Building Science Measurements for the Hospital Microbiome Project

Thesis defense
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Built Environment Research @ IIT

Hospital Microbiome
hospitalmicrobiome.com

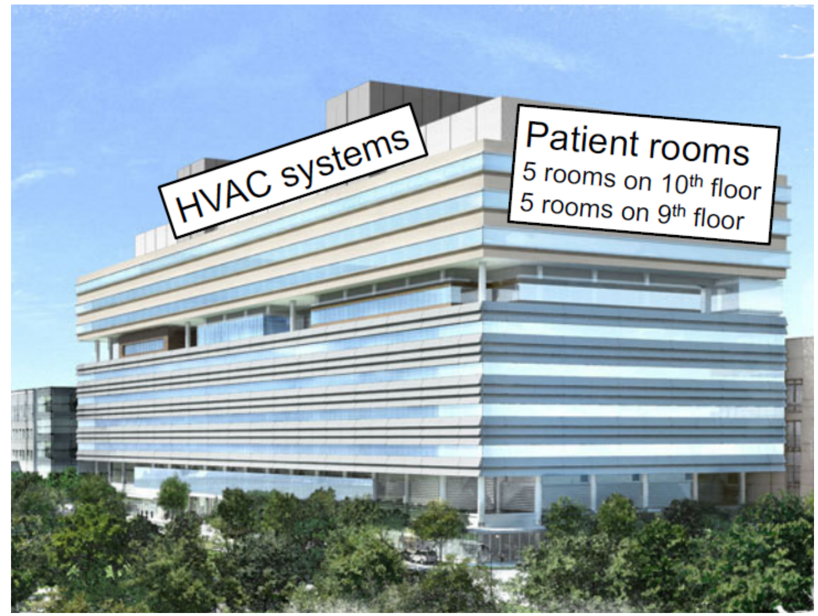
Alfred P. Sloan Foundation

Overview

- Introduction of Hospital Microbiome Project (HMP)
- Literature review of recent indoor microbial community research
- Description of potentially influential built environment parameters
- Description of measurement plan, including field equipment, calibrations, installation, data retrieval and analysis methods
- Analysis and results
- Conclusions

The Hospital Microbiome Project (HMP)

- The HMP collected microbial samples from surfaces, air, staff, and patients from the University of Chicago's new hospital pavilion in order to better understand factors that influence bacterial population development in healthcare environments



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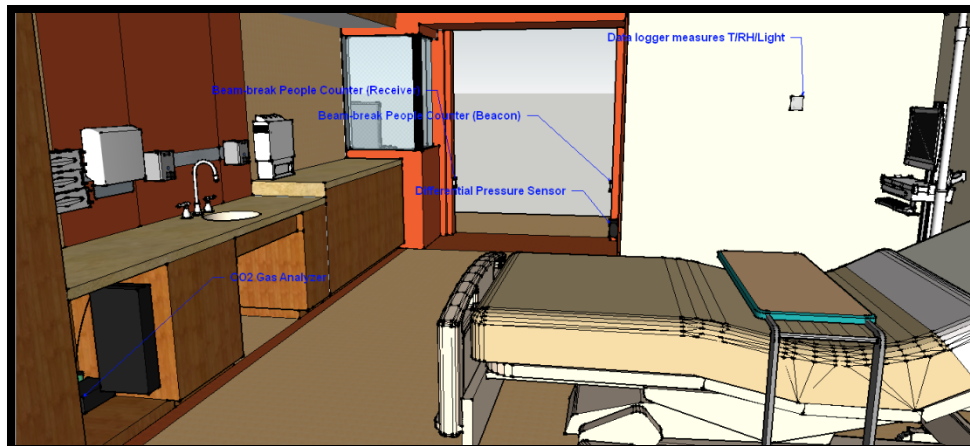
Building science measurements in HMP

- Provided data on environmental and operational parameters that may influence microbial growth within a new hospital’s initial year of occupation
- Timeline: January 2013 to January 2014
- Parameters:
  - Air temperature
  - Relative humidity
  - Light intensity
  - Human occupancy
  - Room pressurization
  - Air sampling
  - HVAC system air flows and outdoor air delivery



Built environment factors and microbiology: Literature

- Basic building characteristics and indoor environmental conditions
  - Indoor temperature associated with bacteria and total inflammatory potential (TIP) of cell assays (Frankel et al, 2012)
  - Accelerated growth of bacteria and fungi shown with higher temperature and RH in HVAC ducts with dust deposition (A. Li, Liu, Zhu, Liu, & Wang, 2010).
  - Absolute humidity can influence microorganism survival (Baughman & Arens, 1996), mold growth on building materials (Nielsen, Holm, Uttrup, & Nielsen, 2004), airborne endotoxin (Park et al., 2000), and inactivation or survival of influenza on surfaces (McDevitt, Rudnick, First, & Spengler, 2010; J. Shaman & Kohn, 2009; Jeffrey Shaman, Pitzer, Viboud, Grenfell, & Lipsitch, 2010)

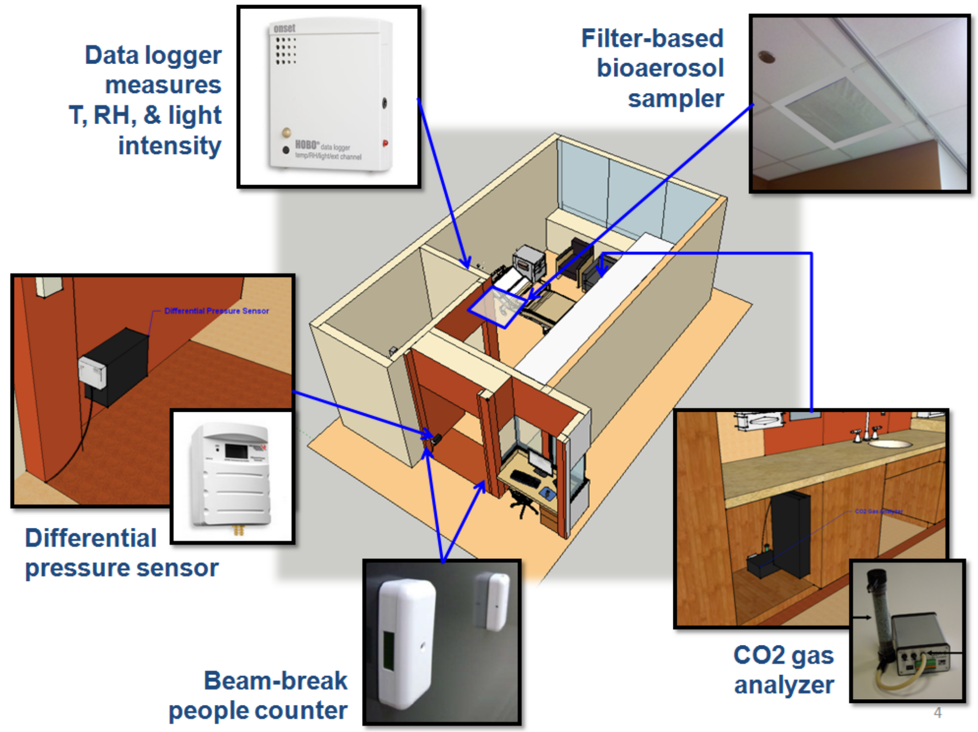
- Human occupancy
  - Human occupancy results in significant emissions of airborne particle mass, bacterial genomes and fungal genomes (Qian et al., 2012)
  - Resuspended floor dust and direct human shedding are important contributors to bacterial populations in indoor air (Hospodsky et al., 2012)

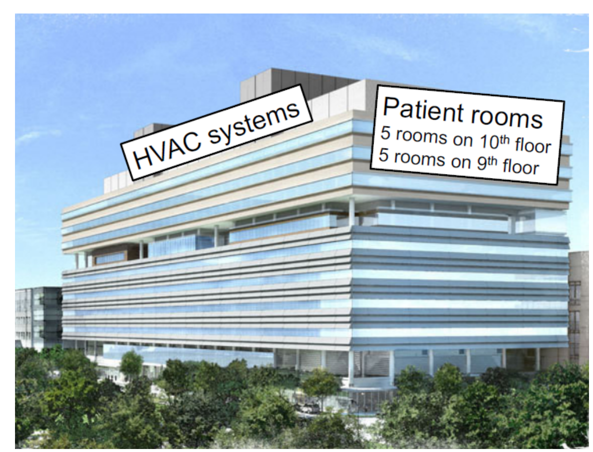
Built environment factors and microbiology: Literature

- HVAC system characterizations and ventilation rate measurements
  - Relative abundance of bacteria closely related to human pathogens higher in rooms with lower airflow rates and lower RH. (Kembel et al., 2012)
  - Airborne bacterial communities in mechanically ventilated rooms were less diverse than window-ventilated rooms (Kembel et al., 2012)
- Air sampling and aerosol dynamics
  - ~53% of the detectable influenza virus particles they found were within the respirable aerosol fraction in healthcare facilities (i.e., less than 4 μm) (Blachere et al.)
  - Bacterial and fungal communities on residential HVAC filters were not different from those obtained from impingers that sampled air for a month (Noris, Siegel, & Kinney, 2011)
- Surface characterizations
  - Water activity, or the relative humidity at equilibrium, of a building material is a major determining factor for fungal growth (Nielsen et al., 2004)
  - Cleaning frequency can effect microbial community composition on building materials (Adams et al., 2013; Flores et al., 2013; Medrano-Félix et al., 2011)

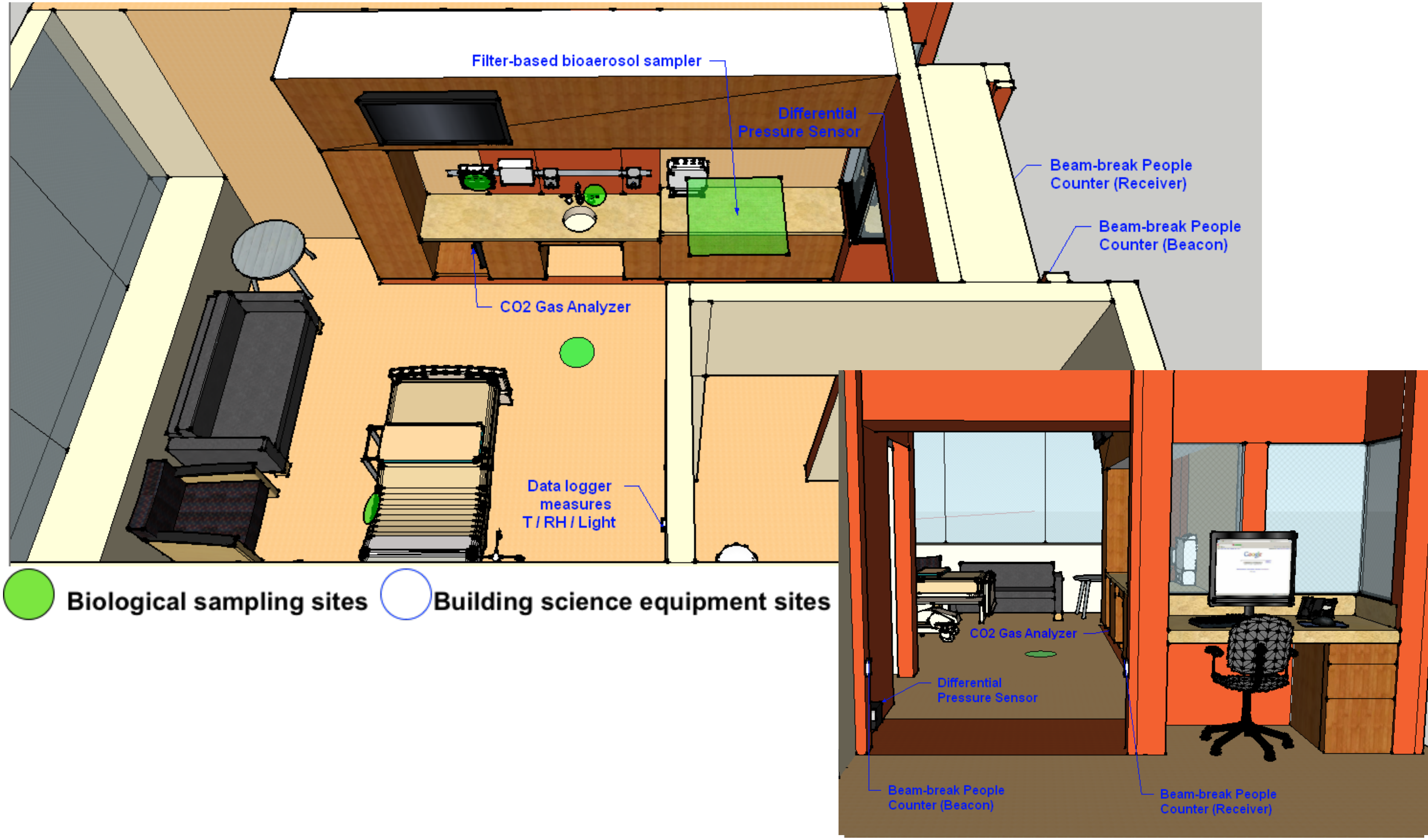
Building science instrumentation

- Assortment of sensors selected considering:
  - Accuracy
  - Battery life
  - Budget
  - Aesthetic impact
  - Data retrieval
- Sampling locations:
  - 10 patient rooms & 2 nurse stations, on 2 floors
  - Air handling units (AHU) on mechanical floors
- Data logging at 5-minute intervals
- Data collected weekly



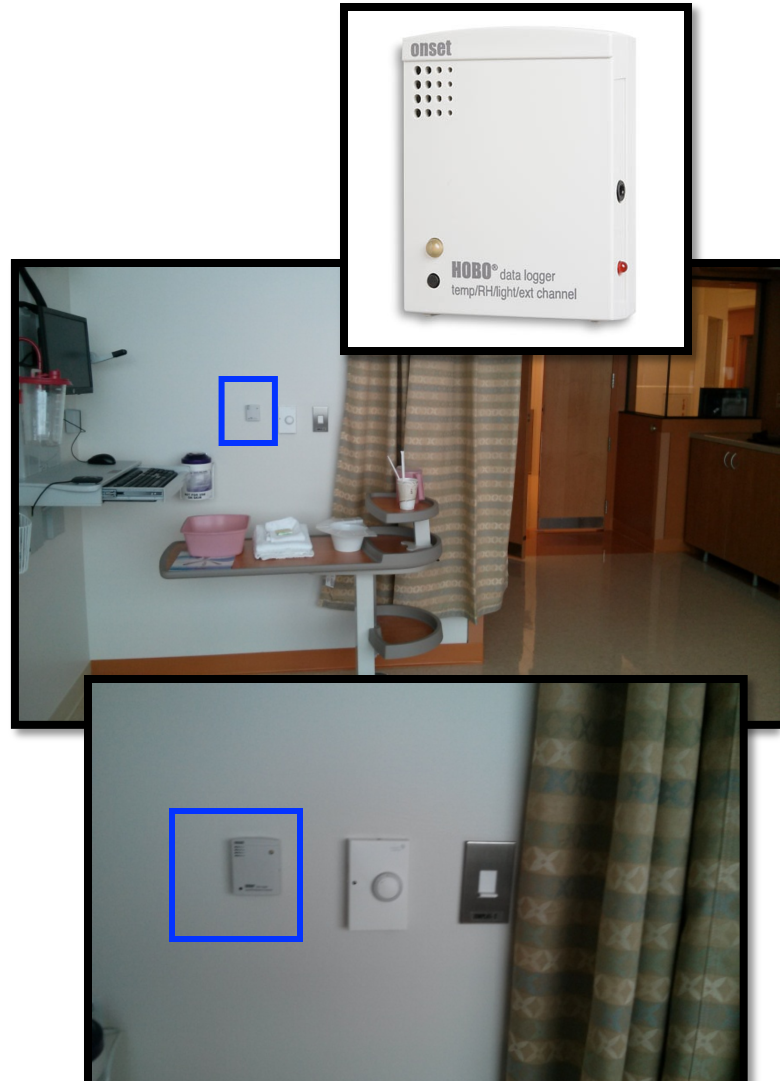


Biological and building science sampling sites



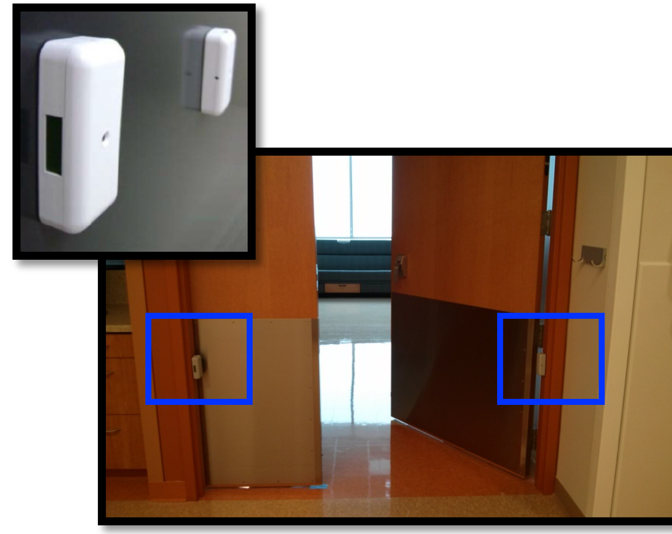
Air temperature, relative humidity & light intensity

- Data logger with T, RH, and light sensing capabilities
  - Located in each patient room and nurse station
  - On wall adjacent to patient bed, opposite windows
  - Attached with 3M command strips for easy removal
  - Captures natural and artificial light
  - Close to areas of microbial sampling
  - Blends with other room controls
  - Proximity from patient bed is minimally invasive



Human occupancy

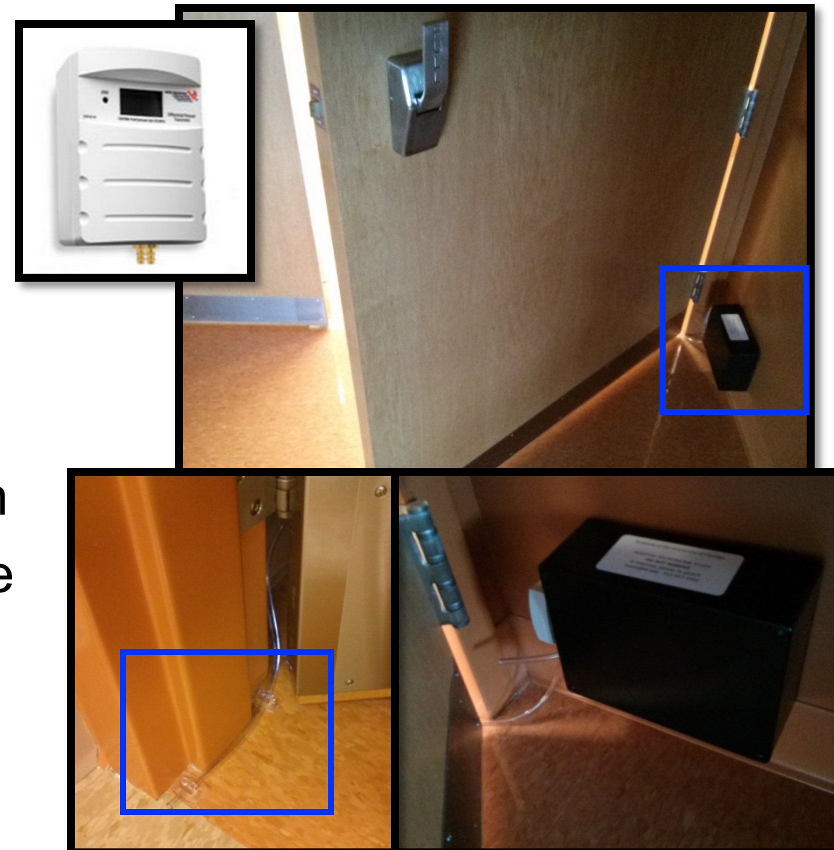
- Infrared non-directional beam-break people counters
  - Measures number of entrances and exits at patient room doorways
  - Attached to doorframe, 2 feet above floor
  - Internal data logger
  - Software and USB interface cable to offload data



- CO2 gas analyzer
  - Measures CO2 levels within room, as a surrogate for occupancy
  - Located in cabinet space, blending with cable box
  - External data logger

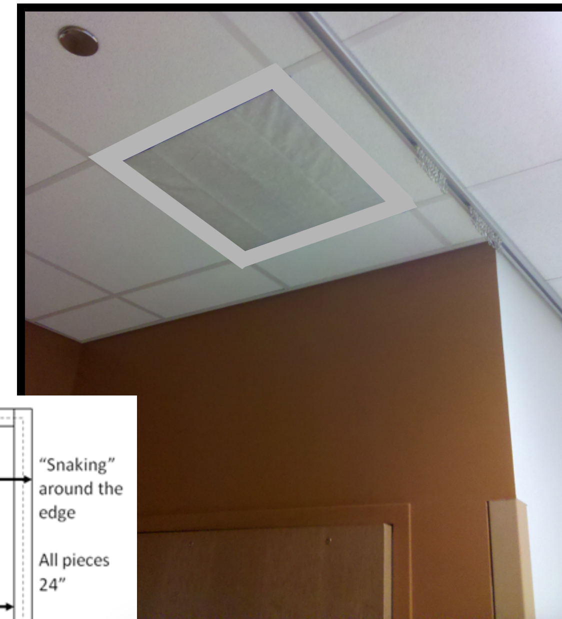
Room pressurization

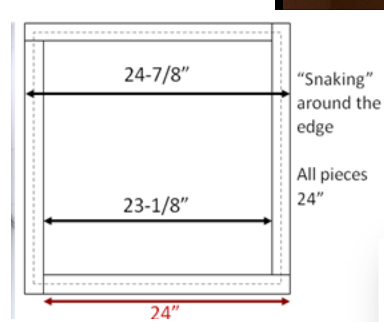
- Differential pressure sensor
  - Installed in patient rooms, close to door frame
  - Enclosed in black box, with batteries for power
  - Two sample lines connected to sensor
    - One exposed to interior of room
    - One exposed to hallway outside room
  - Connected to data logger, attached to exterior with command strips

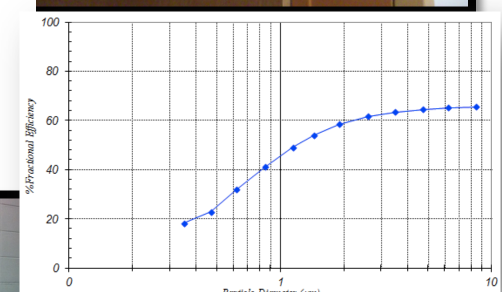


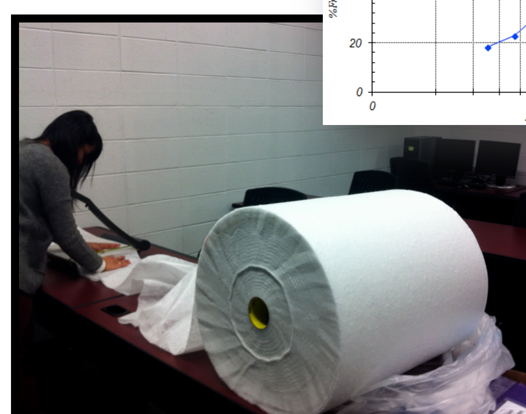
Microbial air sampling

- Filter media used as a passive sampler of airborne particle-bound contaminants
  - Thin sheet
  - High-efficiency
  - Placed on ventilation return grille; located on ceiling
  - Attached with large, custom-fit magnets
  - Removed and replaced weekly, preserved for microbial extraction



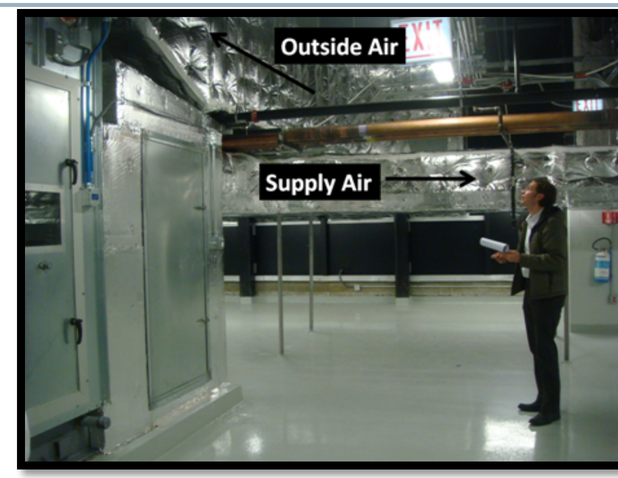


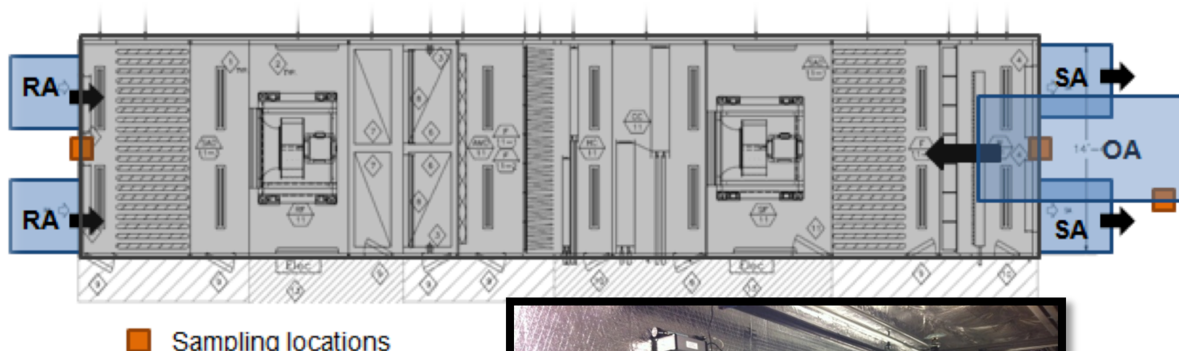




HVAC system characterizations

- Outdoor air ventilation fraction (%OA) delivered to each floor
- Each floor served by a different air handling unit (AHU)
- CO_2 measured at outdoor intake, supply, and recirculation streams





$$F_{OA} = 1 - \frac{C_{supply} - C_{out}}{C_{return} - C_{out}}$$

Summary of collected data

Parameter	N	Mean	S.D.	Min	Max
Temperature (°C)	1.20×10^6	23.6	1.4	13.4	31.6
RH (%)	1.20×10^6	34.8	6.8	5.2	88.0
Light intensity (lux)	1.20×10^6	173	448	4	32280
IR beam-break (counts/5 min)	9.46×10^5	0.74	1.68	0	98
CO_2 (ppm)	8.63×10^5	416	40	325	699
Differential pressure	7.06×10^5	0.09	0.57	-1.78	1.77
TOTAL	6.12×10^6				

Parameter	N	Mean	S.D.	Min	Max
CO_2	478,339	393	37	309	594
Temperature	476,851	14.0	8.3	-24.7	34.5
RH	106,749	34.6	6.6	13.7	60.0
Vapor pressure	180,846	1.014	0.301	0.308	2.22
TOTAL	1.24×10^6				

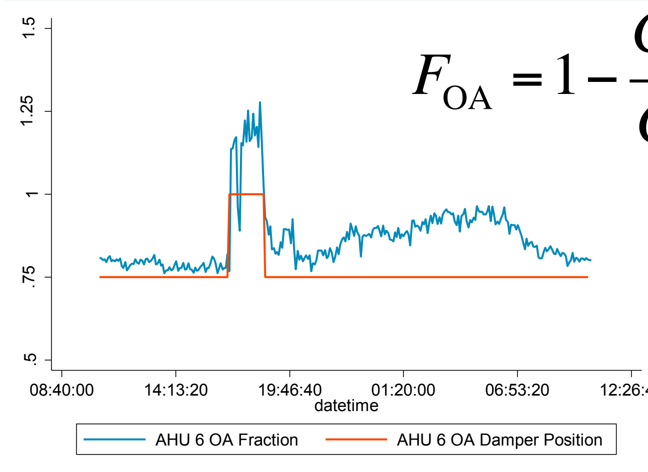
More than 8 million data points collected over the course of one year

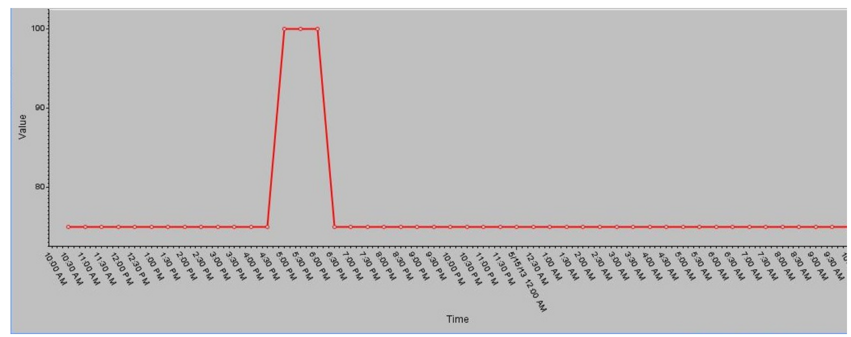
RESULTS

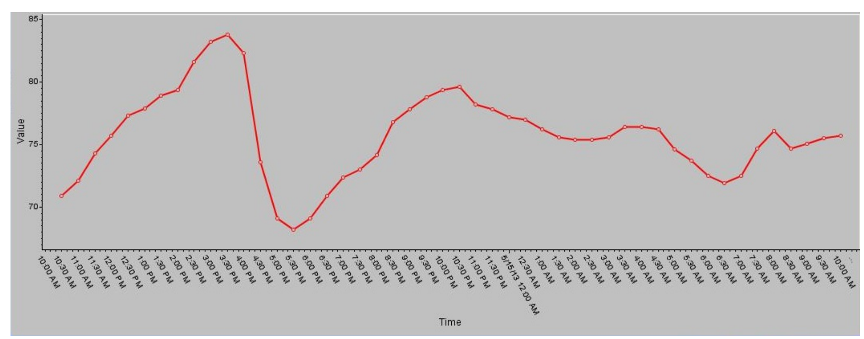
OA fraction calibration

- 24-hour data provided by hospital facilities dept.
- Minimum OA damper positions also provided
- Well correlated with our data
- Correlated with temperature (economizer)

$$F_{\mathrm{OA}} = 1 - \frac{C_{\mathrm{supply}} - C_{\mathrm{out}}}{C_{\mathrm{return}} - C_{\mathrm{out}}}$$

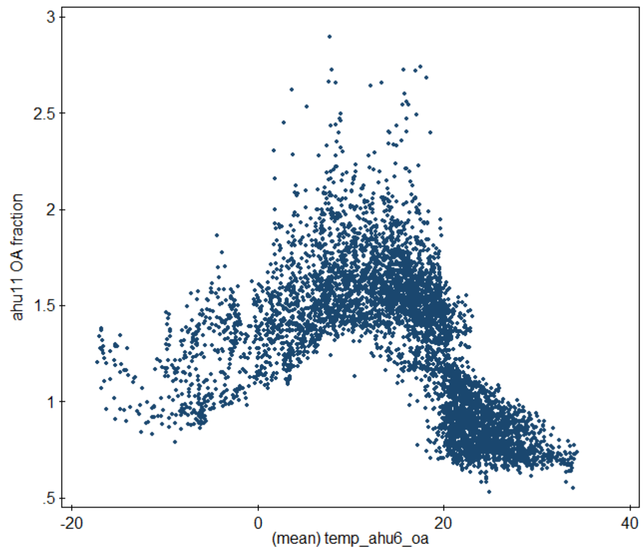


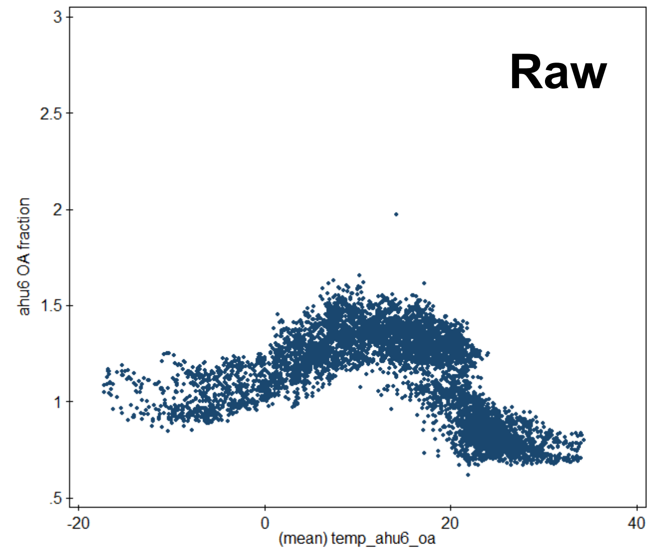


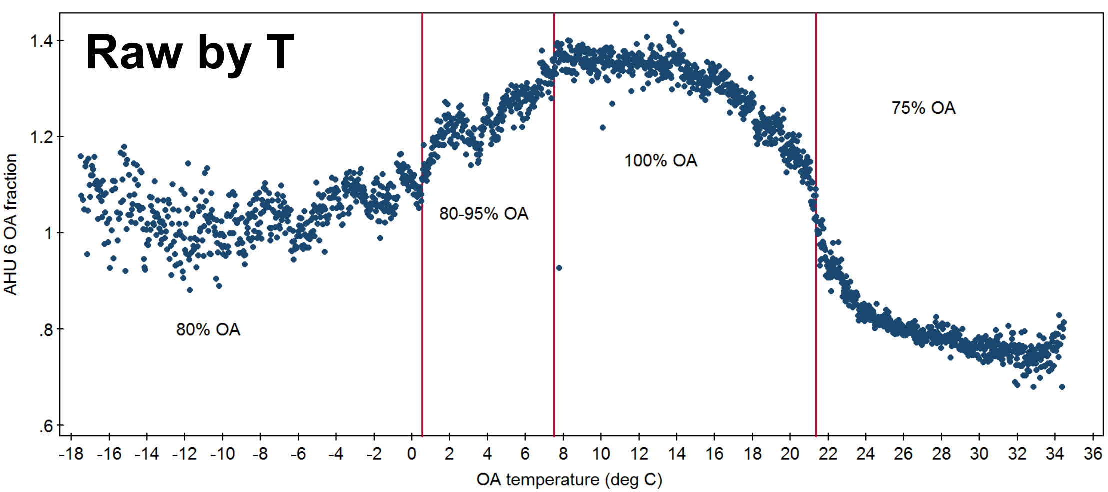


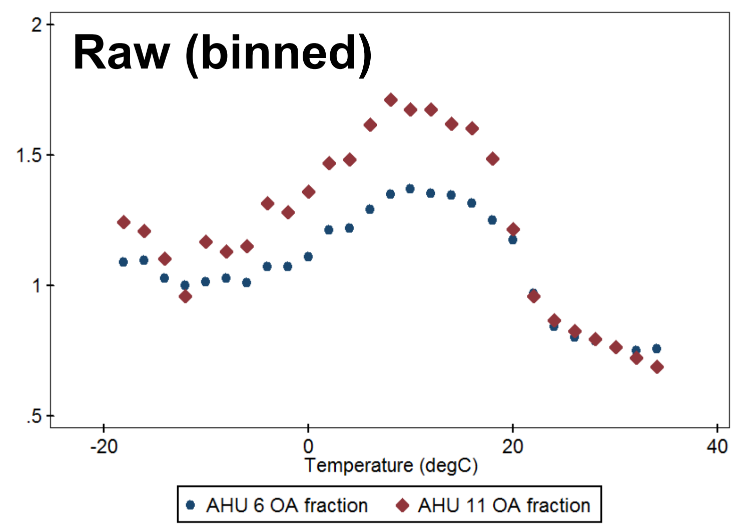
OA fraction calibration

- OA fraction and temperature correlated well
- Minimum OA fraction above 21°C
- 100% OA between 6°C and 21°C



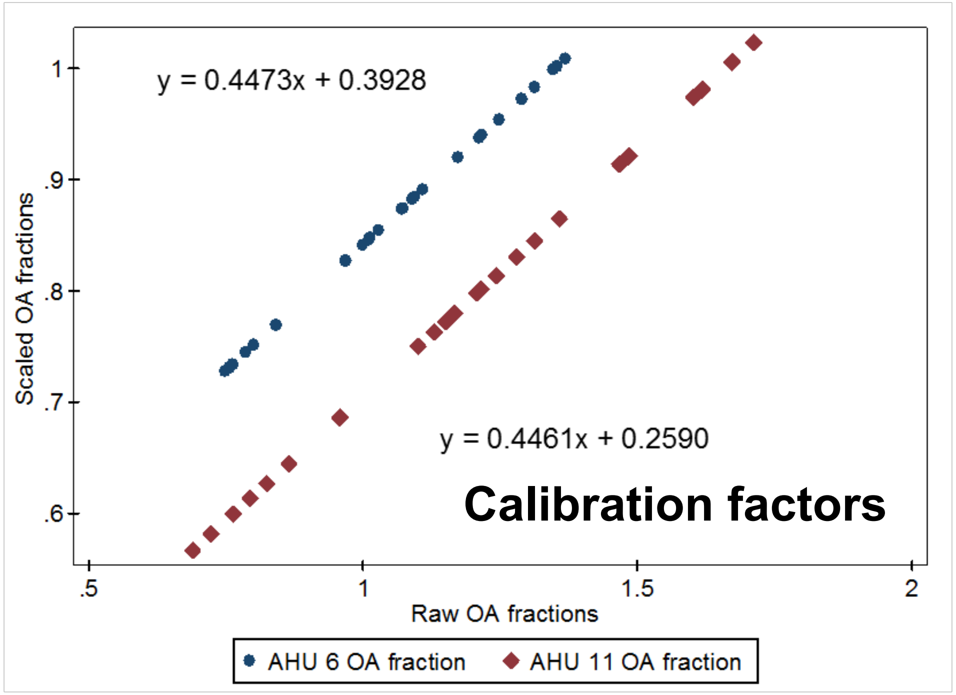




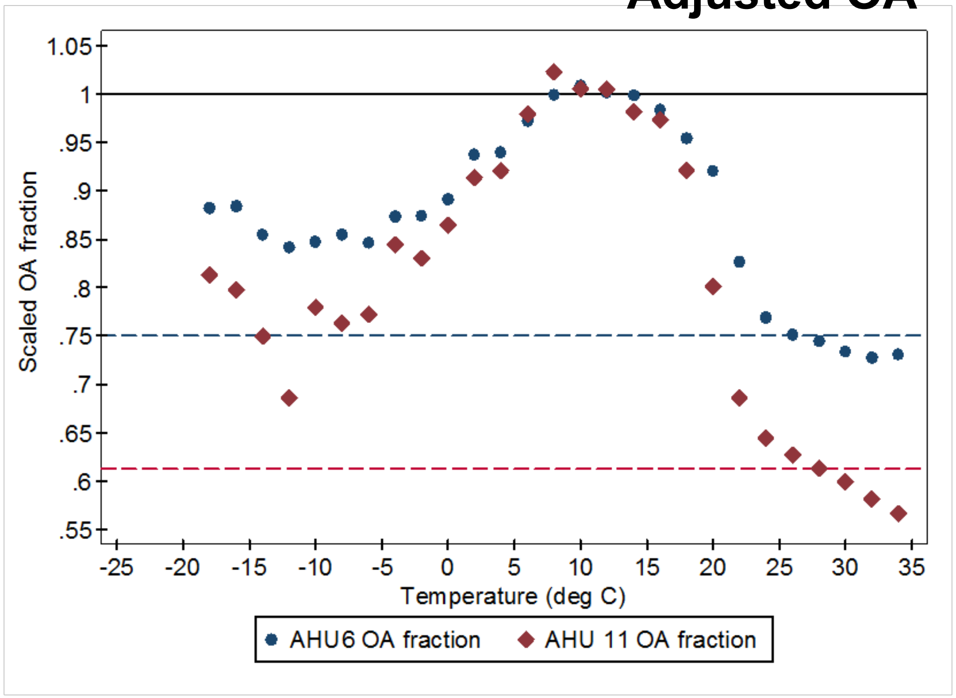


OA fraction calibration

- AHU 11-14 (9th floor)
  - Minimum OA fraction: 61.25% (average of 4 AHUs)
- AHU 6 (10th floor)
  - Minimum OA fraction: 75%
- Regression Analysis
  - Used minimum and maximum (100%) values

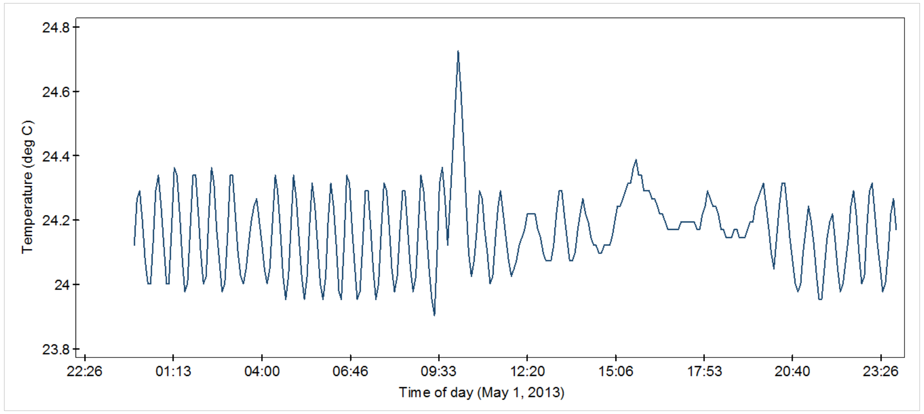


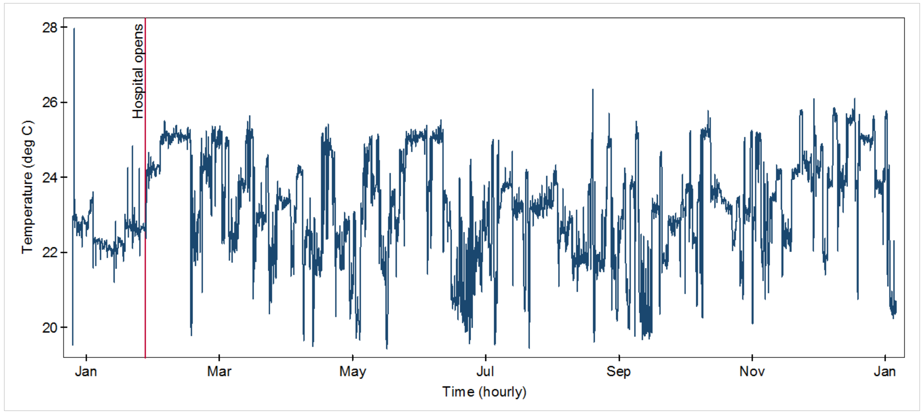
Adjusted OA



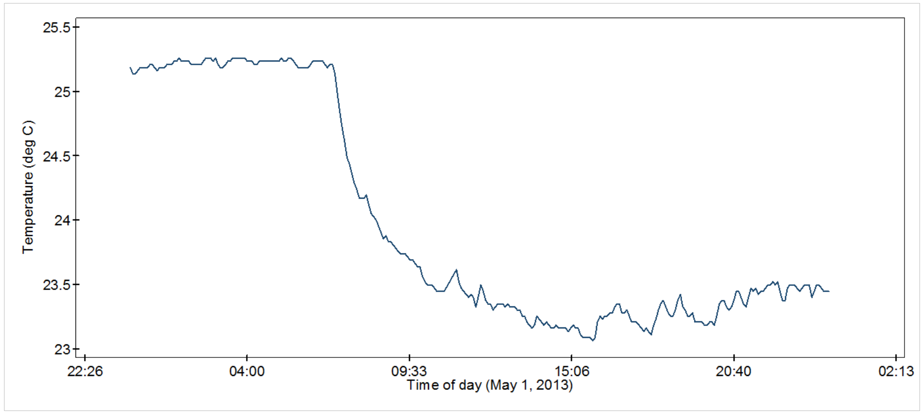
Example time-series data: Temperature (°C)

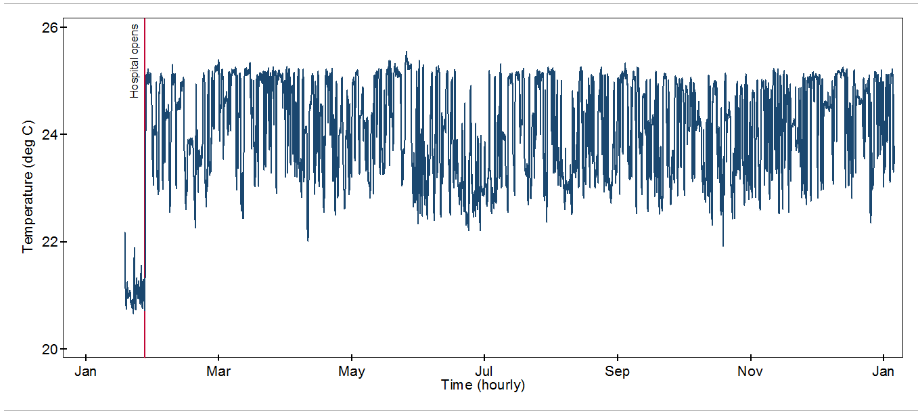
Patient rooms





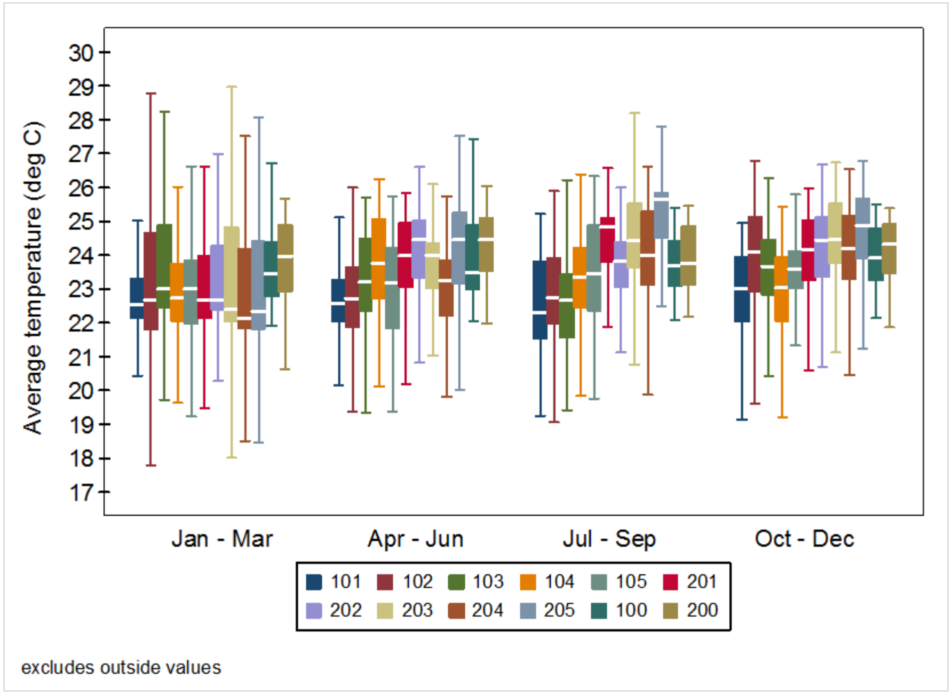
Nurse stations





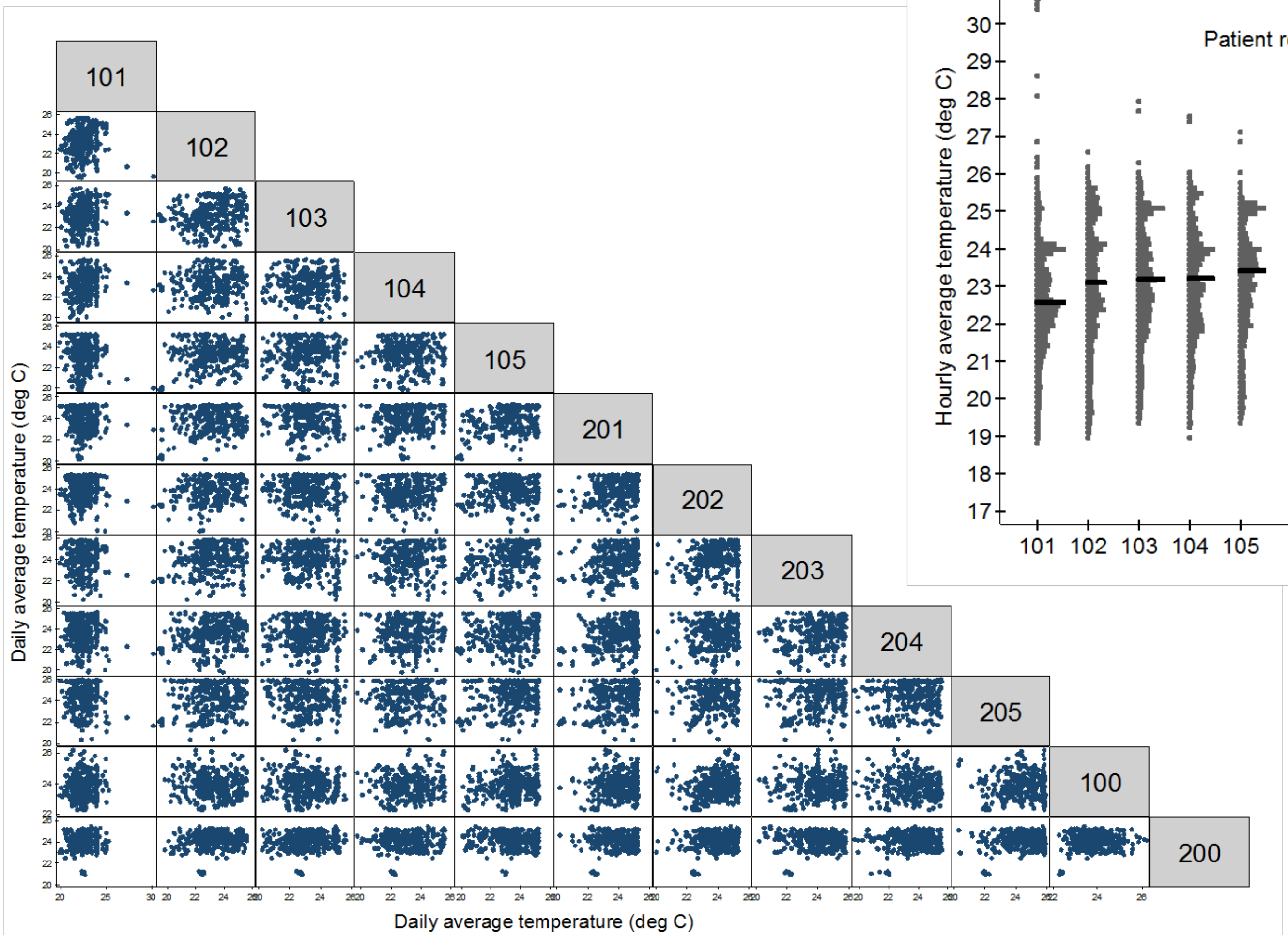
Seasonal variations: Temperature

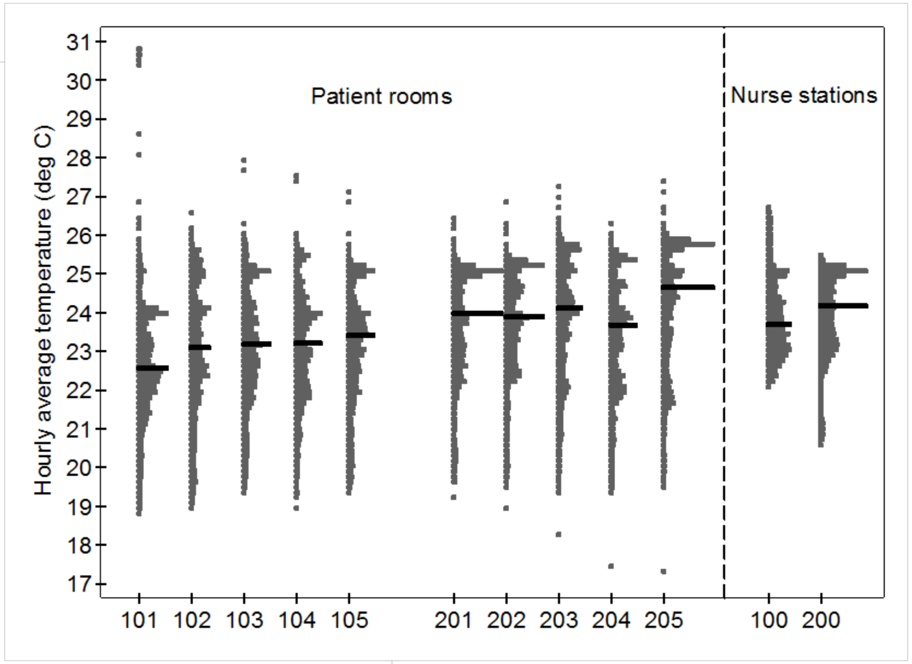
- No seasonal effect
- Indoor temperatures not effected by outdoor temperatures



Variations between and within rooms: Temperature

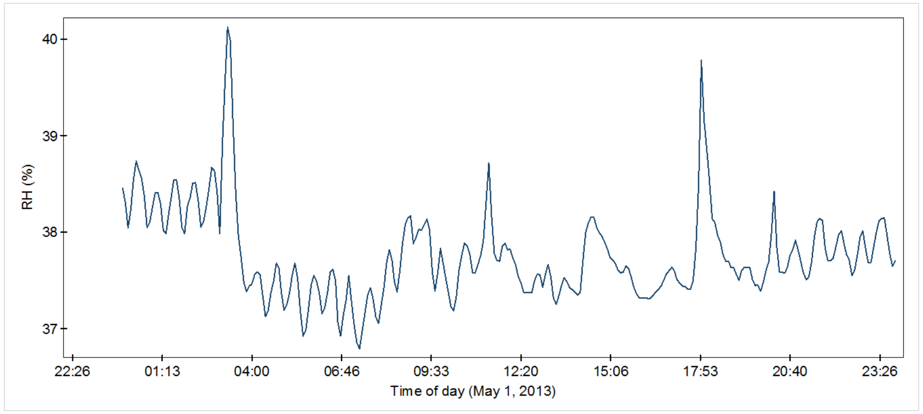
- Little correlation between rooms
- High variation within rooms and nurse stations: 19-26°C

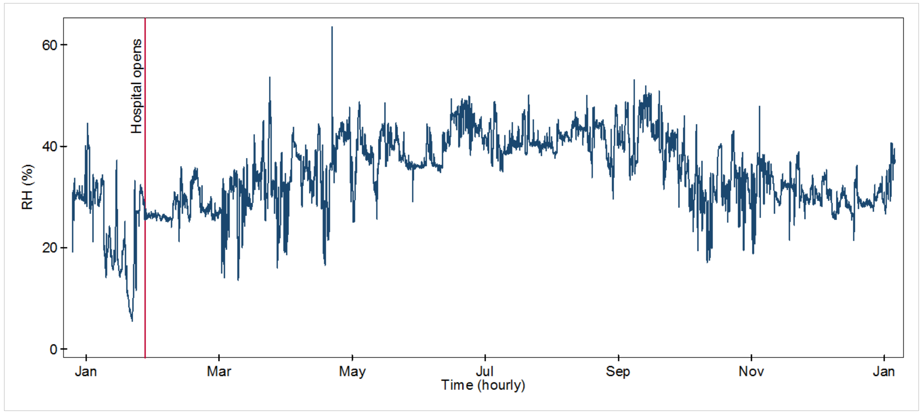




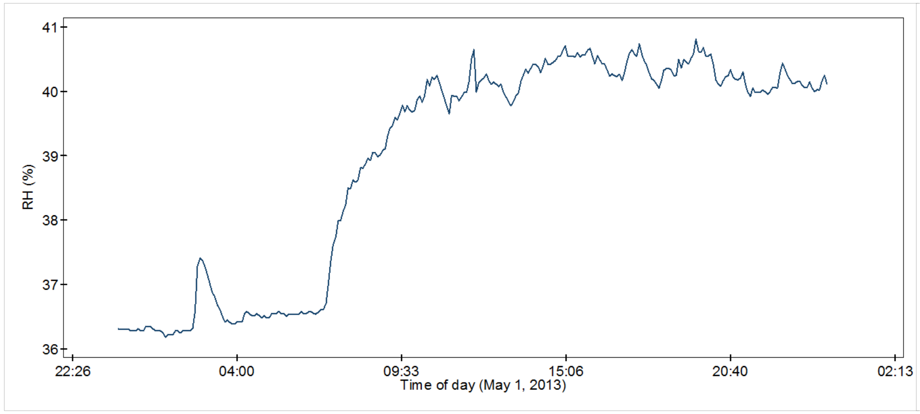
Example time-series data: Relative humidity (RH%)

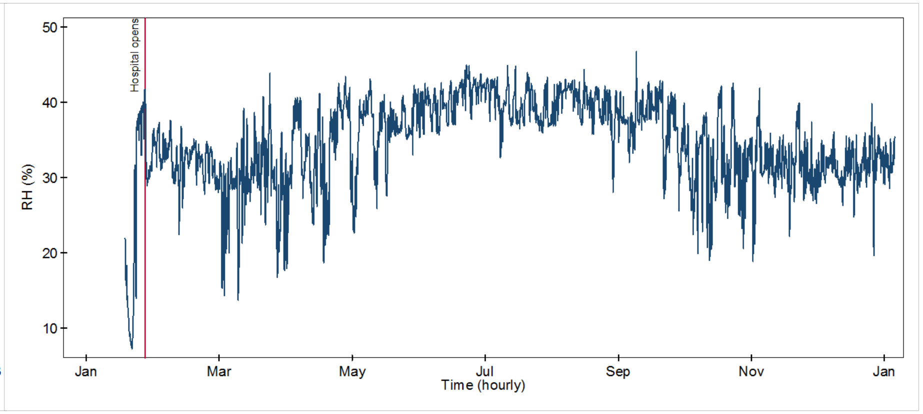
- Patient rooms





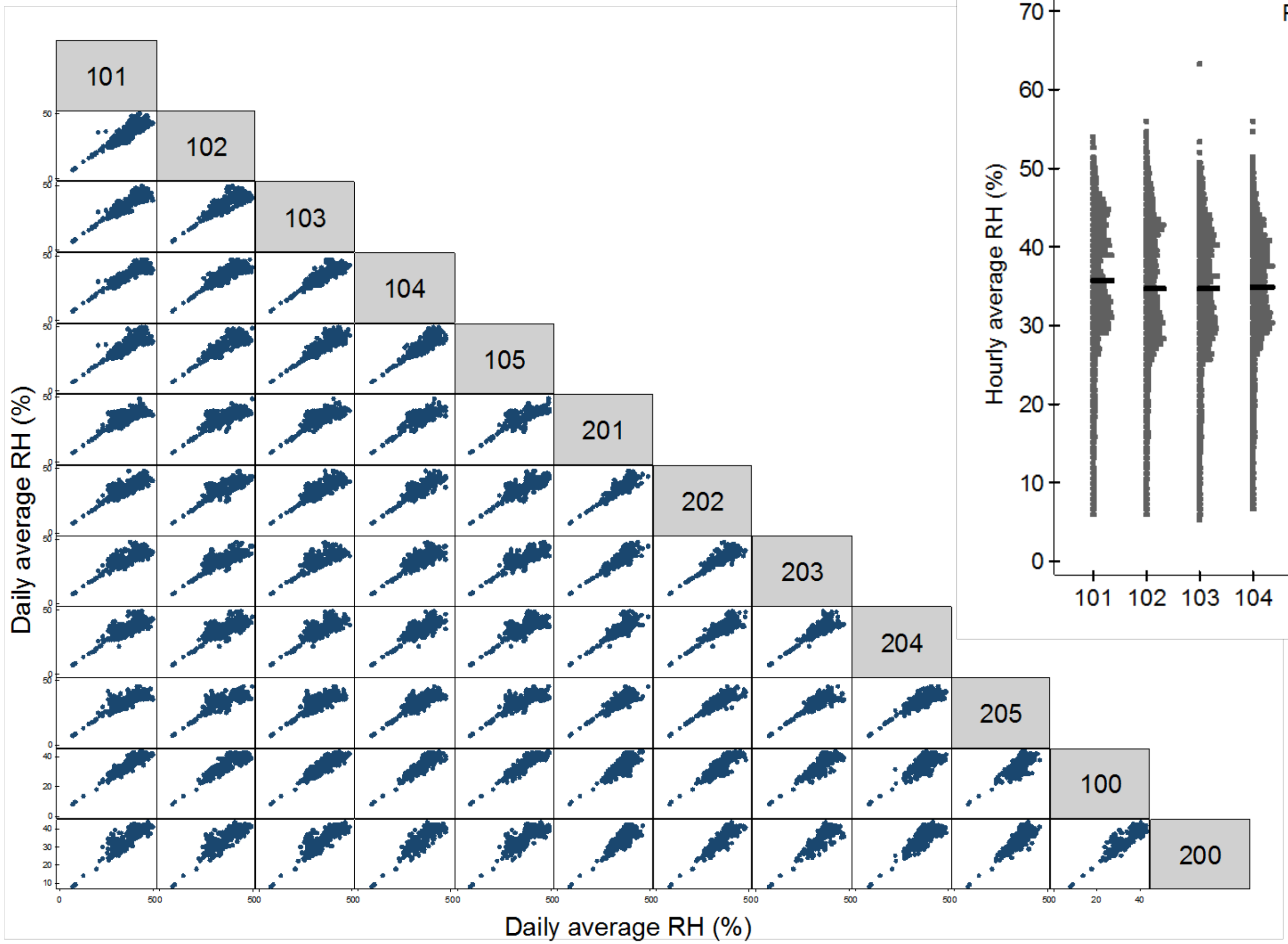
- Nurse stations

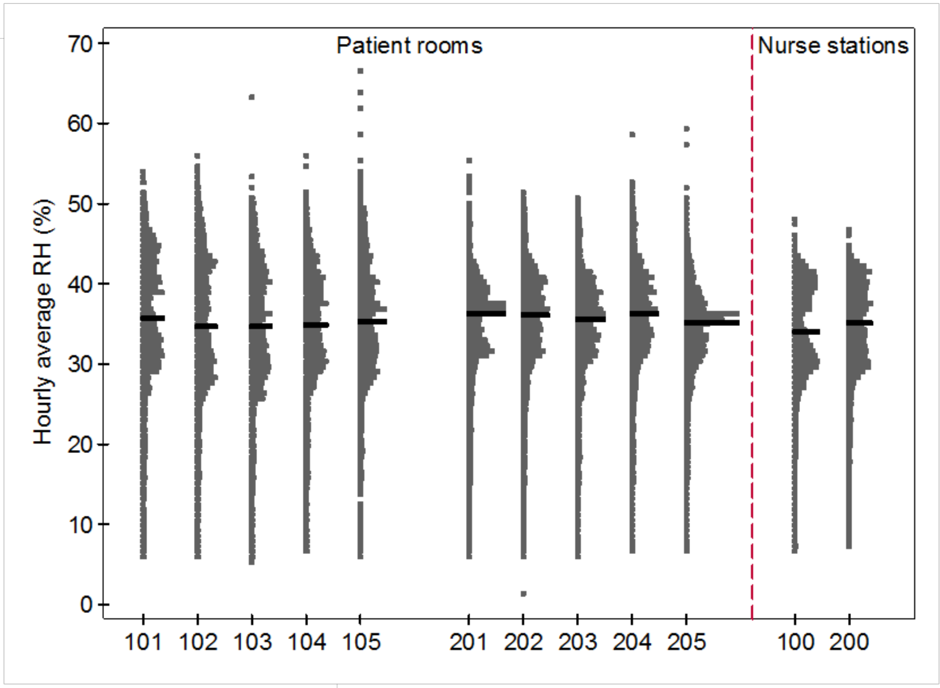




Variations between rooms: Relative Humidity

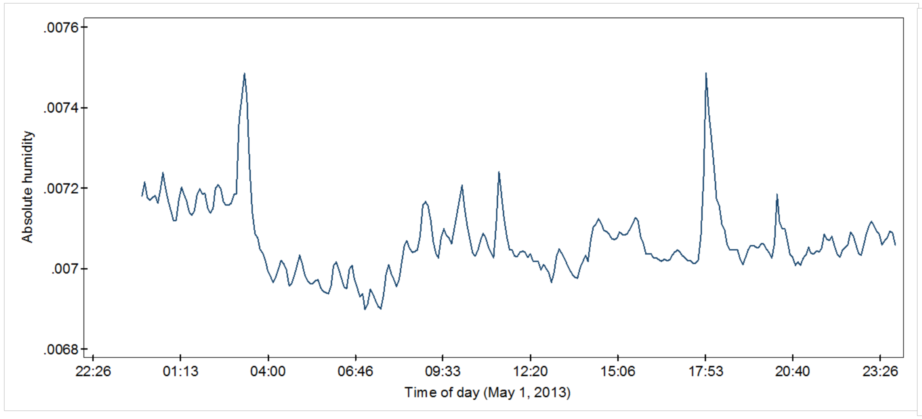
- Strong correlation between rooms and nurse stations
- High variation within rooms and nurse stations: 20-50%

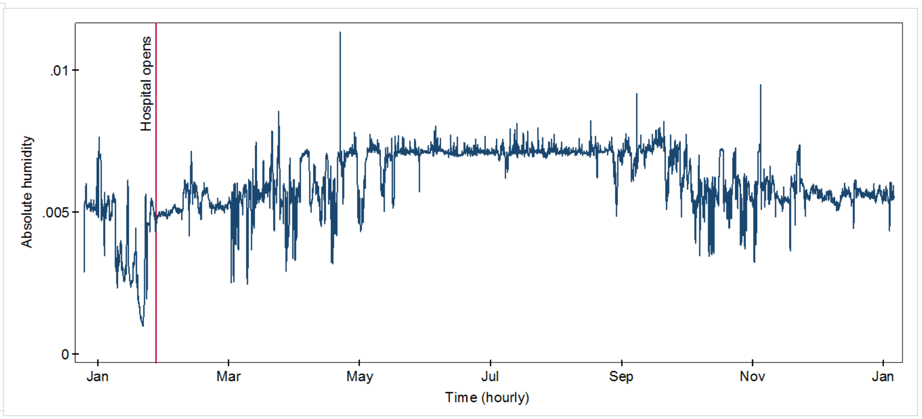




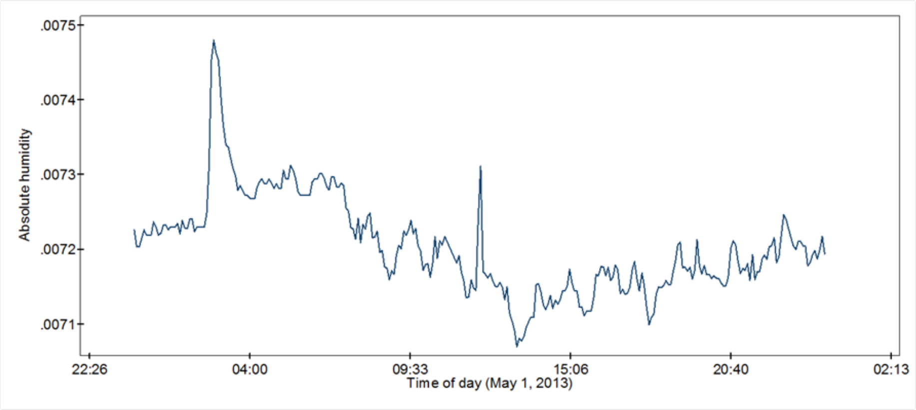
Example time-series data: Absolute humidity

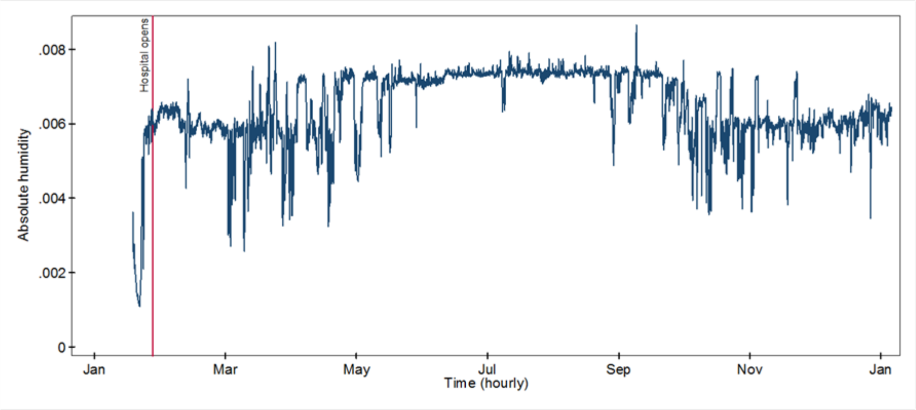
- Patient rooms





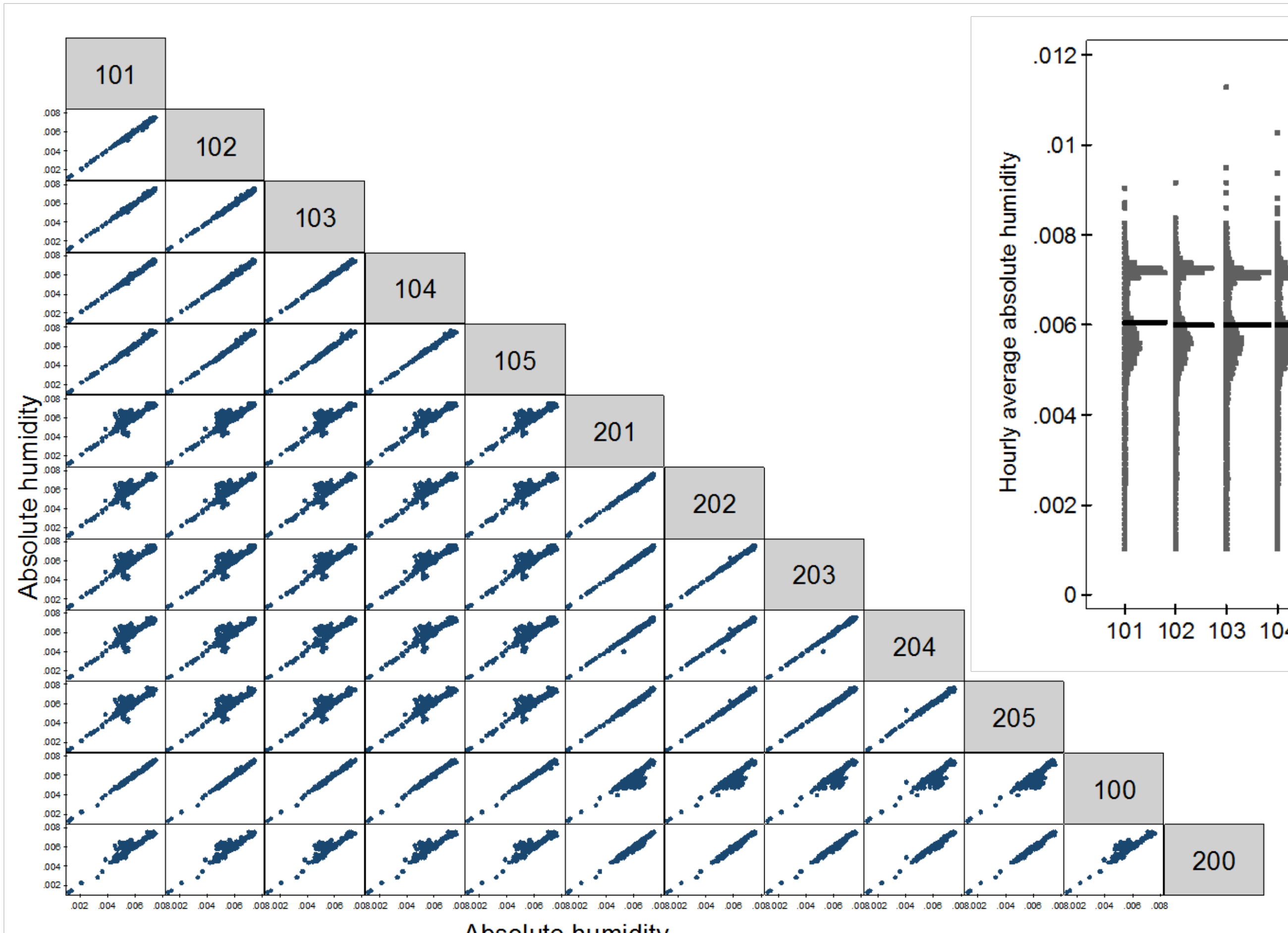
- Nurse stations

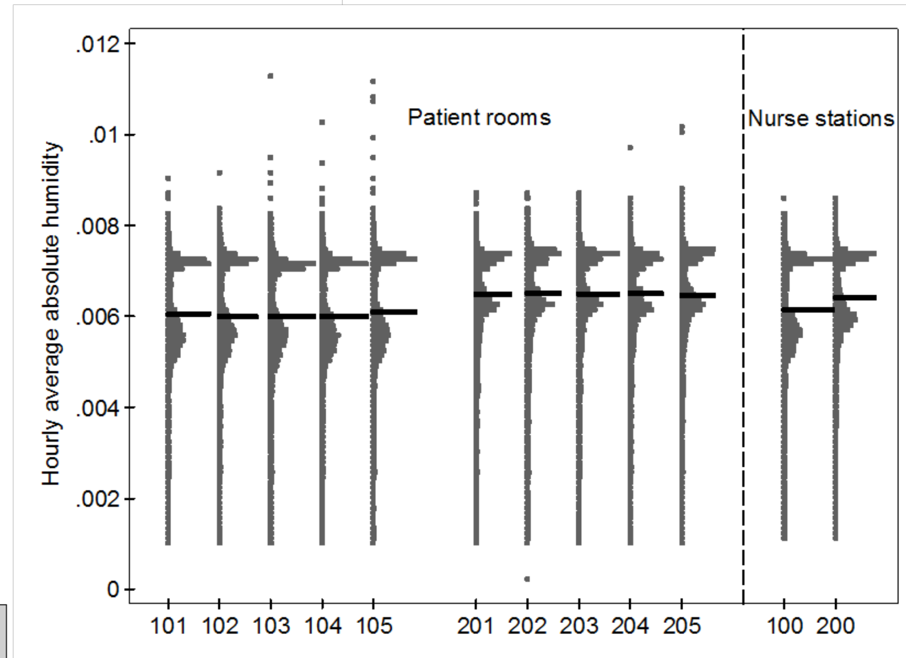




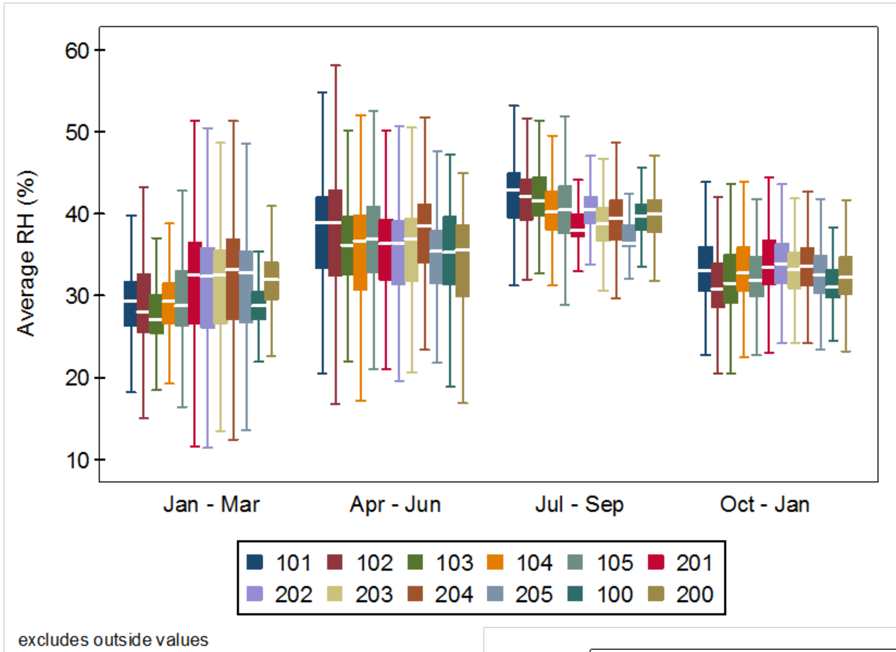
Variations between rooms: Absolute humidity

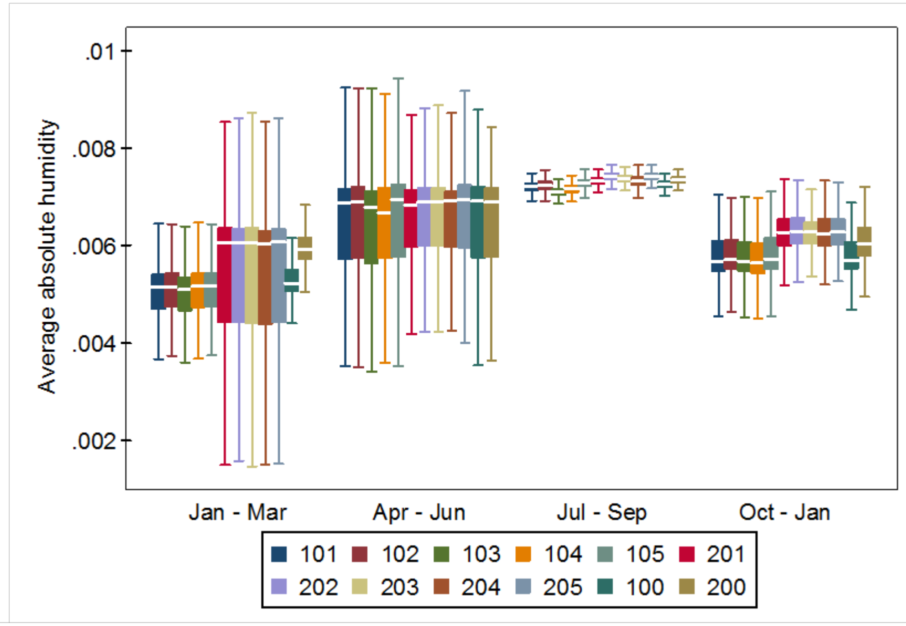
- Strong correlation between rooms and nurse stations, especially those on the same floor
- High variation within rooms and nurse stations: 5-8 g_w/kg_{da}



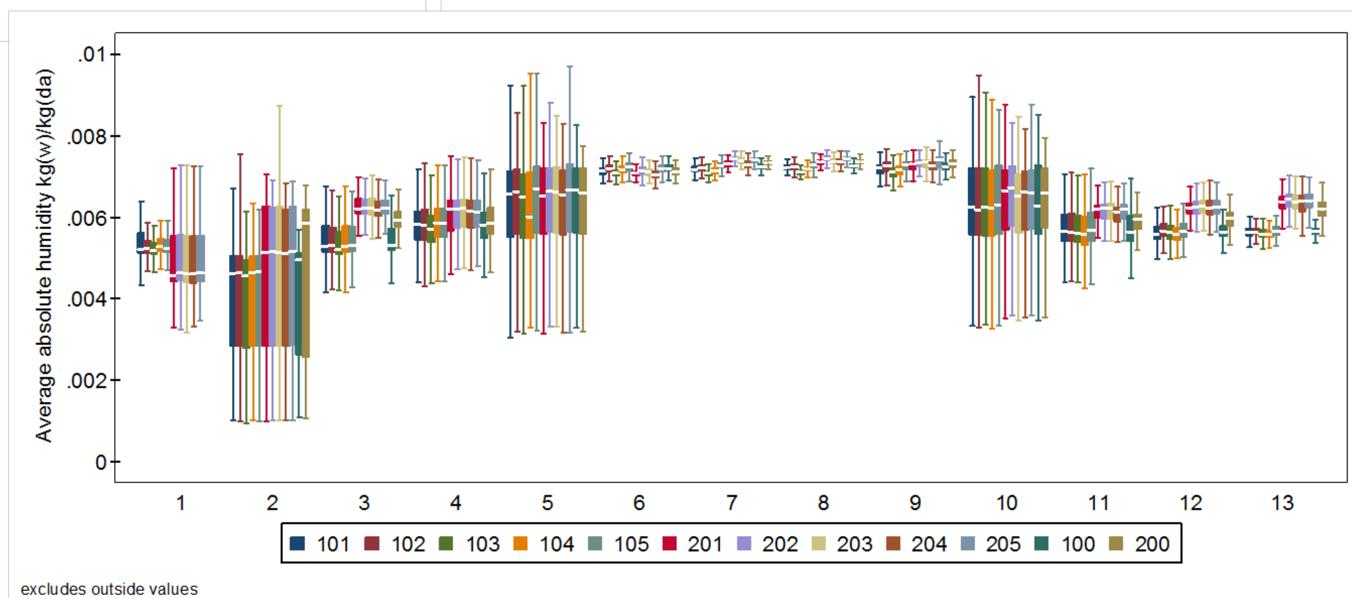


Seasonal and monthly variations: RH and absolute humidity



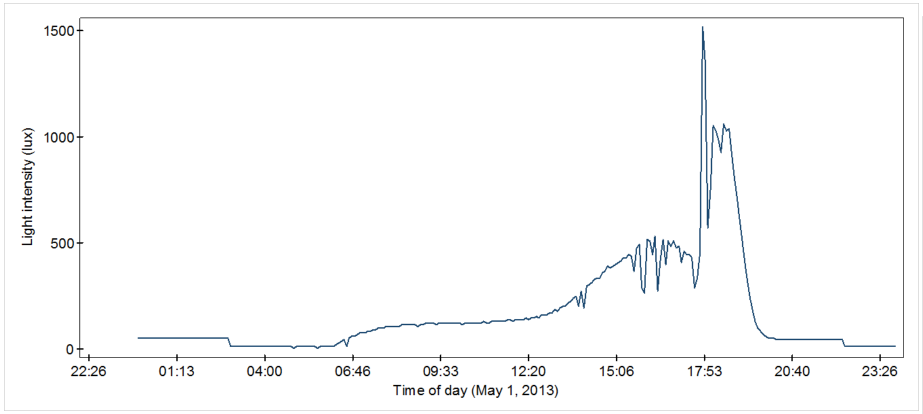


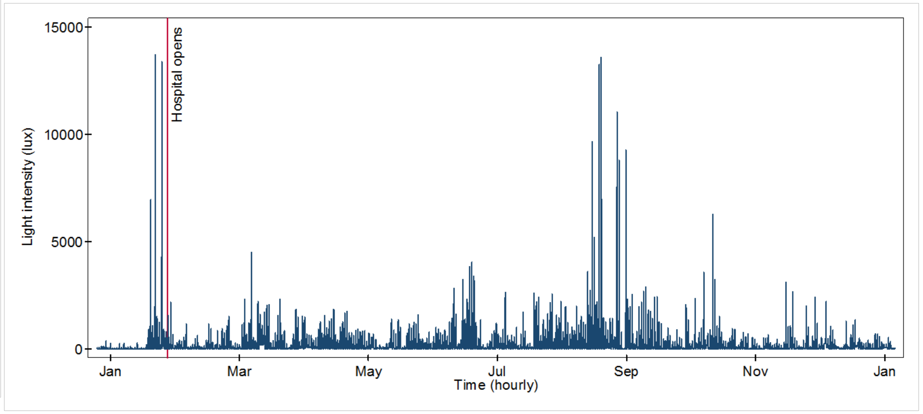
- Distinct seasonal effect
- Higher control during summer and winter months



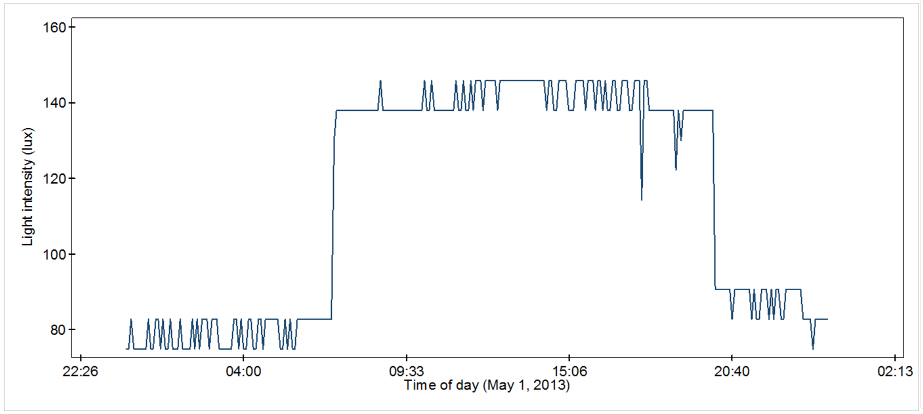
Example time-series data: Light intensity

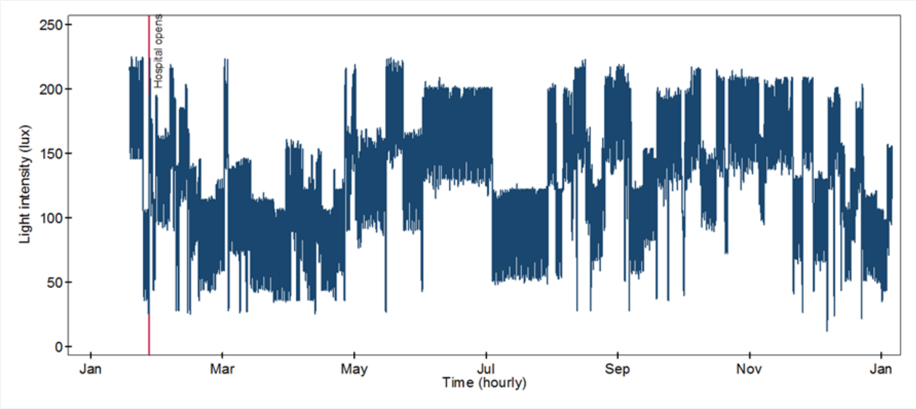
- Patient rooms





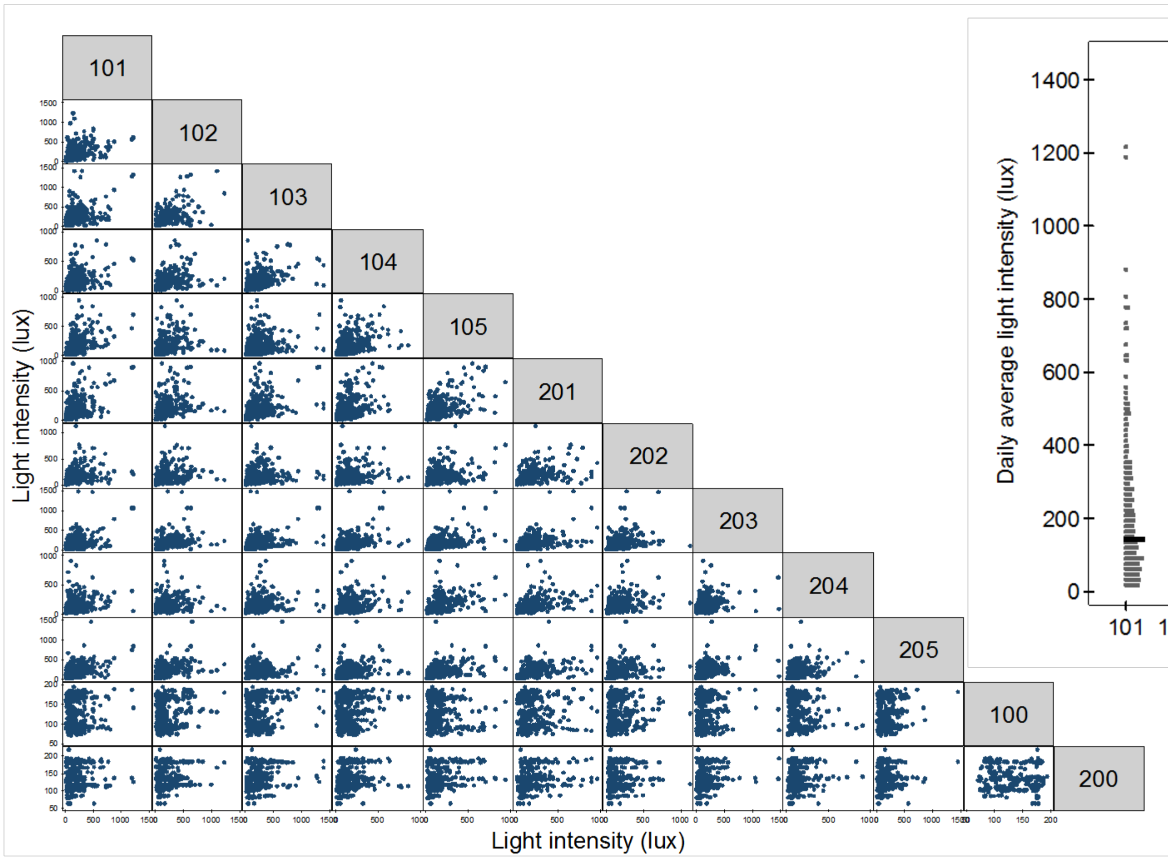
- Nurse stations

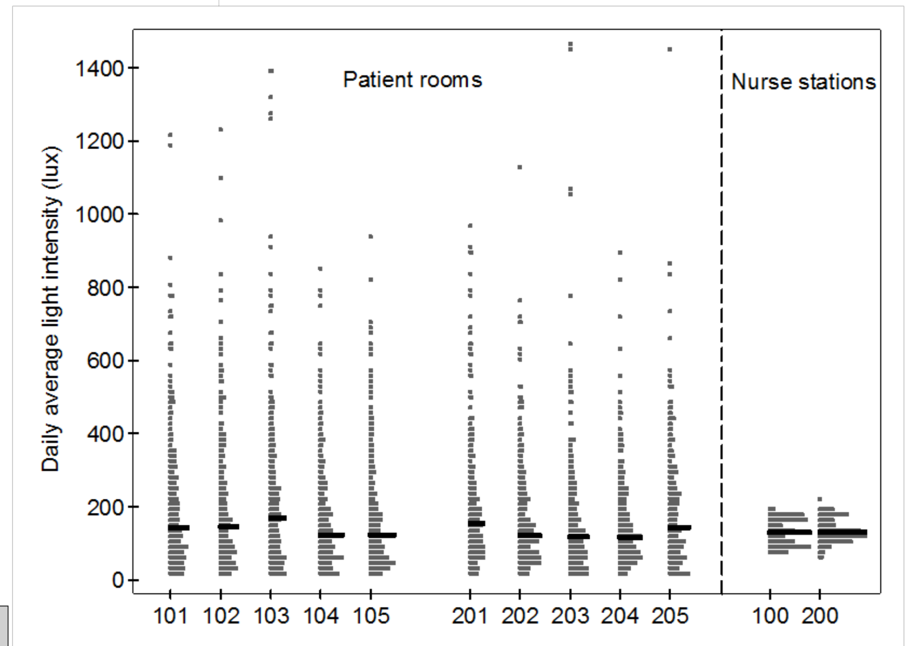




Variations between rooms: Light intensity (lux)

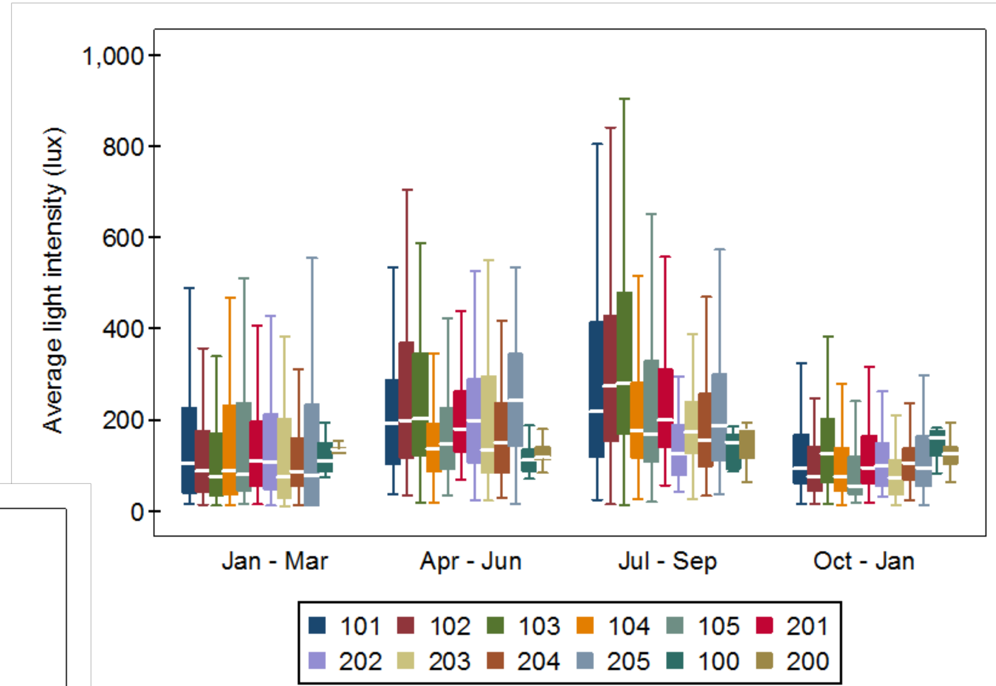
- Moderate correlation between rooms, little correlation between nurse stations
- High variation within rooms: 0-1,500 lux (avg./day)
- Low variation within nurse stations: 100–200 lux

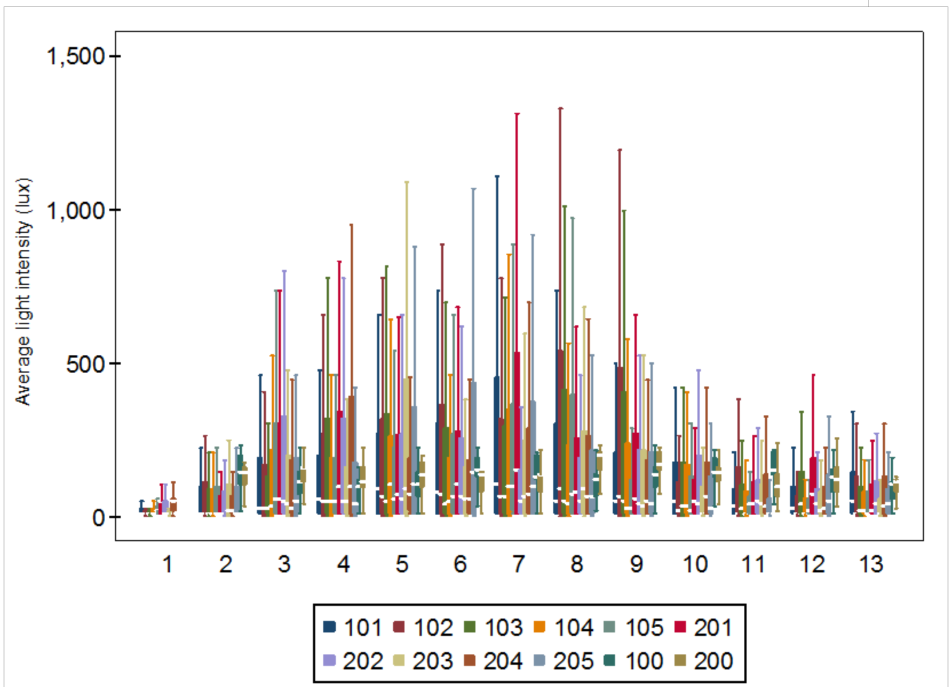




Seasonal and monthly light intensity

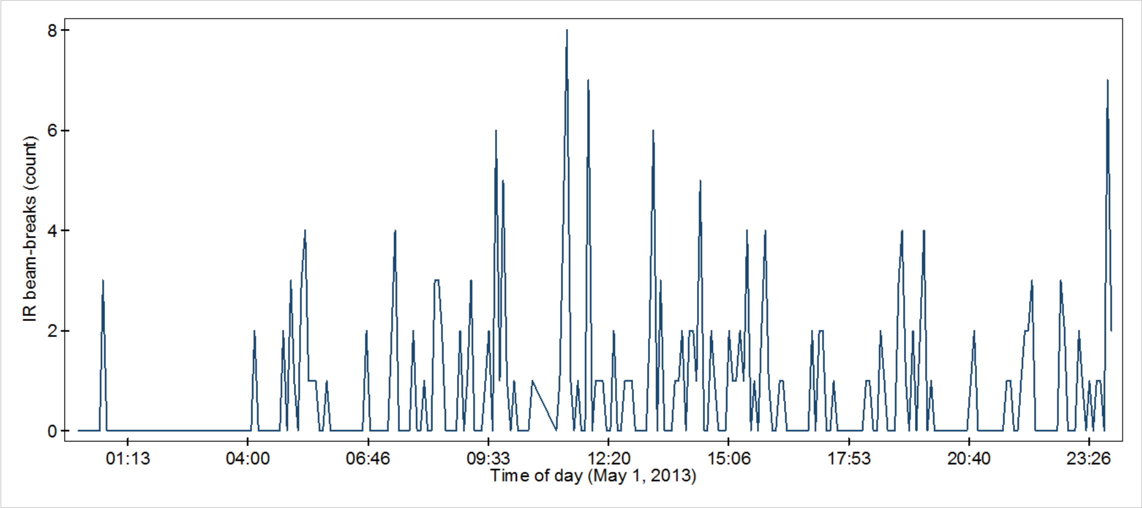
- Seasonal effect
- Higher between March and September

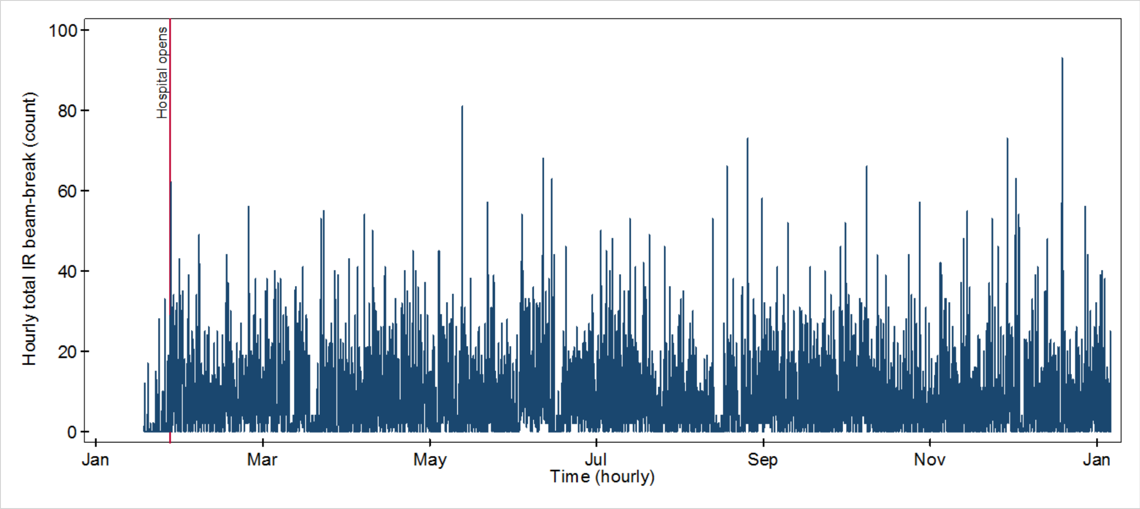




Example time-series data: IR beam-break (counts)

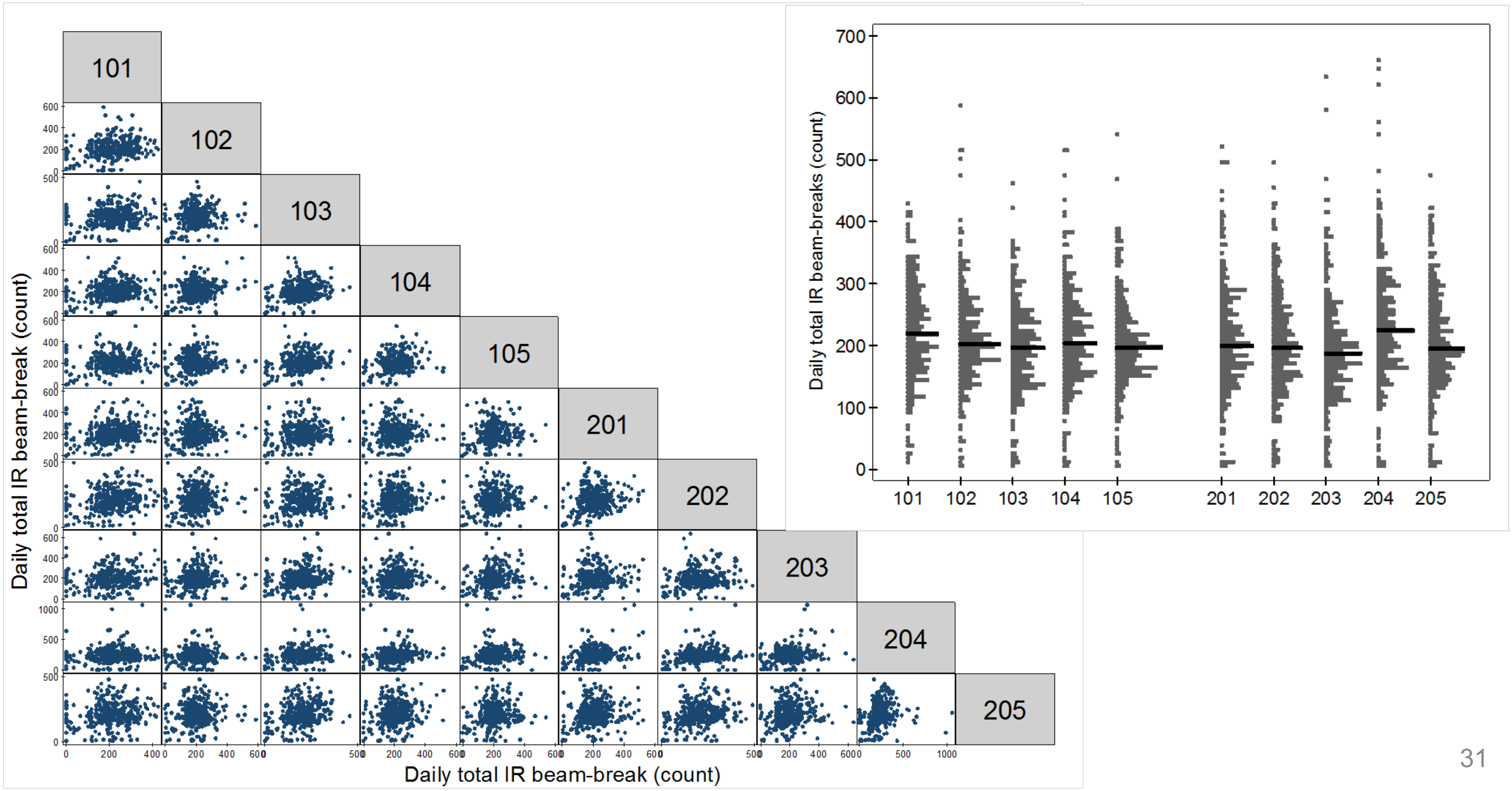
- Higher beam-break counts during active hours
- Hourly totals as high as ~100/hour



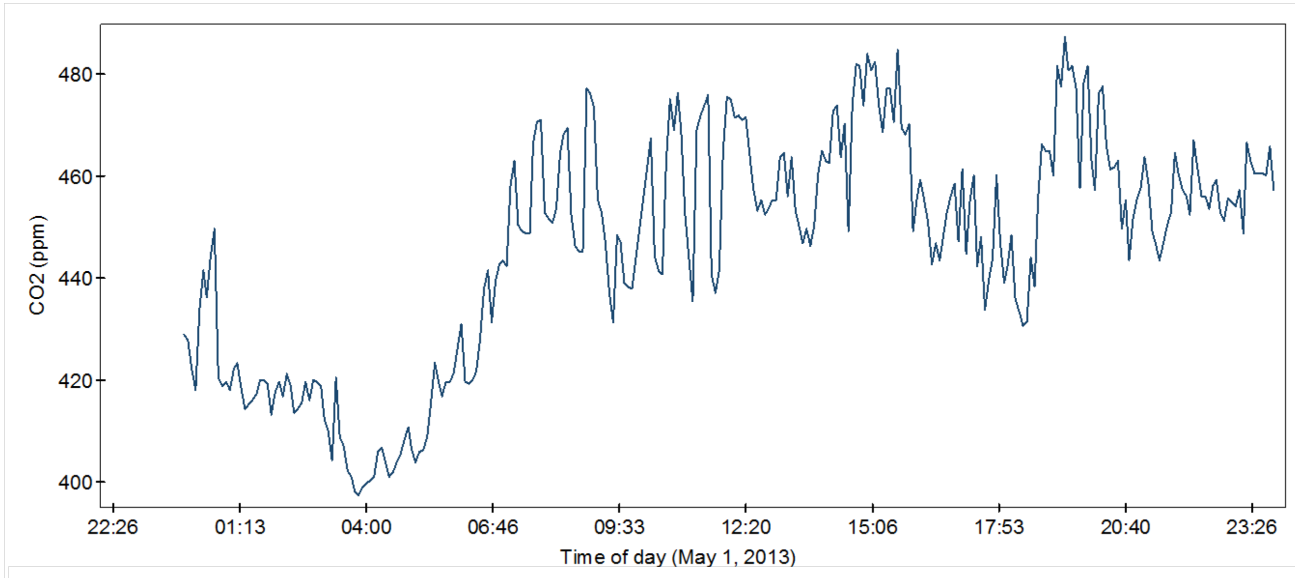


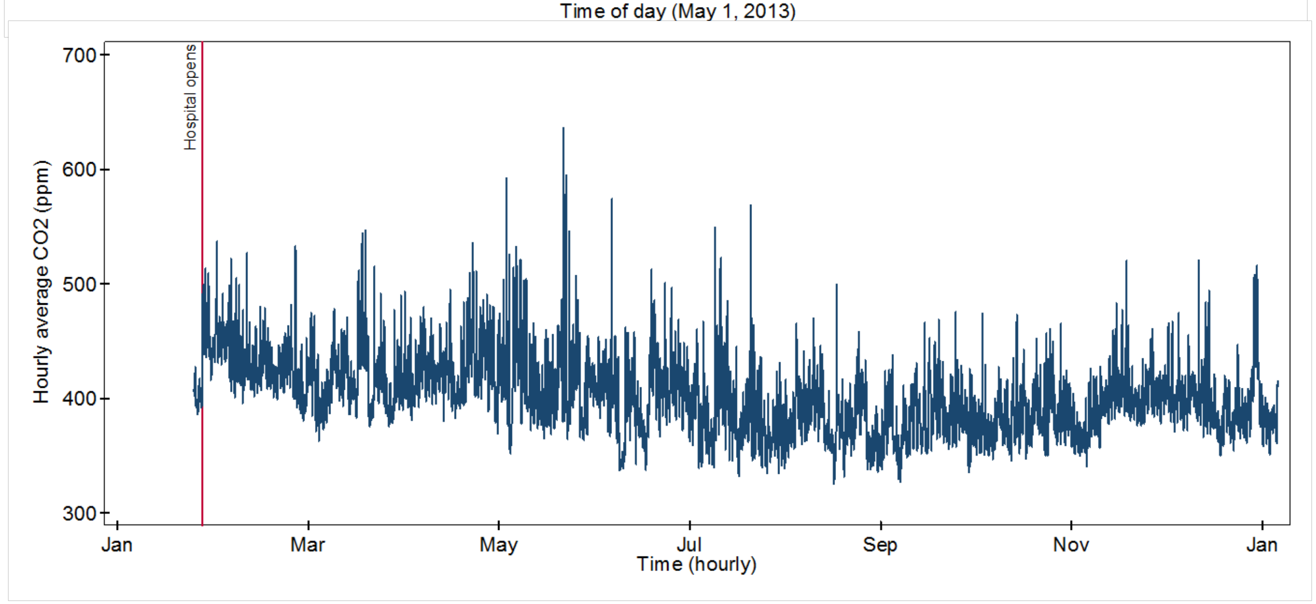
Variations between rooms: IR beam-break (daily counts)

- Little correlation between rooms
- High variation in daily total beam-breaks: 100 – 400/day



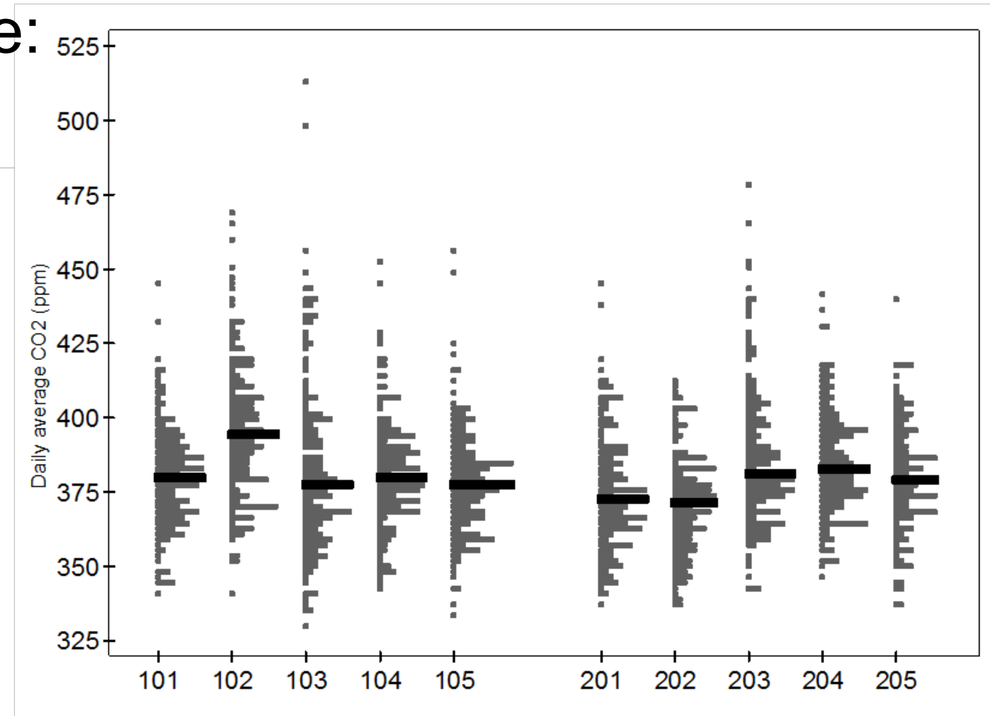
Example time-series data: CO_2 (ppm)

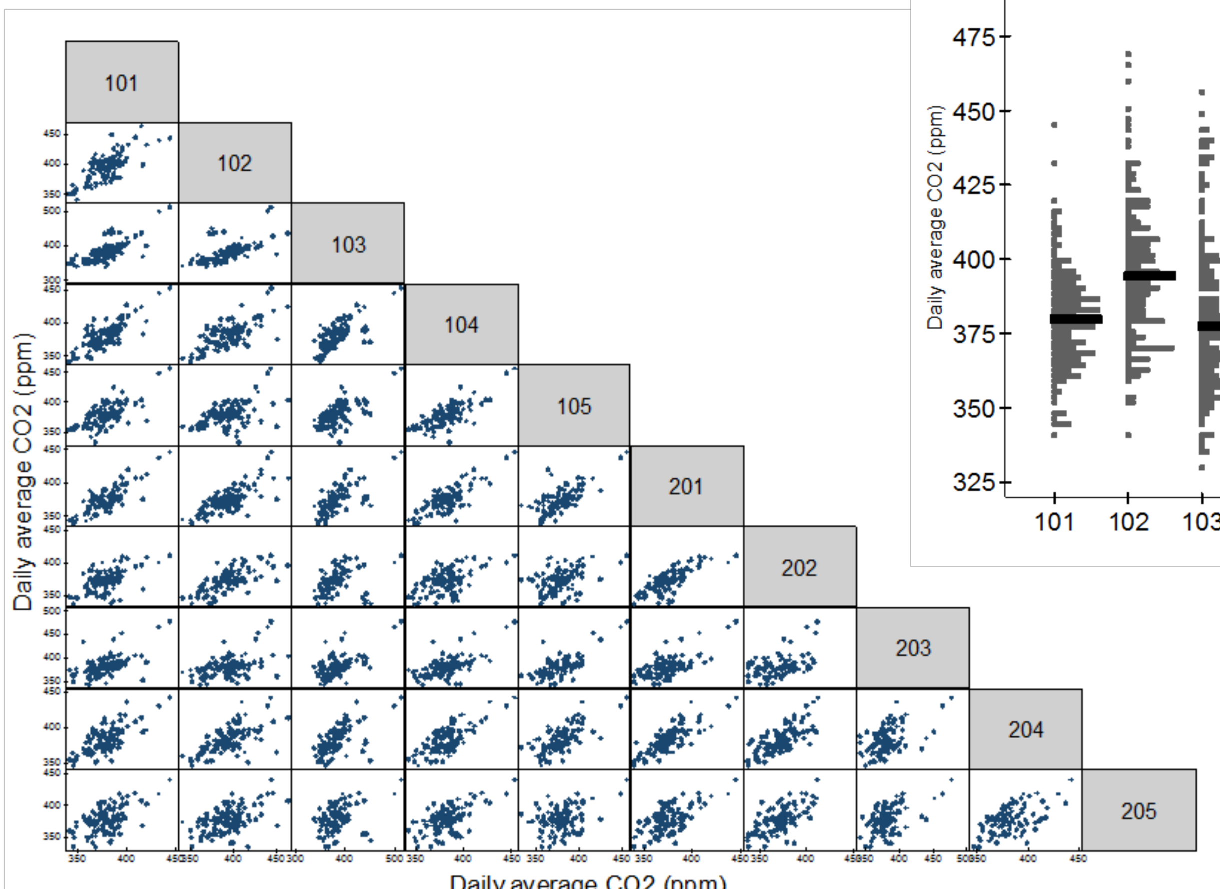




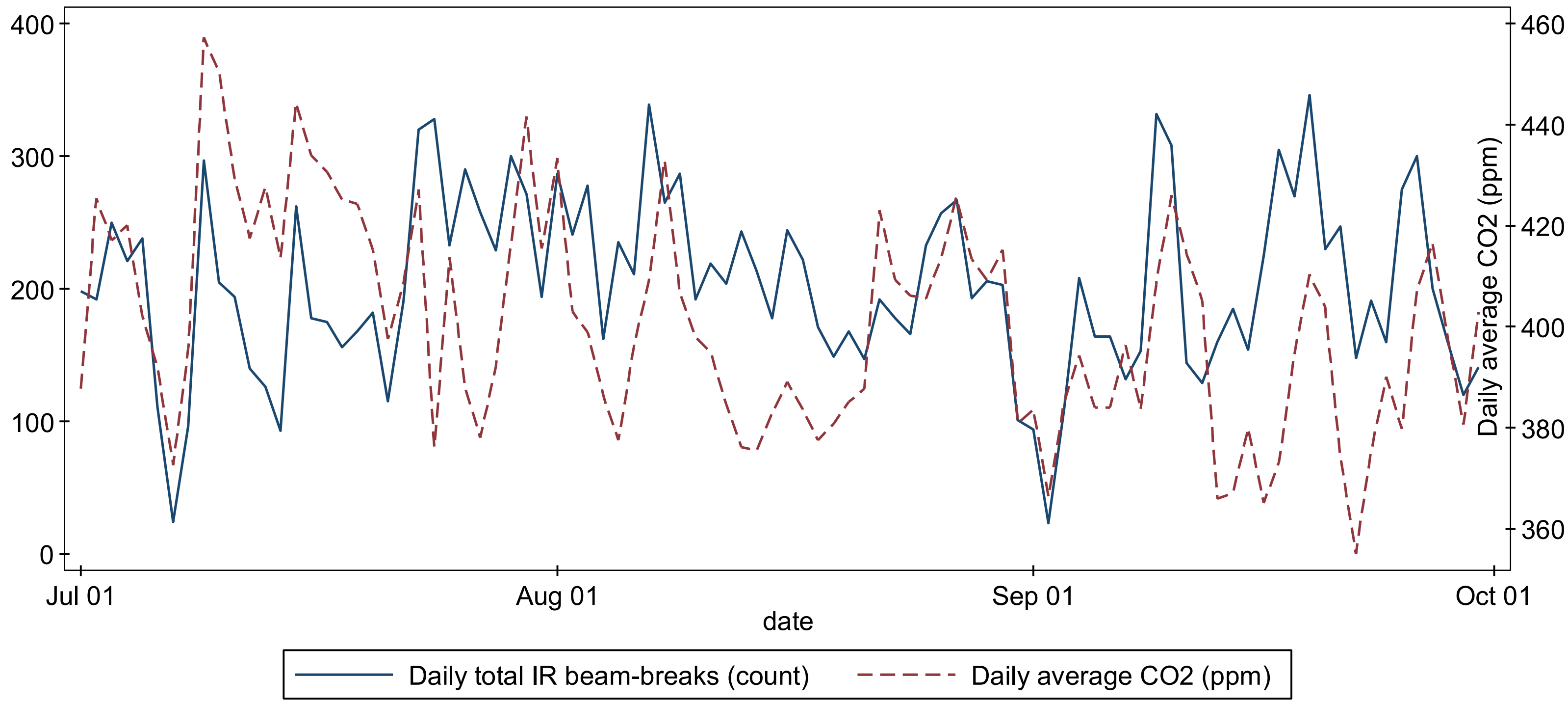
Variations between rooms: CO_2, total (ppm)

- Moderate correlation between rooms
- Variation within rooms range:
  350-450 ppm



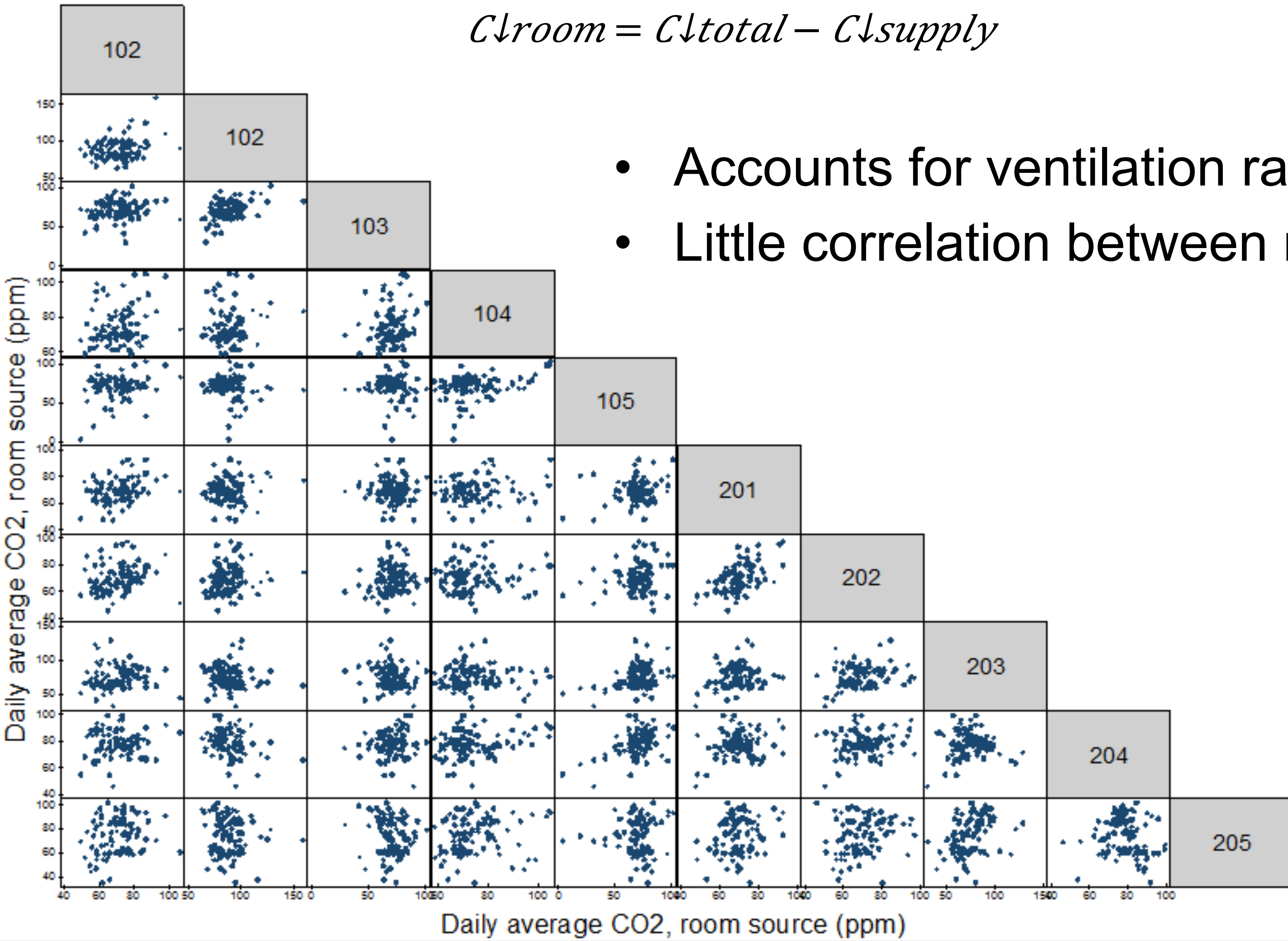


Example time-series: IR beam-break + CO_2



Variations between rooms: CO_2, room source (ppm)

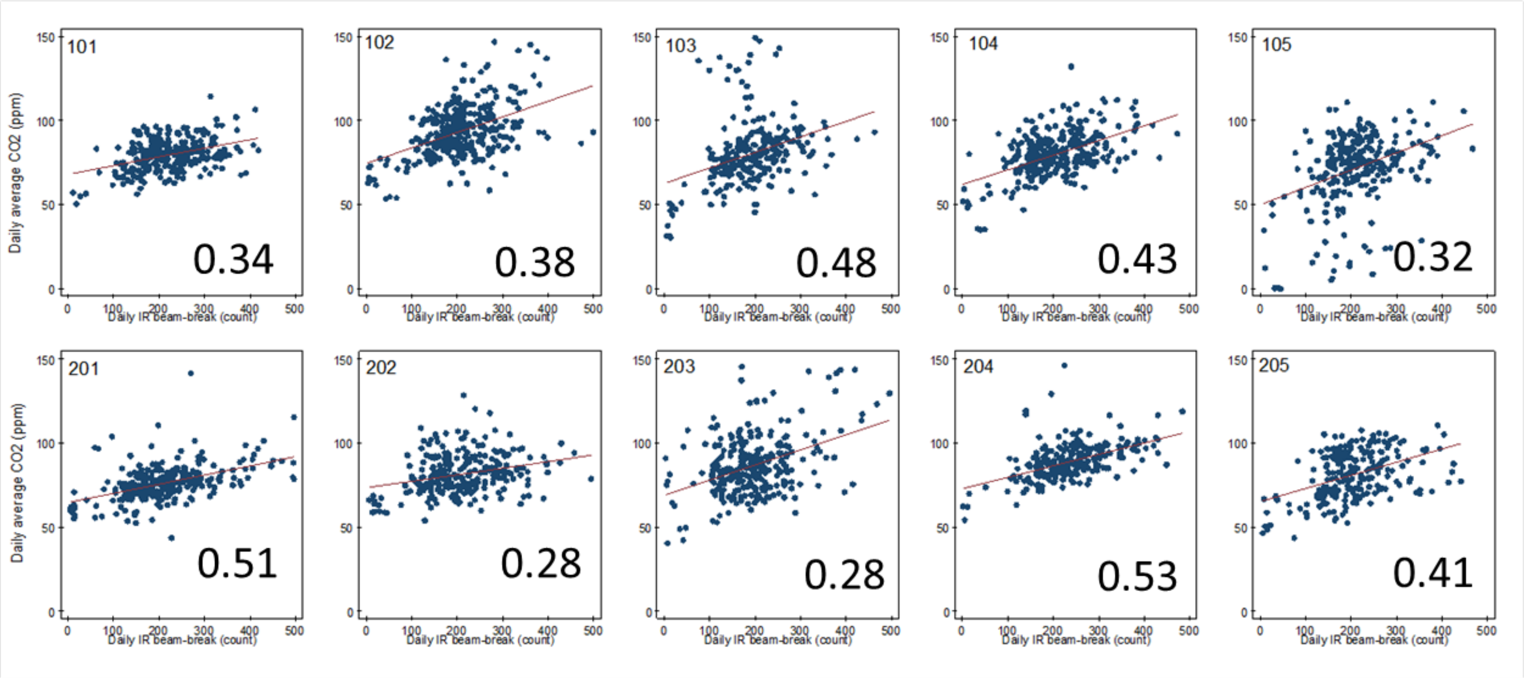
$$C_{room} = C_{total} - C_{supply}$$



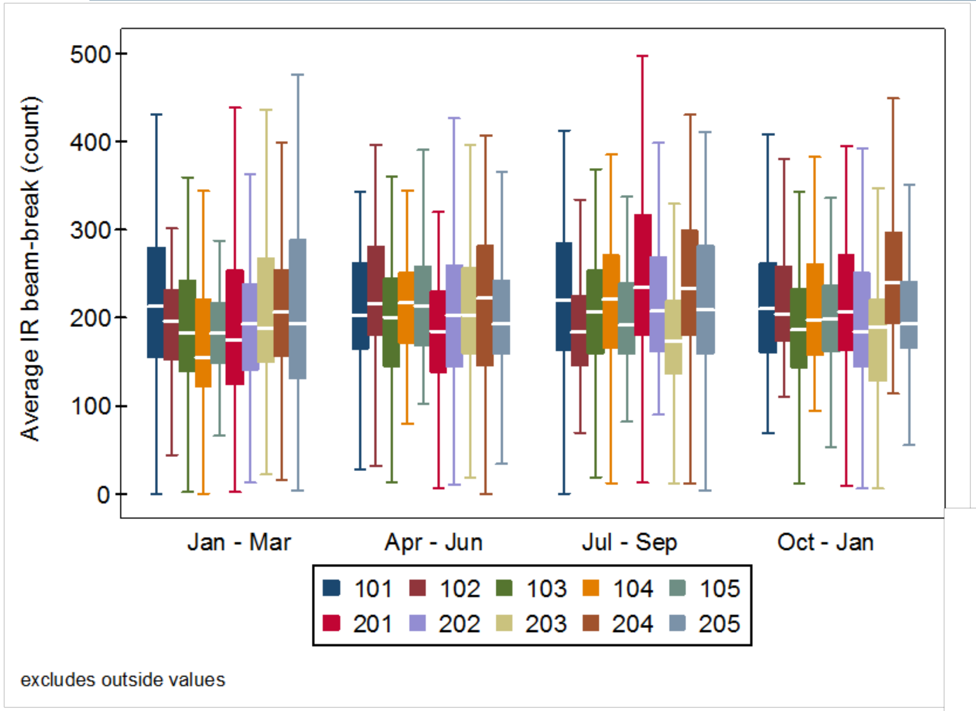
- Accounts for ventilation rate effects
- Little correlation between rooms

Room source CO2 and daily IR beam breaks

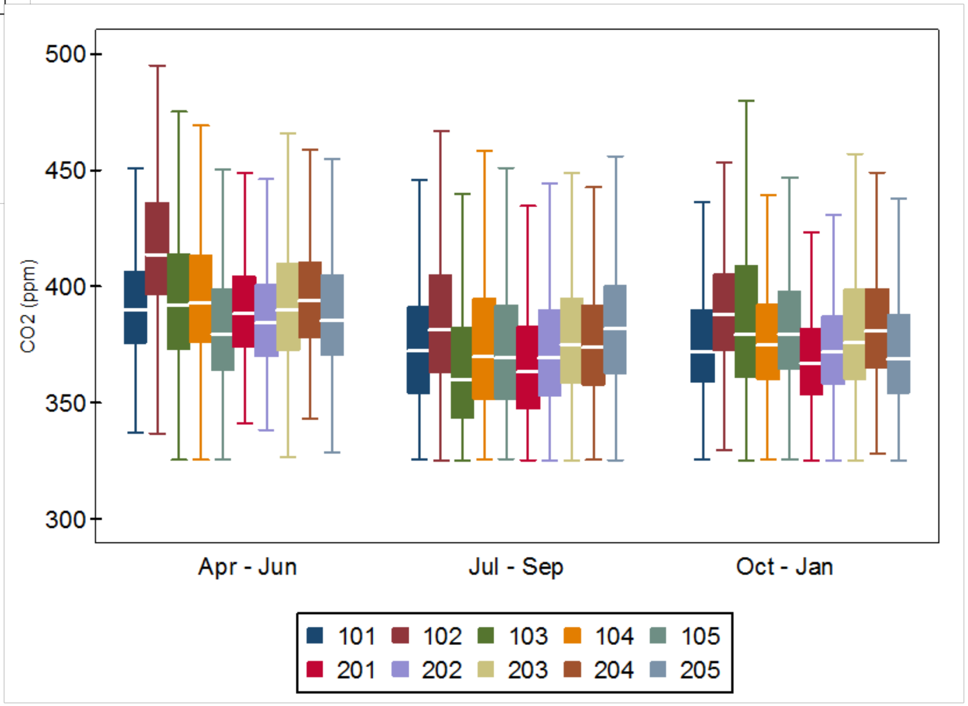
- Decent correlation with daily total IR beam-breaks



Seasonal variations: IR beam-break and CO2

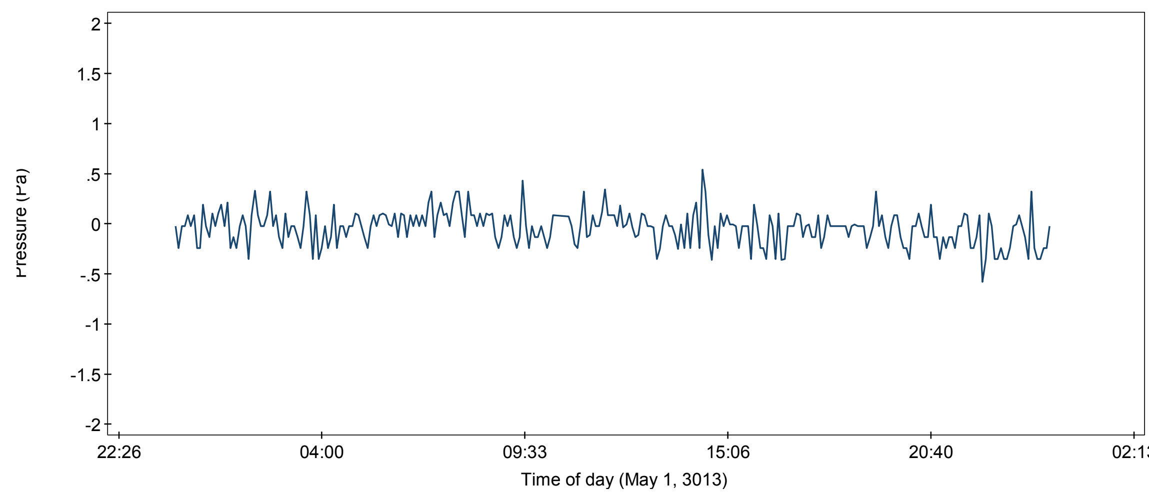


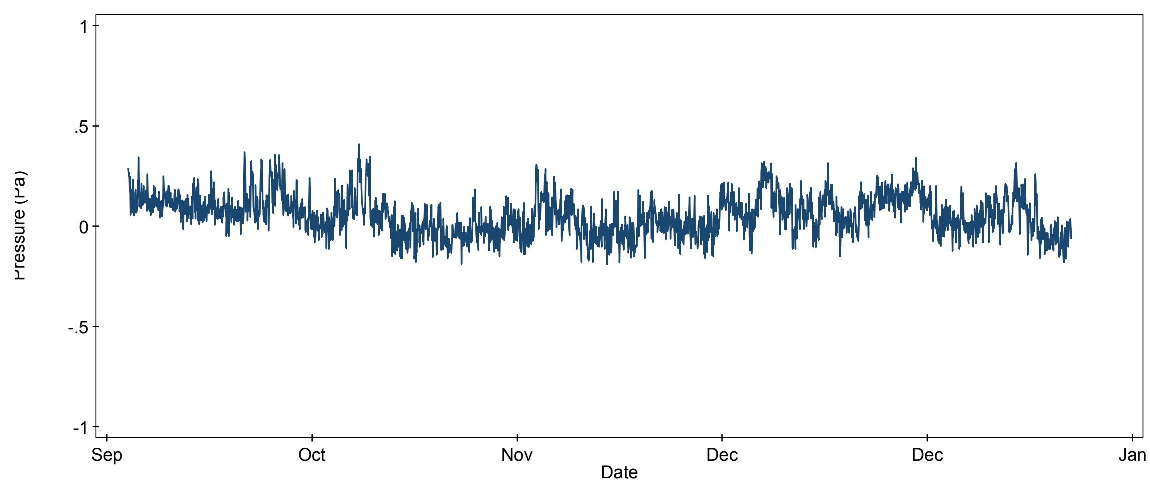
- No distinct differences between seasons



Example time-series data: Differential pressure

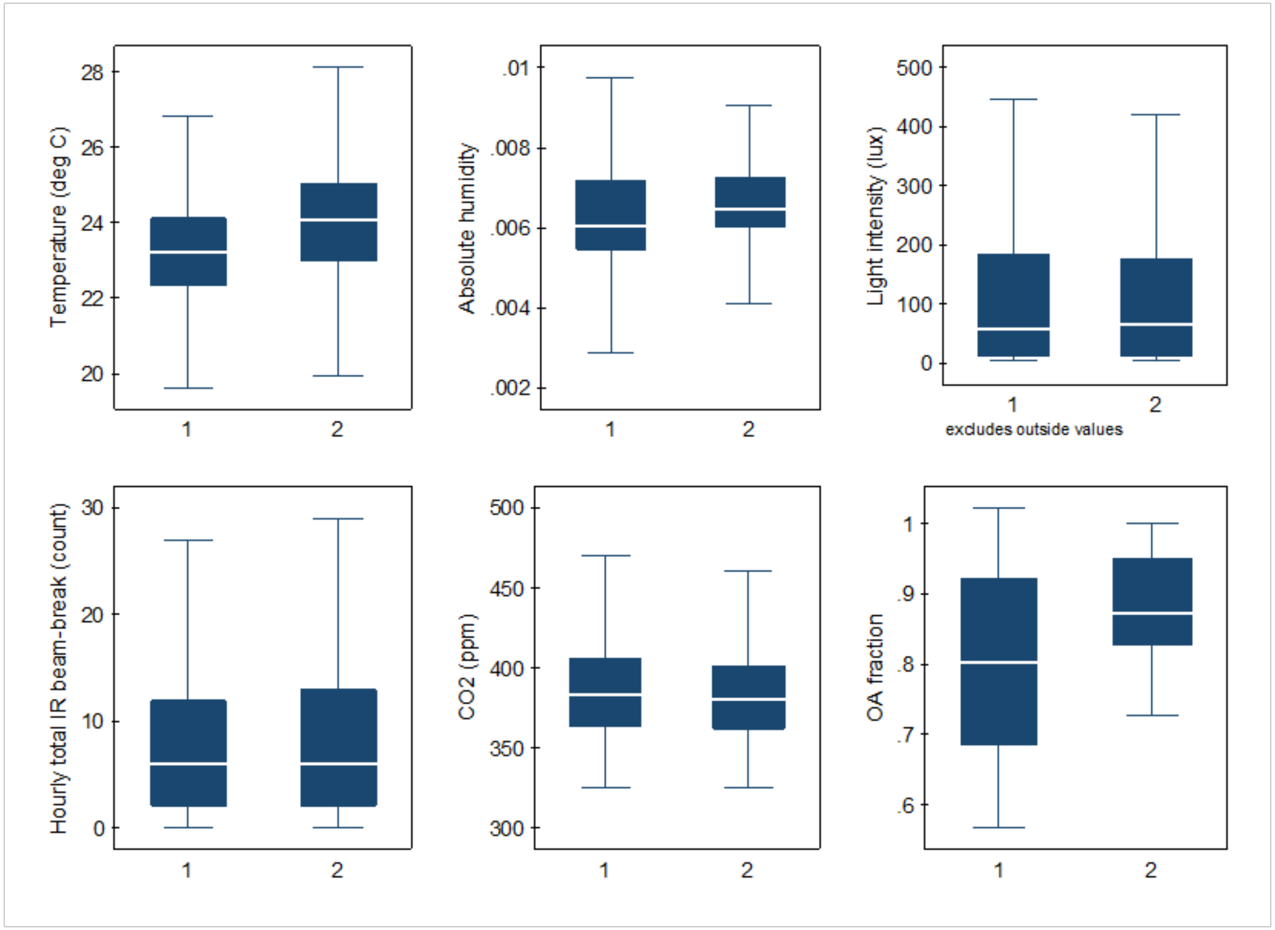
- Bounced around zero for the duration of the project
- Spot checks using a DG-700 differential pressure sensor confirmed neutral pressure





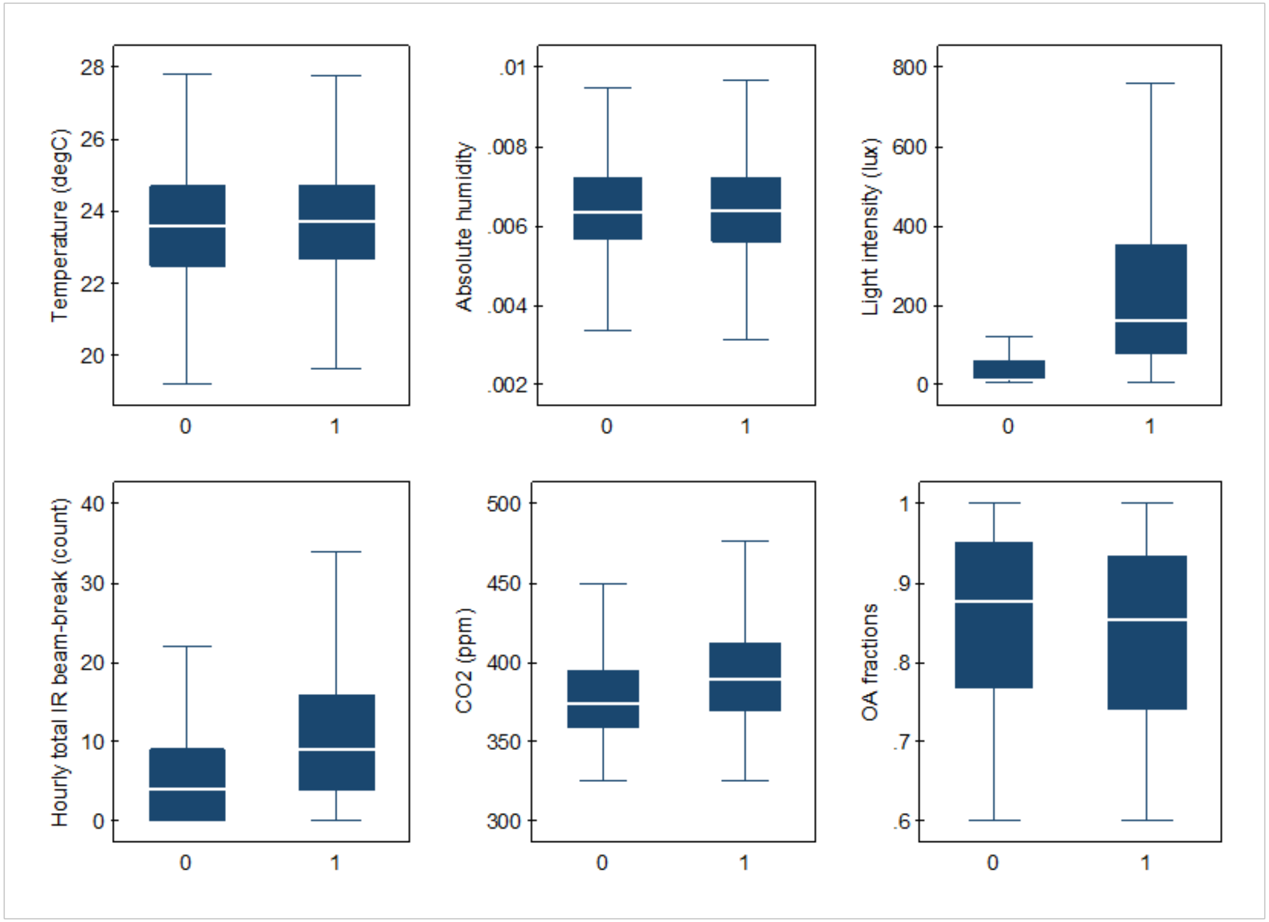
Parameter variations **between floors**

- Slightly higher temperatures on 10th floor
- Smaller range and slightly higher humidity on 10th floor
- Light intensity, IR beam-break and CO2 similar
- OA fractions higher in 10th floor



Within-day variation (night & day)

- Temperature and humidity similar between floors
- Light intensity higher during the day
- IR beam-break and CO2 also higher during the day
- OA fractions slightly higher at night



Conclusions

- Reviewed existing literature on important building environmental and operational parameters that can affect microbial growth and survival indoors
- Developed study design to systematically collect robust data on these parameters, providing more than 8 million data points for future comparison
  - Temperature varied more than expected, largely effected by occupant control
  - Humidity highly controlled over each floor, with significant seasonal differences
  - Light intensity has a strong seasonal effect
  - IR beam-break and CO2 concentrations correlated well
  - OA fraction higher in 10th floor, due to higher minimum value

Outcomes of this work

- This work represents one of the largest field measurement campaigns to assess long-term built environment parameters for microbial investigations
- We were able to provide a large dataset to have a meaningful context for microbial communities sampled
- Demonstration of methodologies for large-scale collection of built environment metadata
- Two papers:
  - "Built environment metadata collection for indoor microbial investigations," submitted to *Environmental Science and Technology*
  - "One year of built environment metadata measurements in the Hospital Microbiome Project," in preparation for submission to *PLOS One*

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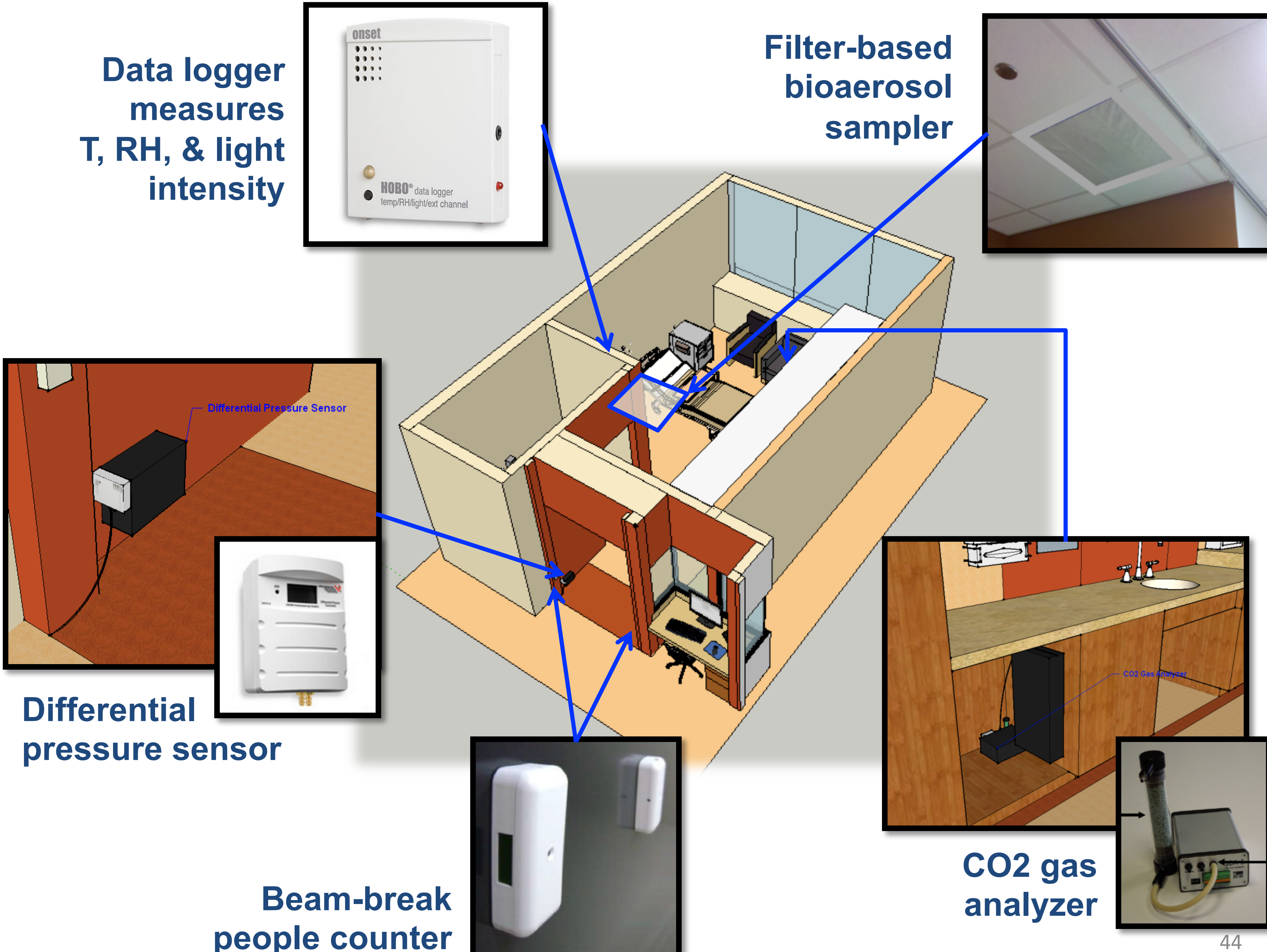

Data logger measures T, RH, & light intensity
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temp/RH/light/ext channel
Filter-based bioaerosol sampler
Differential Pressure Sensor
Differential pressure sensor
Beam-break people counter
CO2 gas analyzer
CO2 Gas Analyzer