Introducing The CAVE Laboratory

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UK Indoor air - research at the science policy interface
6th November 2025

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The Controlled Active Ventilation Environment Lab (CAVE)

UCL Dagenham East Site, **CAVE** and **PEARL Laboratories**

CAVE is located on the UCL Dagenham East site.

Contact:

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Website:

https://www.ucl.ac.uk/civil-environmental-geomatic-engineering/controlled-active-ventilation-environment-cave ; X: @cave_lab

CAVE - People

Prof Liora Malki-Epshtein, Urban Air Quality and Fluid Mechanics, Director of CAVE

Dr Filipa Adzic, Lecturer, Computational Fluid Dynamics

Prof Jose Torero, Head of Dept, CEGE, Fire Engineering and weakly buoyant flows

Dr Augustin Guibaud, NYU, Honorary Lecturer, Air pollution, Fire

Dr Chris Iddon, Honorary Researcher, Ventilation and Modelling

Mr Oliver Wild, Research Technician, Air Quality Sensing

Mrs Shayeeka Alam, PhD student, Green Infrastructure and Wellbeing

Dr Yutao Li, Research Associate, Wildfire smoke pollution

Mr Aohua Yang, Research Assistant, Green Air purifiers

CAVE (Controlled Active Ventilation Environment) Laboratory

The first laboratory in the world designed to tackle Air Quality challenges and ventilation at full scale

CAVE, a large-scale facility with bespoke HVAC systems completed construction in April 2023

A Portakabin interior full-scale building: a building-within a building, completed construction in July 2025

The large facility makes it possible to run experiments with people participants to understand how air quality and temperature affect them in a typical building environment

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Field Studies OR a Dedicated Laboratory?

Field studies - challenging projects due to:

- Local risk assessments,
- Bringing equipment on site
- Disturbance to the usual activities occurring on site
- Monitoring and data sharing from existing buildings partners can be at odds with commercial and reputational interests

Experimental Studies:

- Controlled conditions can be created and maintained
- Validation of realistic and complex models; these models can then be applied to a wider range of situations.
- Results are more generalisable to other settings.
- Stronger and wider collaborations between academia, industry and other research agencies made possible
- Data sharing and dissemination
- Different technical solutions can be tested in the laboratory at a fraction of the cost of implementation on a real site

CAVE environment - HVAC systems

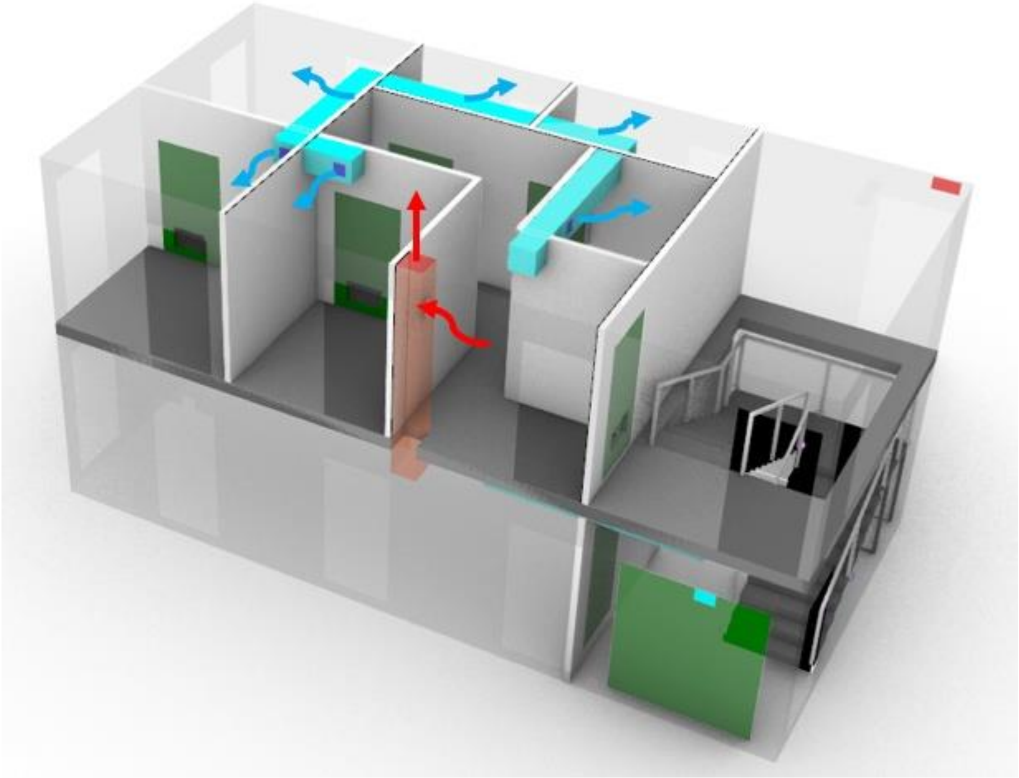
The CAVE laboratory is a fully insulated large chamber: floor plan area: 204m^2 floor-to-ceiling height 9.54m

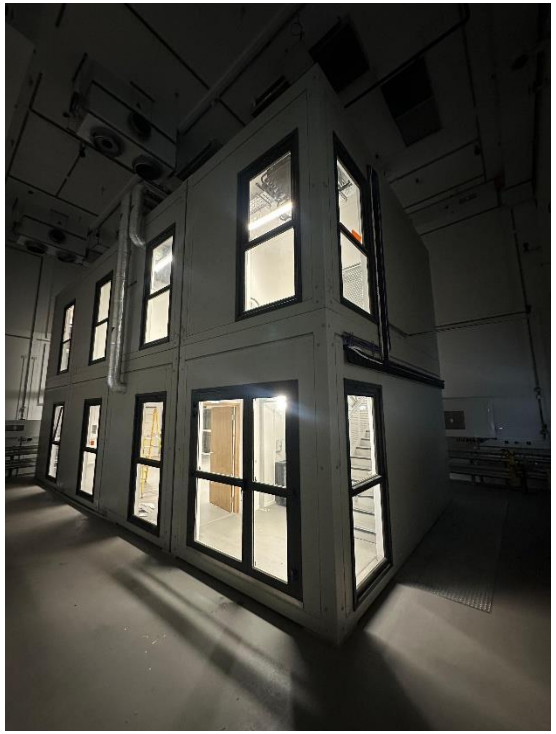
The Temperature and Humidity of the lab environment of the lab is controlled, and is able to sustain:

Temperatures between -7°C and +43°C
Humidity between 35% and 92 %

Portakabin Test building

- The two-storey modular building will serve as the main test bed for CAVE research in the coming years
- The building was fitted with a bespoke ventilation system that enables air exchange with the CAVE environment

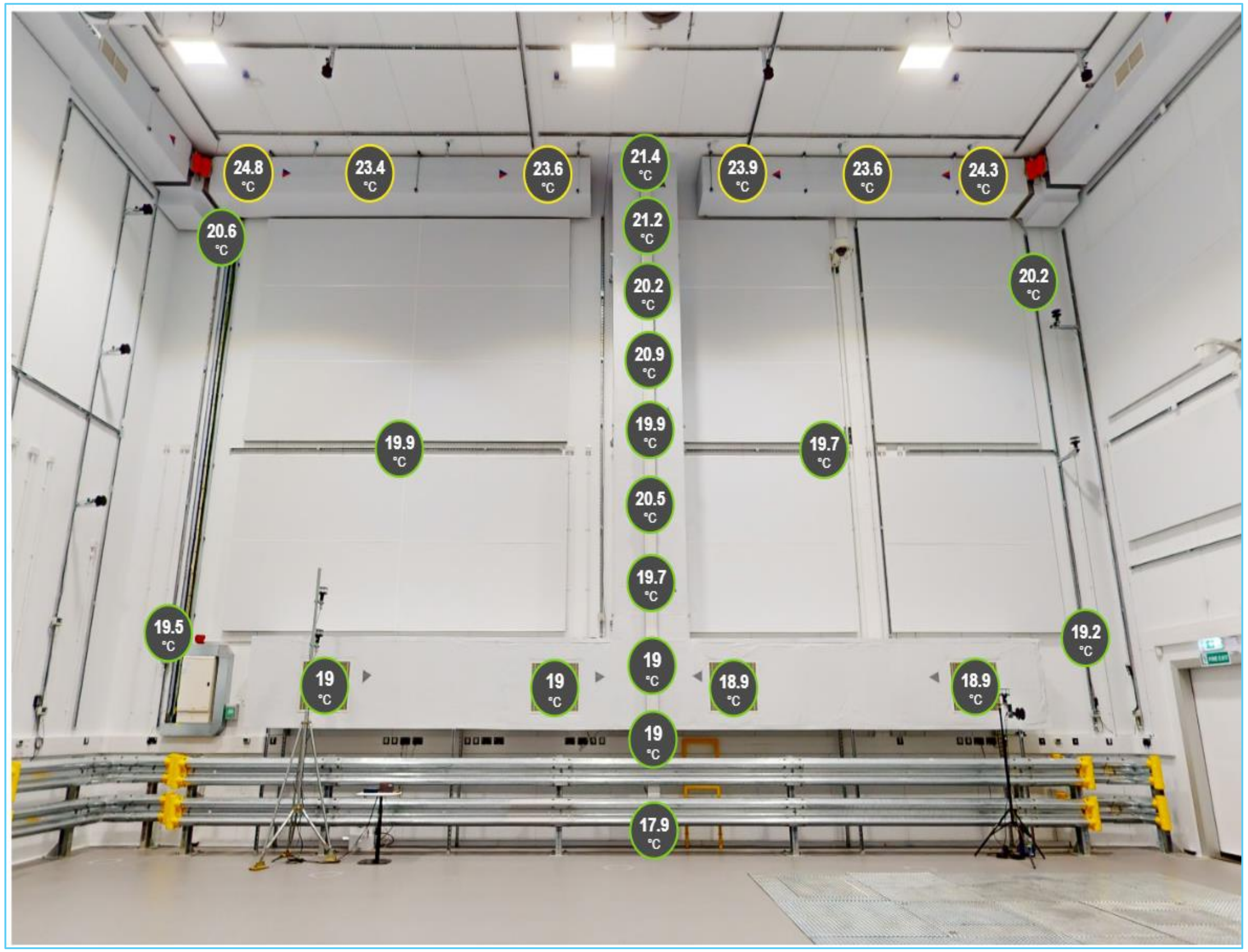




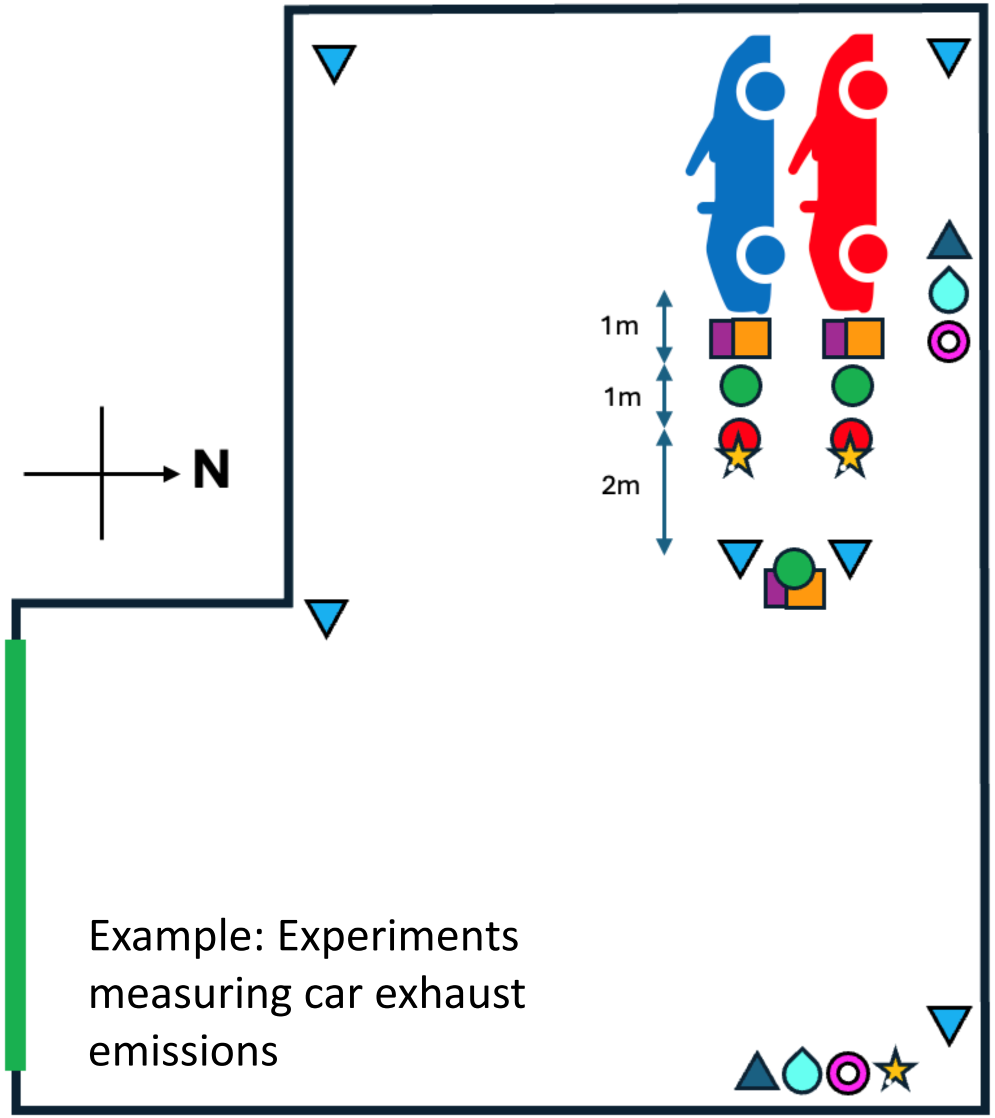
Instrumentation

High resolution monitoring is set out throughout the facility to enable full understanding of the distribution of heat and pollutants, the links to the ventilation systems and dispersion

- 20 fixed and 9 mobile anemometers measuring air velocity and direction
- 32 Thermocouples measuring surface temperatures of walls and floor, and FLIR thermal images
- >100 Explora CO_2, RH and T° loggers fixed on walls, ceiling, supplies and extracts



High resolution AQ Instruments



* Every ★ is equivalent to 3 SidePaks (PM 10, 2.5 and 1)

▲ DustTrak Environmental Monitors
PM (all sizes)

■ EVM Series 7 Air Quality Monitors
Temp, RH, PM 2.5, VOC, CO_2 and NO_2

★ SidePak Personal Aerosol Monitors

● BlueSky Air Quality Monitors
PM (all sizes), CO_2, CO, O_3, NO_2, SO_2

▼ AirAssure Indoor Air Quality Monitors
PM (all sizes), CO_2, CO, O_3, NO_2, SO_2

■ TSI Quest AirProbe - Windspeed

● Ultrasonic Wind Sensor – Windspeed
(directional and X Y Z plane)

◎ Optical Particle Size Spectrometer *(OPSS)*

💧 Versatile Water Condensation Particle Counter *(CPC)*

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Data Dashboards - CO_2, T, RH

Duomo Digital Dashboard for Explora sensors

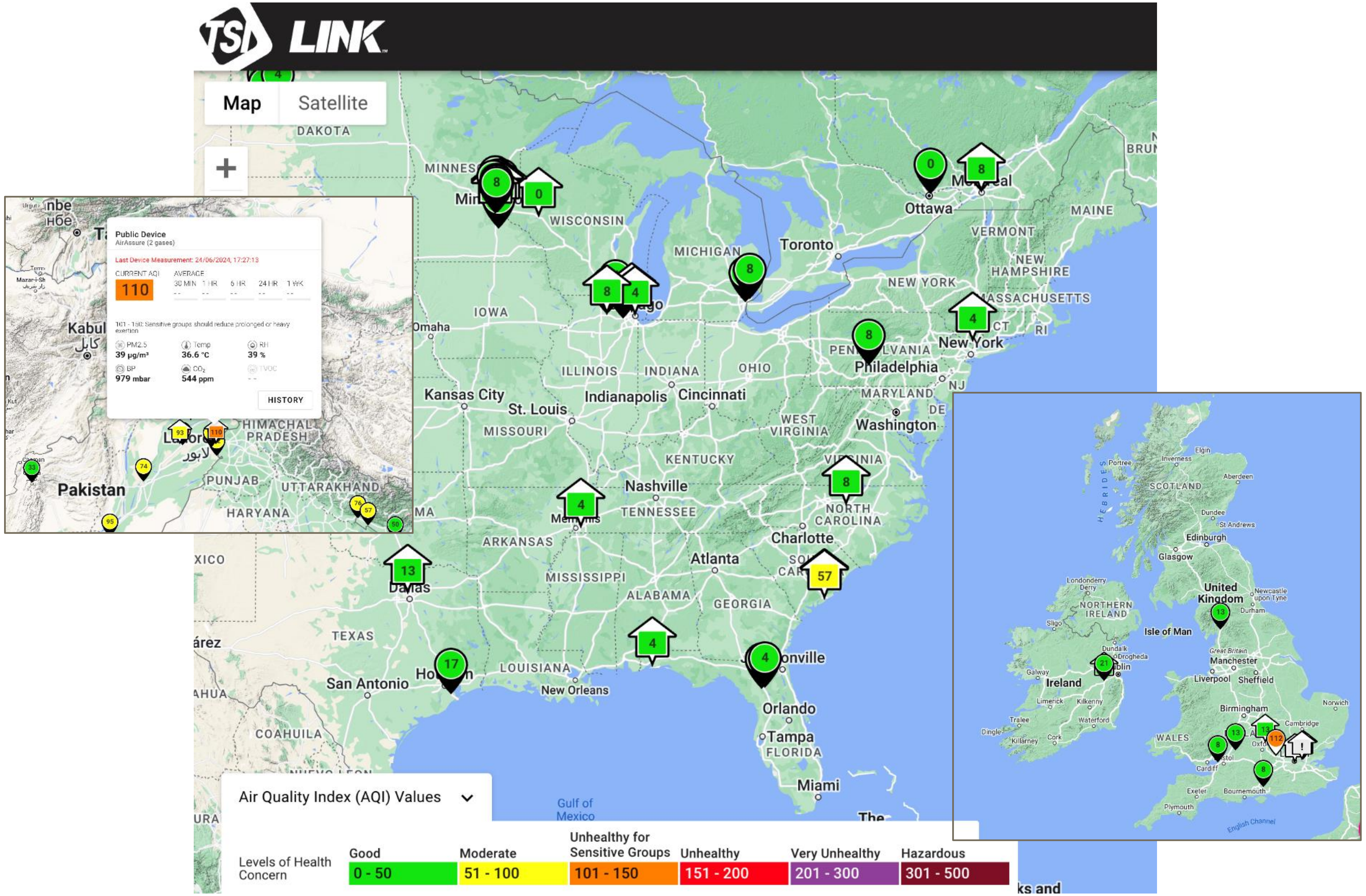
Data Dashboard - Pollutants

TSI Dashboard

Outdoor and Indoor Readings

Private/Public Devices

Standardised AQI Values



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CAVE - Workflow

Problem Statement

- Desk study
- Field studies

Modelling

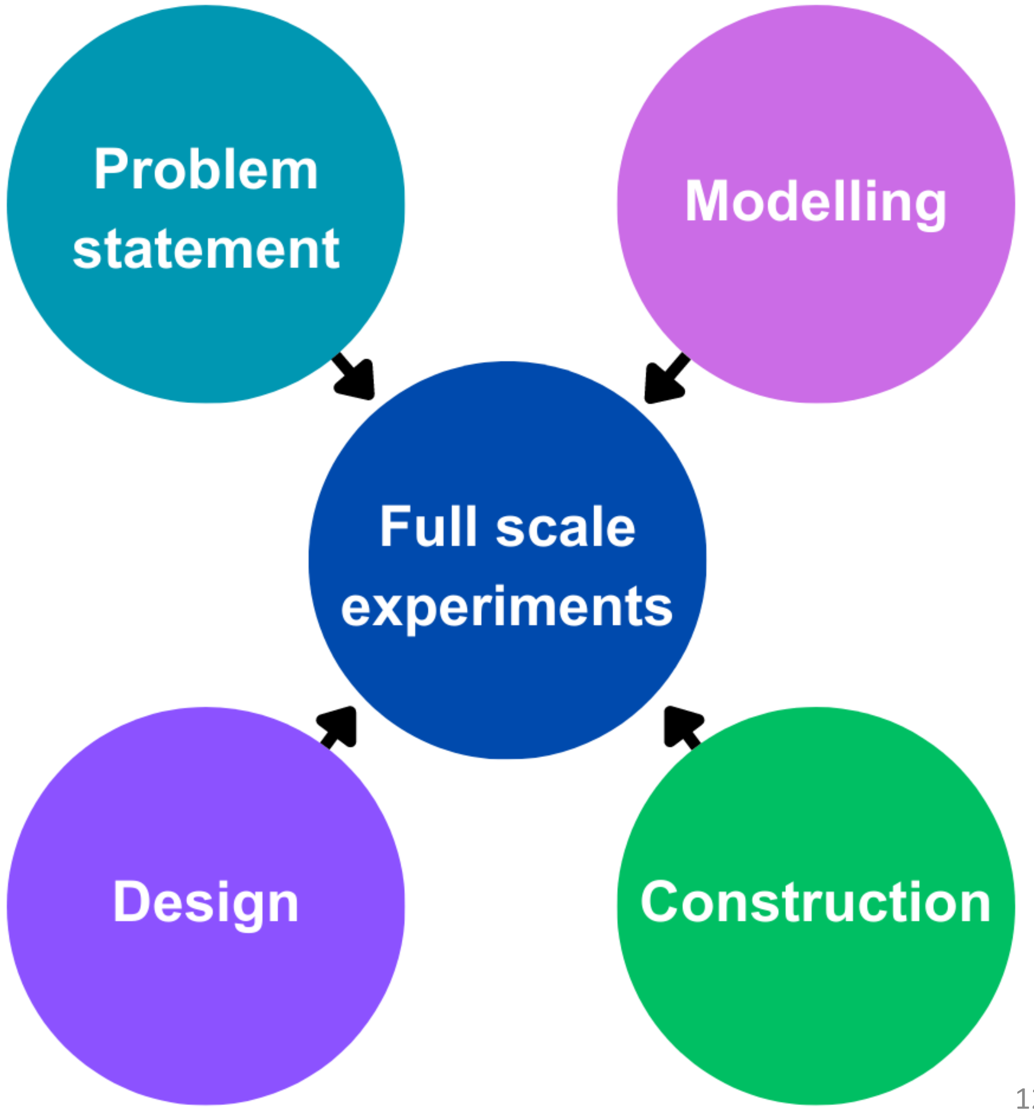
- Energy, heat exchange (IES)
- Airflows, buoyancy effects (CFD)
- Contaminants, dispersion (CONTAM – building scale/ ADMS – street scale / CFD – both)

Design

- Building envelope
- Ventilation systems
- Building components
- Occupant scenarios

Construction

- Building envelope
- Building interiors
- HVAC systems
- Building components



CAVE – Research Projects

CAVE is still in its "start-up" stage and the CAVE group are working on a number of projects concurrently, with all team members collaborating and supporting all projects. These projects are supporting the development of core methodologies of the lab including setting out low cost instrumentation, design and operation of HVAC systems, developing a global coordinate system for the lab, methods for pollution data analysis etc.

A few projects and project leads are presented in the following slides, including:

- Design of CAVE Environment - Stratification System
- Visualising live spatio-temporal data
- Design of Portakabin ventilation system
- Assessing impact of cars on air pollution in car parks
- CFD Analysis of Ventilation and Leakage in Buildings
- Wildfire Indoor Safety and Environmental Resilience
- The Impact Of Green Living Walls On Indoor Air Quality Of Office Buildings
- A Moss & Mechanical Hybrid-Powered Residential Air Purifier
- CONTAM modelling and model validation

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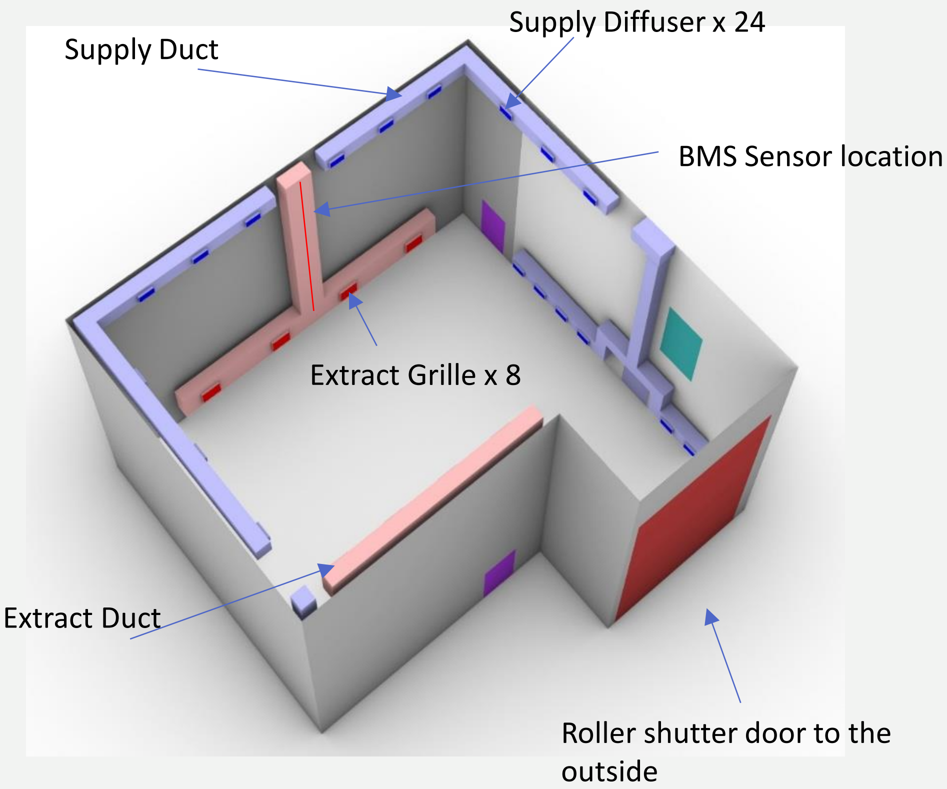
CAVE Environment - Stratification system

A dedicated AHU controls the environment of the overall CAVE chamber to provide an "exterior" environment for any test building/vehicle experiments

Air can be supplied at different temperatures and/or extracted both at high and low levels, to create a range of internal environments : these can be thermally stratified, vigorously or gently mixed, flushed out quickly using displacement ventilation, etc

Prof Liora Malki-Epshtein, Urban Air Quality and Fluid Mechanics, Director of CAVE

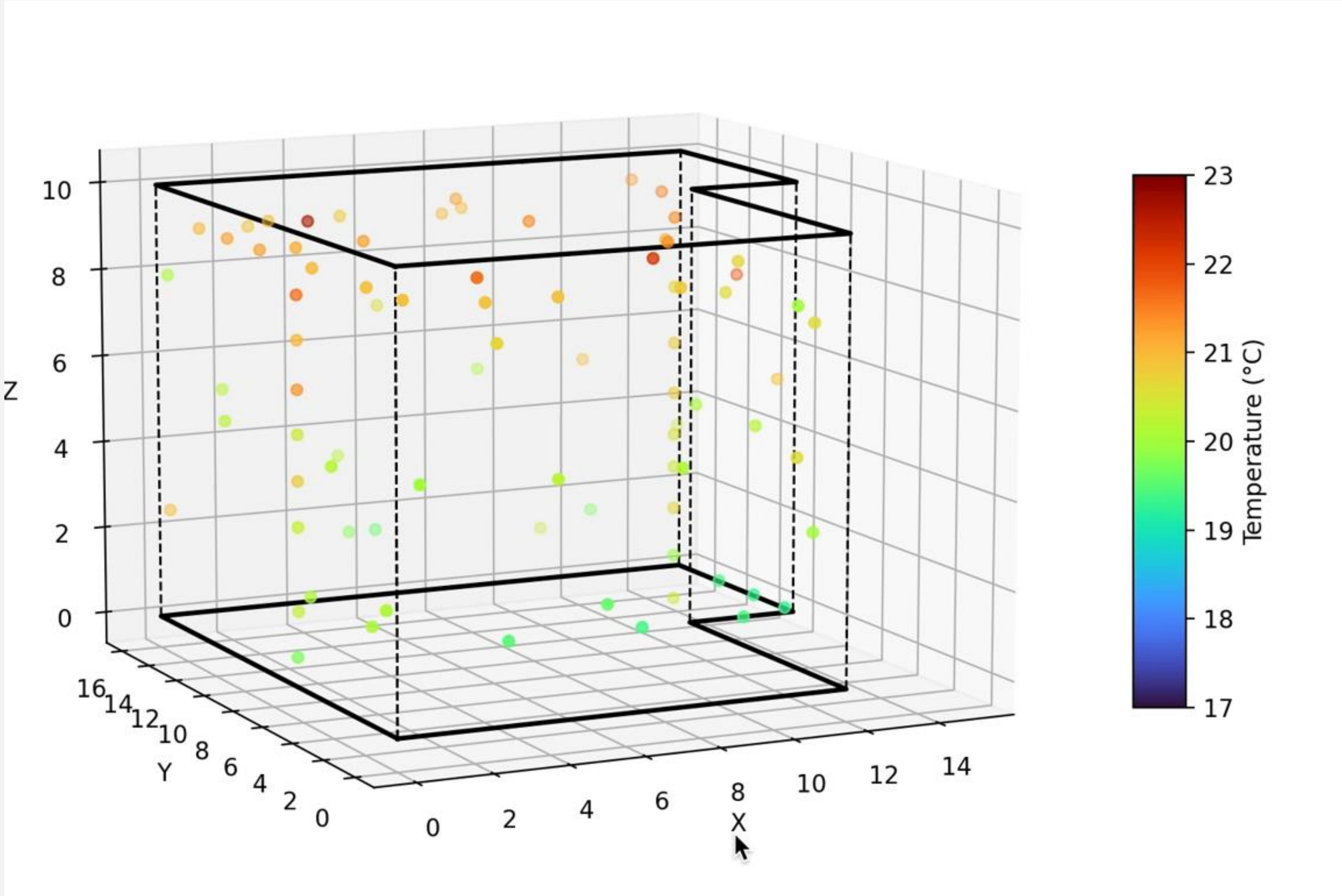


Visualising Live Spatio-Temporal Temperature Data in 3D

3D Snapshot of Temperature Data for a stratified scenario

Installation, Management, data collection and analysis of all the CAVE sensor arrays

Creating online dashboards for live data visualization during experiments

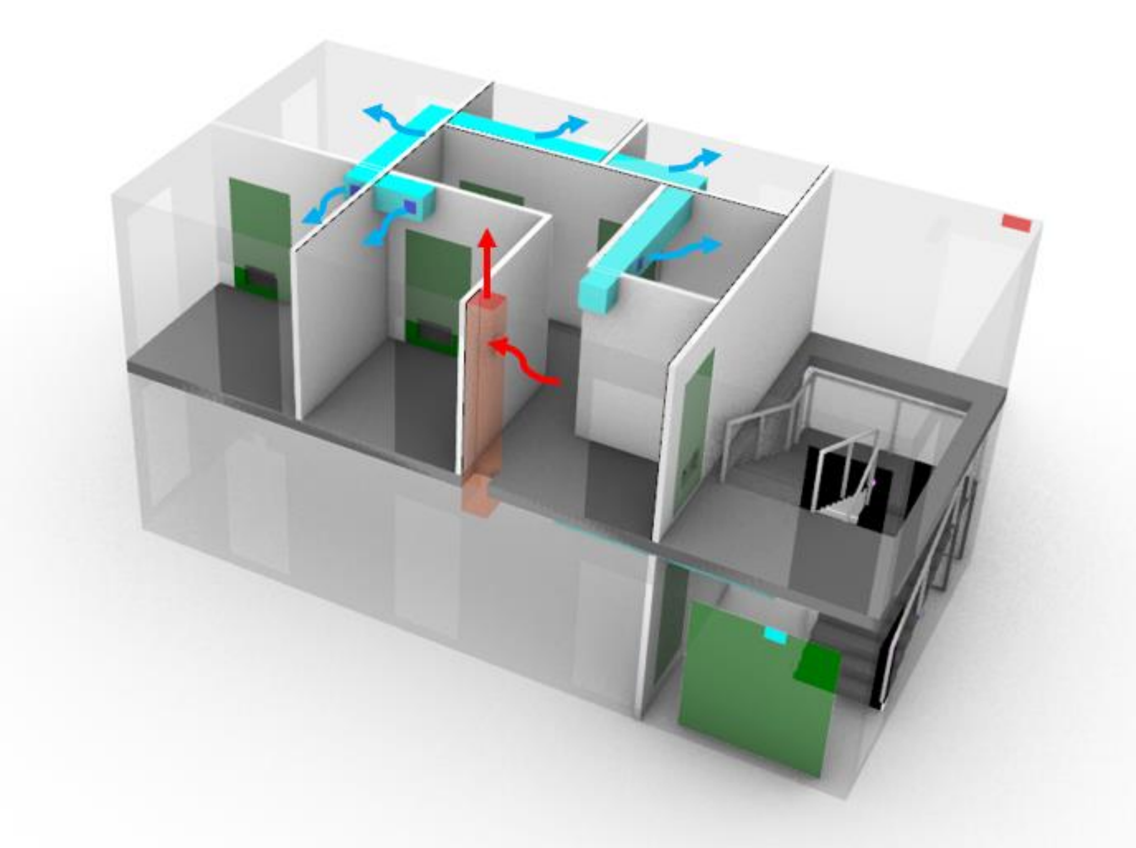


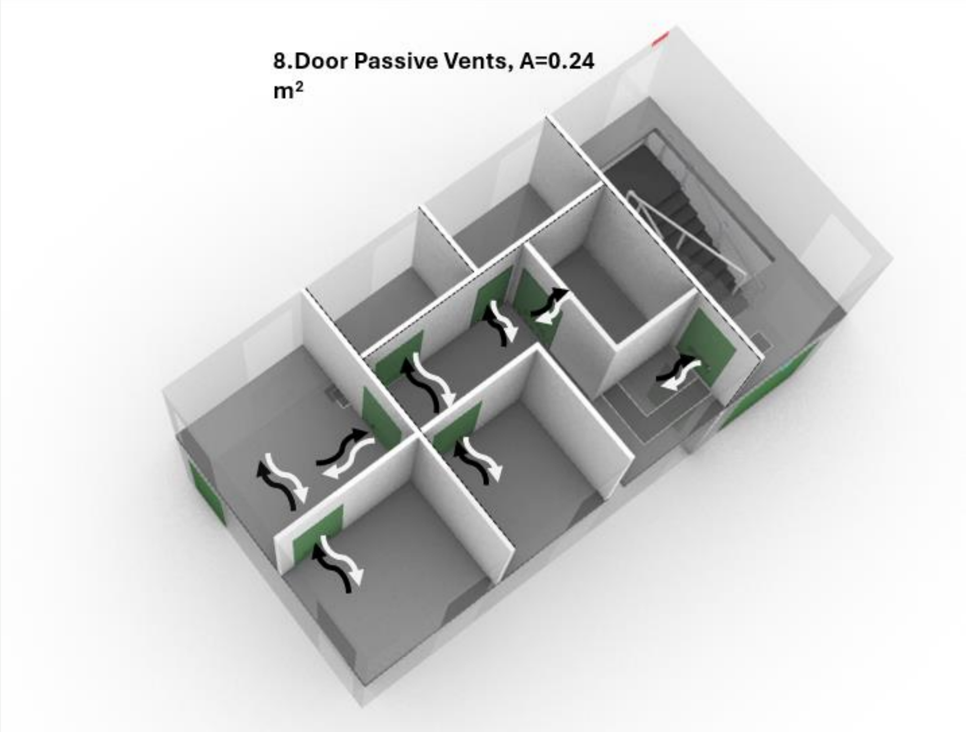
Mr Oliver Wild, Research Technician, Air Quality Sensing

Portakabin modular building HVAC system design

A dedicated AHU controls the Portakabin building to provide an “interior” environment for the test building experiments.
Air can be supplied from within the CAVE environment, recirculated internally in the test building, heated or cooled to create variety of mechanical and natural ventilation scenarios

Dr Chris Iddon, Honorary Researcher, Ventilation and Modelling

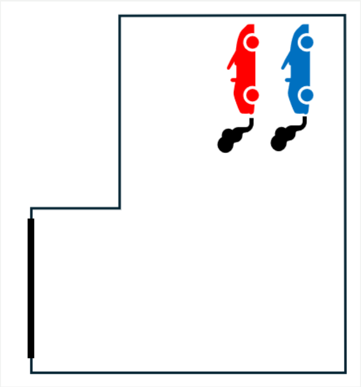


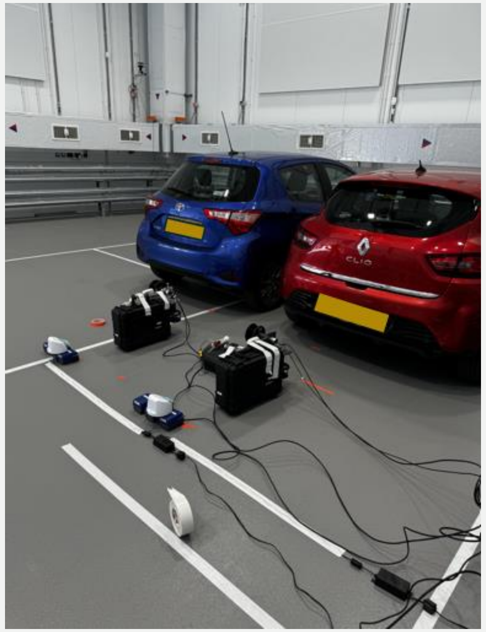


Leakage as inlet   Leakage as outlet   Passive Vent/Opening   Mechanical supply   Mechanical extract

Assessing impact of cars on air pollution in car parks

Dr Augustin Guibaud, NYU, Honorary Lecturer, Air pollution, Fire





Investigated the impact of three distinct ventilation strategies on the concentration and spatial distribution of gases and particles emitted from two idling car engines.

Methodology:

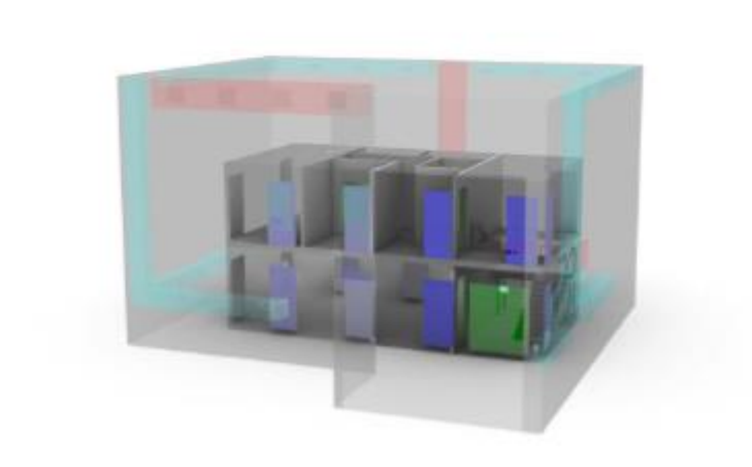
- Operated two idle car engines, one at a time or simultaneously, to simulate real-world emission conditions.
- Implemented and tested three separate ventilation configurations, including a "no ventilation with cars" condition.
- Monitored gas and particulate concentrations at multiple spatial points using specialised sensors and instruments

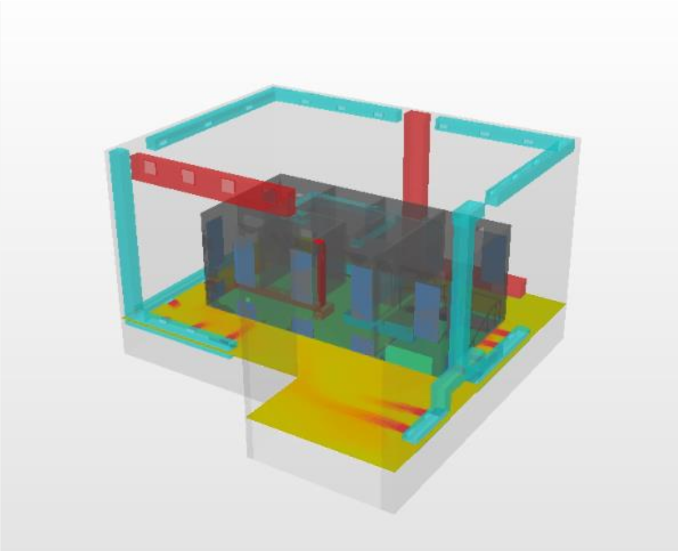
Outcomes:

Provide actionable insights into the design of effective ventilation systems for enclosed or semi-enclosed vehicle testing facilities.

Gain further insight into indoor pollutant transport in fluid mechanics, including natural and forced flows, buoyancy-driven dispersion, and dilution from leaks.

CFD Analysis of Ventilation and Leakage in Buildings





Dr Filipa Adzic, Lecturer, Computational Fluid Dynamics

Evaluate the effects of building leakage and mechanical ventilation on indoor air quality using CFD simulations.

Methodology:

- CFD simulations were performed using OpenFOAM with HELYX GUI, employing a RANS approach with the SST k-ω turbulence model.
- A transient pressure-based solver with the PIMPLE algorithm and variable time step was used.
- Simulated various configurations of mechanical ventilation and leakage to assess their impact on indoor air quality within the Portakabin.

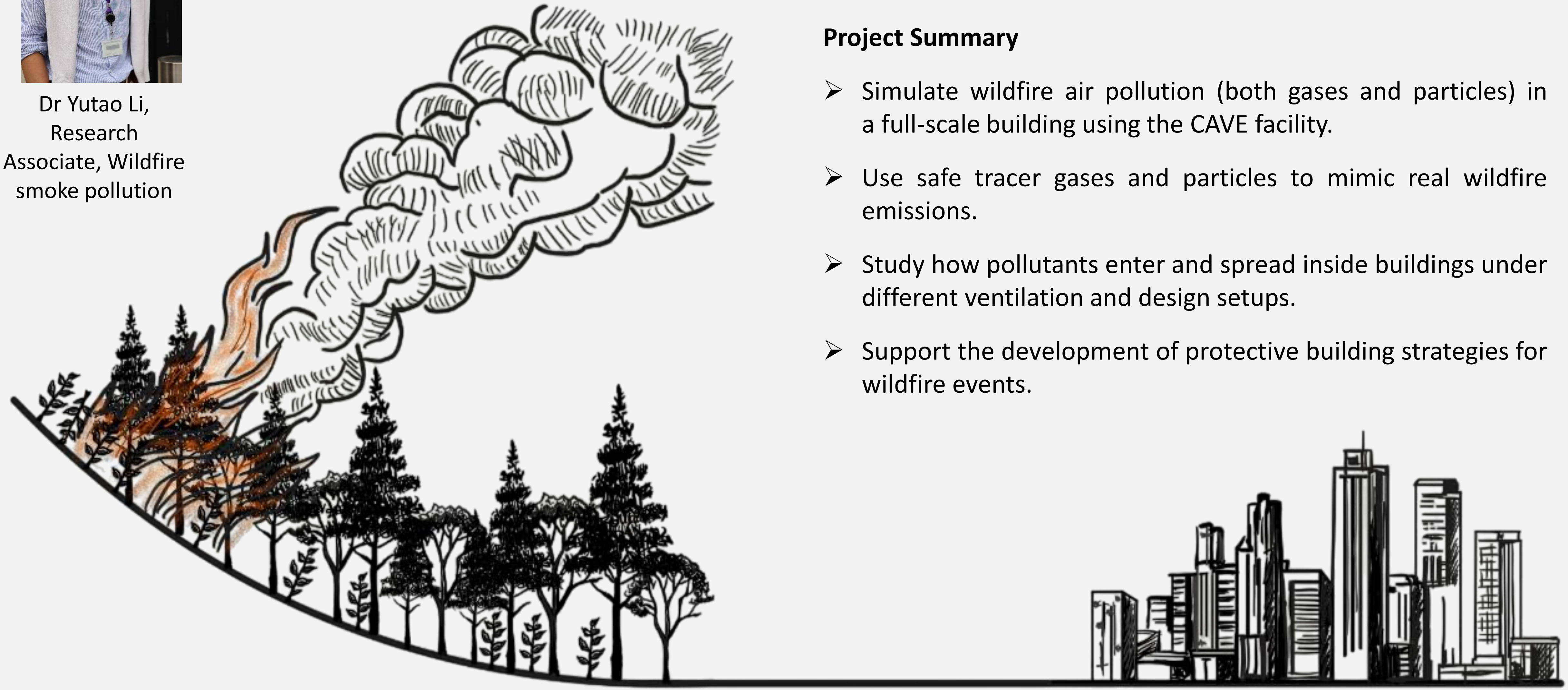
Outcomes:

Assessed the impact of 100% outdoor ventilation and recirculation ventilation on indoor air quality in the presence of leakage, providing insights into how each strategy performs under different conditions.

Gained understanding of how temperature differences influence indoor air movement, revealing the role of buoyancy-driven flows in pollutant distribution within the Portakabin.

WISER - Wildfire Indoor Safety and Environmental Resilience

Dr Yutao Li, Research Associate, Wildfire smoke pollution



Project Summary

- Simulate wildfire air pollution (both gases and particles) in a full-scale building using the CAVE facility.
- Use safe tracer gases and particles to mimic real wildfire emissions.
- Study how pollutants enter and spread inside buildings under different ventilation and design setups.
- Support the development of protective building strategies for wildfire events.

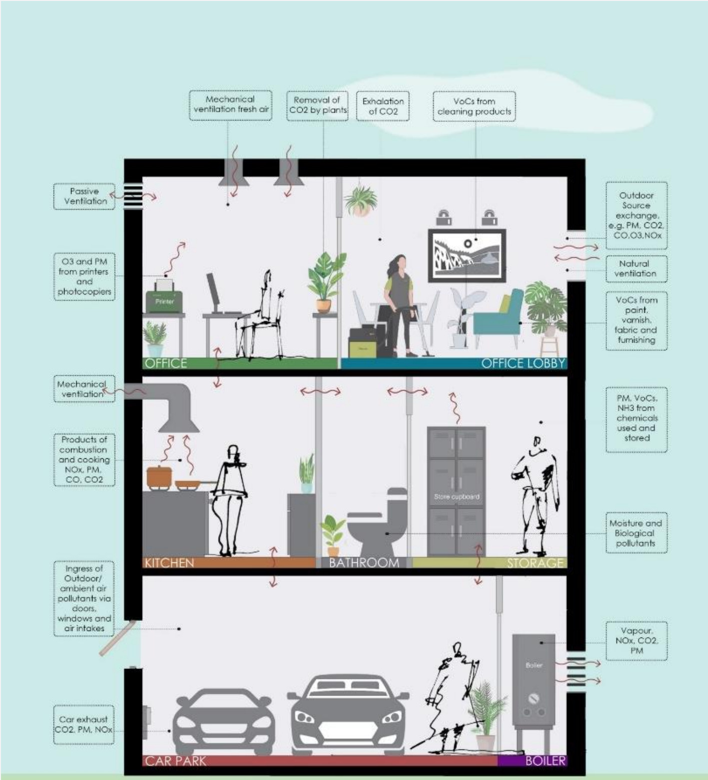
The Impact Of Green Living Walls On Indoor Air Quality Of Office Buildings

Exploring the potential advantages of integrating green living walls into office buildings, focusing on indoor thermal quality and air quality.

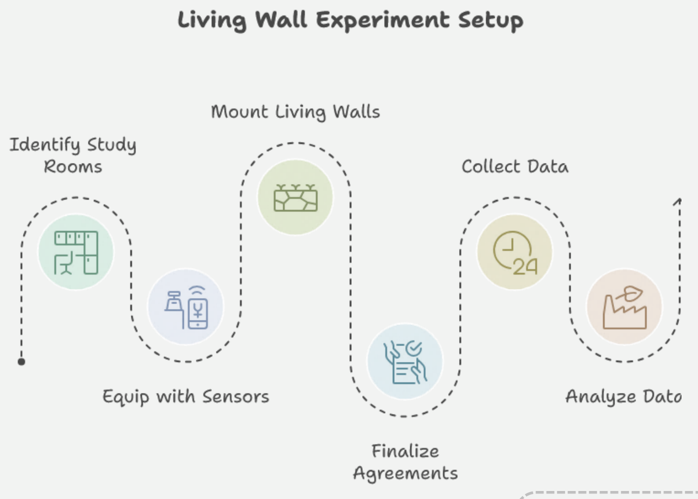
The study rooms in CAVE are equipped with high-resolution air quality sensors collecting humidity, temperature and air pollutant data.

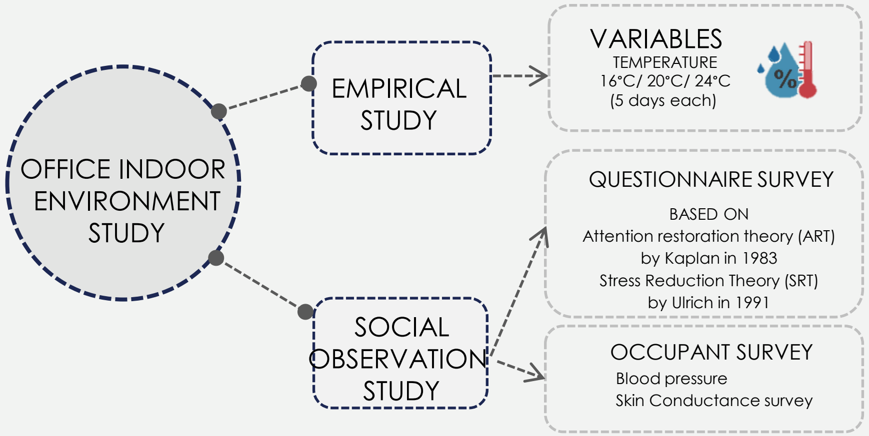
Following the installation of the living walls, a series of experiments with different climatic scenarios will investigate various aspects of plant interactions with the indoor environment, to understand how these living systems contribute to environmental quality.

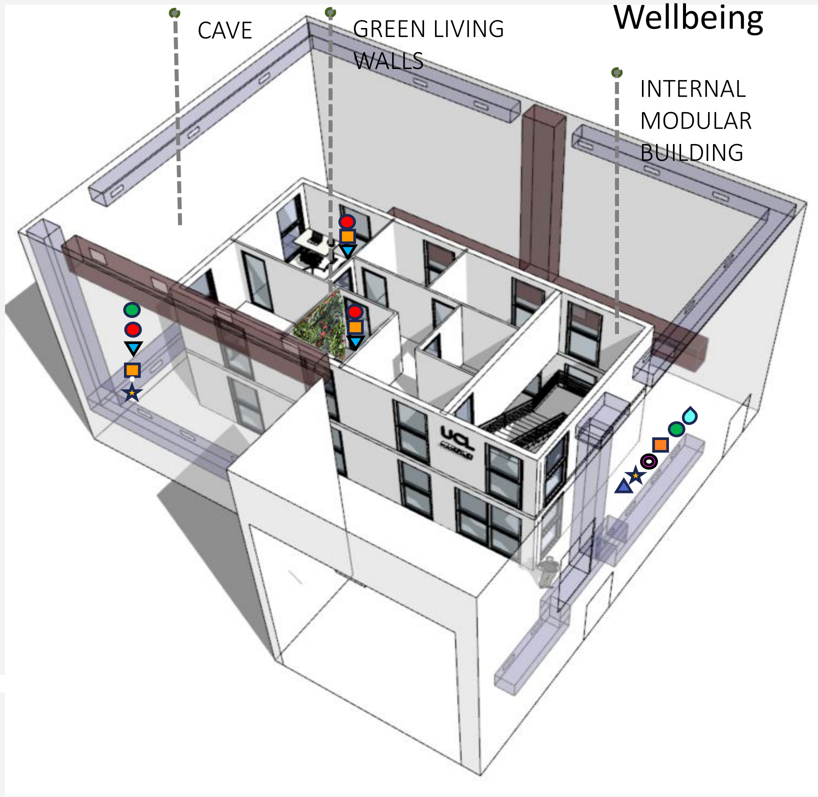
Mrs Shayeeka Alam, PhD student, Green Infrastructure and Wellbeing



SCHEMATIC OF IAQ SOURCES, PATHWAYS AND RECEPTORS



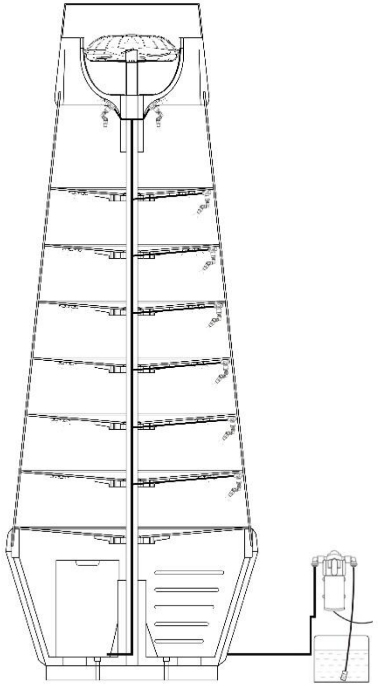


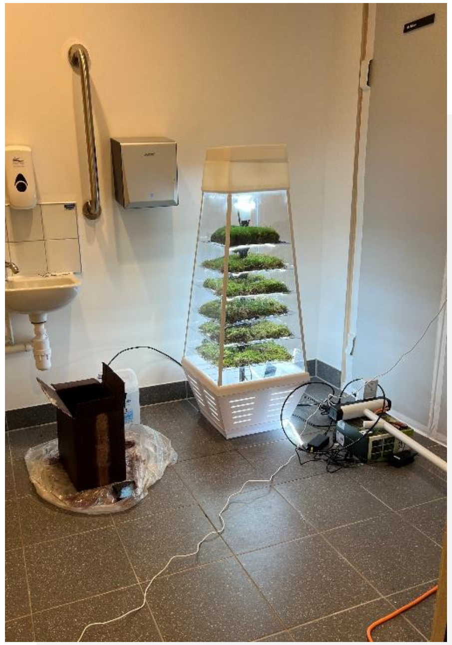


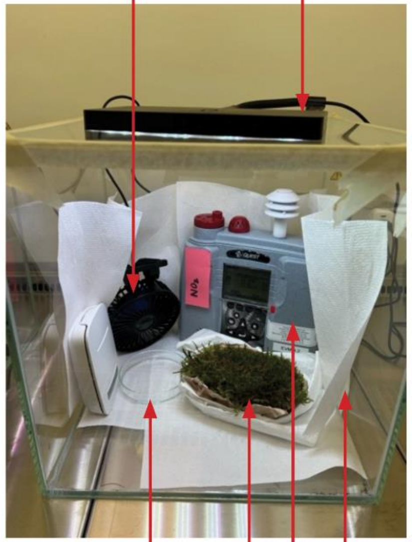
INSIDE CAVE STUDY MODEL

Møssøra

A Moss & Mechanical Hybrid-Powered Residential Air Purifier







Mr Aohua Yang, Research Assistant, Green Air purifiers

Evaluate the moss's Purification Performance of various pollutants (PM, VOCs, Ozone, NO2, SO2) under controlled chamber experiments.

Optimize the current prototype.

Test inside the Portakabin to simulate the real-world scenario and evaluate its performance.

Optimize the prototype according to the Portakabin results. (moss species; climate zone influence, indoor humidity influence, indoor activity influence)

Deploy in a real residential environment and explore the benefits to residents with rhinitis, asthma, and respiratory disorders.

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