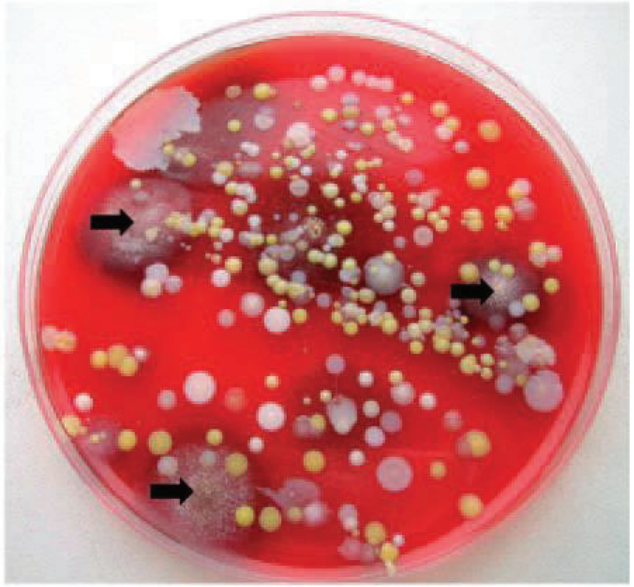


Influence of Ventilation design on the prevalence of anti-microbial resistant bacteria in homes

Stage 1: Microbiology

Prof. Stephanie Dancer, NHS Lanarkshire

Dr Marco-Felipe King, University of Leeds

Arts & Humanities Research Council

NHS Lanarkshire

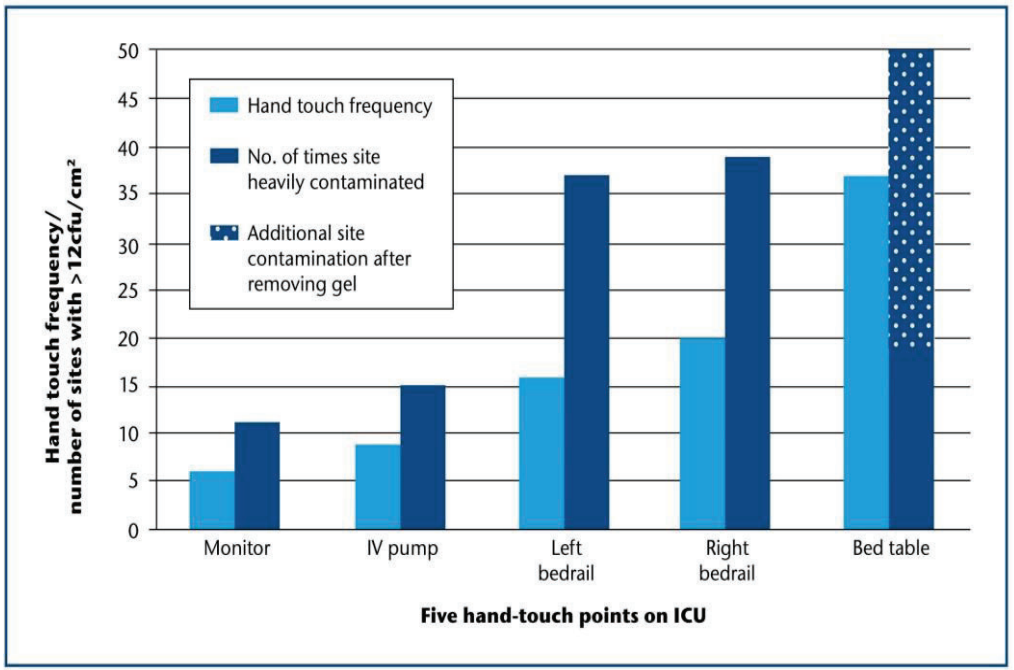
Mackintosh Environmental Architecture Research Unit The Glasgow School of Art

University of Leeds

Sites chosen for microbiological sampling

1. Bathroom (inside) Door Handle
2. Telephone
3. Kettle Handle
4. Bedside Table
5. Top of Door
6. TV Remote
7. Toilet Handle
8. Bedroom Window Sill

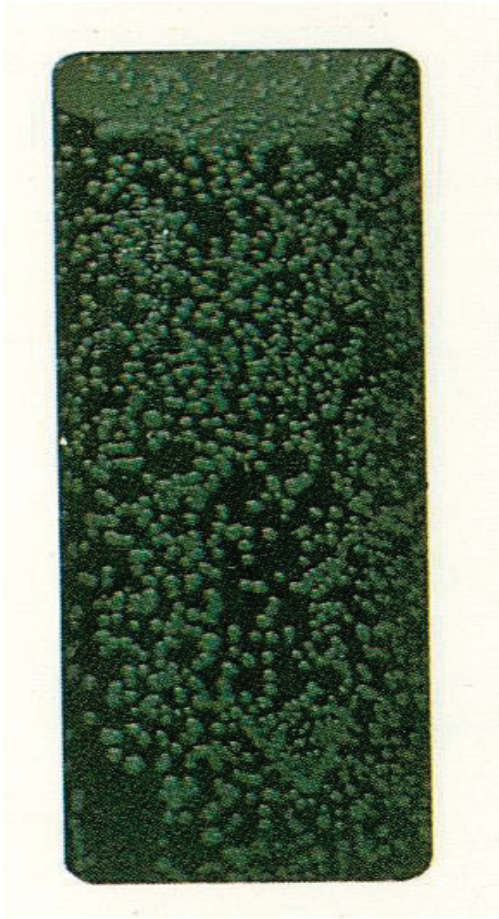
Figure 1: Hand touch frequency and gross microbial soil for five near patient sites on ICU



Adams et al, J Hosp Infect 2017

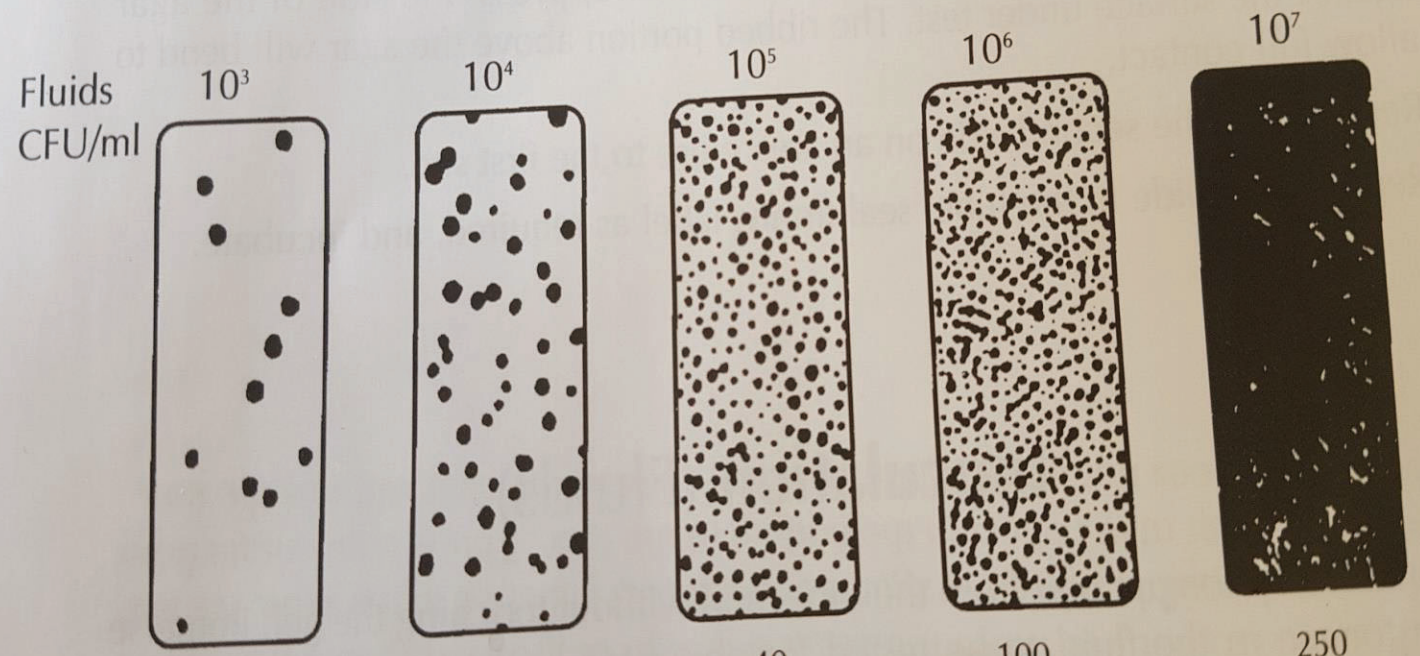
Dipslides

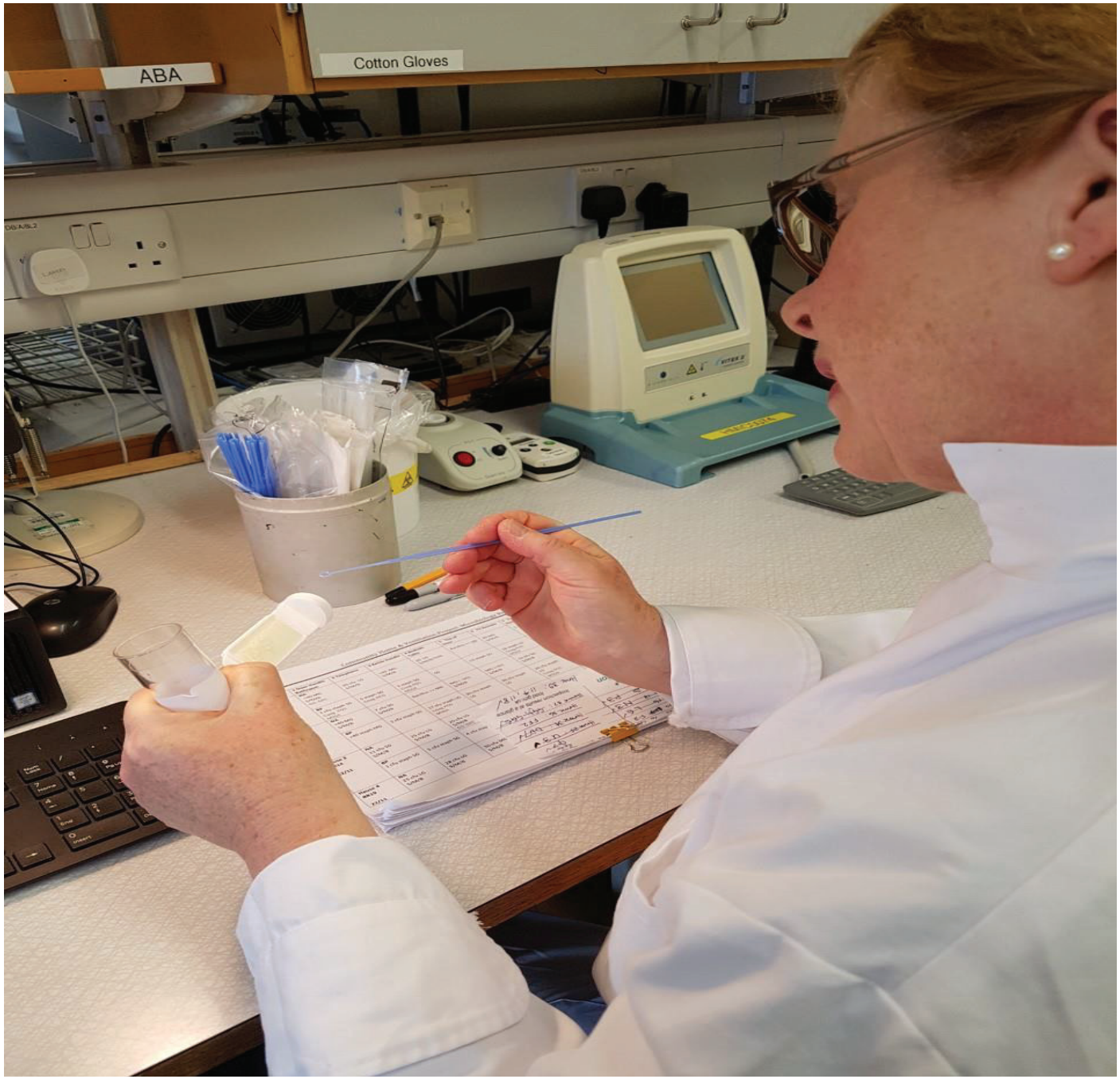
5 cfu/cm^2



45 cfu/cm^2

Comparison Charts Bacteria/Yeasts




ABA
Cotton Gloves


Due Out:
29/3

Most common finding from all sites except top of the door

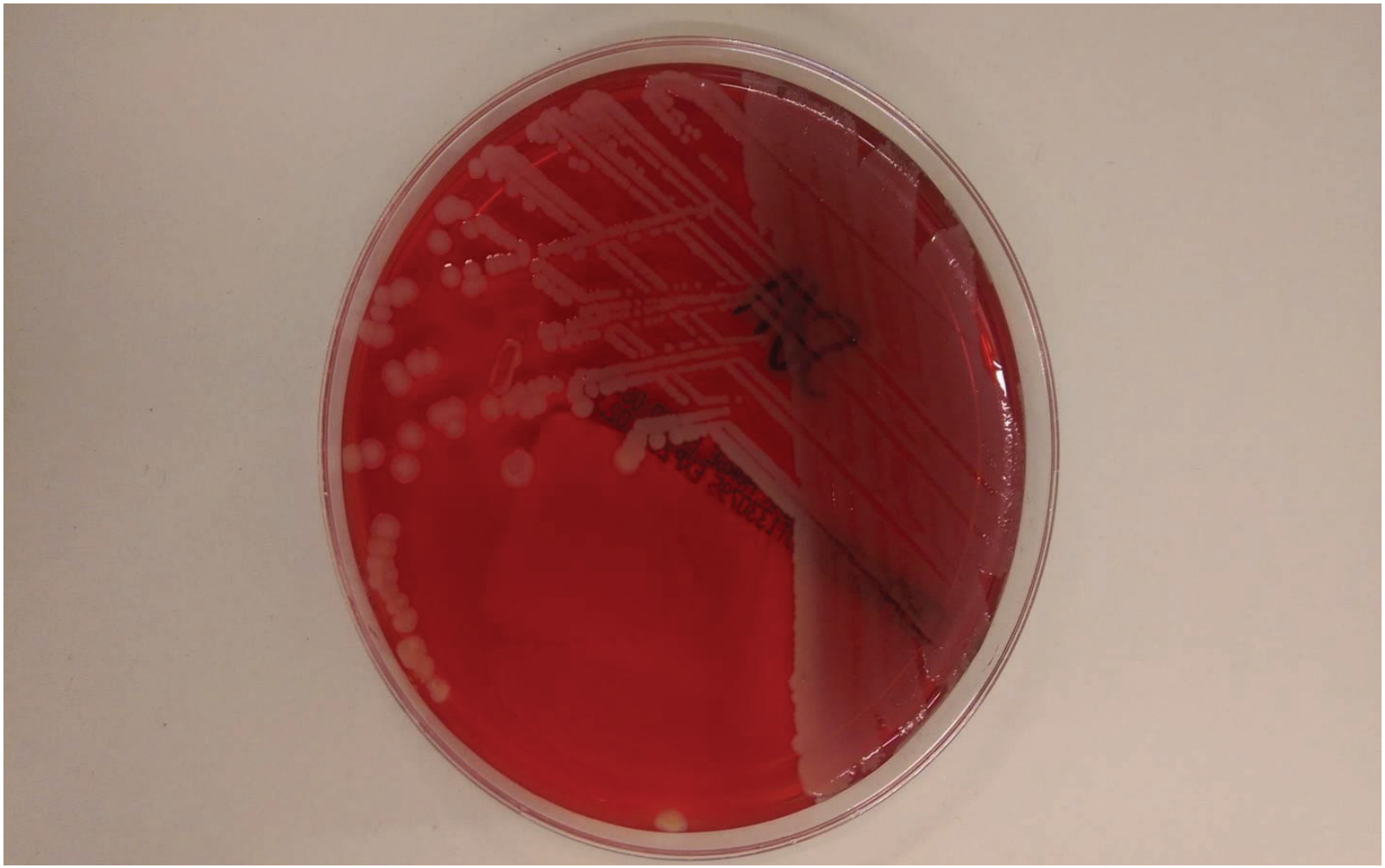
Site 5: Top of the Door

Site 8: Window sill

Site 7: Toilet handle

Site 1: Bathroom door handle (inside)

What's so special about *S.aureus*?



Baird Parker selective agar showing black colonies of *Staphylococcus* spp.

Site 3: Kettle handle

Sites 2 and 6: Telephone and TV Remote

Main microbiological characteristics of each site

Site 1 (**Bathroom door handle**): Staph, Micrococci, **Gram neg**, **Candida**

Site 2 (**Telephone**): Staph, Micrococci, **Gram neg**, ***S.aureus***

Site 3 (**Kettle handle**): Staph, Micrococci, **Gram neg**, ***S.aureus***

Site 4 (**Bedside table**): Staph, Micrococci, **Bacillus**, **Fungi**

Site 5 (**Door top**): **Bacillus**, Staph, Micrococci, **Fungi**

Site 6 (**TV remote**): Staph, Micrococci, ***S.aureus***, **Gram neg**

Site 7 (**Toilet handle**): Staph, **Gram neg** (*20% no growth!)*

Site 8 (**Bedroom window sill**): Staph, Micrococci, **Bacillus**, **Fungi**

Staph aureus; Gram-negative bacteria; and fungi

Staph aureus: one or more sites positive in 35*/100 homes
Found predominantly on **kettle handle**; **TV remote;** and **telephone;**
No MRSA detected

Gram negative bacteria (mostly environmental): one or more sites positive in 70/100 homes; found predominantly on **kettle handle**; **TV remote**; **telephone;** and **bathroom door handle**

Fungi (filamentous) usually with Bacillus spp: one or more sites in 32/100 homes
Found predominantly on **door top**; **window sill;** and **bedside table**

Candida predominantly favoured bathroom door handle (site 1)

Most heavily contaminated site was the **top of the bedroom door**;
the site most likely to yield 'no growth' was the **toilet handle**!!

**S.aureus is carried by approx. one third of humans*

Identification of cultivable Gram-negative bacteria

Most isolates identified as *Pantoea* spp. or *Pantoea agglomerans*

Also found:
Acinetobacter baumannii (standard resistance patterns)
Sphingomonas paucimobilis
Lerclercia adecarboxylata
Paracoccus yeei
Klebsiella pneumoniae (one isolate resistant to amoxicillin)
Enterobacter cloacae
Roseomonas gilardii
Acinetobacter lwoffii
Moraxella spp.
Methylobacteria

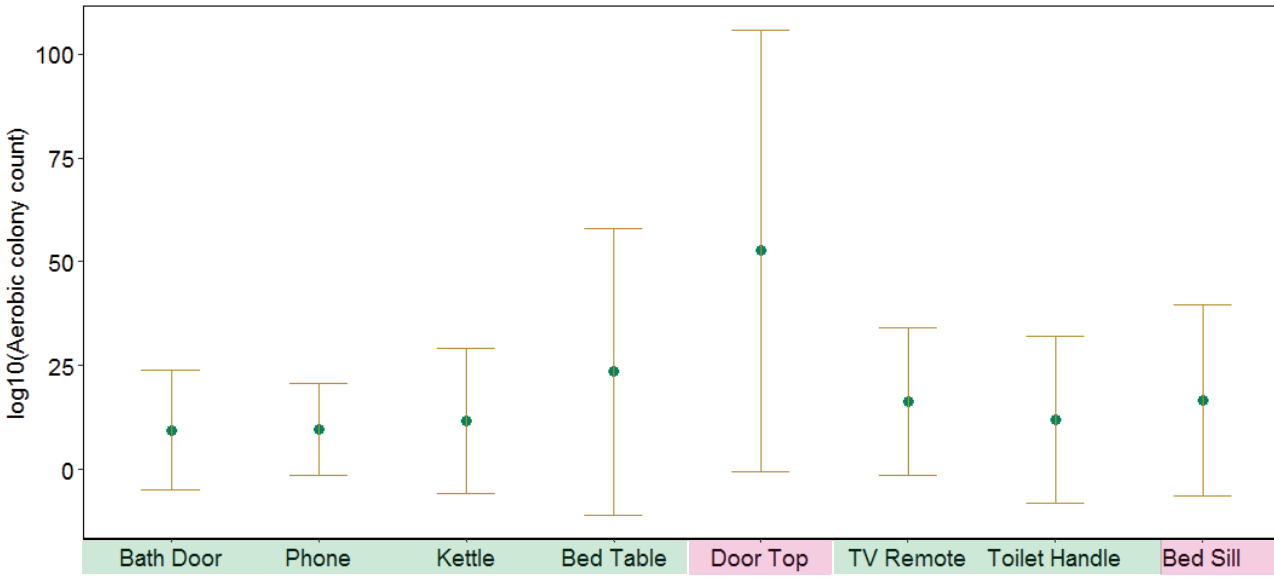
NB. Most awarded 'poor discrimination' by VITEK

None were multiply resistant to antibiotics

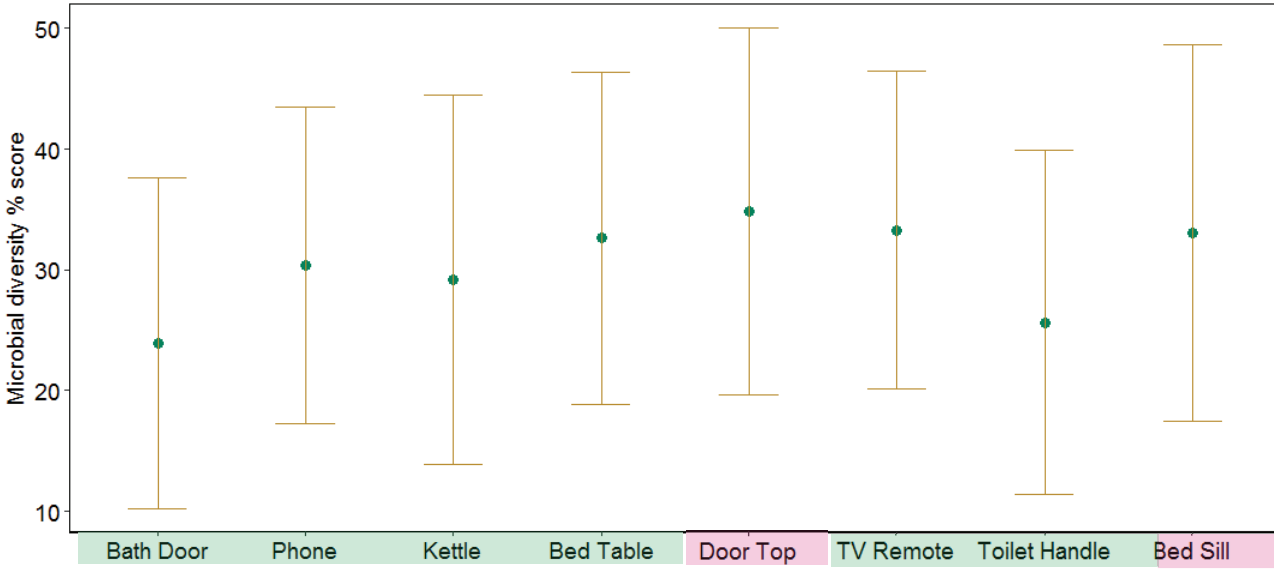
Conclusions so far

1. **Each site demonstrated common microbiological features;**
2. **Each home has its own unique microbiome;**
3. **Kettle handle, TV remote and telephone were most likely to host *S.aureus* and Gram-negative bacteria;**
4. **Fungi and Bacillus are most commonly found on bedroom door top, window sill and bedside table;**
5. **Yeasts were mostly recovered from bathroom door handle;**
6. **The site most likely to yield 'no growth' was the toilet handle!**
7. **While some bacterial pathogens were identified, none were multiply resistant to antibiotics**

Microbial quantity and diversity



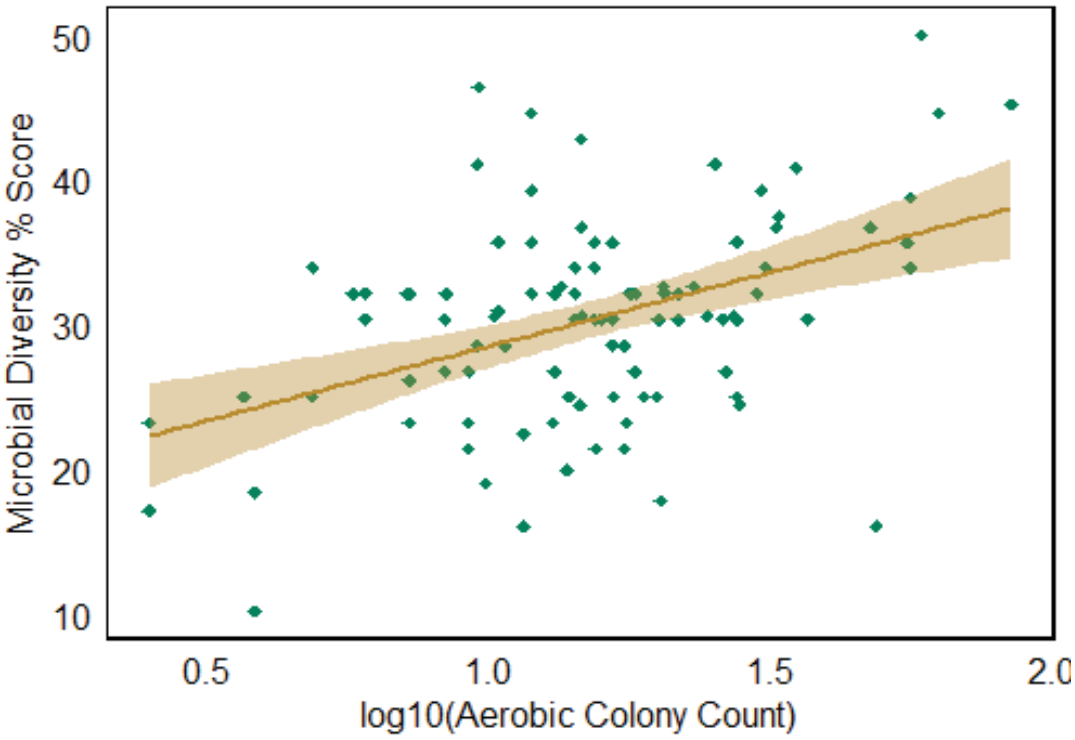
- **Significant difference in microbial count between sites (p<0.001) as well as touch sites vs non-touch sites (e.g. Door top vs Kettle)**
- **For each of the following: *Staphylococcus aureus*, *Micrococcus*, *Bacillus*, Fungi, Gram-positive cocci, Gram-negative rods and Gram-negative cocci a mark was given if they were found in a particular sample and the overall diversity score for that sample was calculated as a %.**



- **Bathroom surfaces had the lowest diversity (p<0.0001) – mainly Gram positives**
- **Houses with young children showed higher ACC and higher diversity**

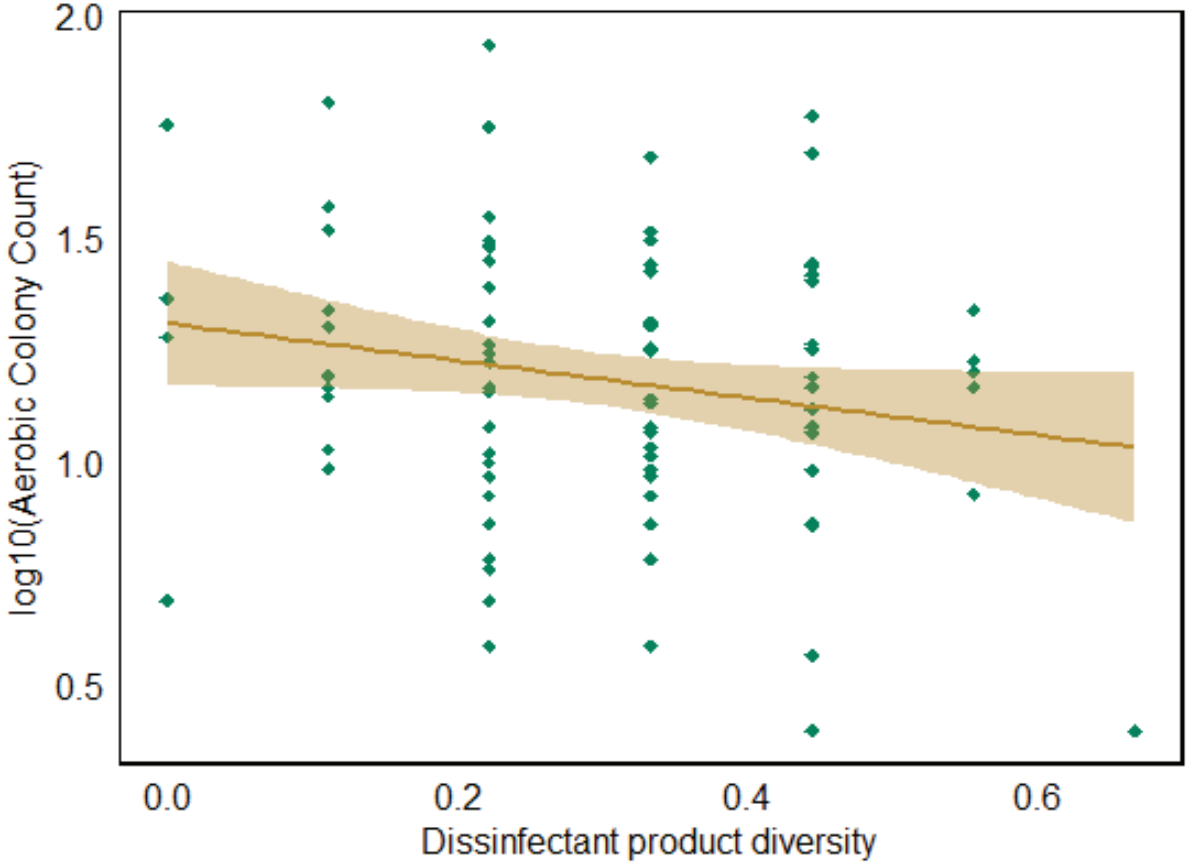
Microbial count and diversity

- As the microbial count increases at a site so does the range of species that are likely to be present ($p<0.001$).
- Fungi presence correlated with increasing ACC count ($p<0.05$) but presence of Gram-negatives did not correlate with increasing diversity.



Microbial diversity % score plotted against log_{10} ACC

Disinfectant Range



Houses that use wider varieties of disinfectant products have a slightly lower ACC ($p<0.05$), but there is no difference for bleach vs no bleach users.

Wider ranges of products also reduces chances of finding Gram-negatives. No effect on fungi

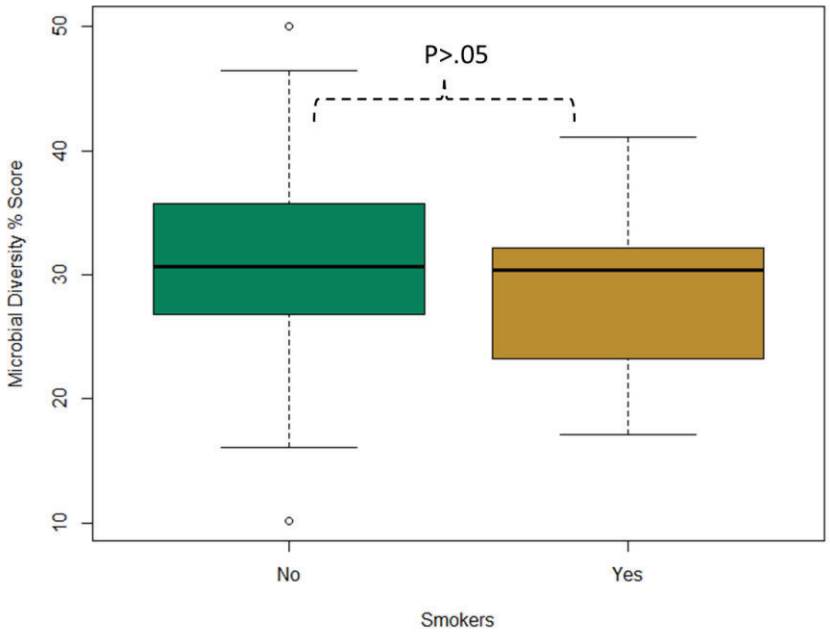
There were no statistically significant relationships between reported window opening, trickle vent usage or ventilation type and either the total ACC or with ACC from three specific sites in the bedroom: bedside table, window sill and door top.

These sites were selected for analysis as they were considered to be the sites that might be most influenced by deposition of microorganisms from the air.

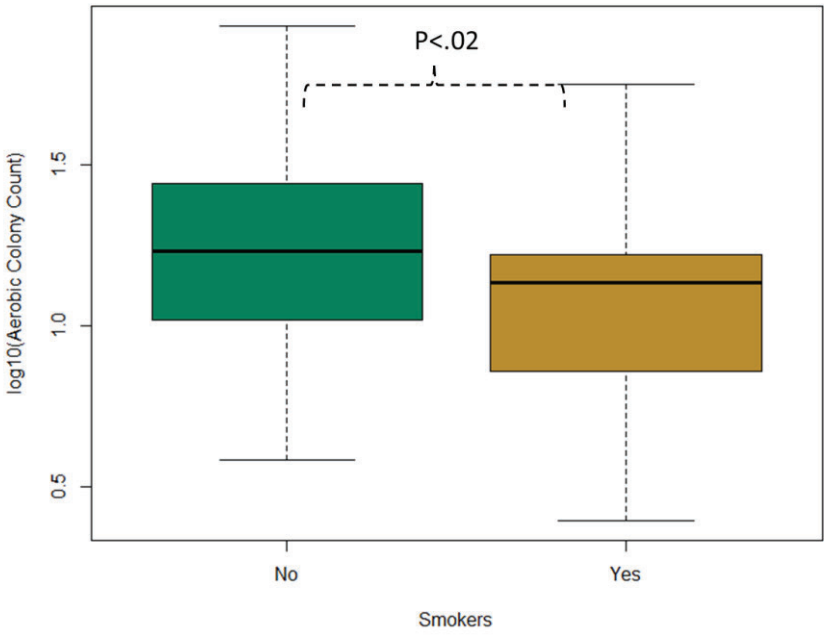
Heavy use of disinfectant may skew the findings for window opening, i.e. the tendency to have a contaminated home from never opening windows could be alleviated by lots of disinfectant use

Smoking

- **There is a reduction in overall microbial quantity in smoking households ($p<0.02$) which seems to get stronger as the number of smokers increases ($p<0.05$). But diversity cannot be distinguished nor is there a change in likelihood of finding Gram –ves (odds ratio =1.7 , 95%CI 0.4-3.6)**



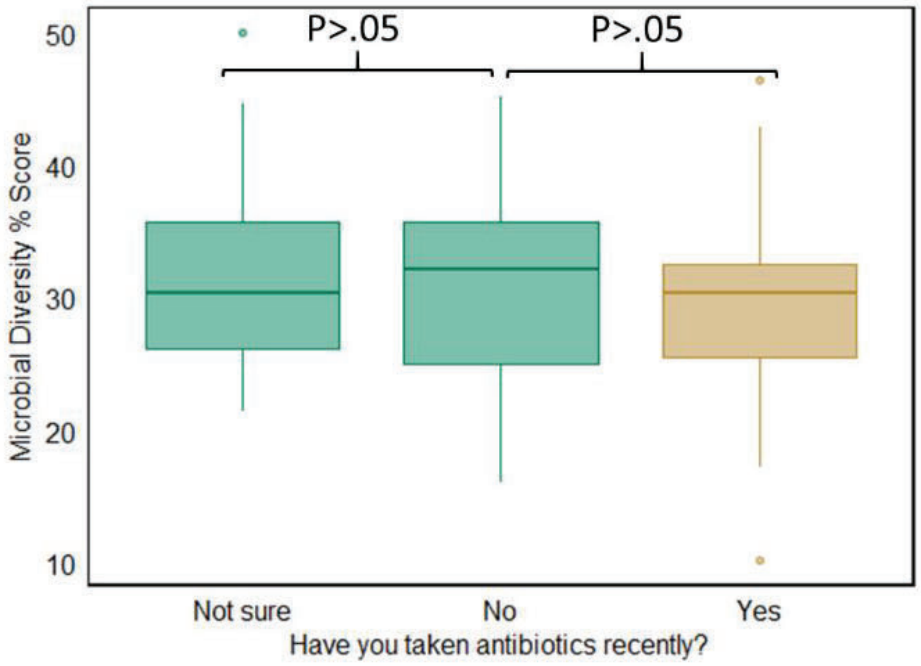
a) Microbial diversity score



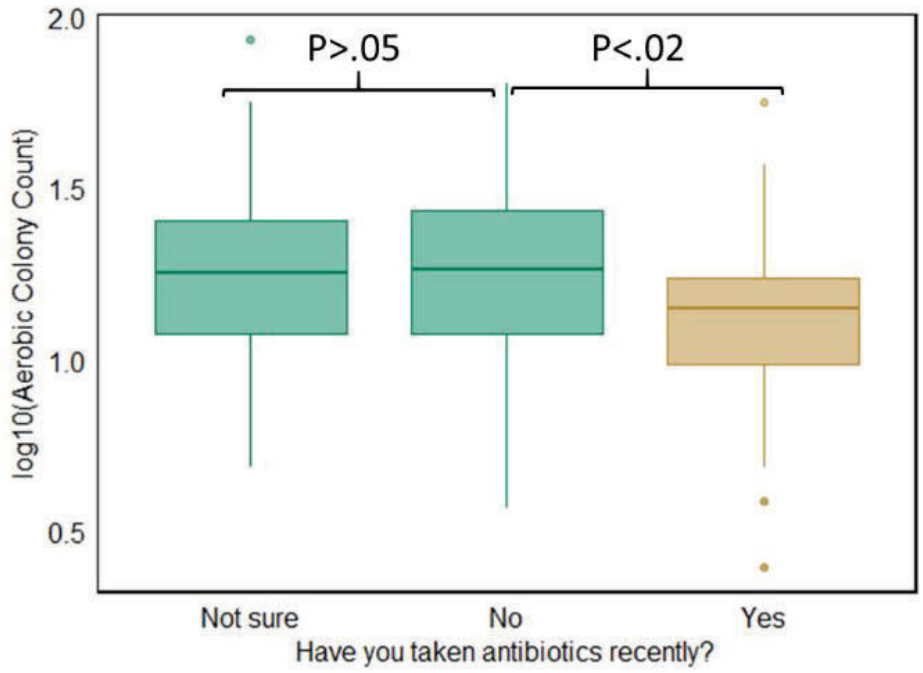
b) log10 ACC

Effect of antibiotics

Those with recent antibiotic use show a small reduction in colony counts. Whether this is a direct effect of the drugs or whether people are more vigilant with cleaning when they have an infection is hard to say.



a) Microbial diversity score

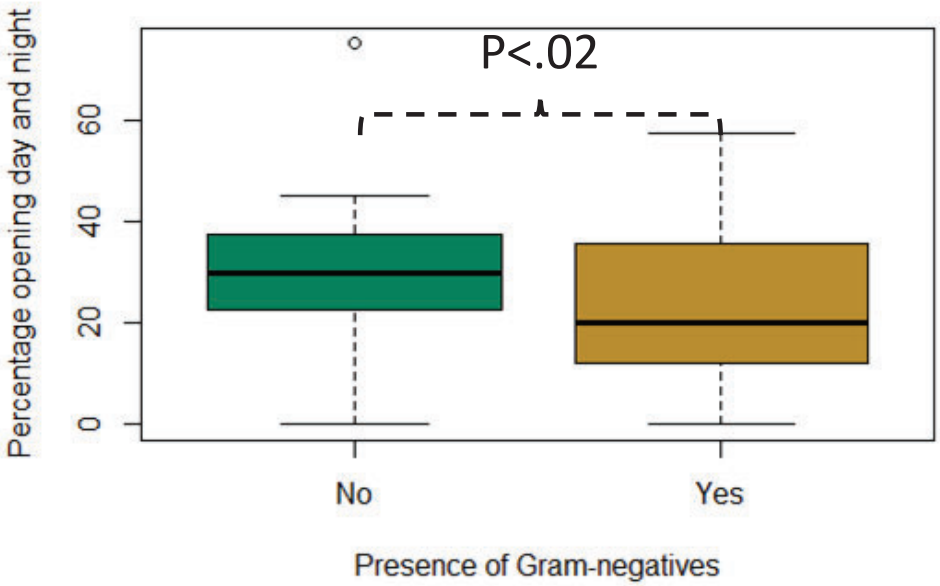


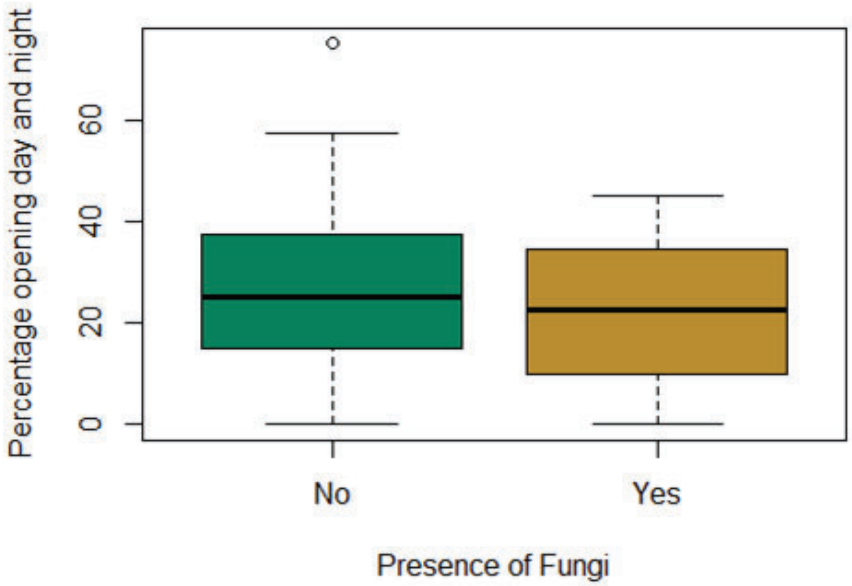
b) log10 ACC

Effect of Window Opening %

Window opening affects presence of Gram negative bacteria (p<0.02). Also, more window opening = less Gram negatives (odds ratio 0.97).

Weak association with fungi presence.





‘Dirty water scandal at Glasgow NHS super hospital’

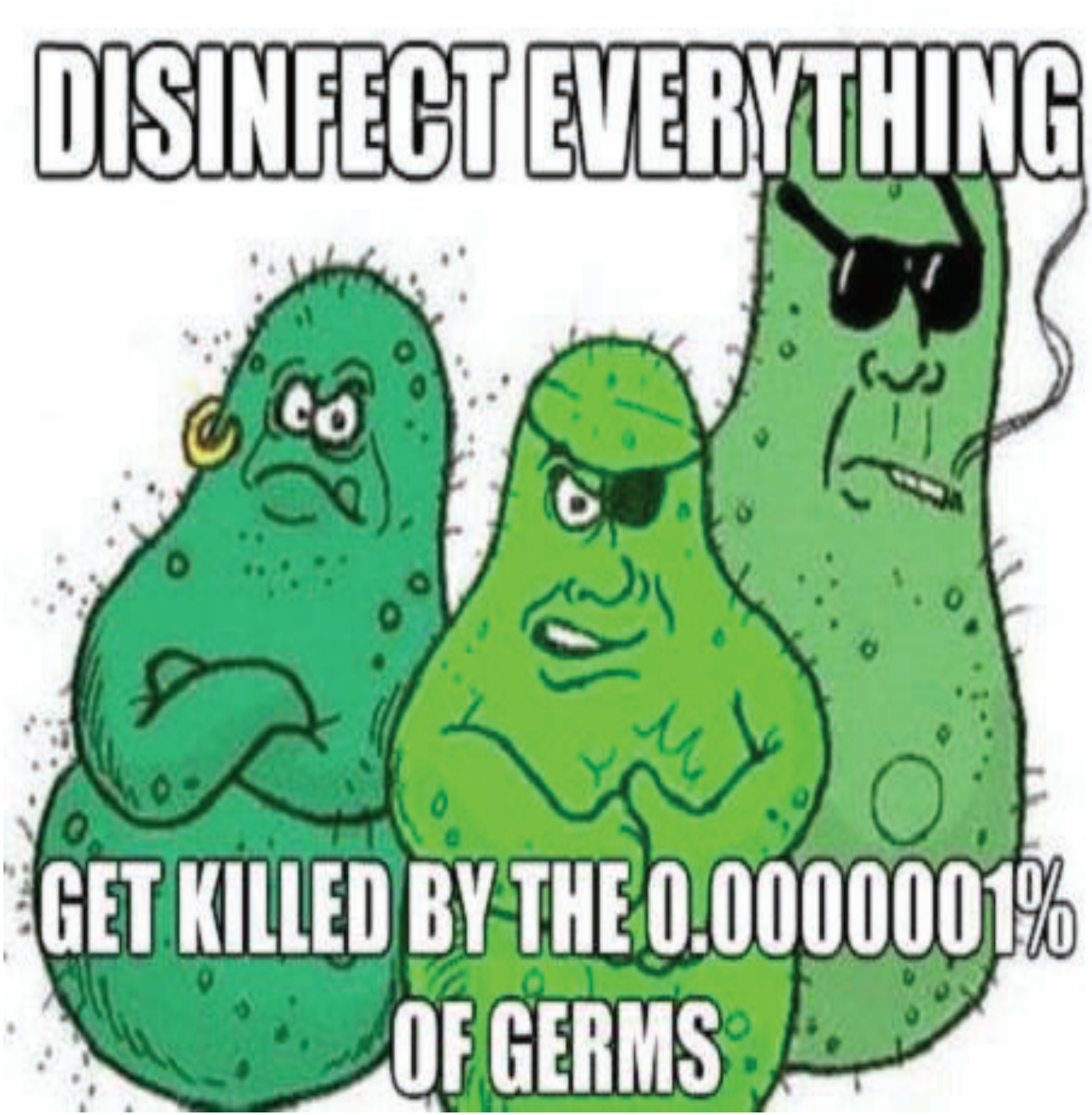
https://www.parliament.scot/S5_HealthandSportCommittee/Inquiries/HS-S5-19-HHHE-A2.pdf

Summary

- Greater ACC correlated with higher diversity
- Window opening frequency reduced Gram-negatives
- Disinfectant range also reduced chances of finding Gram-negatives (but is this because these people simply cleaned more often?)
- Smoking households had lower ACC and *tendency* to lower diversity
- Antibiotic use appeard to reduce ACC and a *tendency* to reduce diversity

Acknowledgements

All the staff in the Hairmyres Microbiology laboratory, especially Janice McLaren and Louise McNally


DISINFECT EVERYTHING
GET KILLED BY THE 0.0000001%
OF GERMS

Influence of Ventilation design on the prevalence of anti-microbial resistant bacteria in homes

Stage 2: Environmental Monitoring

Dr. Gráinne McGill, MEARU, Glasgow School of Art

Arts & Humanities Research Council

NHS Lanarkshire

Mackintosh Environmental Architecture Research Unit The Glasgow School of Art

University of Leeds

Selection of homes

- Household survey data used to select homes for Stage 2
- 96 Households interested in participating (contact numbers available for 37)
- Delay due to fire may have affected recruitment
- Selection of homes based on:
  - Willingness to participate
  - Ventilation provision (homes selected with different ventilation strategies)
  - Ventilation behavior (homes selected based on reported window opening
  - Dwelling age (homes constructed since 2009)

Three main categories:

1. MVHR (6 homes)
2. Naturally ventilated - low window opening (6 homes)
3. Naturally ventilated – high window opening (10 homes)

Selection of homes

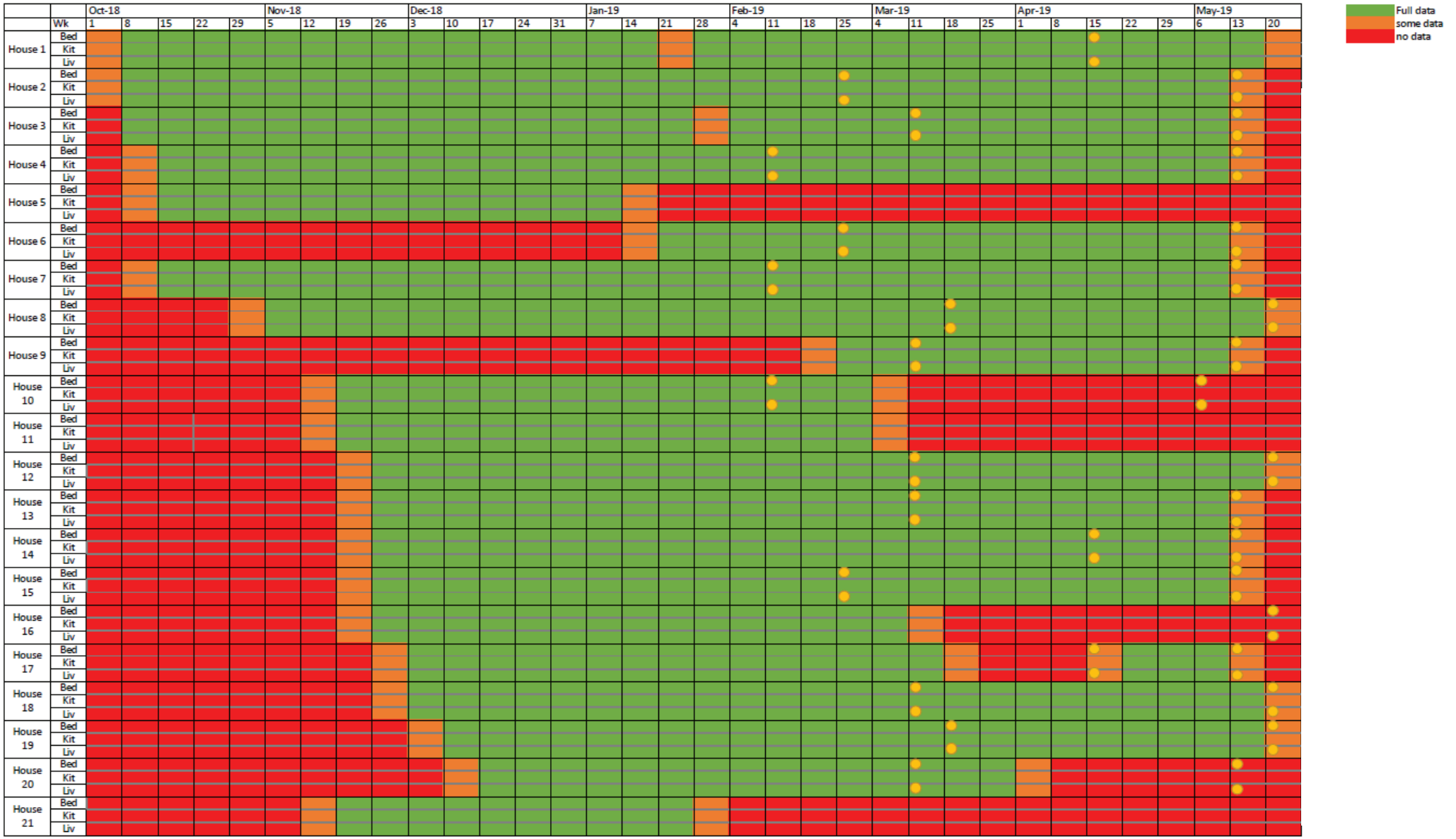
Cat.	Code	Site	Build year	Typology	No. people	Occupant age	Pets?	Bed window night	Total window opening freq
MVHR	House 19	Lunestone	2017	Terraced	3	21,22,52	No	Never	25%
	House 10	Lunestone	2017	Flat	2	62,65	No	Never	24%
	House 04	Lunestone	2017	Flat	1	66	No	Never	0%
	House 07	Lunestone	2017	Flat	2	48,77	No	Never	18%
	House 11	Lunestone	2017	Flat	2	70,76	No	Never	23%
	House 09	Lunestone	2017	Terraced	4	21,24,55,56	Yes	Daily	48%
Nat – Low window opening	House 16	Doonholm	2016	Flat	1	63	No	Never	0%
	House 18	Doonholm	2016	Flat	1	56	1 dog	Never	0%
	House 01	Murray	2011	Semi-detached	2	68, 71	No	Never	3%
	House 22	Mosspark	2016	Flat	1	64	Hamster	Never	0%
	House 14	Kirktonholme	2009	Flat	1	75	Cat	Never	15%
	House 20	Lincoln	2017	Flat	1	60	No	Never	15%
Nat vent - high window opening	House 13	Chantinghall	2013	Cottage	2	78, 80	Dog	Daily	43%
	House 03	Waterford	2016	Flat	2	61, 64	No	Daily	45%
	House 15	Fenwick	2013	Flat	1	60, 63	Dog	Never	38%
	House 08	Kirktonholme	2009	Flat	2	69, 71	No	Weekly	43%
	House 17	Lincoln	2017	Flat	2	58, 60	No	Weekly	40%
	House 12	Lincoln	2017	Flat	1	63	No	Daily	45%
	House 21	Lincoln	2017	Flat	2	43, 59	Dog	Daily	38%
	House 05	Slamannan	2010	Flat	1	64	Dog	Never	38%
	House 06	Slamannan	2010	Flat	1	64	Dog	Never	38%
	House 02	Slamannan	2010	Flat	1	64	No	Never	38%

Environmental monitoring

- Information sheet & consent form
- Sensors installed in main bedroom, living room, kitchen & outside
- Temperature, RH & CO_2 logged at 10 minute intervals
- Low cost foobot IAQ sensors (temp, RH, TVOCs, PM2.5, CO2)
- Mifi device – wifi connection
- First time using these devices – identified some technical issues (poor signal, no. sensors needed replaced, needed to change wifi passwords, lack of notification when sensors not logging

Data availability

Temperature and RH data availability (microbial sampling in yellow)

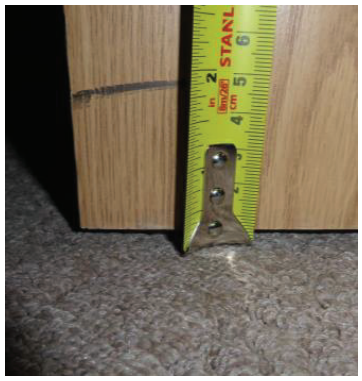


Data availability

Carbon dioxide data availability (microbial sampling in yellow)

Ventilation audit

- Airflow rate measurements – mechanical vent systems
- Trickle vent location, size & position
- Make and model of mechanical ventilation systems
- Operating condition of mechanical ventilation systems
- Filter condition
- Door undercuts
- Airflow pathways
- Occlusions to ventilation grilles / openings



Building survey

- Photo survey
- Building walk-through
  - Floor plan layouts, window locations etc.
  - Floor level
  - Type of heating source
  - Wall surfaces
  - Floor surfaces
  - Visible mould (if present)
  - Cleaning products
  - Meter readings

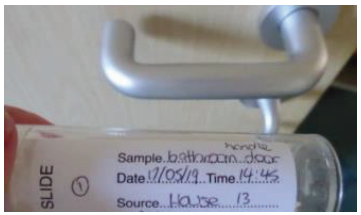
Occupant interview

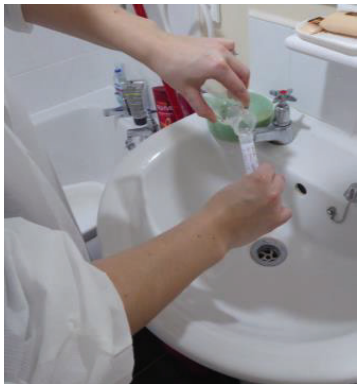
- Semi-structured interviews undertaken with building occupants to gather data on:
  - Occupancy regimes and profiles
  - Cleaning regimes and products
  - Pet ownership (including use of antibiotics)
  - Bedroom night time conditions (door position, window position, time go to bed etc.)
  - Any problems with water damage / mould
  - Medication and health, particularly antibiotic use
  - Ventilation behaviour (knowledge and use of mechanical ventilation systems)
- Interviews recorded with Dictaphone

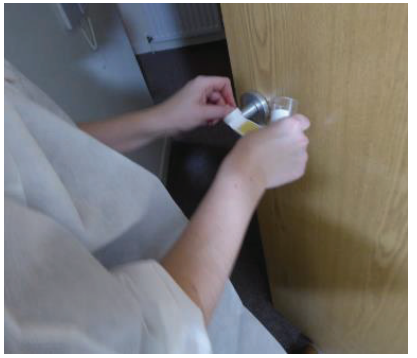
Microbial sampling

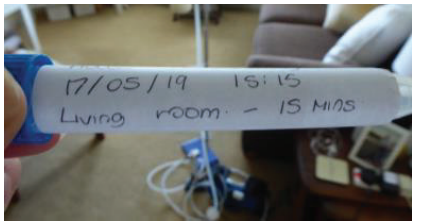
- Air samples: two seasons (Spring and Summer)
  - Bedroom (30 minutes)
  - Bathroom (15 minutes)
  - Living room (15 minutes)
  - Outside (15 minutes)
- Surface samples – 13-15 sites
- Finger tip samples (building occupants)
- Samples placed in cold storage box for transport
- Air samples posted to University of Leeds for analysis
- Surface and finger samples analysed by Hairmyres Microbiology Lab

Surface sampling locations
Bathroom door handle
Telephone/mobile
Kettle handle
Bedside table
Top door frame (bed)
Remote control
Toilet handle
Window ledge (bed)
Top door (bathroom)
Behind radiator (bed)
Extract (bathroom)
Supply (bed)
Top window frame (bed)
MVHR left filter
MVHR right filter





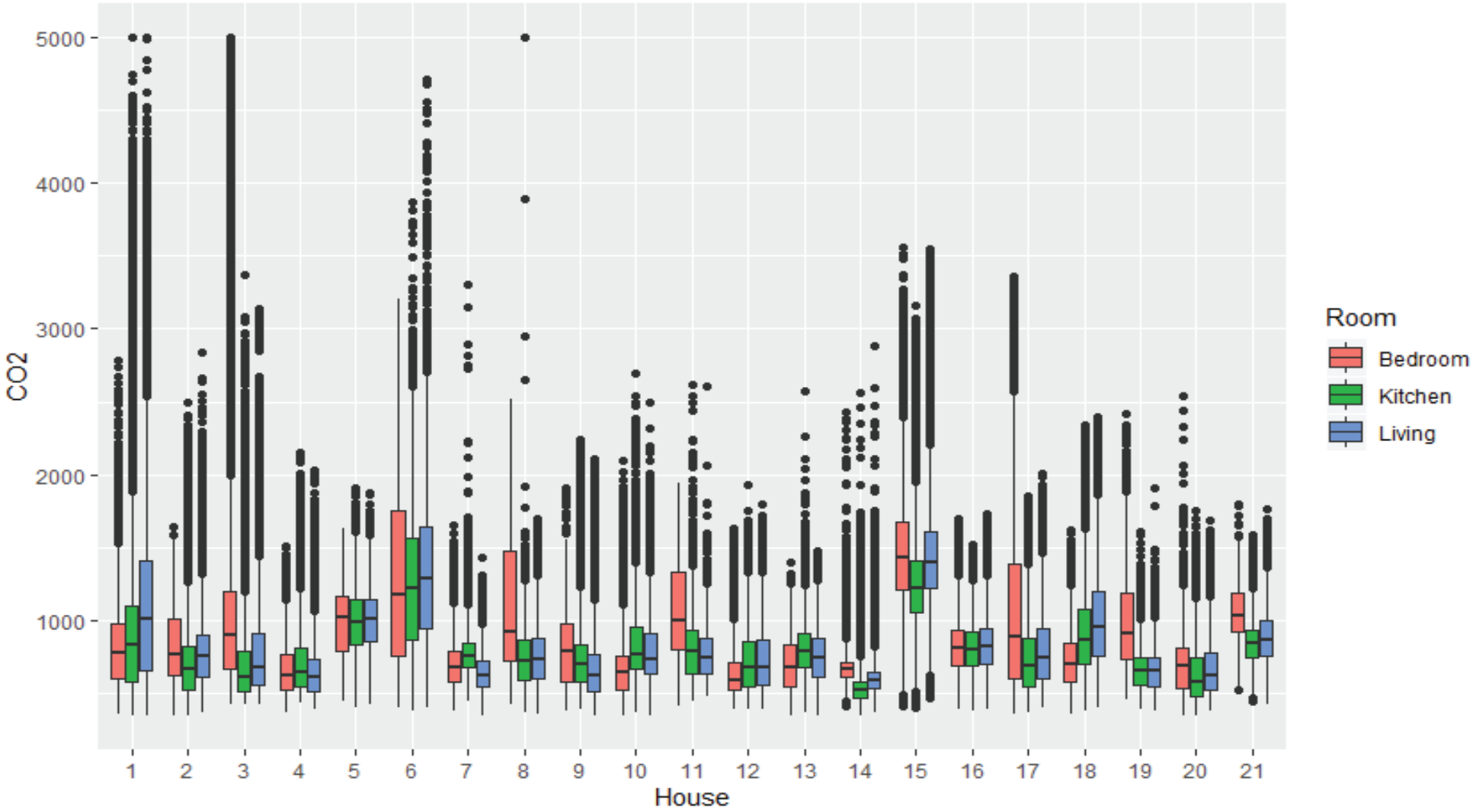




Initial results: Carbon dioxide

Overall CO_2 levels (whole monitoring period) by room, for each home

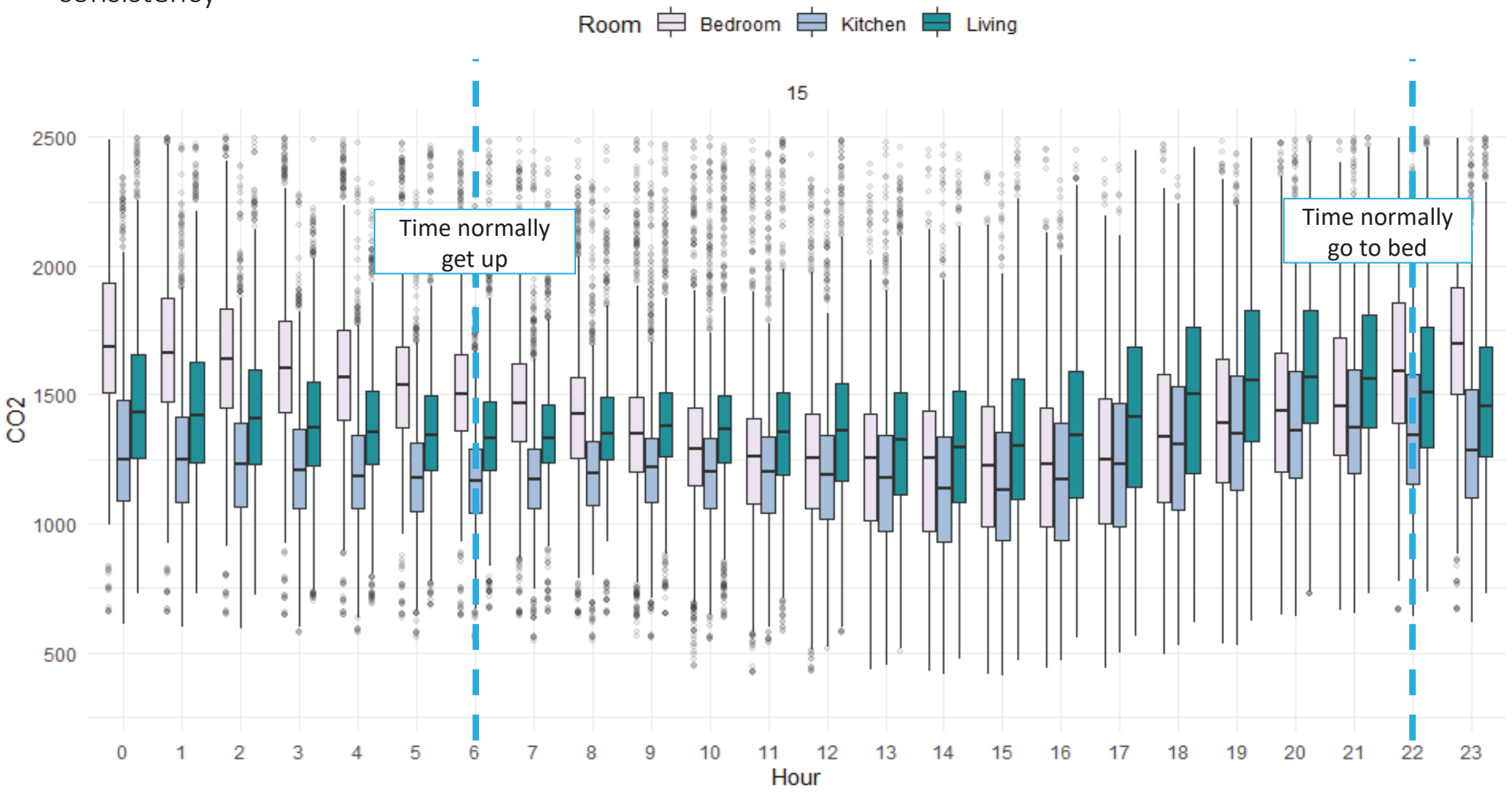
- CO_2 levels typically higher in bedroom
- CO2 levels generally remained below 1,500ppm, however two homes (House 6 and 15) notably higher



Initial results: Carbon dioxide

Determining typical bedroom ‘night time’ occupied period

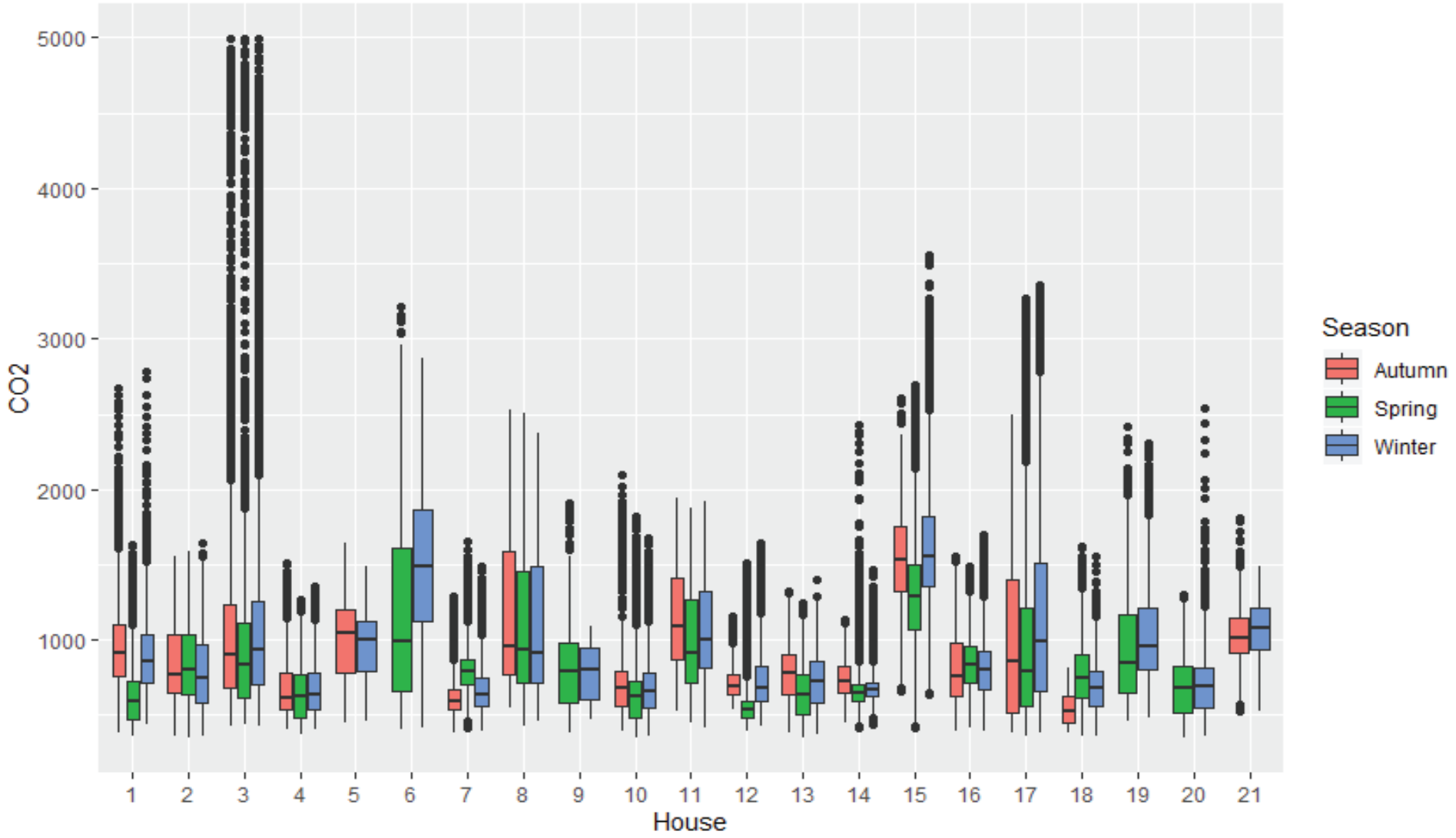
- Bedroom night time occupancy determined based on reported time occupants normally go to bed and get up each morning
- This information was compared with hourly bedroom CO2 data – found reasonable level of consistency



Initial results: Carbon dioxide

Bedroom carbon dioxide levels in each home, by season

- Bedroom carbon dioxide levels considerably higher during night time occupied periods
- Bedroom carbon dioxide levels did not vary considerably by season



Initial results: Carbon dioxide

Bedroom night time carbon dioxide levels

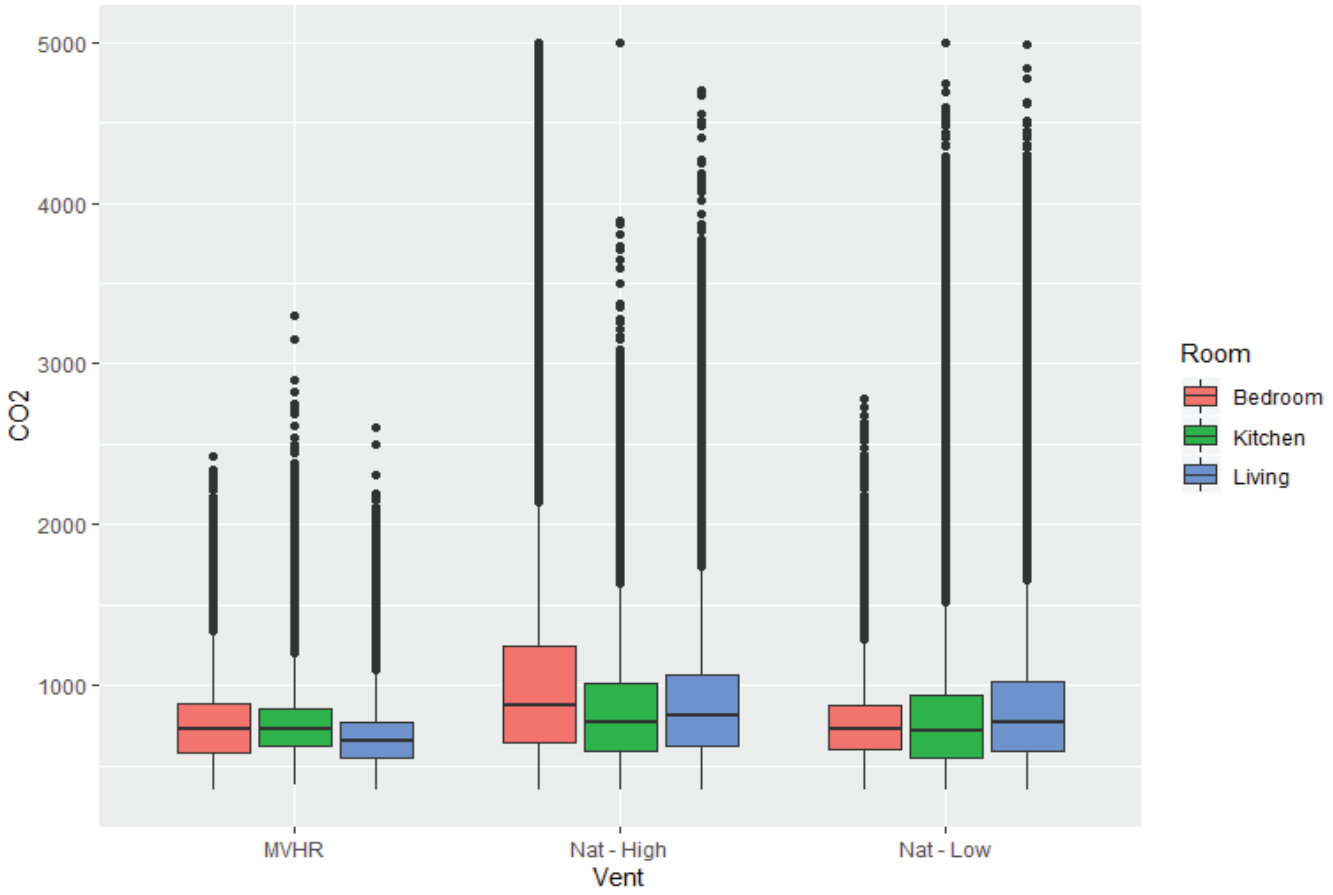
- Mean bedroom night time carbon dioxide levels ranged from 716ppm to 1678ppm
- All homes exceeded the recommended carbon dioxide guideline level of 1,000ppm at night.

House No.	Vent cat	Window opening (%)	SD CO_2	Max CO_2	Mean CO_2	% time exceeding 1,000ppm
1	N - Low	3%	290	1951	914	38%
2	N - High	38%	250	1565	950	51%
3	N - High	45%	773	4995	1465	78%
4	MVHR	0%	114	1509	760	1%
5	N - High	38%	253	1638	1067	77%
6	N - High	38%	558	2738	1520	76%
7	MVHR	18%	167	1522	720	6%
8	N - High	43%	422	2523	1566	89%
9	MVHR	48%	194	1906	988	45%
10	MVHR	24%	243	1912	821	17%
11	MVHR	23%	198	1878	1378	95%
12	N - High	45%	299	1611	739	31%
13	N - High	43%	159	1296	844	19%
14	N - Low	15%	93	1333	718	25%
15	N - High	38%	391	3555	1678	97%
16	N - Low	0%	182	1632	887	25%
17	N - High	40%	725	3311	1533	69%
18	N - Low	0%	213	1450	716	9%
19	MVHR	25%	433	2163	1059	63%
20	N - Low	15%	172	2535	755	6%
21	N - High	38%	385	1804	1017	71%

Initial results: Carbon dioxide

Ventilation categories and measured CO_2 levels (by room)

- There was no clear association between ventilation categories and measured carbon dioxide levels
- Reported whole house window opening did not appear to correspond to measured carbon dioxide levels in any room
- May be explained by small sample size and wide range of factors affecting CO2, such as mechanical ventilation systems, occupancy levels, floor area, door opening, ventilation pathways, cooking etc.



Initial results: Temperature

Percentage of time temperature thresholds were exceeded

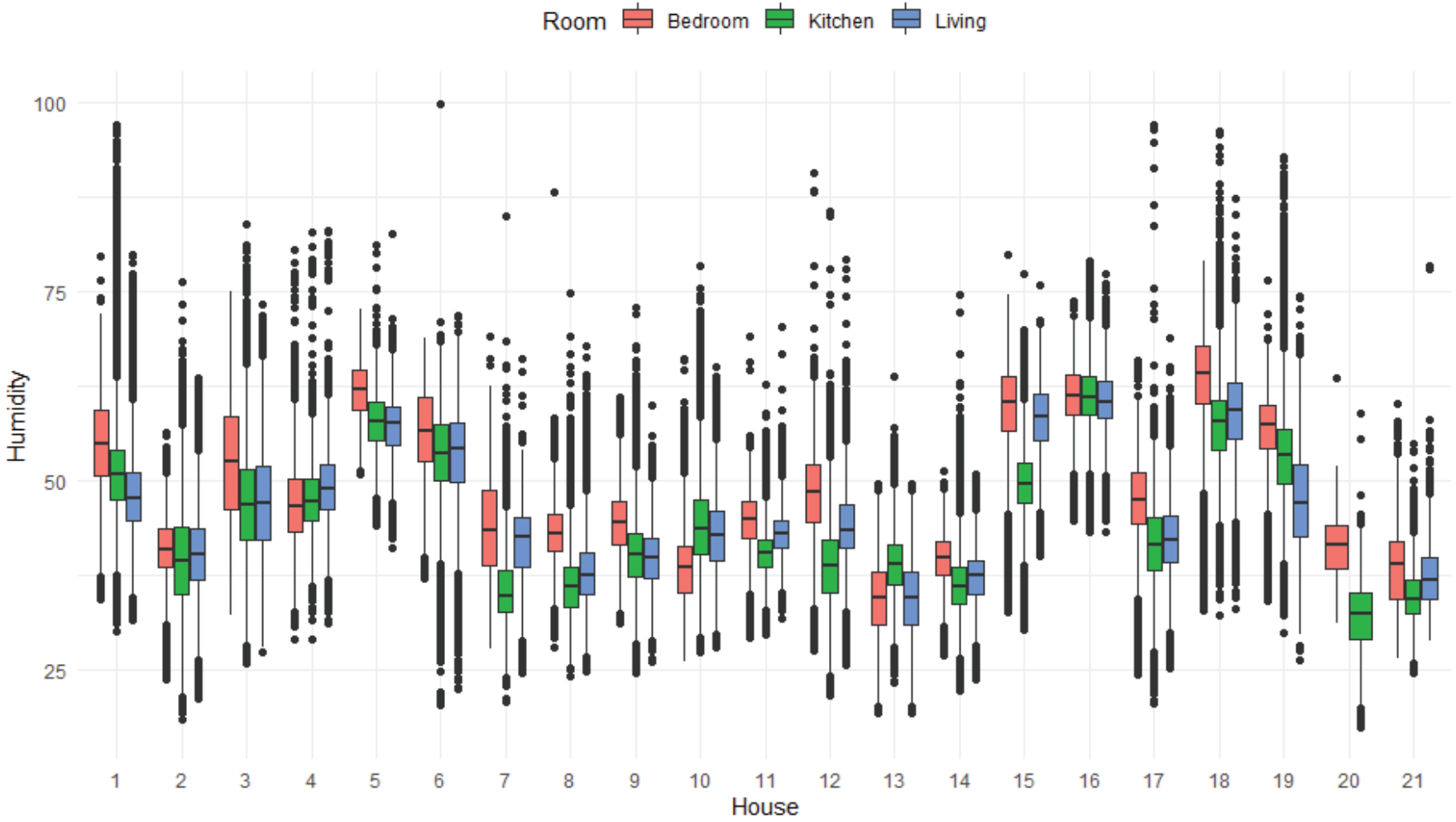
- While measurements were not undertaken during the summer season, high incidences of overheating were still observed.
- Overall, nine homes (43%) exceeded the CIBSE overheating threshold of 25 °C for more than 5% of the occupied time, in at least one of the monitored rooms.

	Occupied hours (based on reported night time occupancy)									
House No.	% time bed temp <16	% time bed temp >25	% time bed temp >26	% time bed temp >28	% time living temp <16	% time living temp >25	% time living temp >28	% time kitchen temp <16	% time kitchen temp >25	% time kitchen temp >28
1	13.0	0.0	0.0	0.0	0.0	11.8	0.1	0.0	5.3	0.0
2	4.8	0.7	0.1	0.0	5.1	11.0	0.0	4.9	29.8	1.0
3	10.8	0.0	0.0	0.0	0.7	0.0	0.0	1.4	0.0	0.0
4	0.1	1.0	0.4	0.0	4.3	0.0	0.0	1.3	0.0	0.0
5	41.8	0.0	0.0	0.0	23.4	0.0	0.0	23.6	0.0	0.0
6	25.9	0.0	0.0	0.0	6.4	0.0	0.0	4.1	0.1	0.0
7	0.0	10.2	2.0	0.0	0.0	13.4	2.3	0.0	59.4	0.7
8	0.8	0.1	0.0	0.0	0.4	26.6	0.2	0.3	62.9	10.7
9	0.0	0.0	0.0	0.0	0.1	2.2	0.0	0.0	1.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	25.4	0.0
12	12.7	0.2	0.1	0.0	1.4	1.4	0.0	0.2	8.1	0.3
13	0.0	14.0	4.1	0.0	0.0	52.1	1.3	0.0	1.0	0.0
14	2.1	0.0	0.0	0.0	1.4	4.5	0.0	1.6	0.9	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.1
16	89.7	0.0	0.0	0.0	77.4	0.0	0.0	72.2	0.0	0.0
17	0.0	1.1	0.2	0.0	0.0	3.8	0.0	0.0	4.1	0.0
18	73.7	0.0	0.0	0.0	21.2	0.0	0.0	10.5	0.0	0.0
19	32.9	0.0	0.0	0.0	15.4	0.0	0.0	3.4	0.0	0.0
20	2.3	0.4	0.0	0.0	n/a	n/a	n/a	0.0	44.6	0.0
21	0.6	42.3	31.2	5.6	0.0	57.5	1.6	0.0	90.1	11.7

Initial results: Relative Humidity

Relative humidity levels (whole monitoring period) by room

- Homes with the lowest observed temperatures recorded highest levels of relative humidity, suggesting that high levels of RH in these homes were more likely a function of temperature
- An exception to this is House 15, where high levels of relative humidity were observed despite warm interior temperatures.



Preliminary conclusions

- Ventilation categories (based on reported window opening) do not appear to correlate with measured CO_2 levels
- Mean bedroom night time CO_2 levels exceeded 1,000ppm in 9/21 homes
- High incidences of overheating during heating season, with 9/21 homes exceeding CIBSE overheating threshold (25°C for >5% occupied time)
- Small no. of homes were noticeably colder, with temperatures rarely exceeding 18°Cin one home (House 16)
- One home (House 15) measured considerably higher vapour pressure levels than other homes
- House 15 also recorded highest CO_2 levels, suggesting poor ventilation

Next steps

- Re-characterise the data based on the measured CO_2 and moisture levels
- Sequencing of bioaerosol samples – to determine breakdown of species
- Complete analysis of Stage 2 microbial sampling (air, surfaces, finger tips)
- Statistical analysis to compare differences between housing types, including environmental conditions, no. & type of microorganisms present and proportion resistant to antibiotics
- Undertake analysis of low-cost sensor data (and assess value of data as proxy indicators)
- Define protocols to allow understanding of levels of measurements needed for larger study
- Assess the implications for future design and legislation

Discussion

Questions and Answers