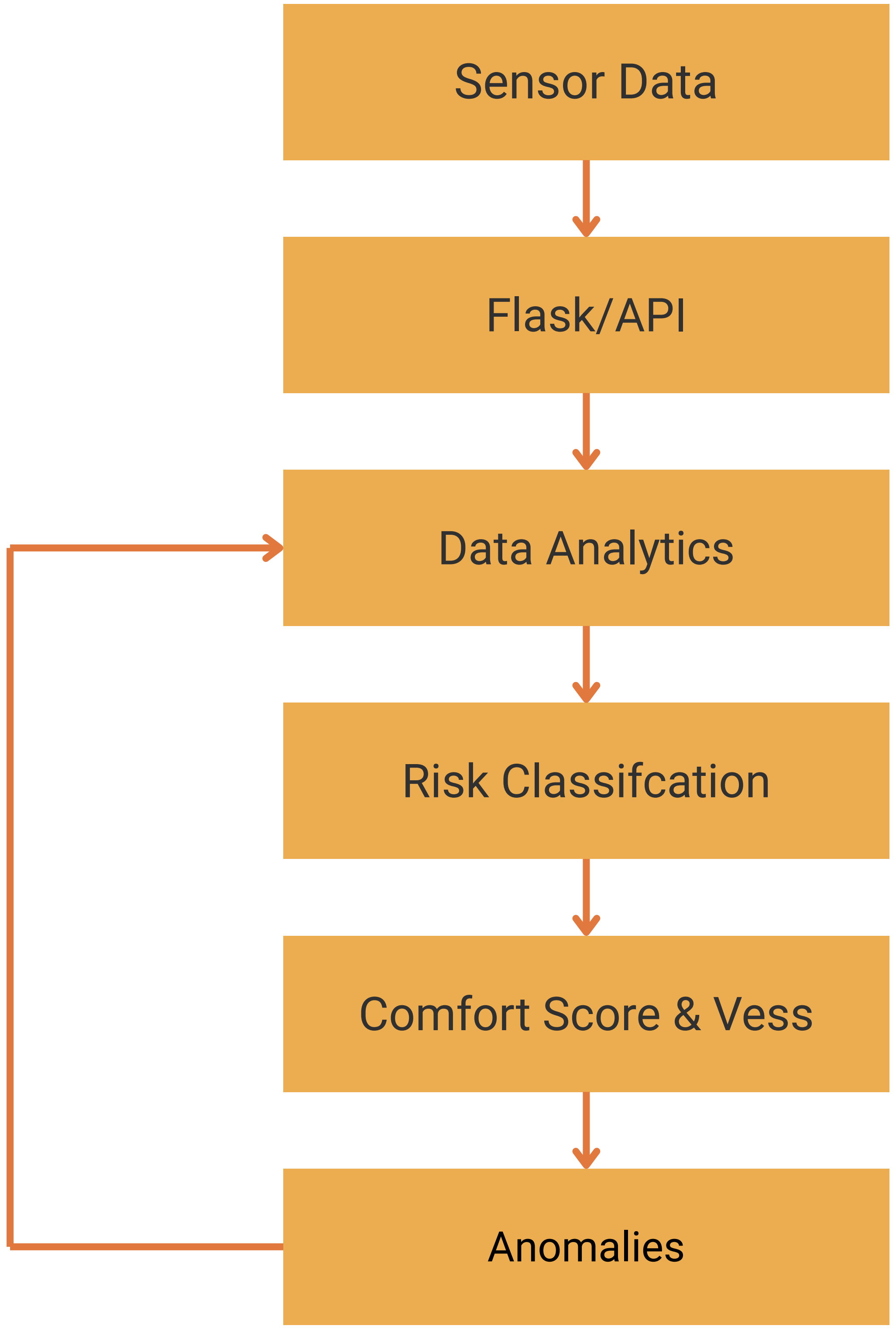
# Digital Twins for Safer Shared Spaces

## Keywords

- A real-time, disease-aware digital twin was successfully built and tested for lifts.
- The system is low-cost, interpretable, and easy to scale to other enclosed environments.
- Combines epidemiological modelling + real-time sensing + ML analytics for layered risk insights.

## Next Step

1. Add occupancy counters for density-aware risk estimation.
2. Develop real-time dashboards for live monitoring and alerts.
3. Expand to other spaces like restrooms, dormitories, and clinics.



# Thank You