Does the location of sensors matter when monitoring indoor air pollutant exposure in UK homes?

Giorgos Petrou[1], HEICCAM Network[2]

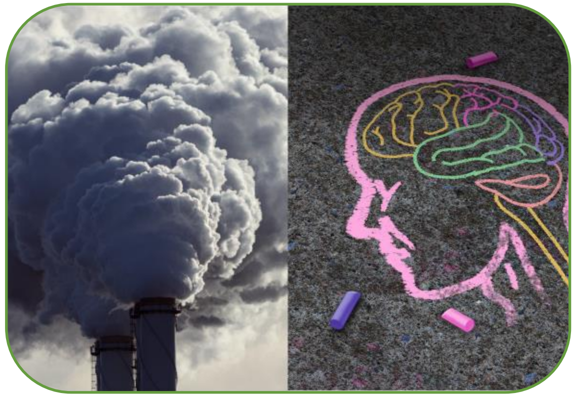
[1] Institute for Environmental Design and Engineering, University College London
[2] Led by School of GeoSciences, The University Of Edinburgh

UCL
THE BARTLETT
INSTITUTE FOR
ENVIRONMENTAL DESIGN
AND ENGINEERING

Context

THE BARTLETT
INSTITUTE FOR
ENVIRONMENTAL DESIGN
AND ENGINEERING

Context



Health Impact of Air Pollution

Indoor Air Quality

Monitoring

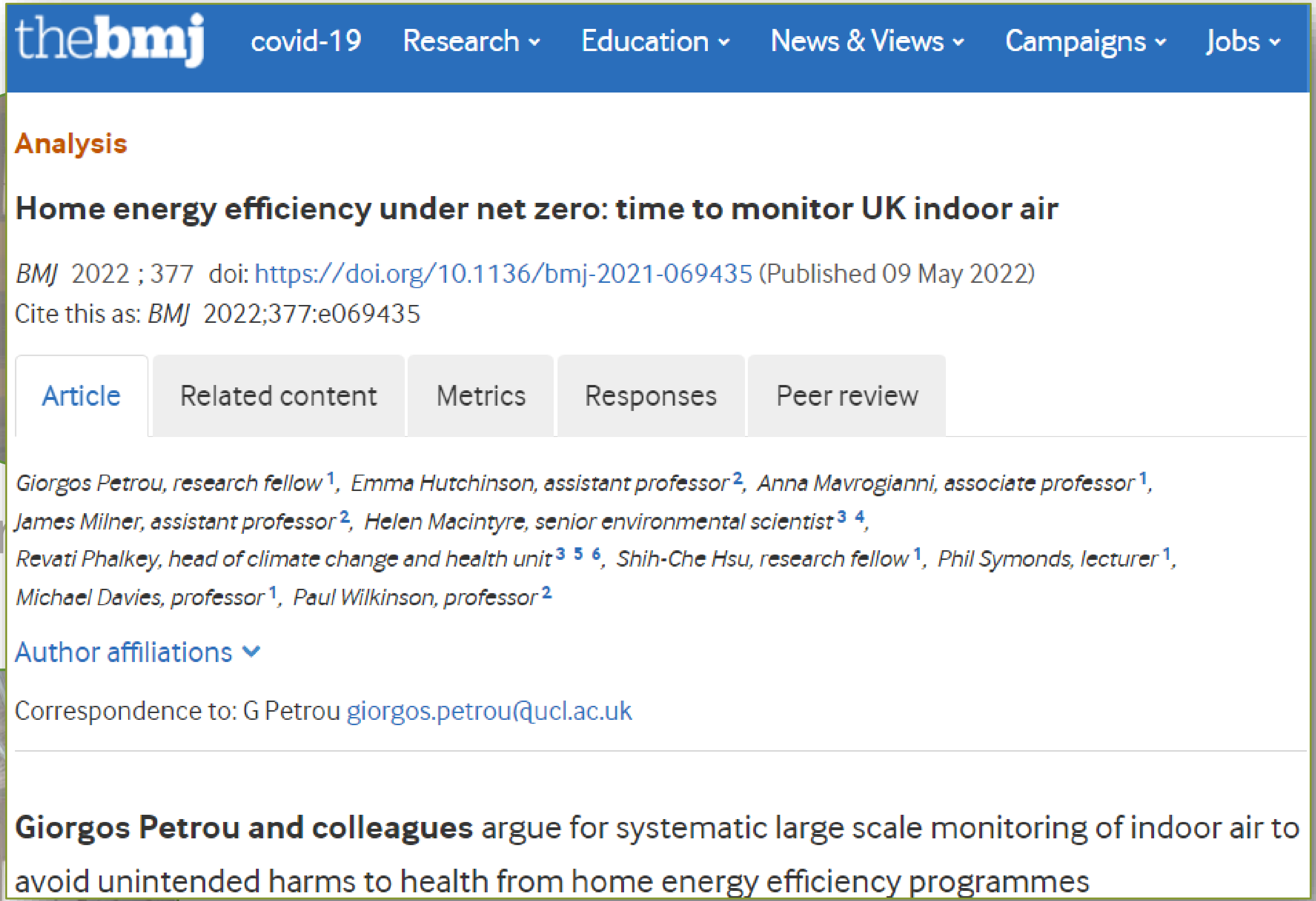
Net Zero

Petrou, G., Hutchinson, E., Mavrogianni, A., Milner, J., Macintyre, H., Phalkey, R., Hsu, S.-C., Symonds, P., Davies, M. and Wilkinson, P. (2022). 'Home energy efficiency under net zero: time to monitor UK indoor air'. *BMJ*, p. e069435. doi: 10.1136/bmj-2021-069435.

Context

Health Impact of Air Pollution

Ir



thebmj covid-19 Research Education News & Views Campaigns Jobs

Analysis

Home energy efficiency under net zero: time to monitor UK indoor air

BMJ 2022 ; 377 doi: https://doi.org/10.1136/bmj-2021-069435 (Published 09 May 2022)
Cite this as: *BMJ* 2022;377:e069435

Article | Related content | Metrics | Responses | Peer review

Giorgos Petrou, research fellow [1], *Emma Hutchinson, assistant professor* [2], *Anna Mavrogianni, associate professor* [1], *James Milner, assistant professor* [2], *Helen Macintyre, senior environmental scientist* [3 4], *Revati Phalkey, head of climate change and health unit* [3 5 6], *Shih-Che Hsu, research fellow* [1], *Phil Symonds, lecturer* [1], *Michael Davies, professor* [1], *Paul Wilkinson, professor* [2]

Author affiliations

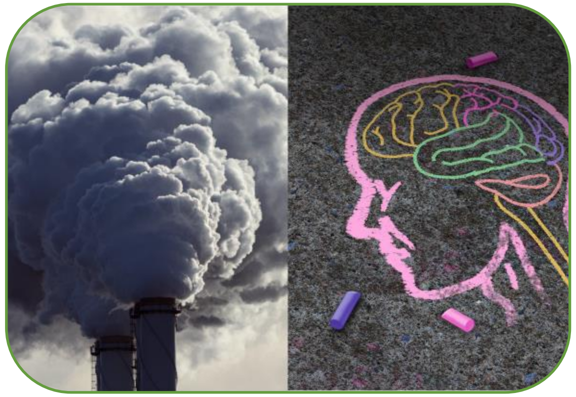
Correspondence to: G Petrou giorgos.petrou@ucl.ac.uk

Giorgos Petrou and colleagues argue for systematic large scale monitoring of indoor air to avoid unintended harms to health from home energy efficiency programmes

Net Zero

Petrou, G., Hutchinson, E., Mavrogianni, A., Milner, J., Macintyre, H., Phalkey, R., Hsu, S.-C., Symonds, P., Davies, M. and Wilkinson, P. (2022). 'Home energy efficiency under net zero: time to monitor UK indoor air'. *BMJ*, p. e069435. doi: 10.1136/bmj-2021-069435.

Context



Health Impact of Air Pollution

Indoor Air Quality

Monitoring

Net Zero

Number and location

Petrou, G., Hutchinson, E., Mavrogianni, A., Milner, J., Macintyre, H., Phalkey, R., Hsu, S.-C., Symonds, P., Davies, M. and Wilkinson, P. (2022). 'Home energy efficiency under net zero: time to monitor UK indoor air'. *BMJ*, p. e069435. doi: 10.1136/bmj-2021-069435.

Research Question

Does the location of sensors matter when monitoring indoor air pollutant exposure in UK homes?

UCL
THE BARTLETT
INSTITUTE FOR
ENVIRONMENTAL DESIGN
AND ENGINEERING

Methods

THE BARTLETT
INSTITUTE FOR
ENVIRONMENTAL DESIGN
AND ENGINEERING

Methods

- Co-simulation
- Pollutants
- Archetypes
- Comparison

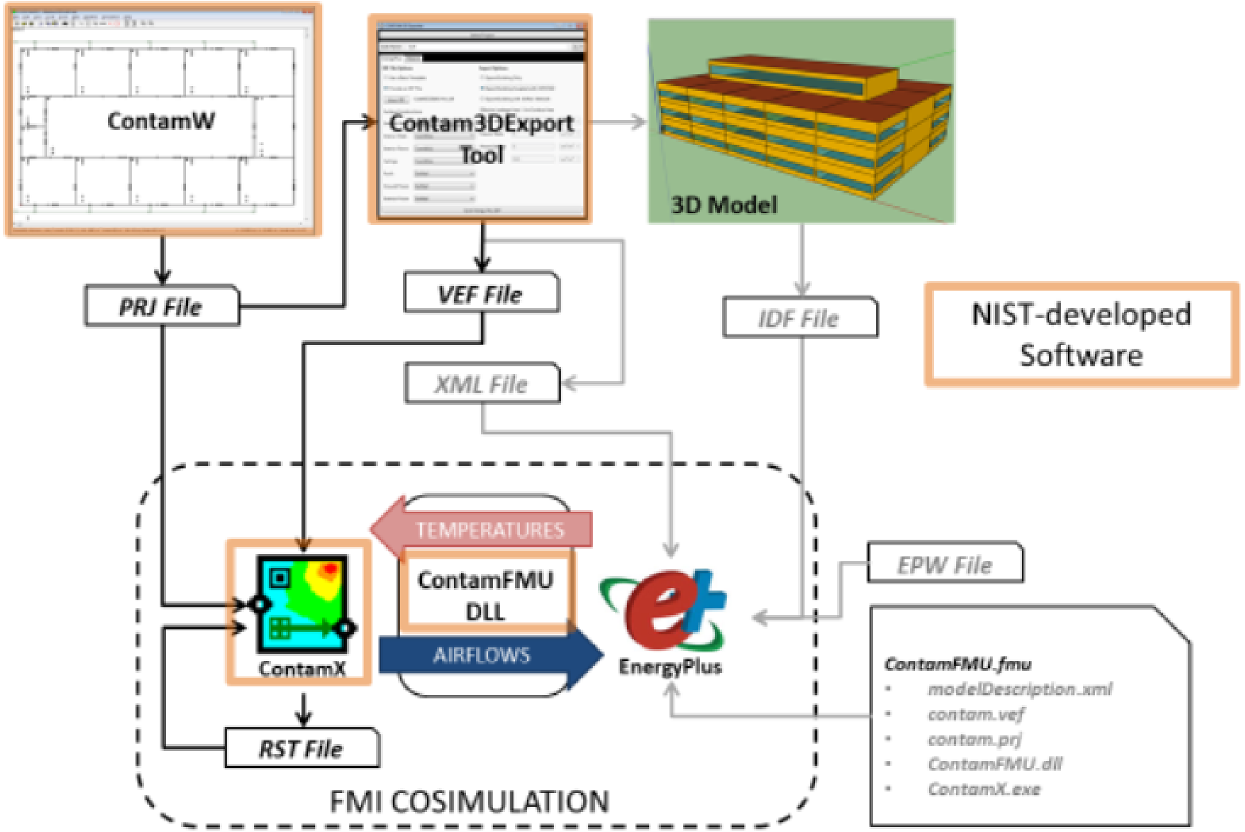


Figure 2. EnergyPlus-CONTAM Coupling Schematic

Dols, W. S., Milando, C. W., Ng, L., Emmerich, S. J. and Teo, J. (2021). ‘On the Benefits of Whole-building IAQ, Ventilation, Infiltration, and Energy Analysis Using Co-simulation between CONTAM and EnergyPlus’. in. *8th International Building Physics Conference*, Copenhagen, Denmark, p. 10.

Methods

- Co-simulation
- **Pollutants**
- Archetypes
- Comparison

Radon

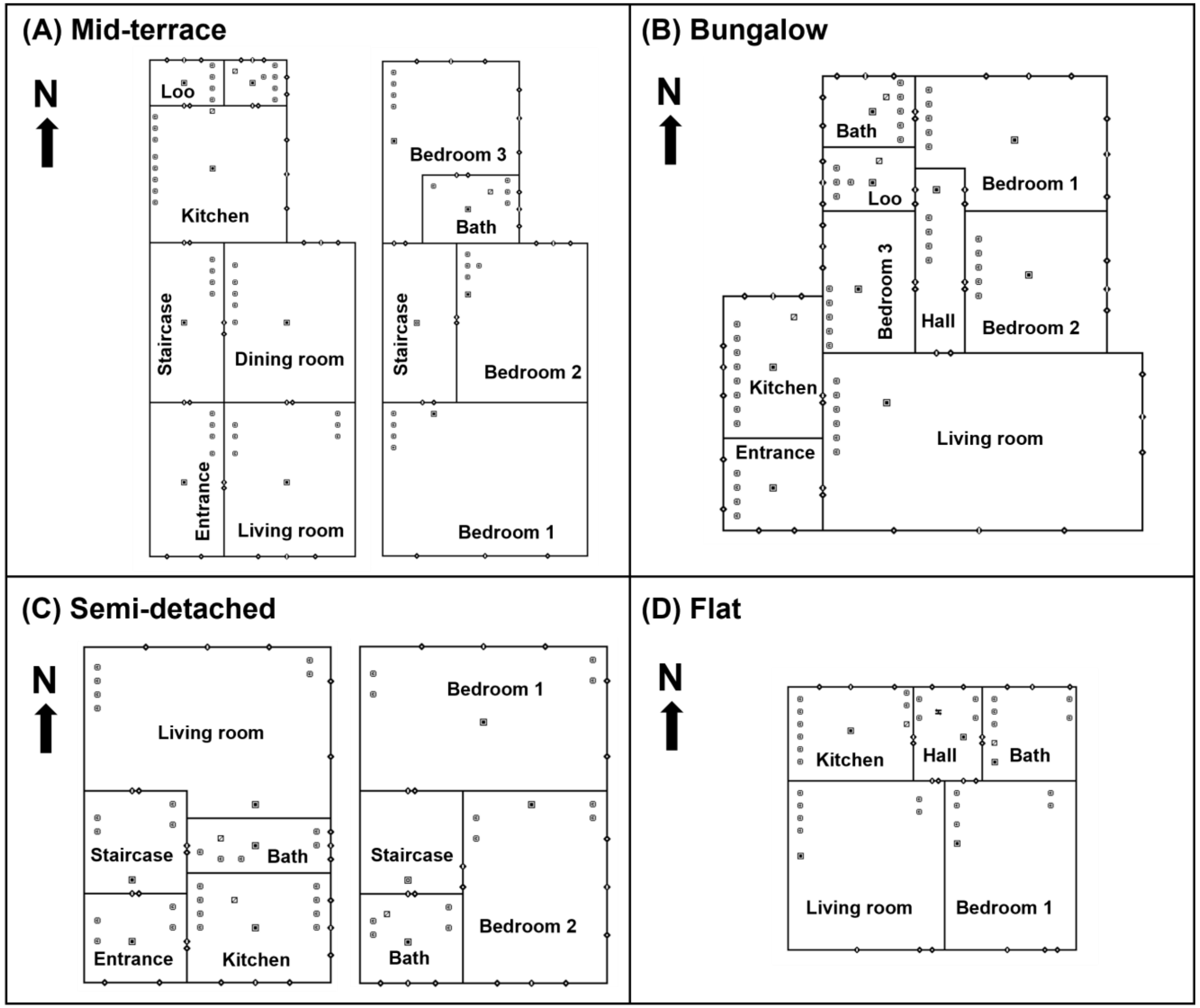
- Naturally occurring radioactive gas
- Seeps into homes through the floor
- 2nd most important risk factor for lung cancer after smoking

Fine Particulate Matter ($PM_{2.5}$)

- Indoors sources: cooking, smoking, wood burning stoves.
- Outdoors sources: road transport, industry.
- Coronary heart disease, lung cancer, asthma, […]

Methods

- Co-simulation
- Pollutants
- **Archetypes**
- Comparison



Building layouts based on Oikonomou et al.

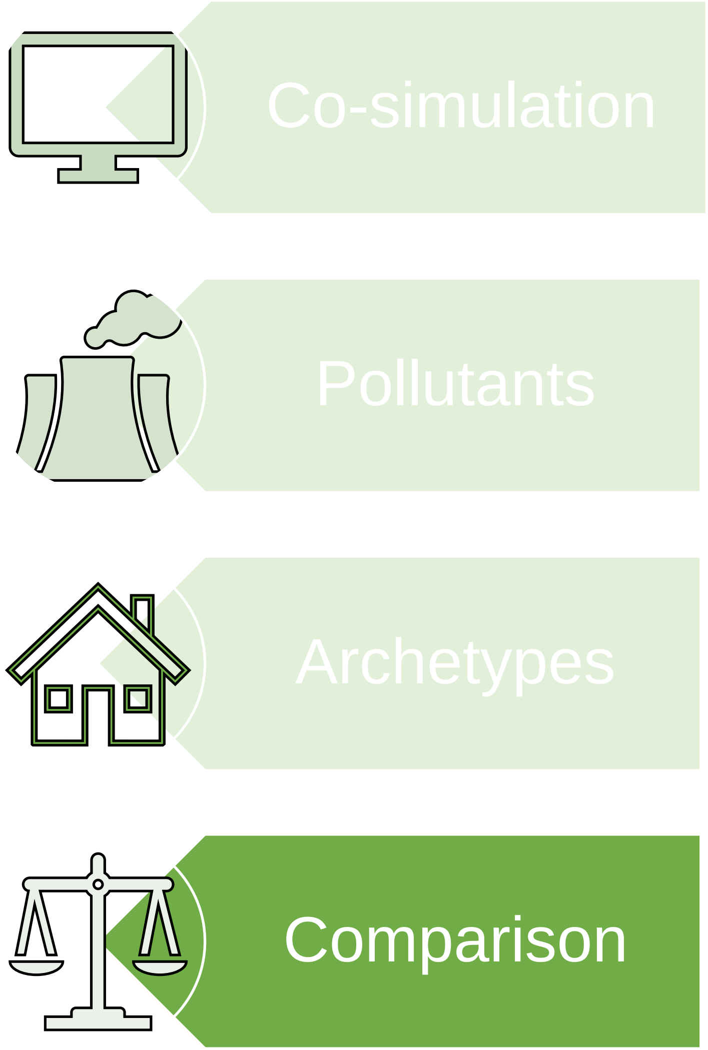
Oikonomou, E., Davies, M., Mavrogianni, A., Biddulph, P., Wilkinson, P. and Kolokotroni, M. (2012). 'Modelling the relative importance of the urban heat island and the thermal quality of dwellings for overheating in London', *Building and Environment*, 57, pp. 223–238.

Methods

- Co-simulation
- Pollutants
- **Archetypes**
- Comparison

Adult 1 (the cook)	• Bedroom 1 • In the kitchen during cooking
Adult 2	• Bedroom 1
Child 1	• Bedroom 2 • Mostly in bedroom and living room
Child 2	• Bedroom 3 • Mostly in bedroom and living room

Methods



- The *exact pollutant exposure* for each occupant, as calculated from the full dataset of concentrations in the main rooms (kitchen, living room and bedrooms)
- The *approximate exposure* estimated when data on pollutant concentrations were available for only subsets of the rooms.

Experiment	Living room	Kitchen	Bed. 1	Bed. 2	Bed. 3
K	N	**Y**	N	N	N
L	**Y**	N	N	N	N
B1	N	N	**Y**	N	N
LB1	**Y**	N	**Y**	N	N
KB1	N	**Y**	**Y**	N	N

Rooms being monitored per experiment.

Methods

- Co-simulation
- Pollutants
- Archetypes
- **Comparison**

$$RMSE(p,i) = \sqrt{\frac{1}{T_i}\sum_{t=1}^{T_i}\left(e_{p,i,t} - e_{p,i,t}^{(a)}\right)^2}$$

$$CV\left(RMSE(p,i)\right) = \frac{1}{\overline{e_{p,i}}} RMSE(p,i) \times 100\ \%$$

$$MBE(p,i) = \frac{1}{T_i}\sum_{t=1}^{T_i}\left(e_{p,i,t} - e_{p,i,t}^{(a)}\right)$$

$$NMBE(p,i) = \frac{1}{\overline{e_{p,i}}} MBE(p,i) \times 100\ \%$$

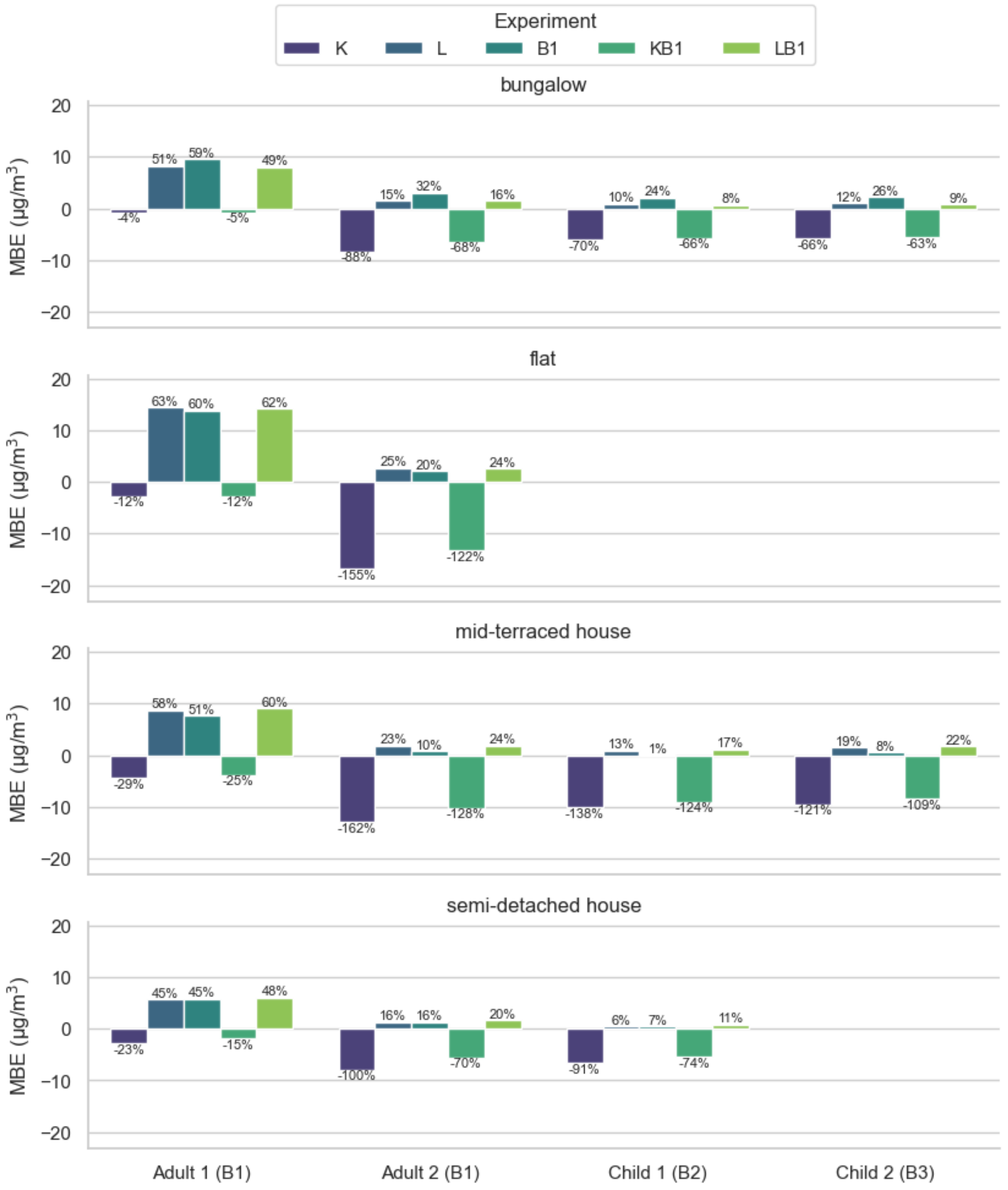
Results

THE BARTLETT
INSTITUTE FOR
ENVIRONMENTAL DESIGN
AND ENGINEERING

Results – $PM_{2.5}$

The cook:

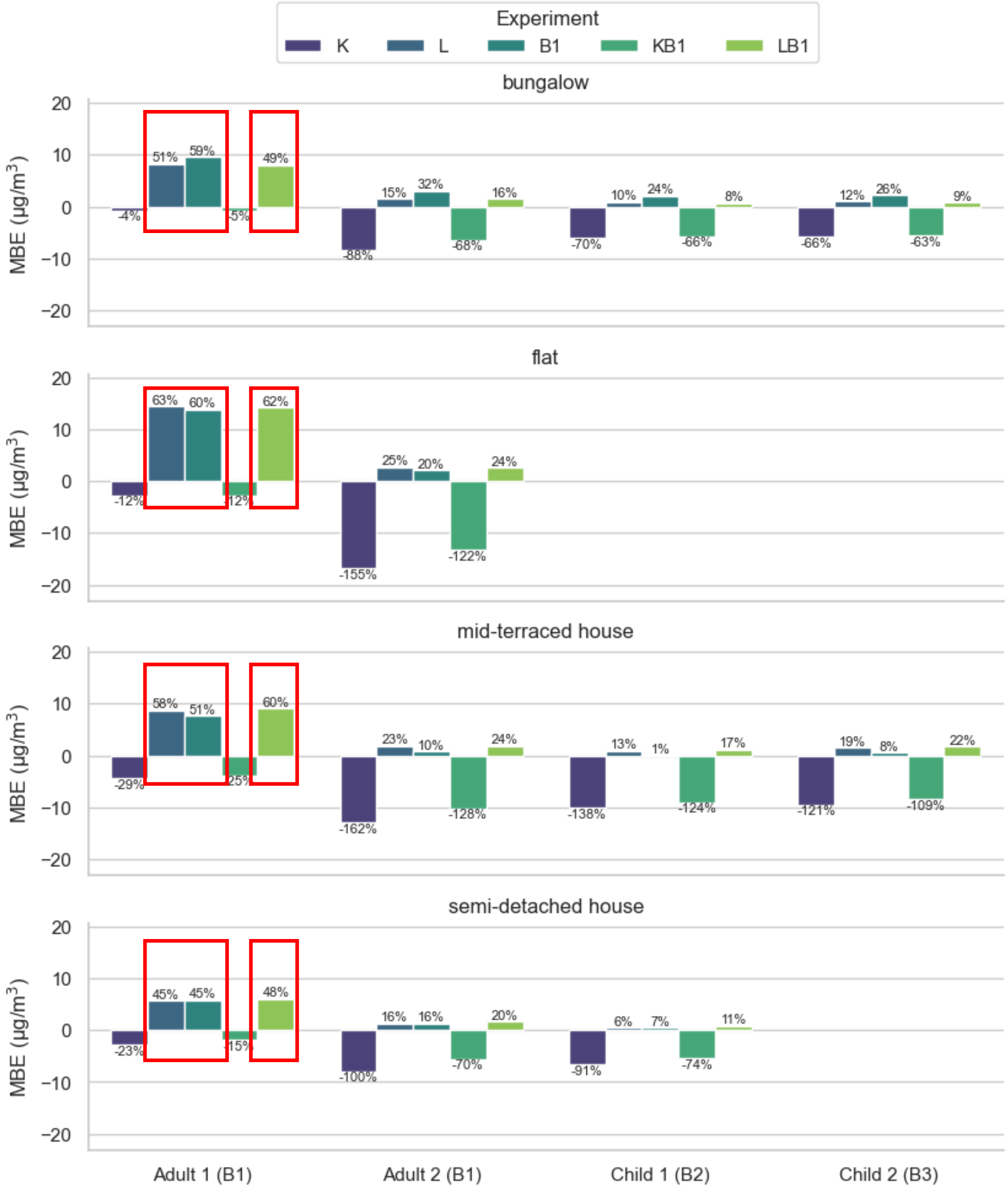
- $PM_{2.5}$ exposure dominated by cooking activities



Results – $PM_{2.5}$

The cook:

- $PM_{2.5}$ exposure dominated by cooking activities
- If data are not collected from the kitchen, we would underestimate their exposure:
  - MBE (NMBE) up to 14.4μg/m^3 (63%)



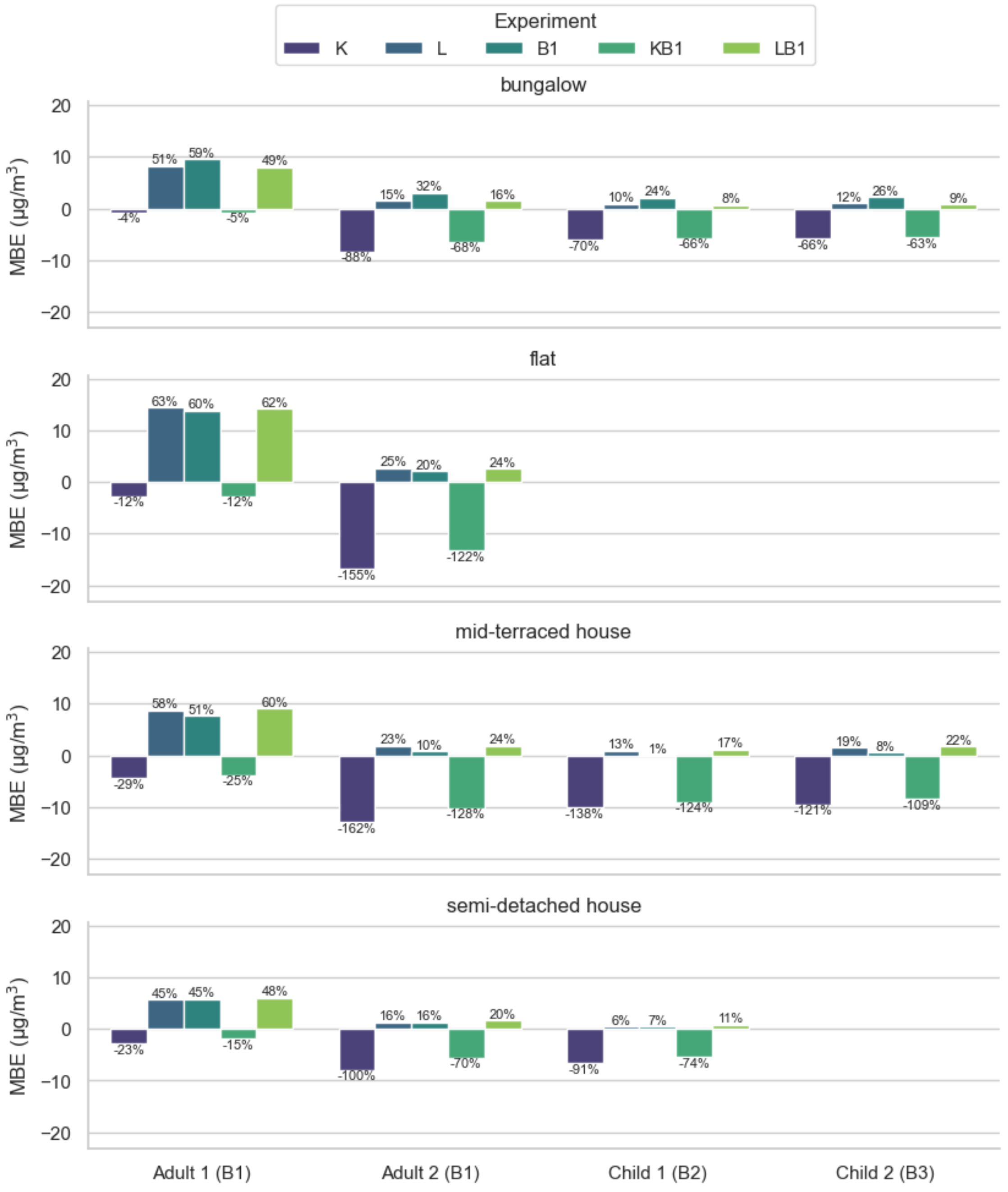
Results – $PM_{2.5}$

The cook:

- $PM_{2.5}$ exposure dominated by cooking activities
- If data are not collected from the kitchen, we would underestimate their exposure:
  - MBE (NMBE) up to 14.4μg/m³ (63%)

Other occupants:

- Cooking activities have a smaller impact on their overall exposure



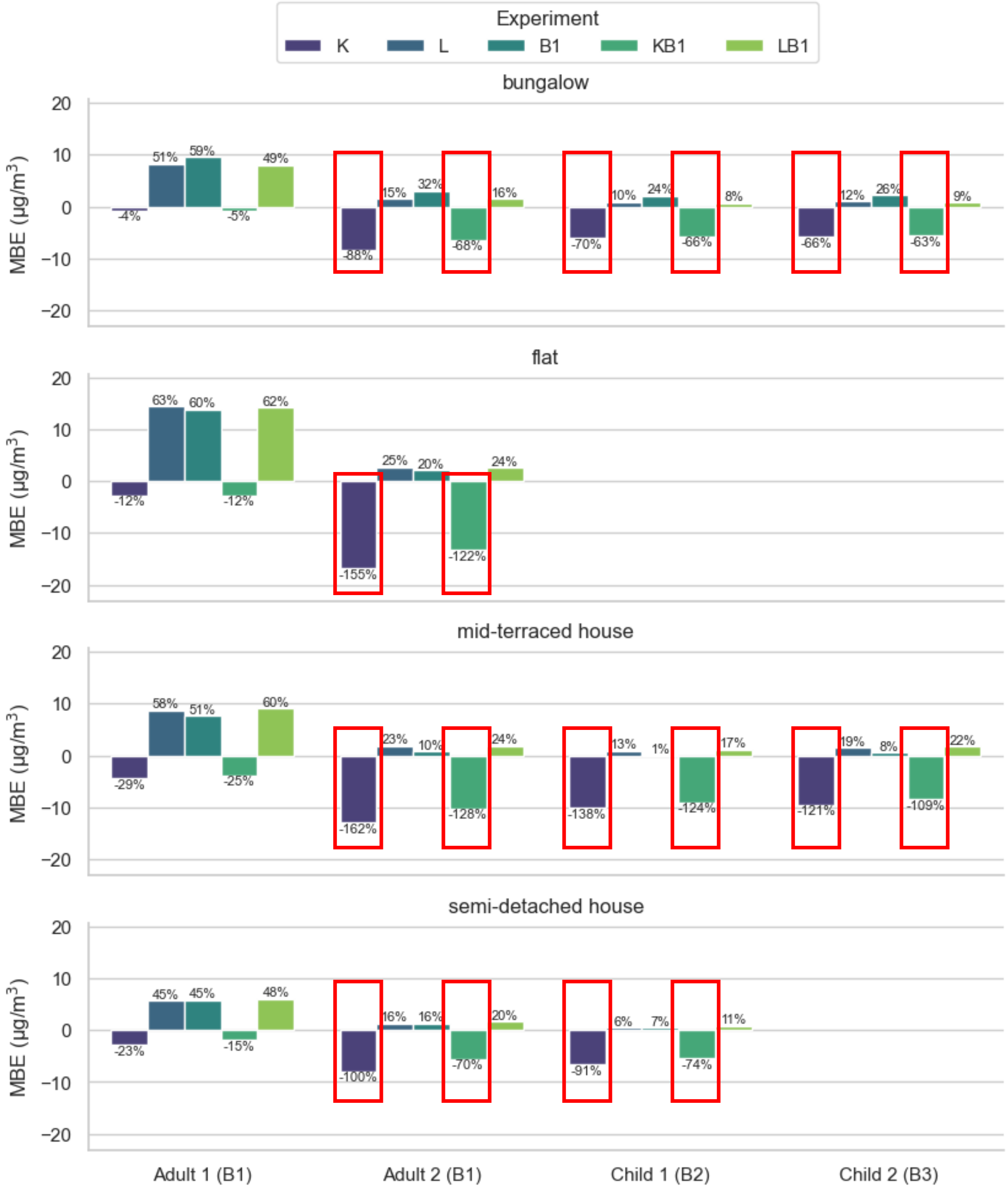
Results – $PM_{2.5}$

The cook:

- $PM_{2.5}$ exposure dominated by cooking activities
- If data are not collected from the kitchen, we would underestimate their exposure:
  - MBE (NMBE) up to 14.4μg/m³ (63%)

Other occupants:

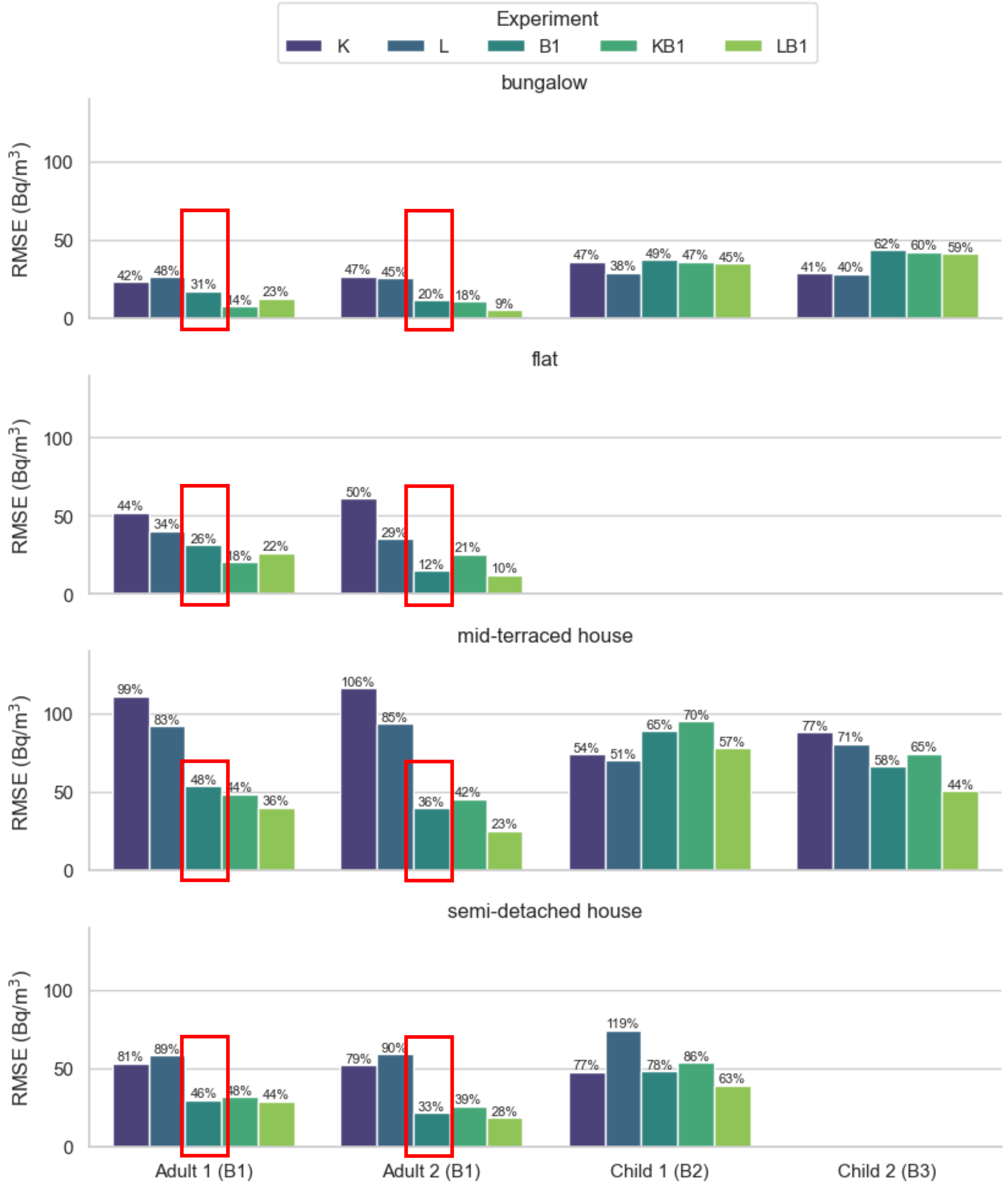
- Cooking activities have a smaller impact on their overall exposure
- Using kitchen measurements – only or supplemented with bedroom measurements – would overestimate their exposure:
  - MBE (NMBE) up to 16.8μg/m³ (155%)



Results – Radon

Main bedroom data:

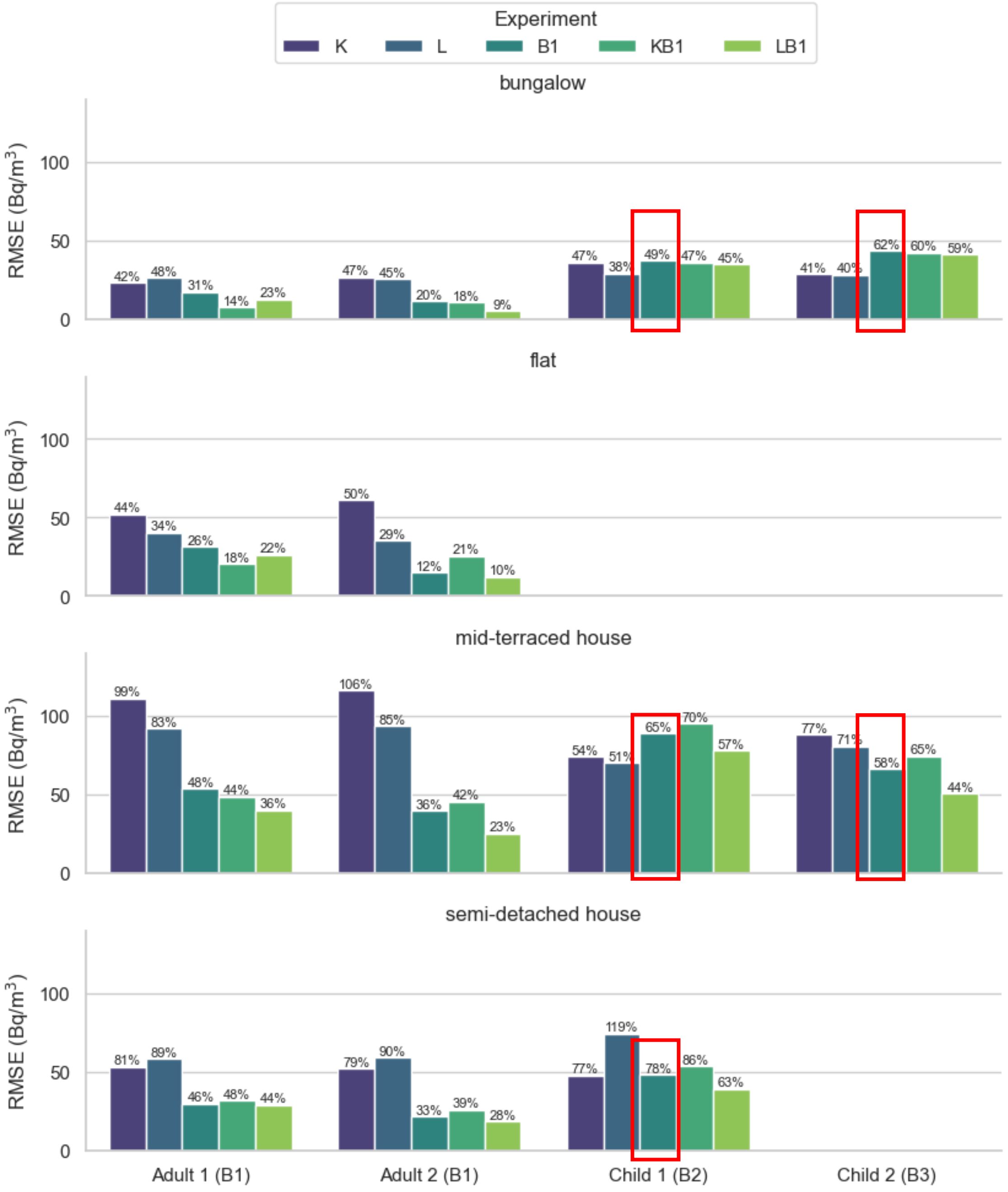
- When using data only from one room, the use of main bedroom data resulted:
  - In the smallest errors for the occupants that sleep in that bedroom



Results – Radon

Main bedroom data:

- When using data only from one room, the use of main bedroom data resulted:
  - In the smallest errors for the occupants that sleep in that bedroom
  - In some cases, in the largest errors for occupants not sleeping in the main bedroom



Discussion

Discussion

Implications

- **"Main Bedroom" -** Generalising based on a subset of rooms can **under- or over-estimate exposure**
- **Comprehensive monitoring**
- Where not possible:
  1. Identify the typical use per room and by each occupant
  2. Identify key pollutant sources
  3. Choose sensor placement

Limitations

- Two air pollutants
- Four archetypes
- Limited occupant behaviour diversity
- Well-mixed indoor air

Summary

Summary

- Investigated the impact that sensor placement has on quantifying indoor occupant exposure to $PM_{2.5}$ and radon.
- **Key messages:**
  - Monitoring a subset of the rooms can result in under- or over-prediction, depending on: sensor location, the occupant, the pollutant, and the archetype.
  - Consider the above factors ahead of detailed monitoring!
- Through further modelling, but also monitoring, **future work** should aim to define best practice for monitoring indoor air quality in homes

Acknowledgments

HEICCAM

Health and Equity Impacts of Climate ChAnge Mitigation measures on indoor and outdoor air pollution exposure

Policy and Implementation for Climate & Health Equity (PAICE)

wellcome

THE UNIVERSITY of EDINBURGH

LONDON SCHOOL of HYGIENE &TROPICAL MEDICINE

UK Health Security Agency

UCL

UCL
THE BARTLETT
SCHOOL OF ENVIRONMENT, ENERGY AND RESOURCES

Thank you for listening!

Dr Giorgos Petrou

giorgos.petrou@ucl.ac.uk

Publications & Contact Details

UCL
THE BARTLETT
INSTITUTE FOR
ENVIRONMENTAL DESIGN
AND ENGINEERING

Methods – Pollutants

Radon:

- Used a pressure-driven approach to model ingress of radon through the floor

PM2.5:

- Outdoor-sourced: Hourly data for Plymouth 2019 (Defra Data Archive)
- Indoor-sourced: Cooking
- Other processes: Deposition and window-dependent penetration

Contaminant activity	**Rate/Factor**	**Schedule**
$PM_{2.5}$ emission from cooking	1.6 mg/min	Weekdays: 7.20-7.35, 18-18.30 Weekends: 8.45-9, 12.30-13, 18-18.30
$PM_{2.5}$ deposition	-0.39/h	24 h
$PM_{2.5}$ penetration factor	0.8	Windows closed
$PM_{2.5}$ penetration factor	1.0	Windows open

Table 1 – $PM_{2.5}$ assumptions based on Shrubsole et al.[7]

[7] Shrubsole, C., Ridley, I., Biddulph, P., Milner, J., Vardoulakis, S., Ucci, M., Wilkinson, P., Chalabi, Z. and Davies, M. (2012). 'Indoor PM2.5 exposure in London's domestic stock: Modelling current and future exposures following energy efficient refurbishment'. *Atmospheric Environment*, 62, pp. 336–343. doi: 10.1016/j.atmosenv.2012.08.047.

Methods – Archetype models

- Naturally ventilated with extract fans in the bathroom and kitchen
- Windows open during the summer occupied hours if the indoor temperature exceeded 22 °C
- Bathroom and kitchen windows open during winter when showering or cooking
- Winter heating with a setpoint of 22 °C

Characteristic	Value
Air permeability	15 $m^{-3} h^{-1} m^{-2}$ @50Pa
Wall U-value	1.7 $Wm^{-2} K^{-1}$
Window U-value	4.8 $Wm^{-2} K^{-1}$
Floor U-value	1.2 $Wm^{-2} K^{-1}$
Loft U-value	0.4 $Wm^{-2} K^{-1}$
Roof U-value	2.3 $Wm^{-2} K^{-1}$

Table 2 – Building characteristics

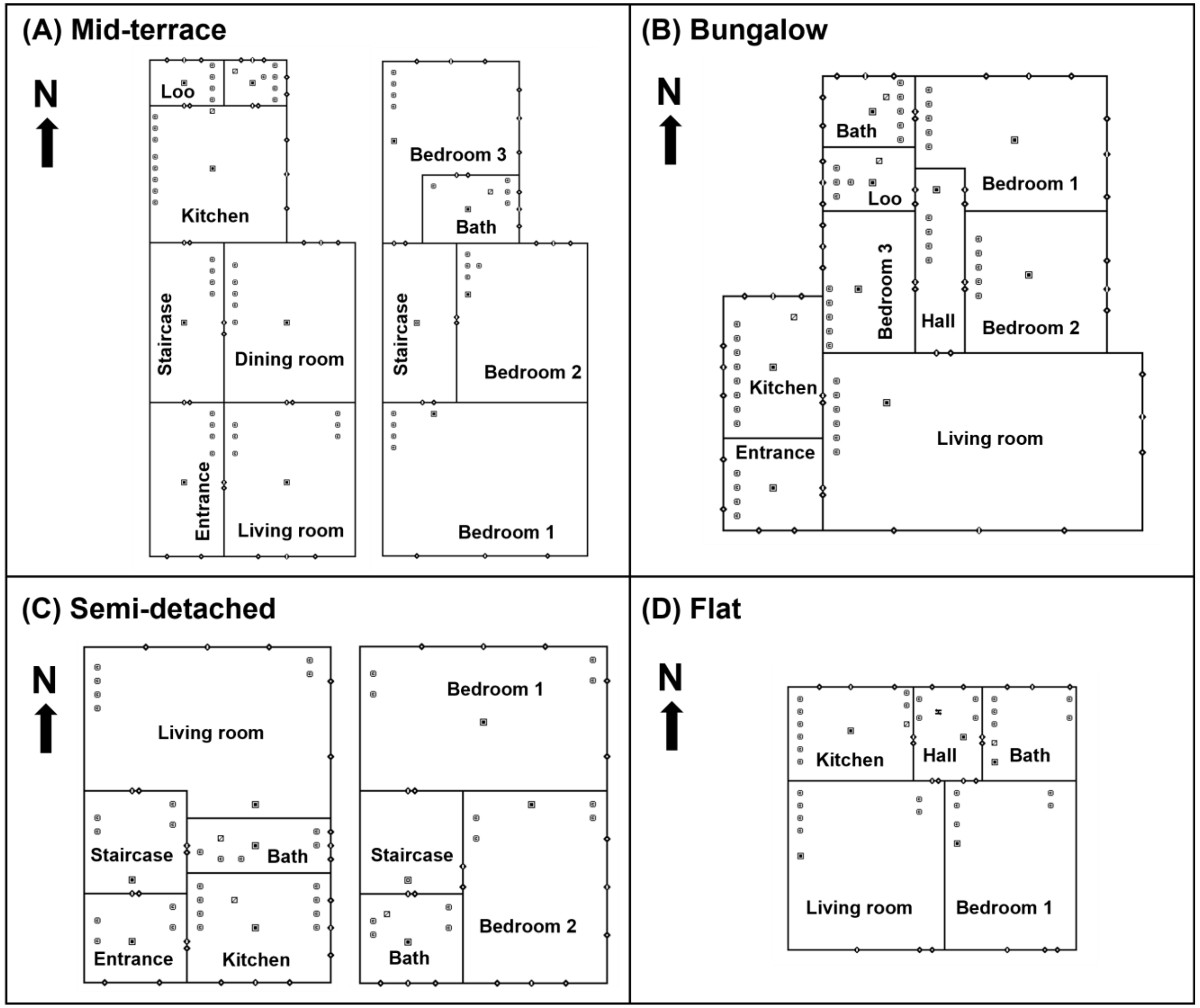


Figure 3 – Building layouts based on Oikonomou et al.[8]

[8] Oikonomou, E., Davies, M., Mavrogianni, A., Biddulph, P., Wilkinson, P. and Kolokotroni, M. (2012). 'Modelling the relative importance of the urban heat island and the thermal quality of dwellings for overheating in London'. *Building and Environment*, 57, pp. 223–238.