Prof Tim Sharpe

MACKINTOSH
ENVIRONMENTAL
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RESEARCH UNIT
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MEARU

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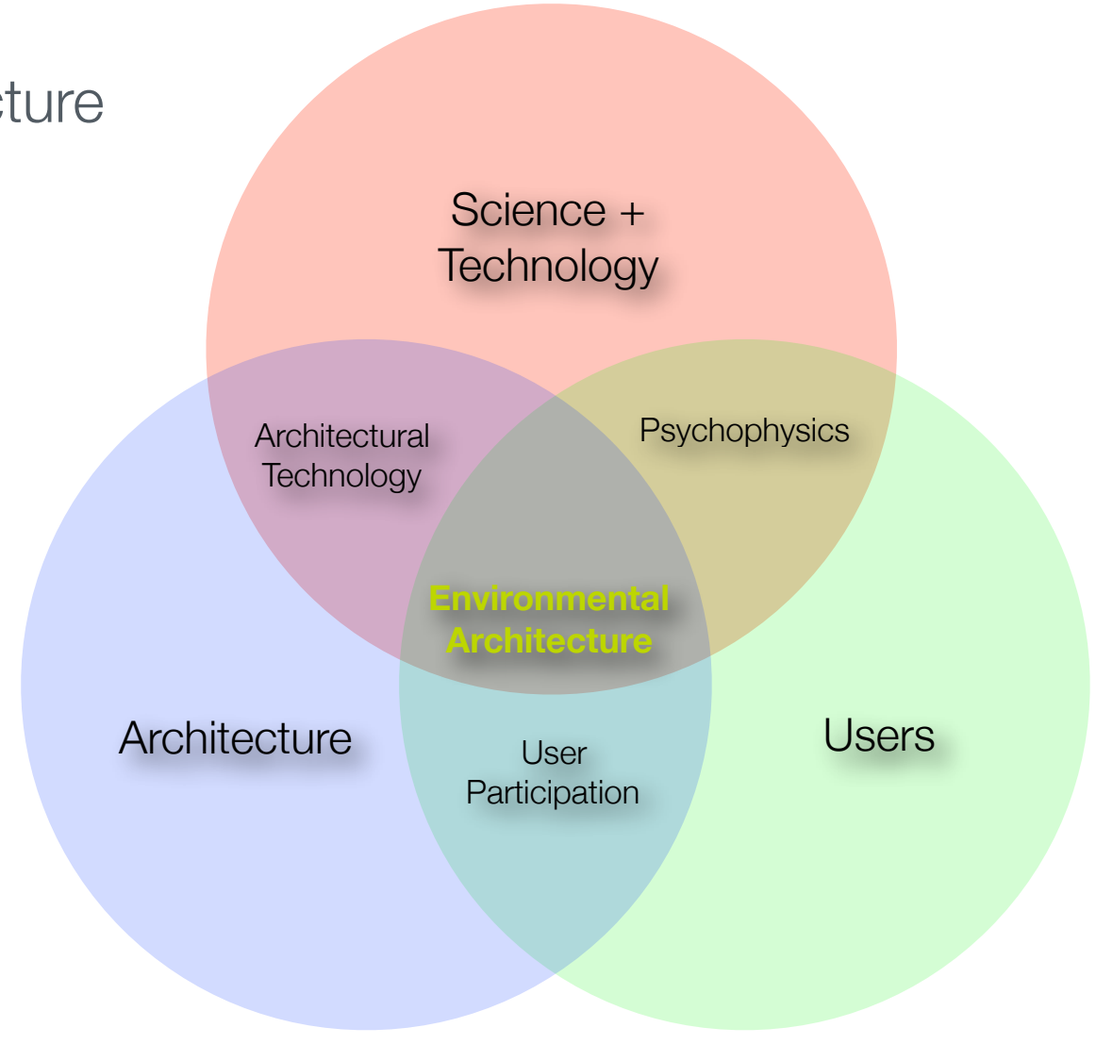
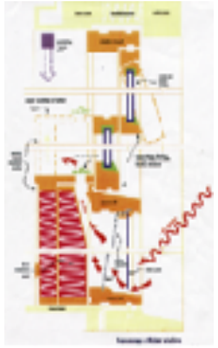
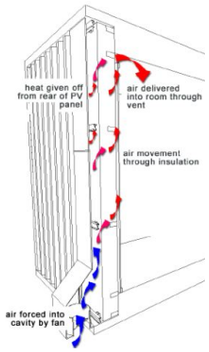
Mackintosh Environmental Architecture Research Unit

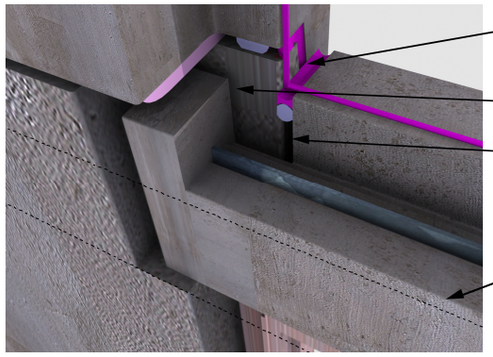
- Based at the Mackintosh School of Architecture
- 20 year track record of high quality research into environmental architecture.
- Operates at a unique interface between architectural design, science based research and human factors.
- User-centred, low energy, eco-sensitive architecture

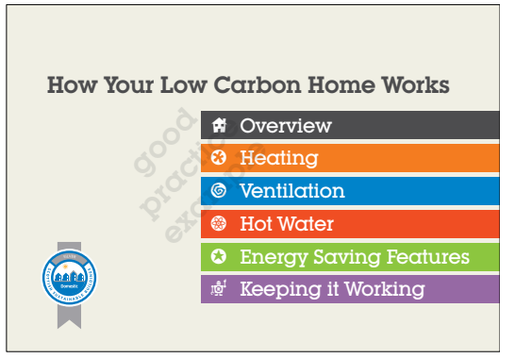
- Health has always been an important issue

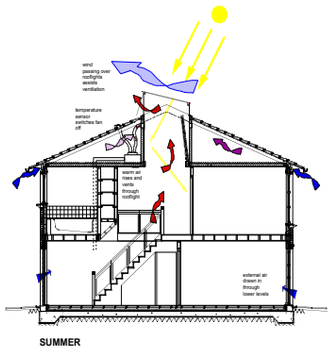


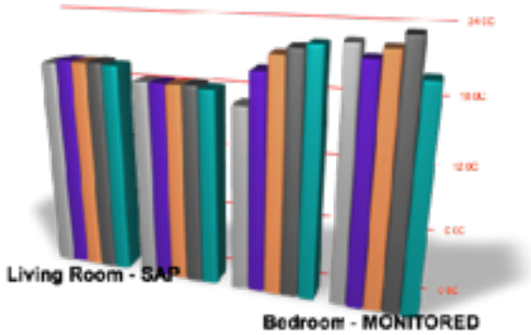


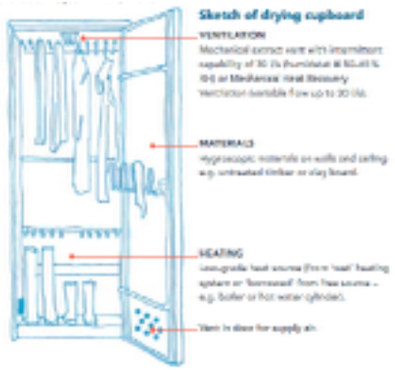

heat given off from rear of PV panel
air delivered into room through vent
air movement through insulation
air forced into cavity by fan

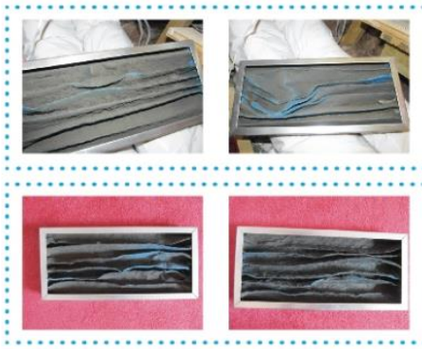

Mastic pointing on foam backer to panel gap
joint to lintol panel/wall panel
Panel gap
line of in-situ slab


How Your Low Carbon Home Works
Overview
Heating
Ventilation
Hot Water
Energy Saving Features
Keeping it Working


SUMMER


Living Room - SAP
Bedroom - MONITORED


Sketch of drying cupboard
VENTILATION
MATERIALS
HEATING



Ventilation Context

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- Energy reduction targets
- Smaller more intensely occupied buildings

- Air tightness

Poor IAQ

High energy

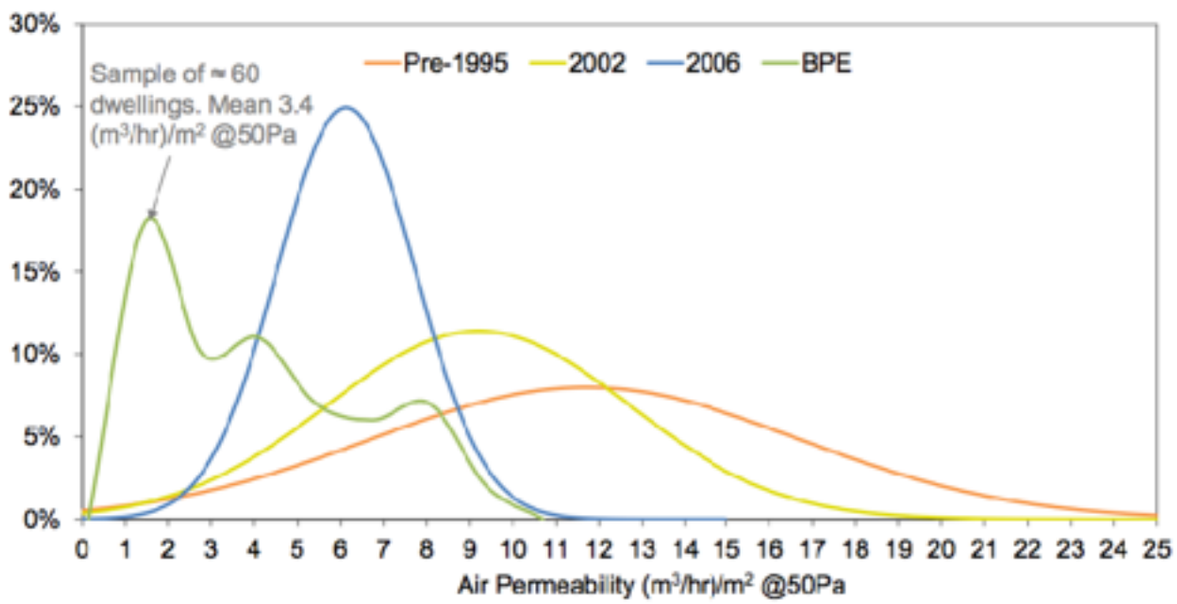
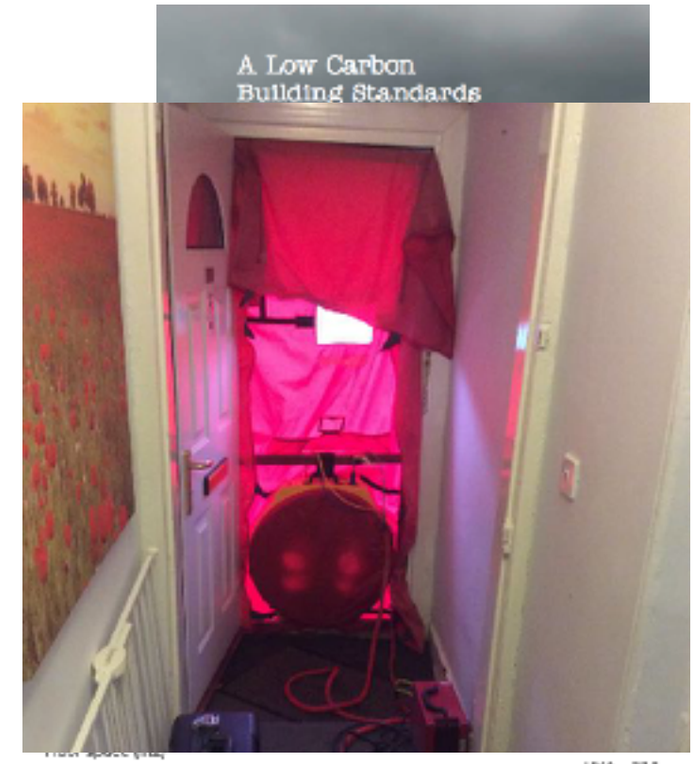


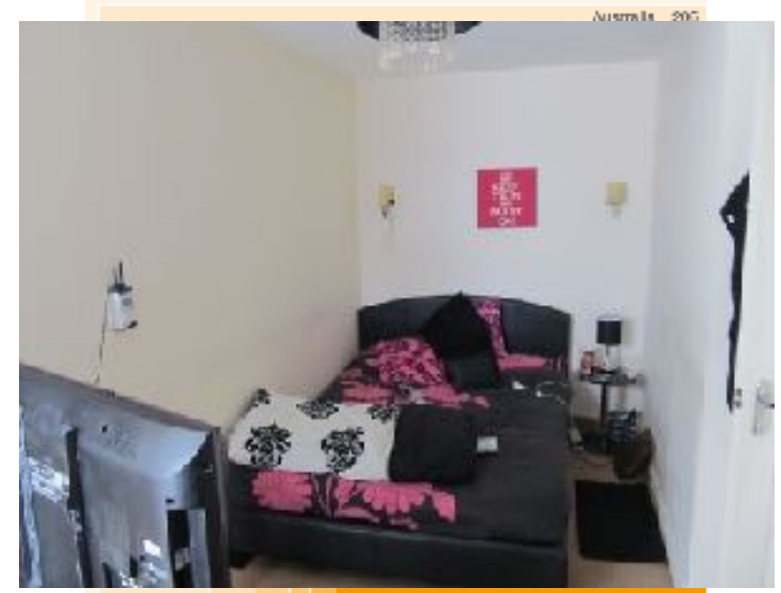
Image - Ian Mawditt, Fourwalls

Source: Building Sciences (RSK), Leeds Beckett University, Innovate UK BPE portfolio, Fourwalls

d energy

- Ir and health
- Performance Gaps - energy and environmental performance
- Potential unintended negative consequences



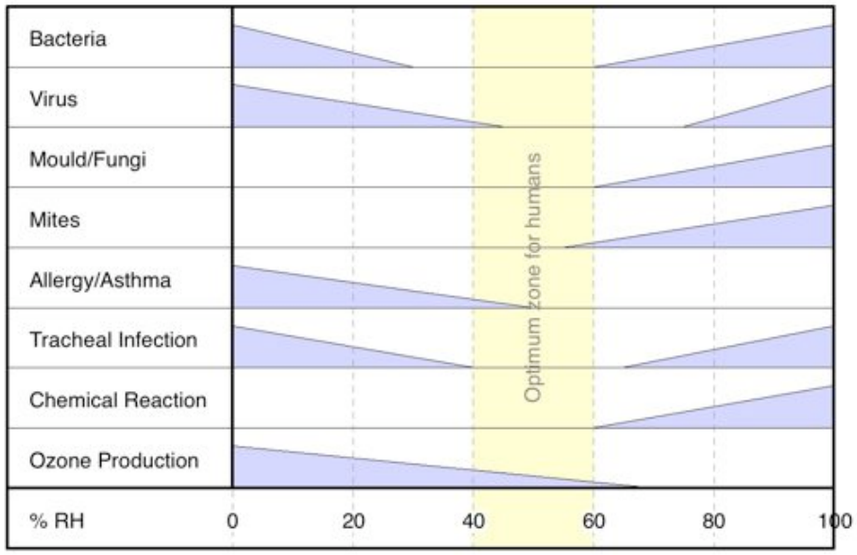


Indoor Air Quality (IAQ):

- Pollutants
- Moisture
- Temperature

  - Radon occurs naturally an may lead to lung cancer.
  - Suspended particles can cause harmful effects on health, particularly on the respiratory system.
  - Microbes, such as moulds and viruses, can contribute to the development of asthma and allergies.
  - Pests such as dust mites, cockroaches, and mice, are important indoor sources of allergens.
  - Low humidity causes eye irritation, dryness of the skin and the nose, and rashes
  - High humidity fosters the growth of moulds and dust mites.
  - High temperatures - heat stress, discomfort
  - Low Temperature - cold, dampness, asthma, rhinitus, heart disease
  - Chemicals - Volatile Organic Compounds

Figure 1: -Arundel, V., et al. Indirect Health Effects of Relative Humidity in Indoor Environments[6]



Relevant recent projects

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- Assessment of Environmental and Energy effects of Domestic Laundering EPSRC £522k
- Sunshine and well-being in housing, AHRC £52k
- Guidance for Occupants of Low Energy Homes, Scottish Building Standards £15k
- Knowledge Transfer Partnership with Cartwright Pickard Architects, London IUK, £135k
- Research Project To Investigate Occupier Influence On Indoor Air Quality In Dwellings, Scottish Building Standards, £40k
- Building Performance Evaluation - BPE Programme, IUK £520k
  - Expert Evaluator
  - The Glasgow House (Phase 1)
  - Inverness expo (8 houses)
  - Bloom Court Livingston (2 + 6 houses)
  - Ti-na-Cladich, Dunoon (3 houses)
  - Queens Cross, Glasgow (6 houses)
  - Murray Place, Barrhead (3 houses)
  - Dormont Park, Dumfries (4 houses)
- Meta study of MVHR system in domestic properties IUK £60k
- Knowledge Transfer Project - John Gilbert Architects. Unintended consequences of retrofit, IUK, £179k
- Network - Health effects of modern airtight construction, AHRC £52k
- BPE monitoring projects for Glasgow Housing Association - MVHR and naturally ventilated houses.
- Gannochy Trust, design advice for low energy, high air quality homes
- Edinburgh City Council, innovative ventilation strategy pilot study

Innovate UK Building Performance Evaluation (BPE)

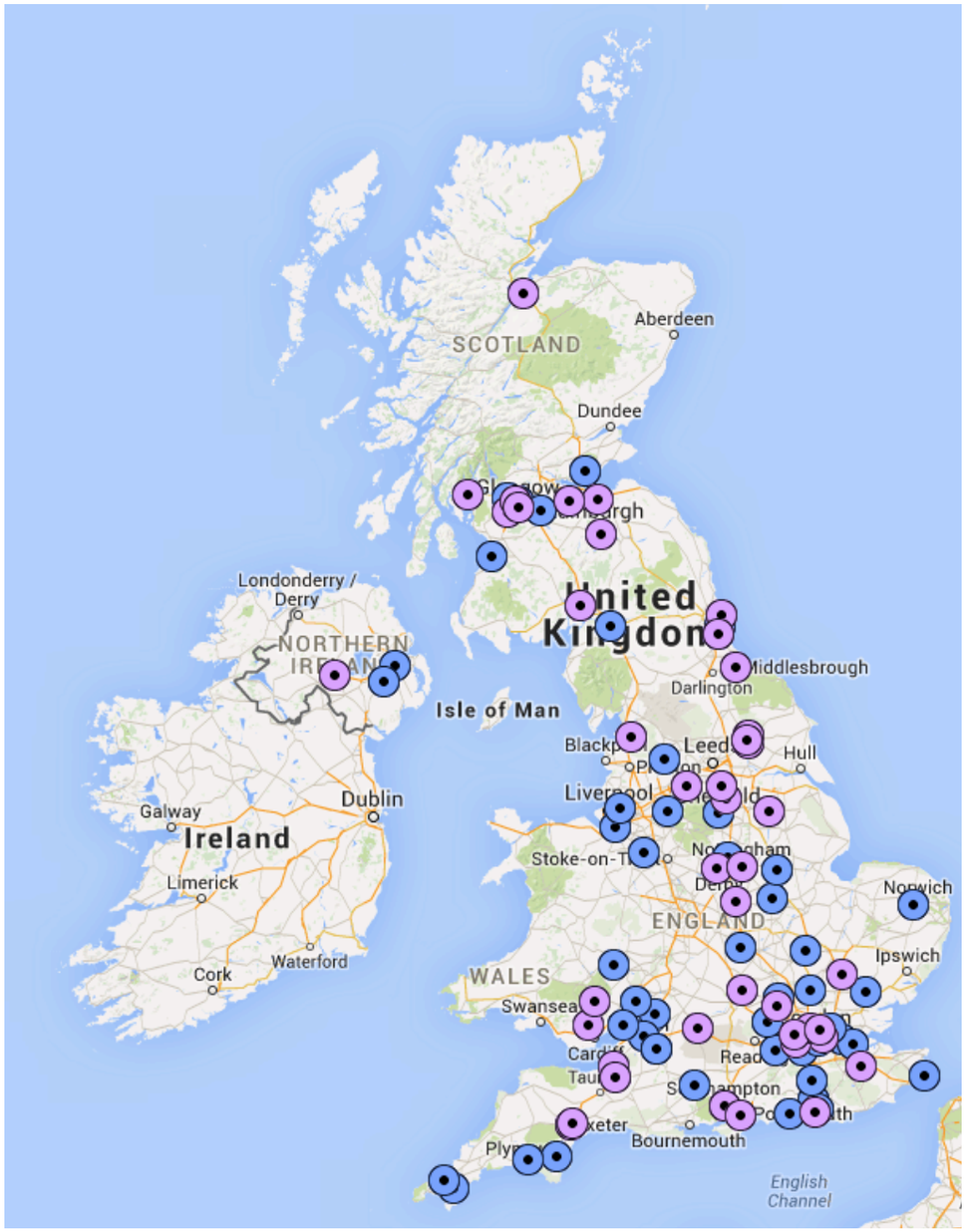
- £8m Innovate UK funding – 2010 to 2014 - total four year programme of project activity

- Domestic: 53 projects (350 dwellings)
- 23 Phase 1 projects

- Post construction & initial occupation
- 30 Phase 2 projects

- In-use performance & post occupancy evaluation

- Non–domestic: 48 projects (55 study buildings)
- 8 Under construction & early occupation
- 40 In-use



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Ventilation in BPE study houses

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- MEARU engaged in monitoring 7 domestic projects in Scotland
- Timber Frame

Ventilation observations

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- IUK studies
- Observed through measurements of CO_2
- < 1000ppm = 8 litres/s per person = good ventilation

"..ventilation rates above 0.4 h-1 or CO_2 below 900 ppm in homes seem to be the minimum level to protect against health risks based on the studies reported in the scientific literature" Wargocki, P. The Effects of Ventilation in Homes on Health. *Int. J. Vent.* **2013**; *12*, 101–118.

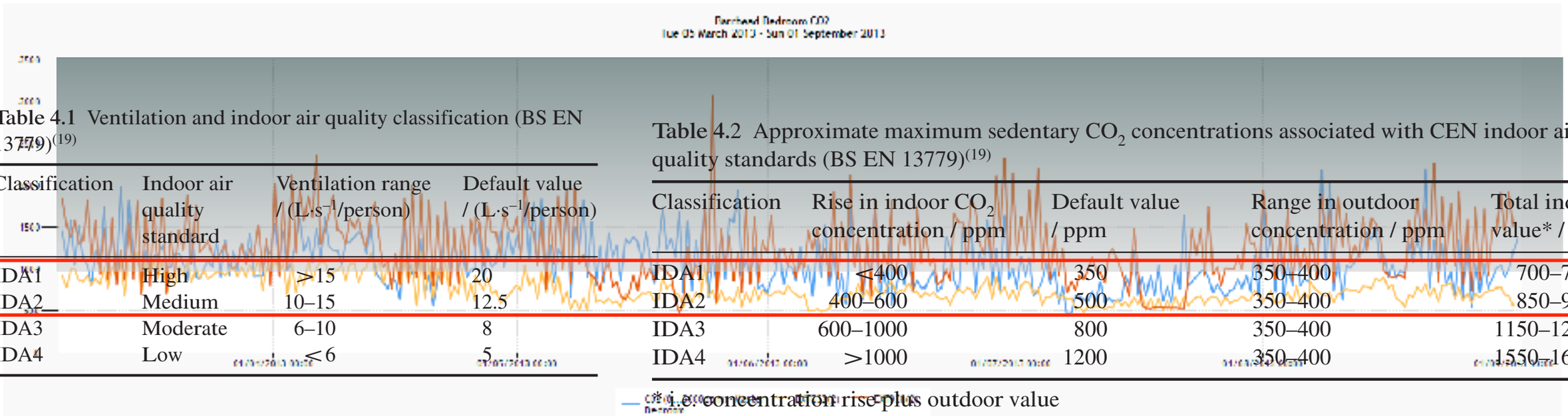

Table 4.1 Ventilation and indoor air quality classification (BS EN 13779)[19]

Classification	Indoor air quality standard	Ventilation range / ($L \cdot s^{-1}$/person)	Default value / ($L \cdot s^{-1}$/person)
IDA1	High	>15	20
IDA2	Medium	10–15	12.5
IDA3	Moderate	6–10	8
IDA4	Low	<6	5

Table 4.2 Approximate maximum sedentary CO_2 concentrations associated with CEN indoor air quality standards (BS EN 13779)[19]

Classification	Rise in indoor CO_2 concentration / ppm	Default value / ppm	Range in outdoor concentration / ppm	Total indoor value* / ppm
IDA1	<400	350	350–400	700–750
IDA2	400–600	500	350–400	850–900
IDA3	600–1000	800	350–400	1150–1200
IDA4	>1000	1200	350–400	1550–1600

* i.e. concentration rise plus outdoor value

Howieson, S.G., Sharpe, T. and Farren, P. (2013) Building tight – ventilating right? How are new air tightness standards affecting indoor air quality in dwellings? Building Services Engineering Research and Technology, 35 (5). pp. 475-487. ISSN 0143-6244

Bedrooms

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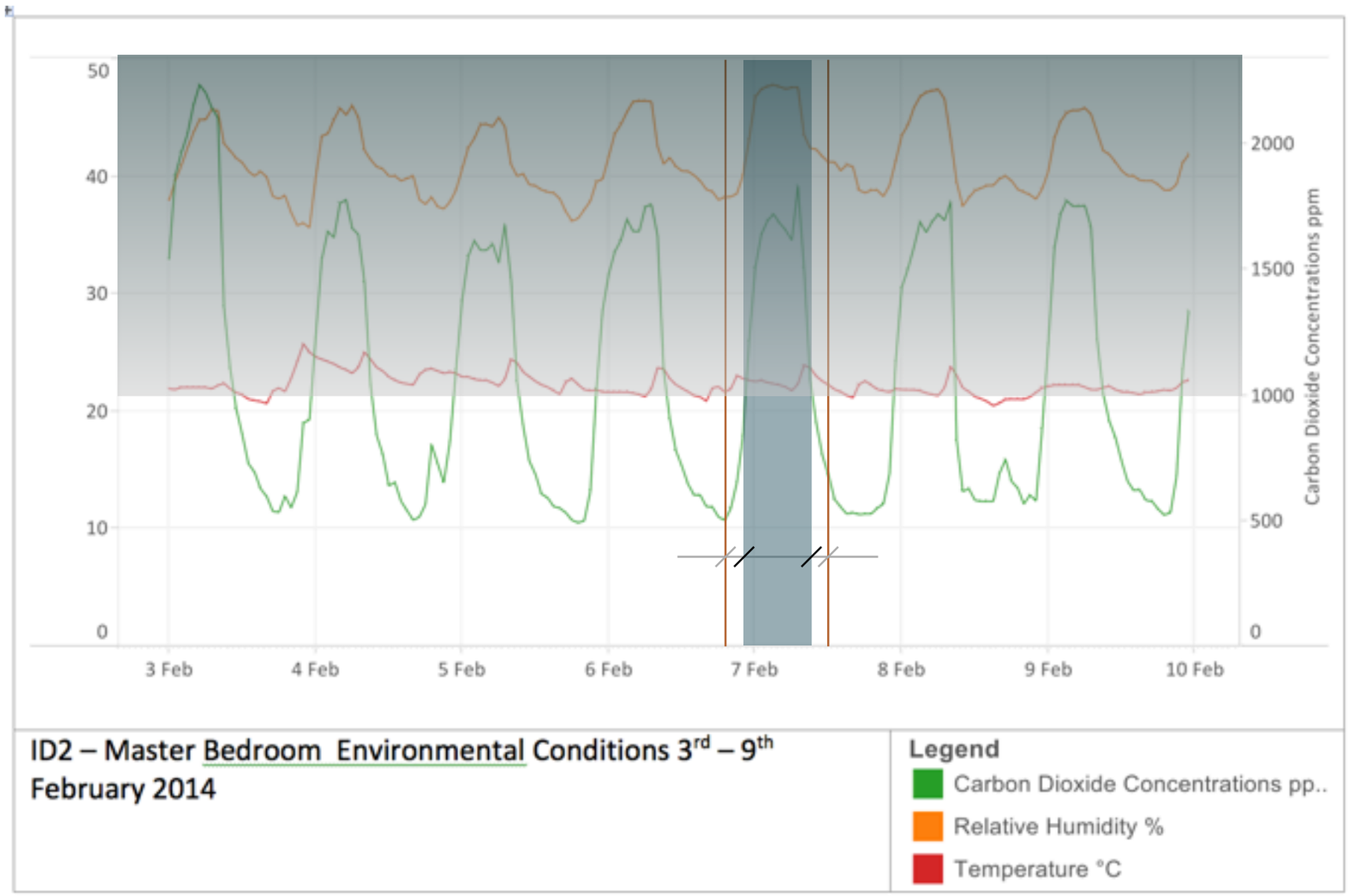

Sharpe, Tim, Porteous, Colin, Shearer, Donald and Foster, Janice (2014) An assessment of environmental conditions in bedrooms of contemporary low energy houses in Scotland. Indoor and Built Environment.

Research Project To Investigate Occupier Influence On Indoor Air Quality In Dwellings

Building Standards Directorate

Prof Tim Sharpe MEARU
Jonathan McQuillan Anderson Bell Christie
Dr. Stirling Howieson, University of Strathclyde
Paul Farren ASSIST DESIGN ARCHITECTS
Dr. Paul Tuohy ESRU, Strathclyde University

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anderson bell+christie architects

University of Strathclyde Engineering

ASSIST DESIGN ARCHITECTS

Methodology

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Literature review

- Health effects and ventilation
- Similar studies
- What is an accepted measure of ventilation?

Large scale survey

- 200 households of recent (post 2010) houses
- Door step survey asking about ventilation habits

Subsurvey

- Selection of >50 of these properties for monitoring
- Temp, CO_2 and RH for a 48 hour period, along with survey and observations

Core survey

- Extract data from long term monitoring of 26 houses in IUL BPE programme
- Week long observation of data with occupant diaries
- VOC and particulate testing in some properties

Key Findings

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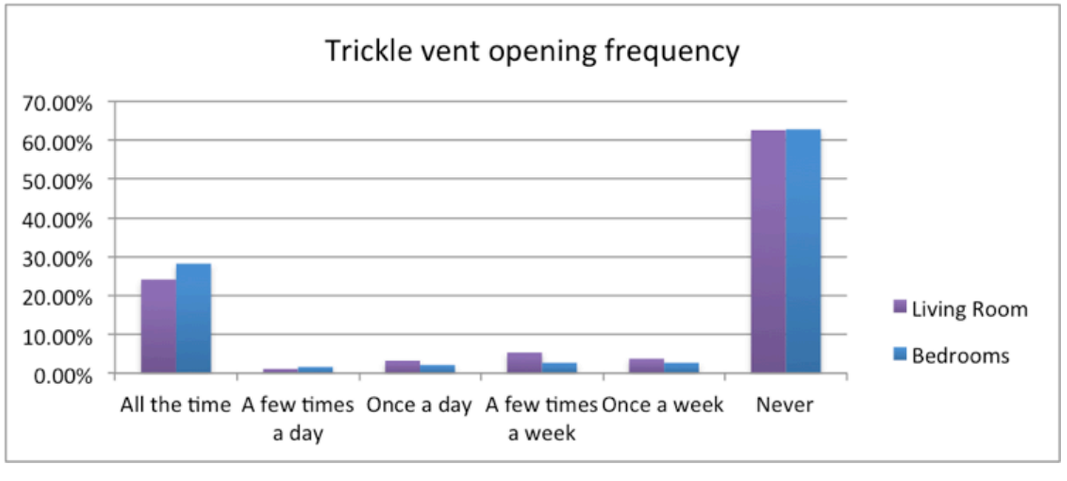
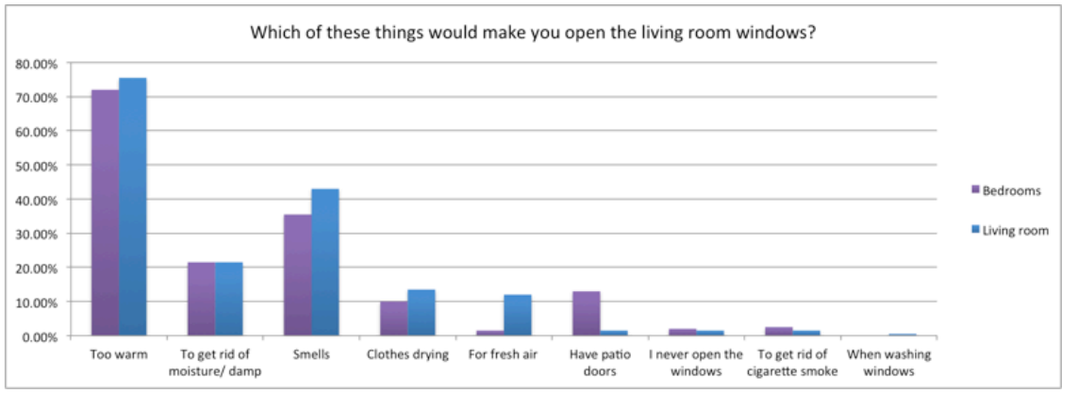
- Survey of ventilation habits

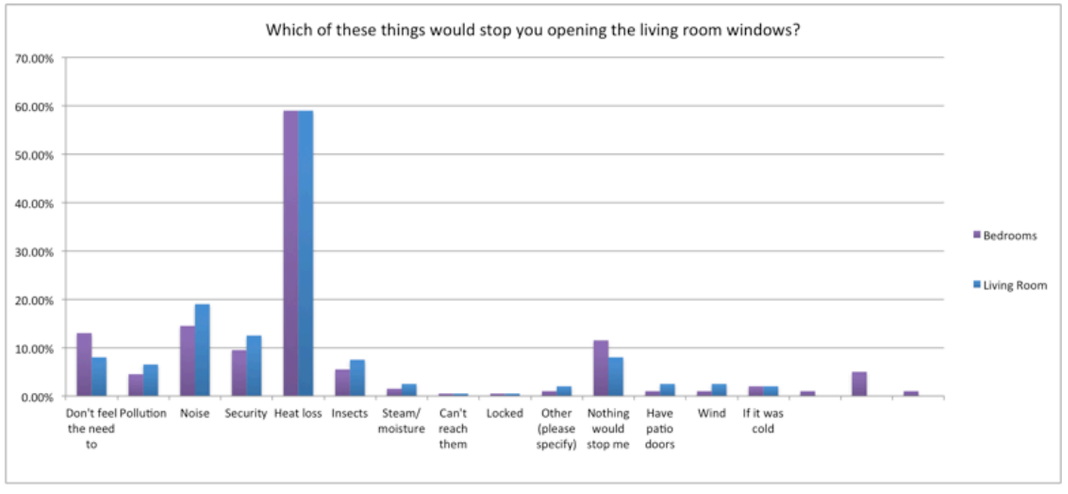
- Most trickle vents closed - 63% closed
- Hardly every changed

- Window opening more frequent - daily
- Drivers - temperature
- Barriers - heat loss
- 20% leave bedroom windows open at night
- 40% have bedroom doors closed at night

- Lack of knowledge - 82% had received no advice on ventilation
- IAQ was considered to be good







Trickle vent performance

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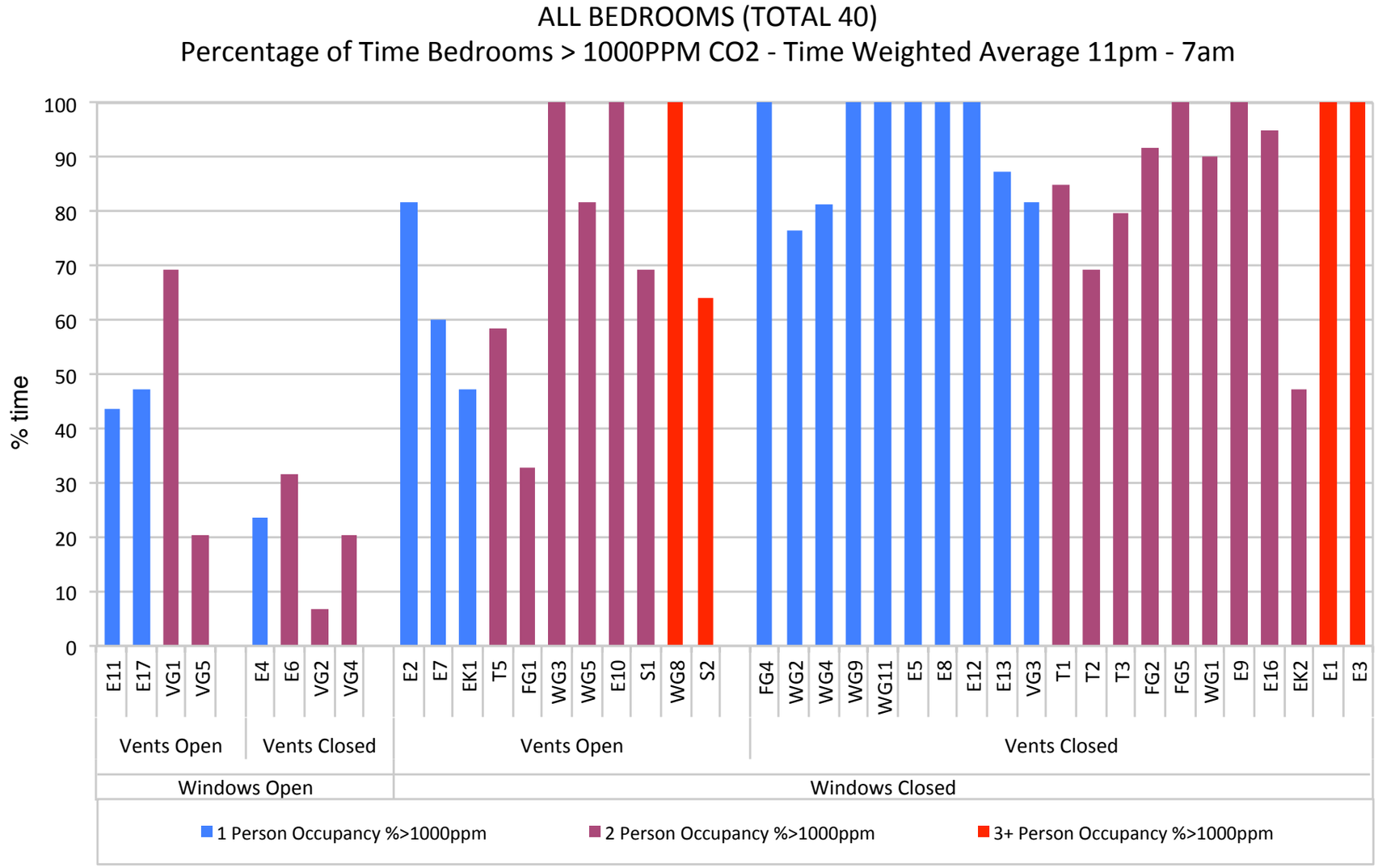
- % time over 1000ppm at night
- Significant periods of time with low ventilation
- Mitigated by window opening
- Better with open vents - but not effective



Sharpe, Tim (2014) Investigation of Occupier Influence on Indoor Air Quality in Dwellings. Technical Report. Scottish Government.

Sharpe, Tim, Farren, Paul, Howieson, Stirling, Tuohy, Paul and McQuillan, Jonathan (2015) Occupant Interactions and Effectiveness of Natural Ventilation Strategies in Contemporary New Housing in Scotland, UK. International Journal of Environmental Research and Public Health, 12 (7). pp. 8480-8497. ISSN 1660-4601

Resultant air change rates

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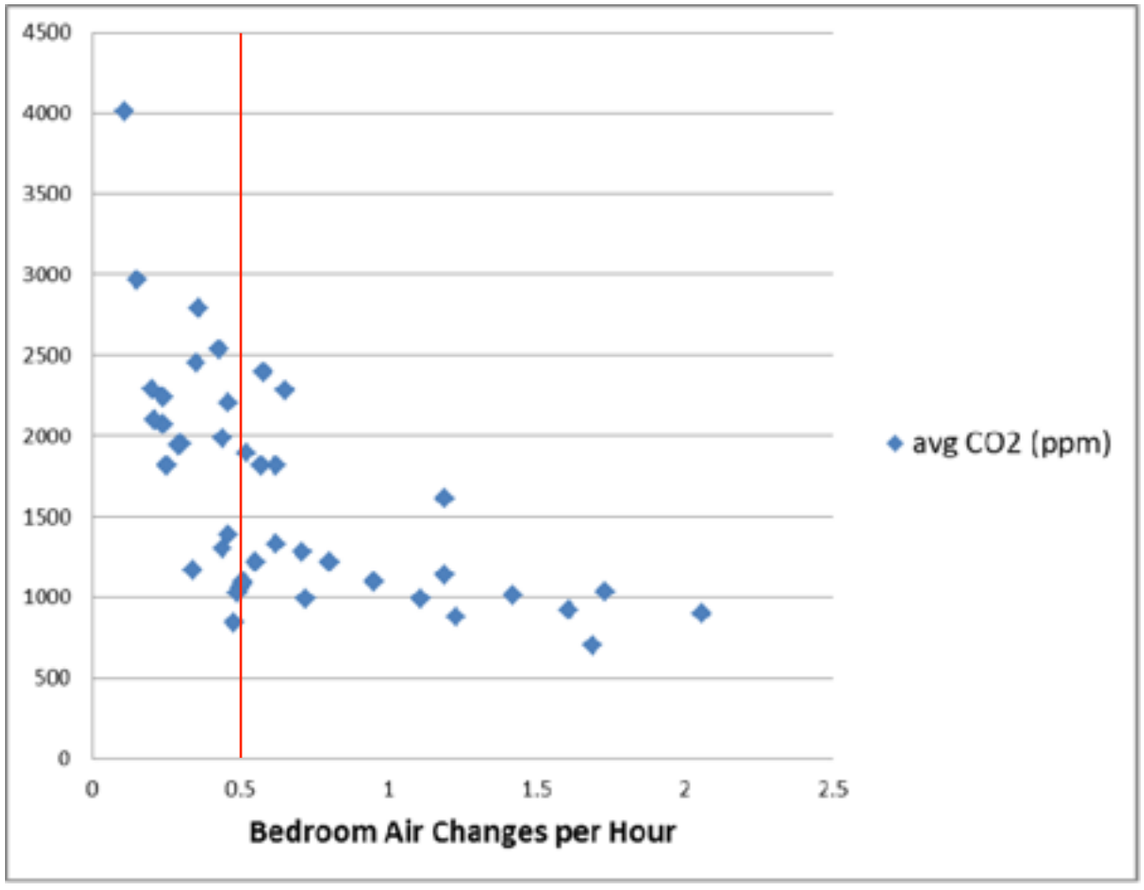
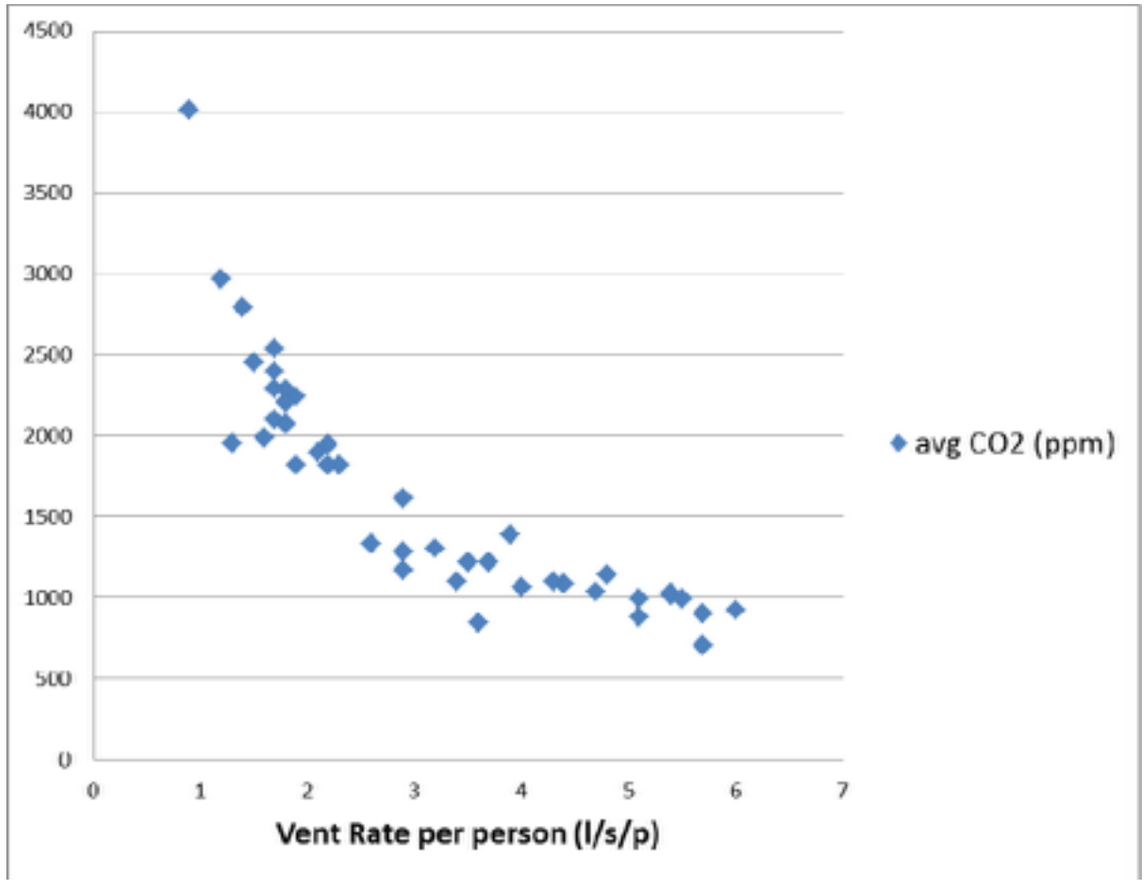
- House with closed windows but open trickle vents
- No houses met requirement for IAQ = 8 l/s/p
- 42% below requirements for moisture control in regulation (0.5ach)
- All (100%) below 8 l/s/p





Sub-Survey

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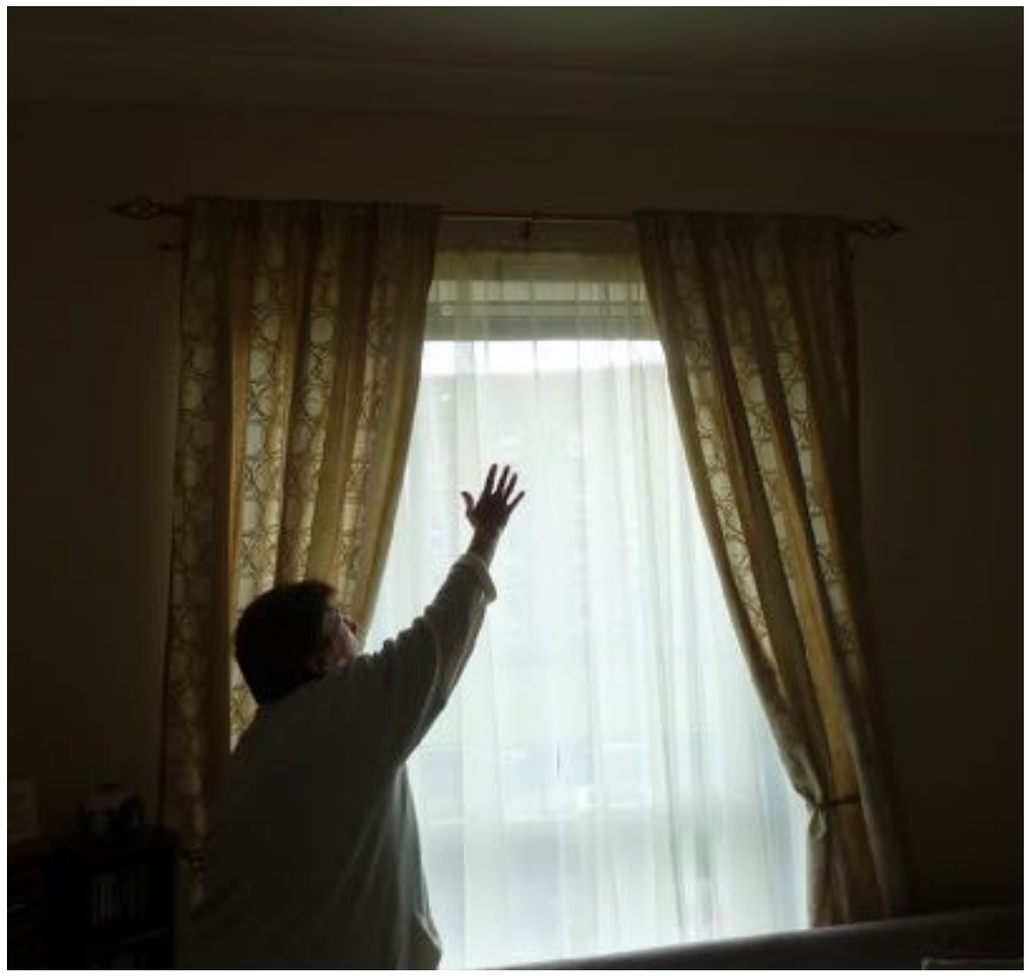
Observations

- Trickle vents are frequently out of immediate reach due to height, furniture and positioning of blinds and curtains.



Sub-Survey

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Observations

- The majority of bedroom windows surveyed have some form of blinds or curtains that would occlude the vents, especially at night when curtains and blinds are most used.
- No instances where vents had been interfered with or blocked

Sub-Survey

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Observations

- Floor coverings frequently obstructed door undercuts - residents comments including that they had to physically shorten doors to allow opening after fitting carpets

Sub-Survey

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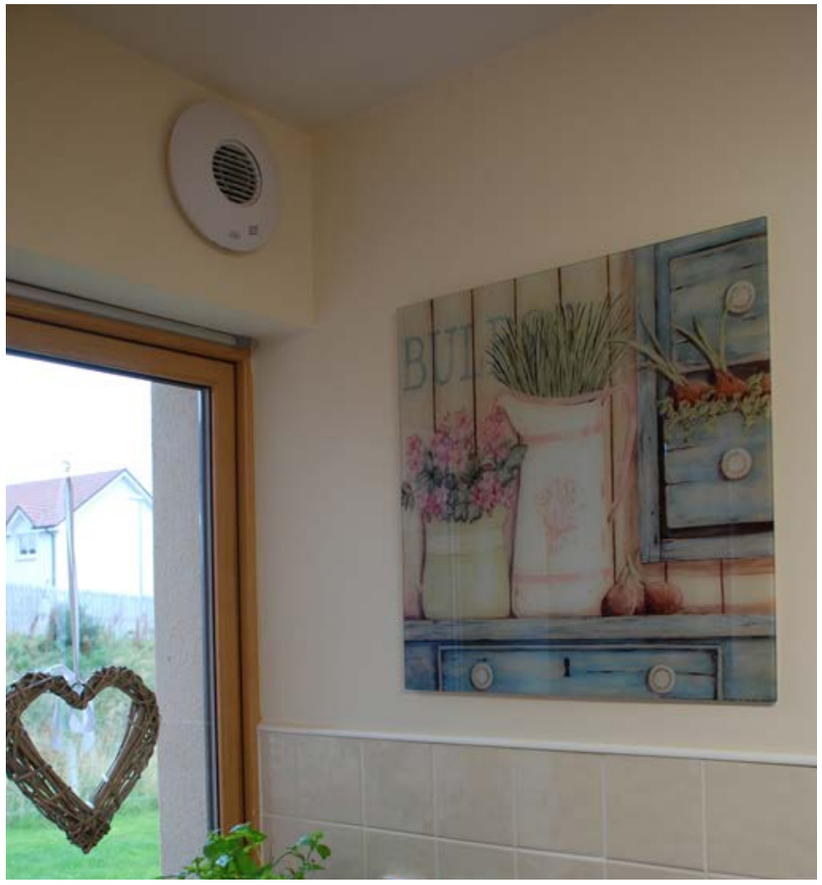
Observations

- Specification of extract units, grilles and ducts, short circuiting



Ventilation observations

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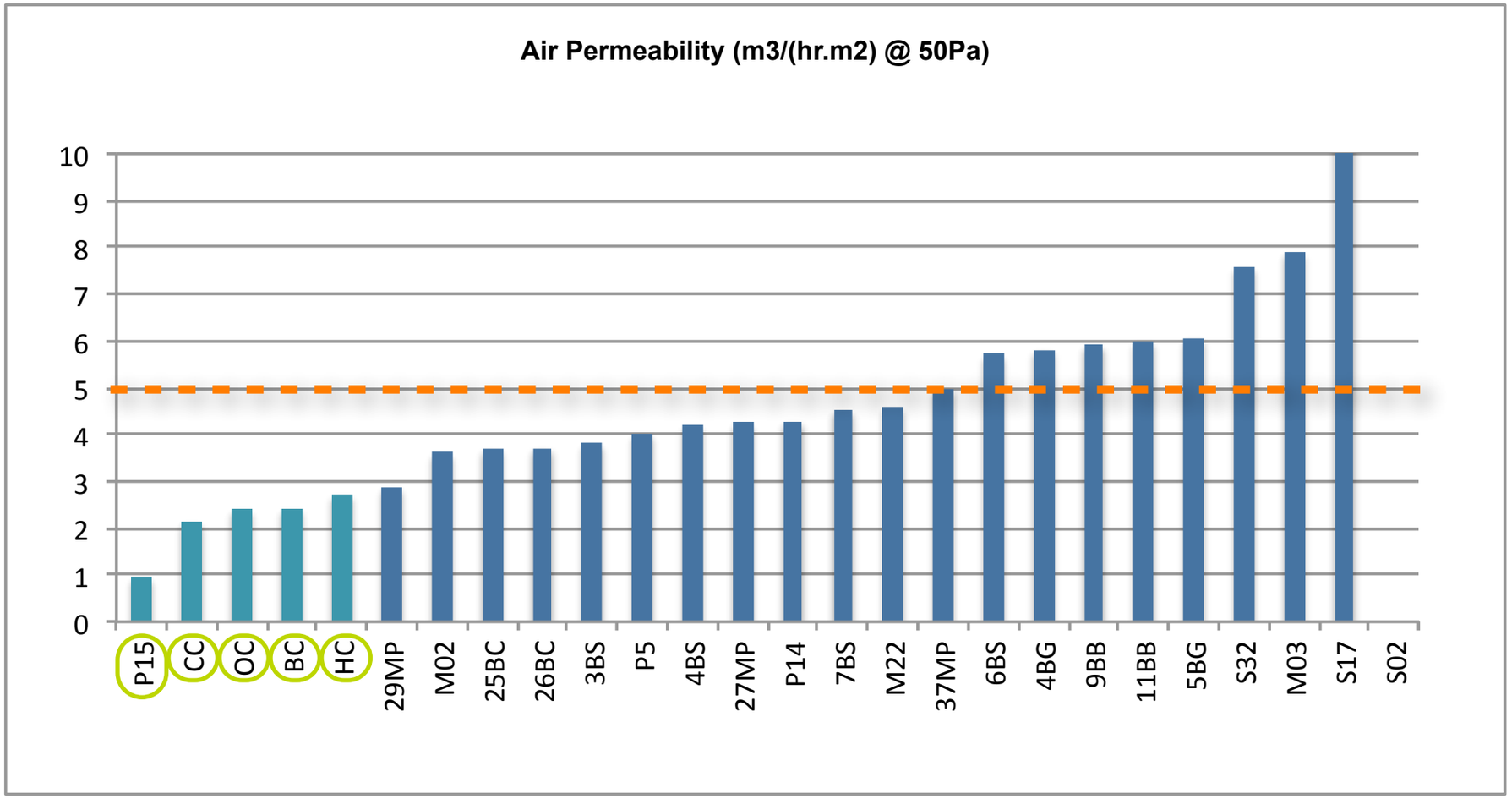
- Scottish Regulations: below 5m^3/m^2/hr@50Pa a ‘planned ventilation’ strategy is required
- Two-thirds have ‘overshot’ the regulation - not checked.



Ventilation observations

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Mechanical extract systems

- 83% underperforming
- 71% failing design performance criteria

Dwelling	Fan	Avg	Design	Pass/Fail
IA1	Kitchen	25.60	60	Fail
	Utility	29.40	30	Pass
	Shower	7.50	15	Fail
	Bathroom	7.50	15	Fail
IA2	Kitchen	34.50	60	Fail
	Utility	31.90	30	Pass
	Shower	3.70	15	Fail
	Bathroom	4.60	15	Fail
IB1	WC	3.20	7	Fail
	Bathroom	4.90	15	Fail
IB2	WC	5.20	7	Fail
	Bathroom	4.00	15	Fail
	Kitchen	62.60	30	Fail
IC1	Kitchen	5.80	60	Fail
	Bathroom	7.30	15	Fail
IC2	Kitchen	8.50	60	Fail
	Bathroom	5.90	15	Fail
ID2	Kitchen	26.10	60	Fail
	Bathroom	6.90	15	Fail
BC1	Bathroom	11.83	15	Fail
	Kitchen	64.27	60	Pass
BB1	Bathroom	17.30	15	Pass
	Kitchen	71.87	60	Pass
BA1	WC	12.40	15	Fail
	Bathroom	2.80	15	Fail
	Kitchen	0.00	60	Fail
GB3	Bathroom	9.20	15	Fail
	Kitchen	32.57	60	Fail
GB1	Bathroom	11.13	15	Fail
	Kitchen	41.43	60	Fail
GB2	Kitchen	30.10	60	Fail
	Bathroom	16.30	15	Pass
LA5	Kitchen	67.80	60	Pass
	Bathroom	4.60	15	Fail
LA6	Kitchen	73.80	60	Pass
	Bathroom	7.40	15	Fail

Meta-Study Of Dwellings With MVHR Systems

Innovate UK

Tim Sharpe, MEARU
Ian Mawditt, Fourwalls
Rajat Gupta, OBU

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fourwalls

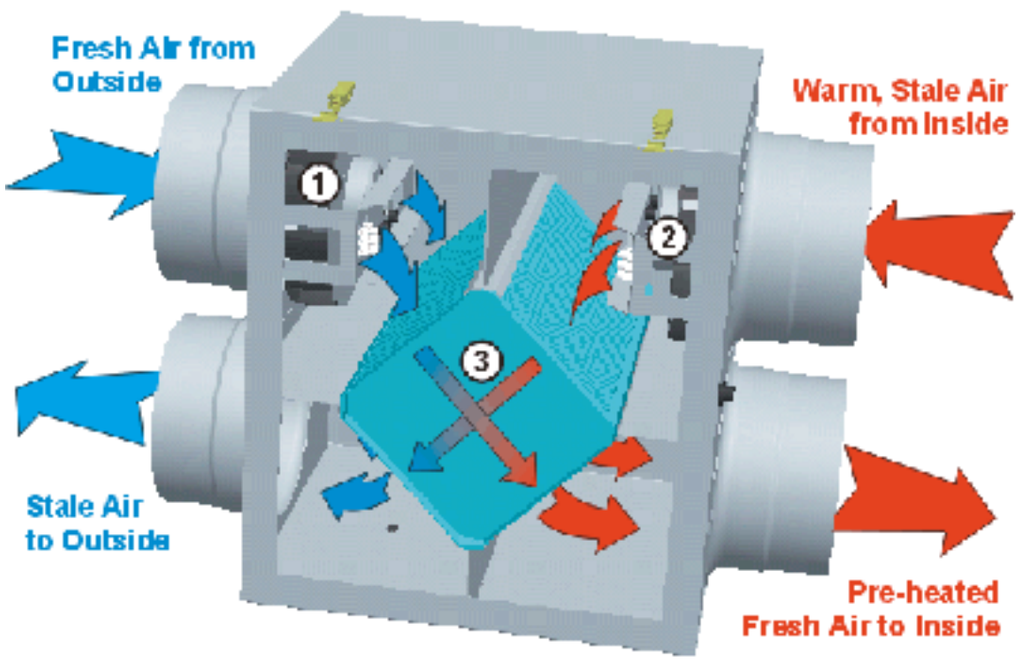
OXFORD BROOKES UNIVERSITY

Innovate UK
Technology Strategy Board

MVHR

- Mechanical Heat Recovery Ventilation
- Widely used in Passivhaus and Low Energy housing
- Recovers heat from wet spaces
- Should allow good ventilation rates, but recover heat

- How well does this work in practice?



MVHR

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- Broad assessment of domestic projects that utilised MVHR systems in the BPE programme
- Not entirely representative

- Aims
  - identify the nature of MVHR systems
  - analyse the available performance data
  - gather insights from projects about the issues affecting the use and performance of these systems

- 54 Dwellings with MVHR
- Assessment of available data
- Additional survey and interviews with design team
- Review of BUS data

- Performance data
- Review of characteristics
- Feedback from projects

Dwelling types	Performance characteristics	Design team interviews	Temp / RH data	BUS survey	CO_2 data	Energy
MVHR	54 homes	15 projects (163 homes)	33-34 homes	27 projects (211 homes)	21 homes	39 homes
Non-MVHR	n/a	n/a	15 homes	15 homes	15 homes	20 homes

Sharpe, Tim, Mawditt, Ian, Gupta, Rajat, McGill, Grainne and Gregg, Mat (2016) Characteristics and performance of MVHR systems A meta study of MVHR systems used in the Innovate UK Building Performance Evaluation Programme. Technical Report. Innovate UK.

In-use performance

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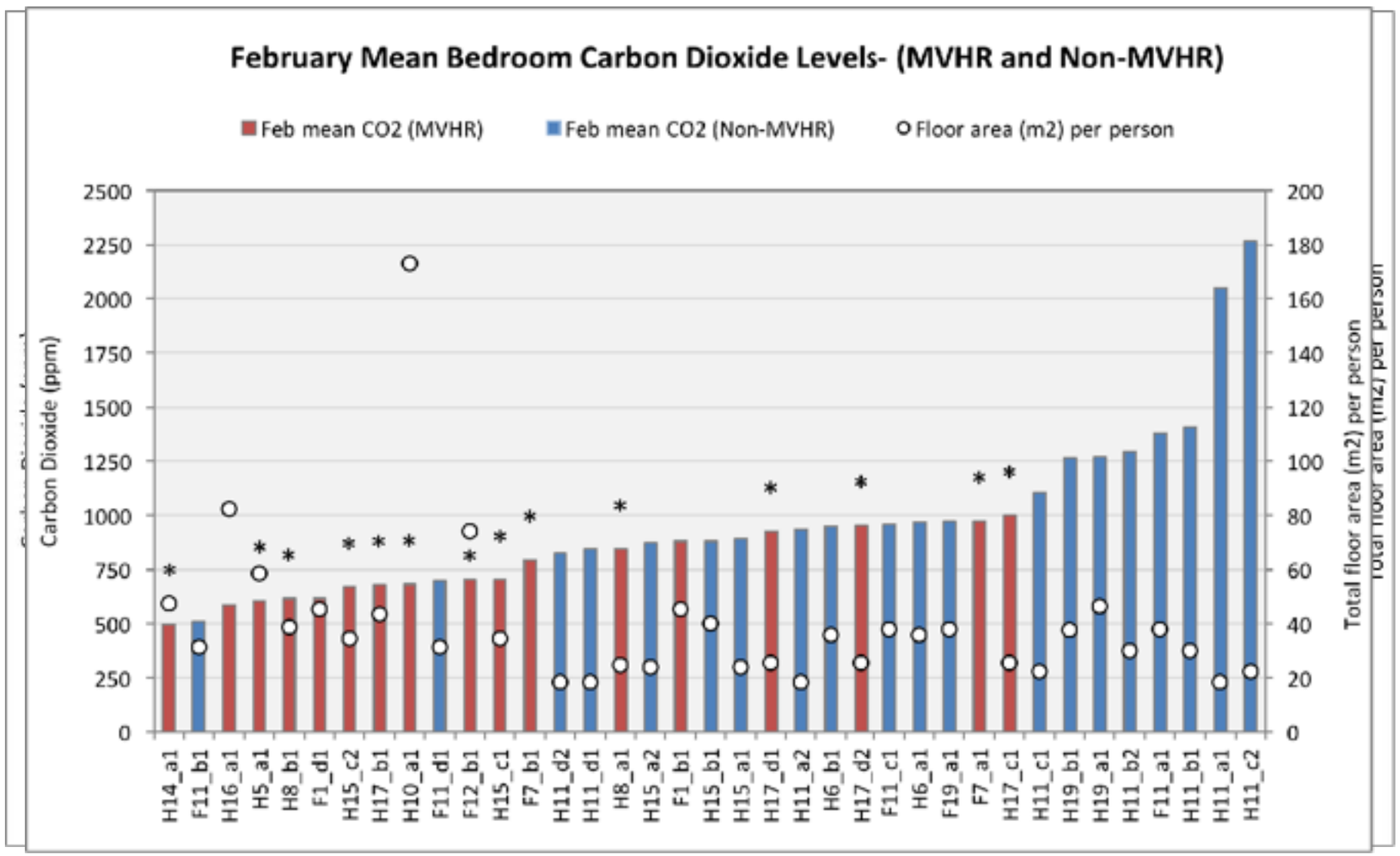
- Comparison of average and peak CO_2 levels in bedrooms of MVHR and non MVHR
  - Not time weighted
  - NB - predominance of Passivhaus MVHR systems
  - Limited datasets



MVHR meta study

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- Range of CO_2 levels in bedrooms of MVHR and non MVHR
- MVHR more stable

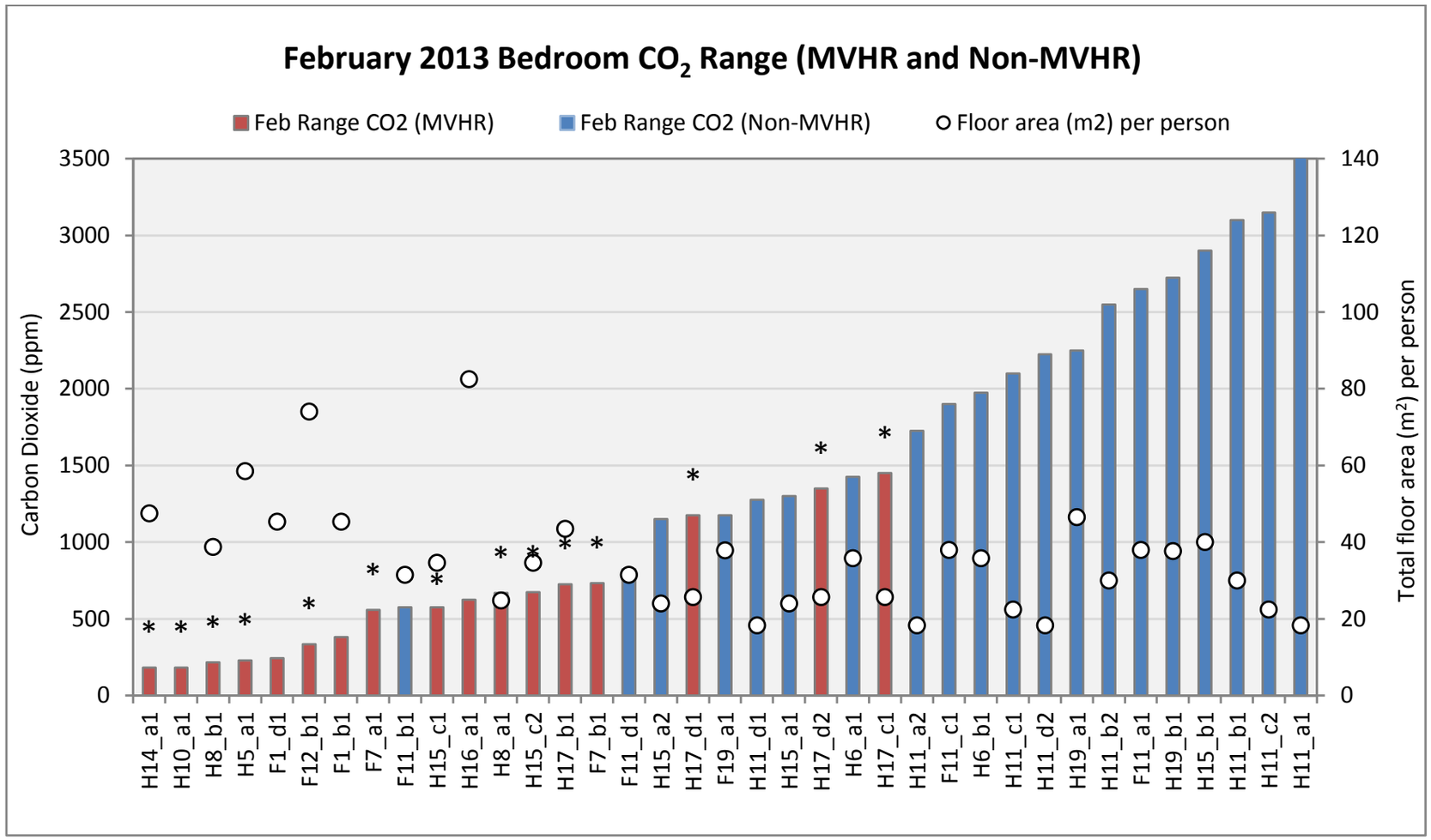

Figure 8.2i. Range of bedroom CO_2 levels during February in MVHR and Non-MVHR homes
** Passivhaus dwellings*

MVHR meta study

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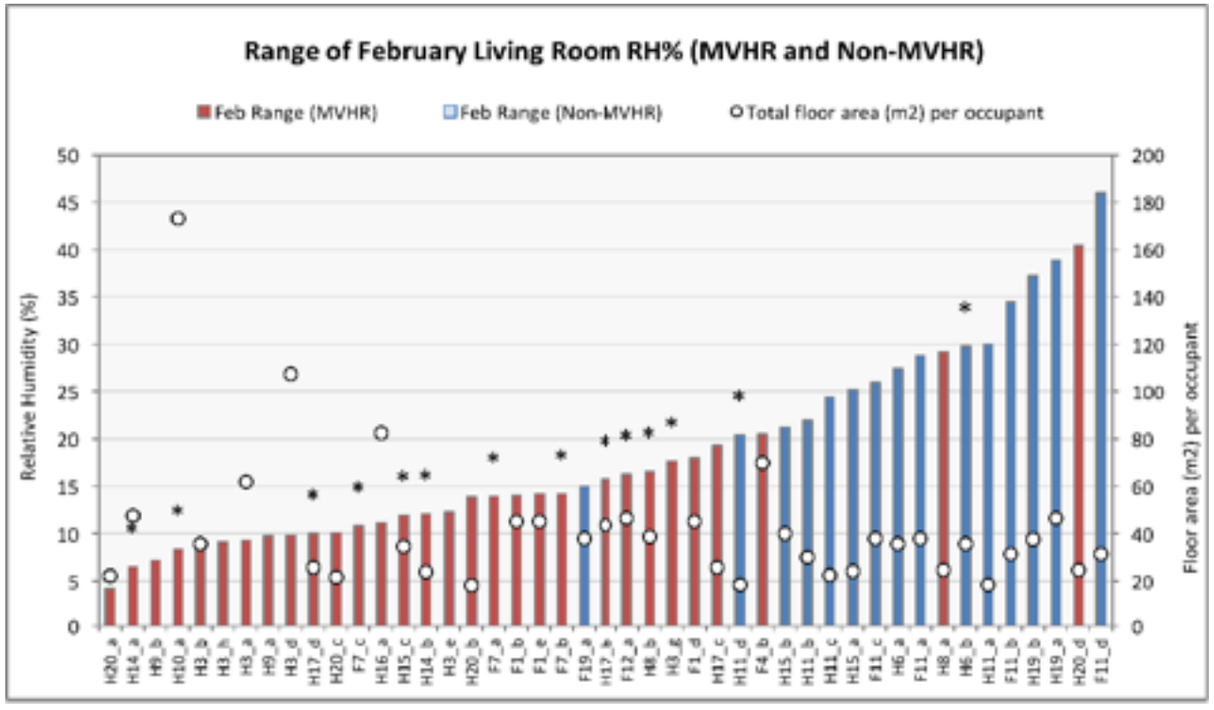
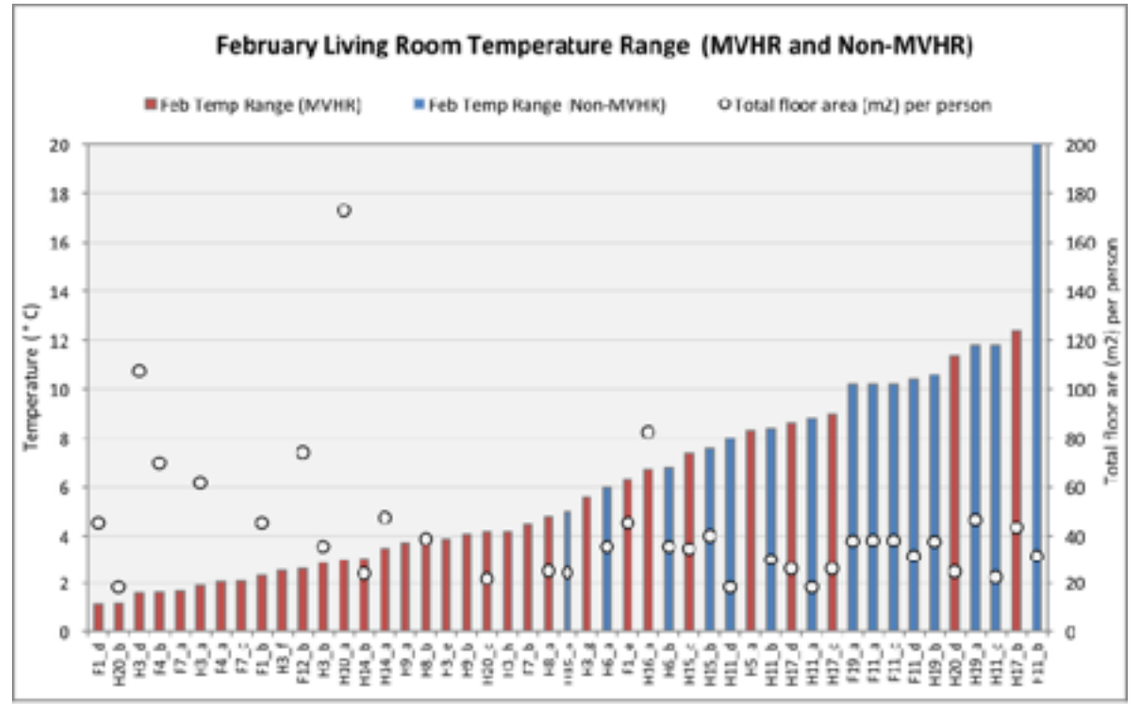
- Range RH and temperature levels in bedrooms of MVHR and non MVHR
- Great stability





Mechanical Ventilation

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- In general lower average and peak CO_2
- Lower ranges of CO_2, temperature, RH and VP
- Lower overall energy use

- But..

Meta Study - air permeability

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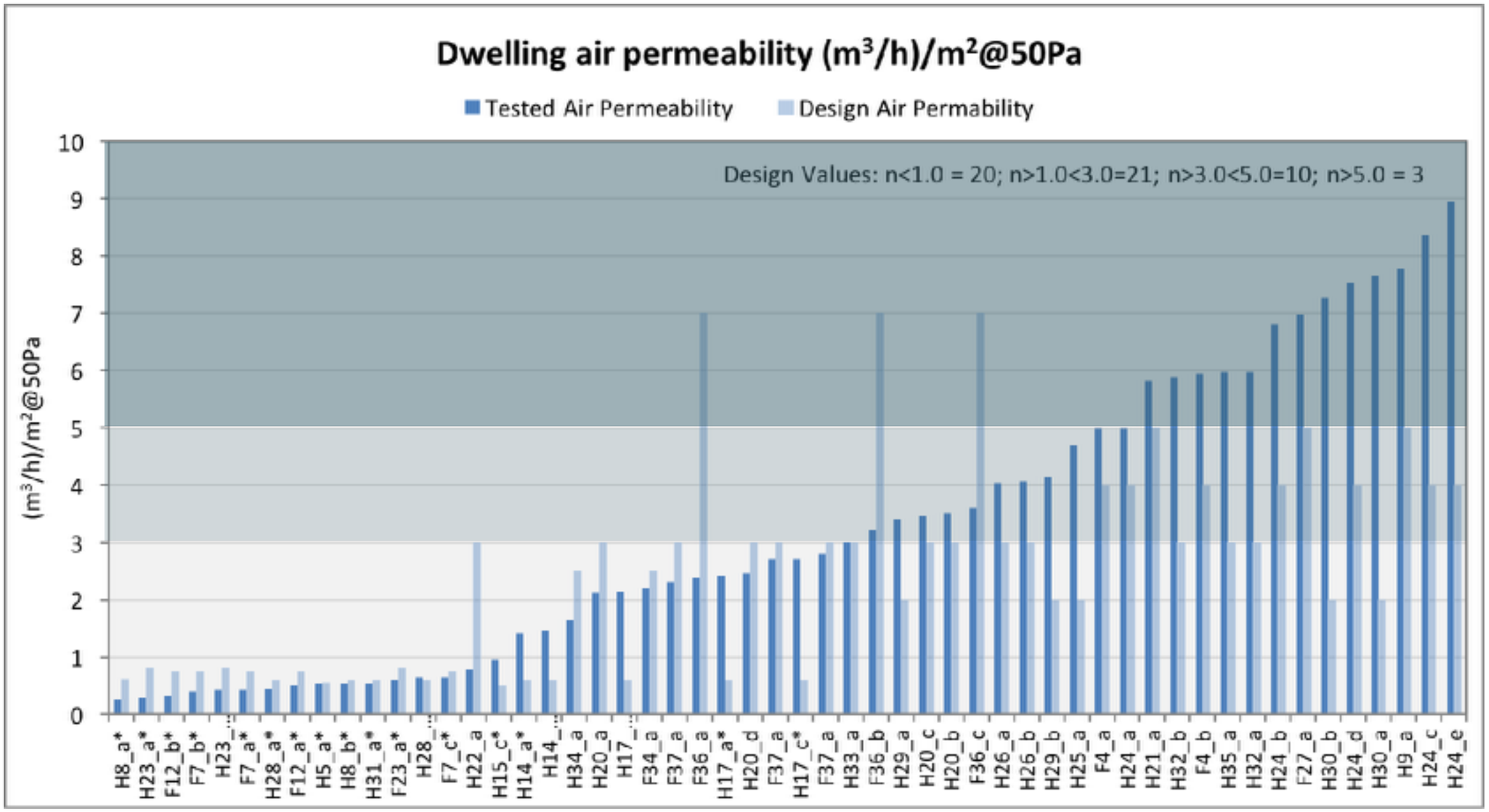
- 44% > 3 (m^3/h)/m^2@50Pa
- 27% > 5m^3/h)/m^2@50Pa
- All passivhaus < 3 (m^3/h)/m^2@50Pa



Meta Study - flow rates

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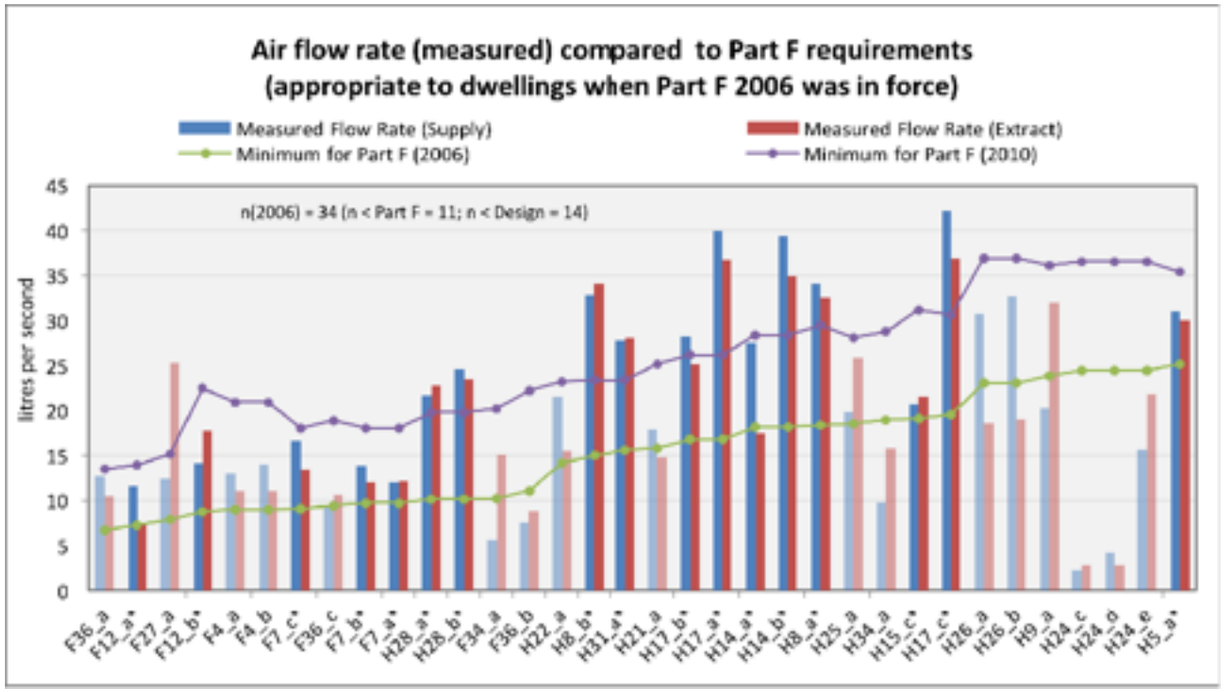
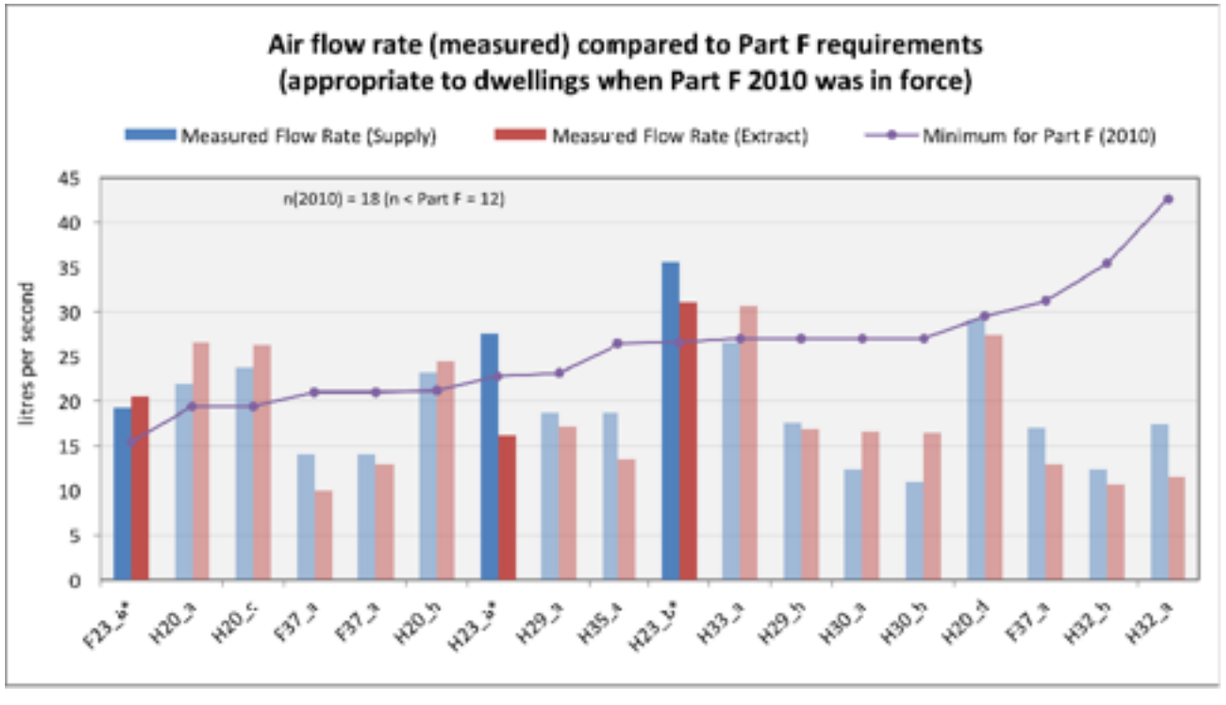
- Building to 2006 and 2010 standards

- For 2006 buildings 32% below
- For 2010 buildings 67% below

- Extract rates below standards:
- 56% kitchens
- 39% bathrooms
- 70% ensuites and 62% utilities

- Passivhaus is generally better, 85% met regs





Flow rates

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- Flow rates to individual rooms

Location	Extract				
	Low Rate (Trickle)		High Rate (boost)		
	Design Volume l/s	Actual Volume l/s	Minimum Volume l/s	Design Volume l/s	Actual Volume l/s
Kitchen	13.6	2	13	16.3	6.5
Bathroom	8	2.7	8	10	6.1
Total	21.6	4.7	21	26.3	12.6
	- 78%			- 52%	

Location	Supply			
	Low Rate (Trickle)		High Rate (boost)	
	Design Volume l/s	Actual Volume l/s	Design Volume l/s	Actual Volume l/s
Living room	13	6		11
Master Bedroom	6	4		7
Bedroom 2	6	3		6
Bedroom 3	6	4		8
Total	31	17		32
	-45%			

Compare with 8 l/s person

Meta Study - balance

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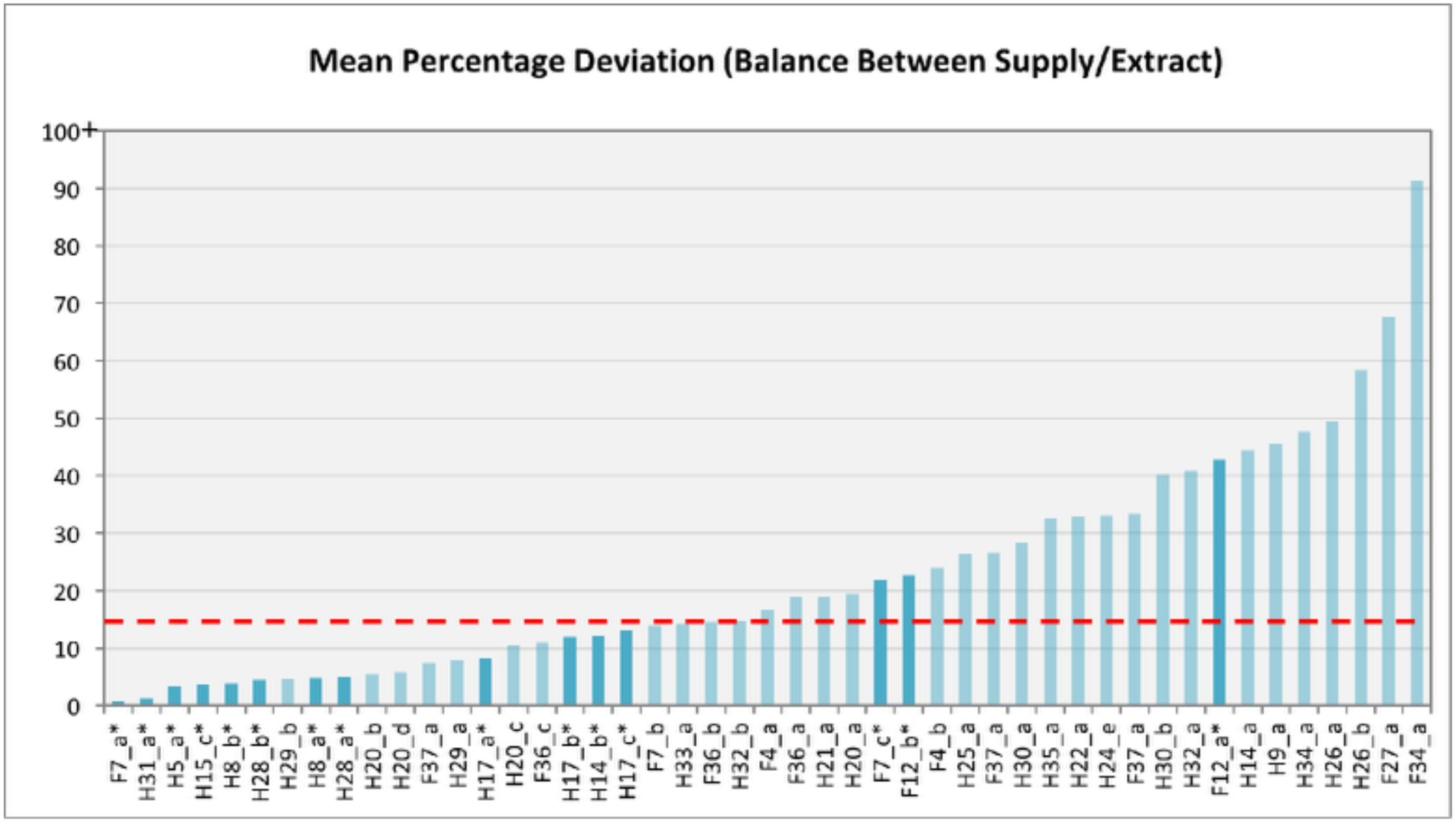
- 60% more than 15% out of balance
- Imbalance will impact on energy recovery - hard to quantify
- Other consequences - interstitial leaks of moisture



Glasgow House - MVHR testing

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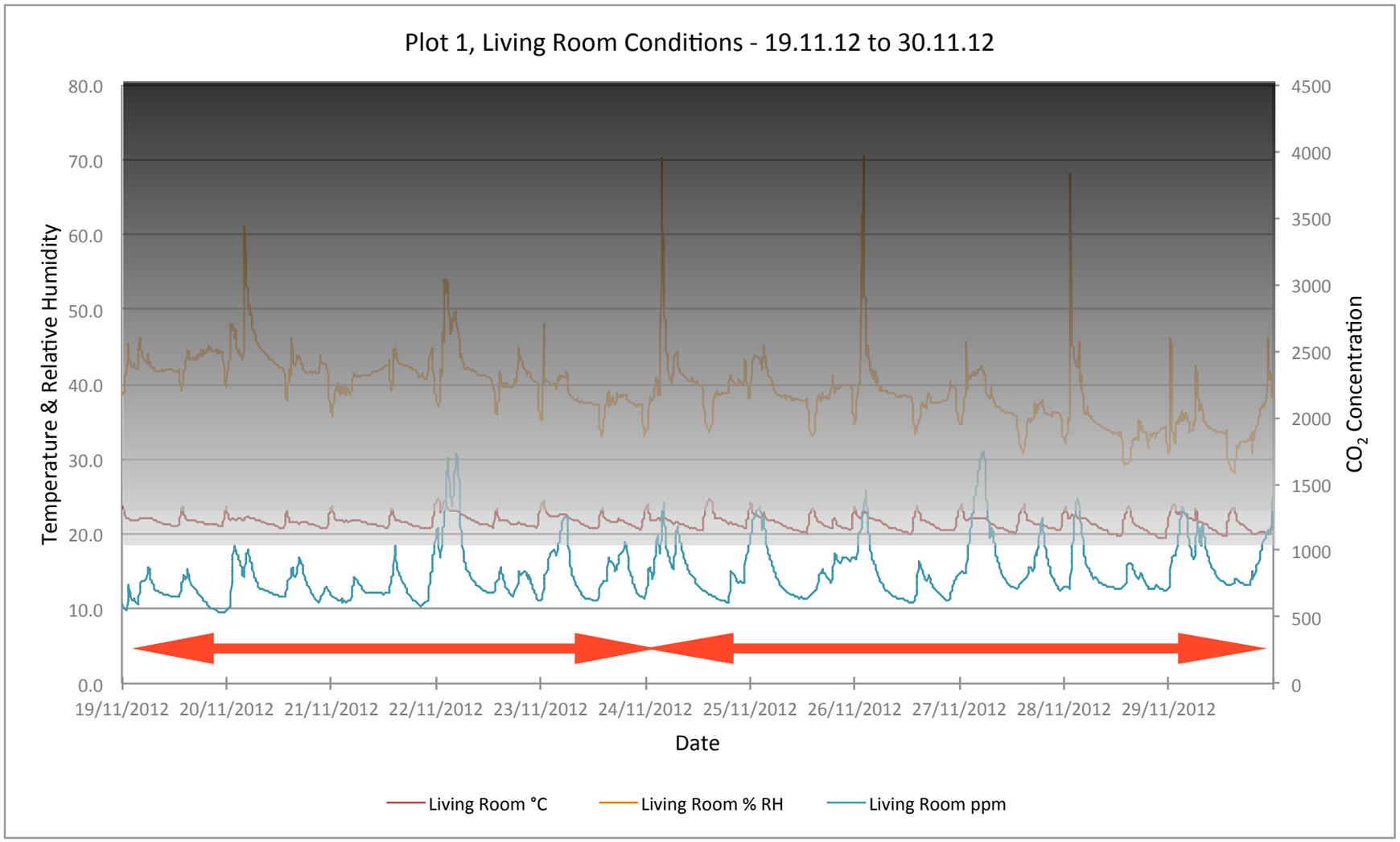
- **SC6**: Comparison of MVHR (week 1) vs window opening (week 2)
- Week 2 - better perception, but measured values worse



Sharpe, Tim and Shearer, Donald (2014) Scenario Testing of the Energy and Environmental Performance of “The Glasgow House”. Buildings, 4 (3). ISSN 2075-5309

KTP Cartwright Pickard Architects

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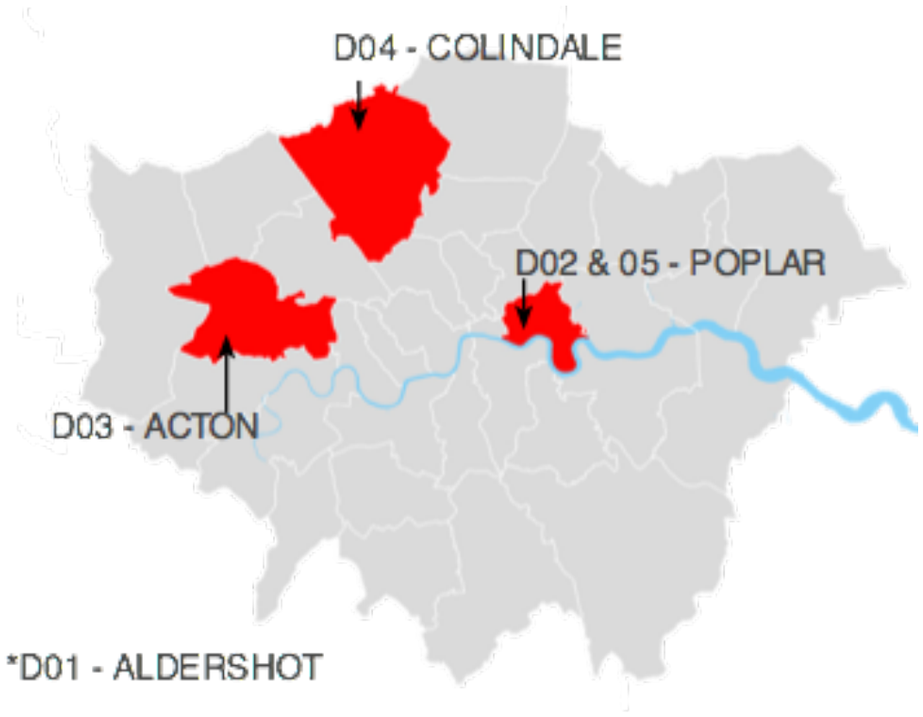
- Evaluation of 20 dwellings across London, 9 with MVHR
- Included testing and evaluation of MVHR system
- CO_2 measurement in living and bedrooms
- 24,000 similar homes in 2012



CO_2 levels overnight

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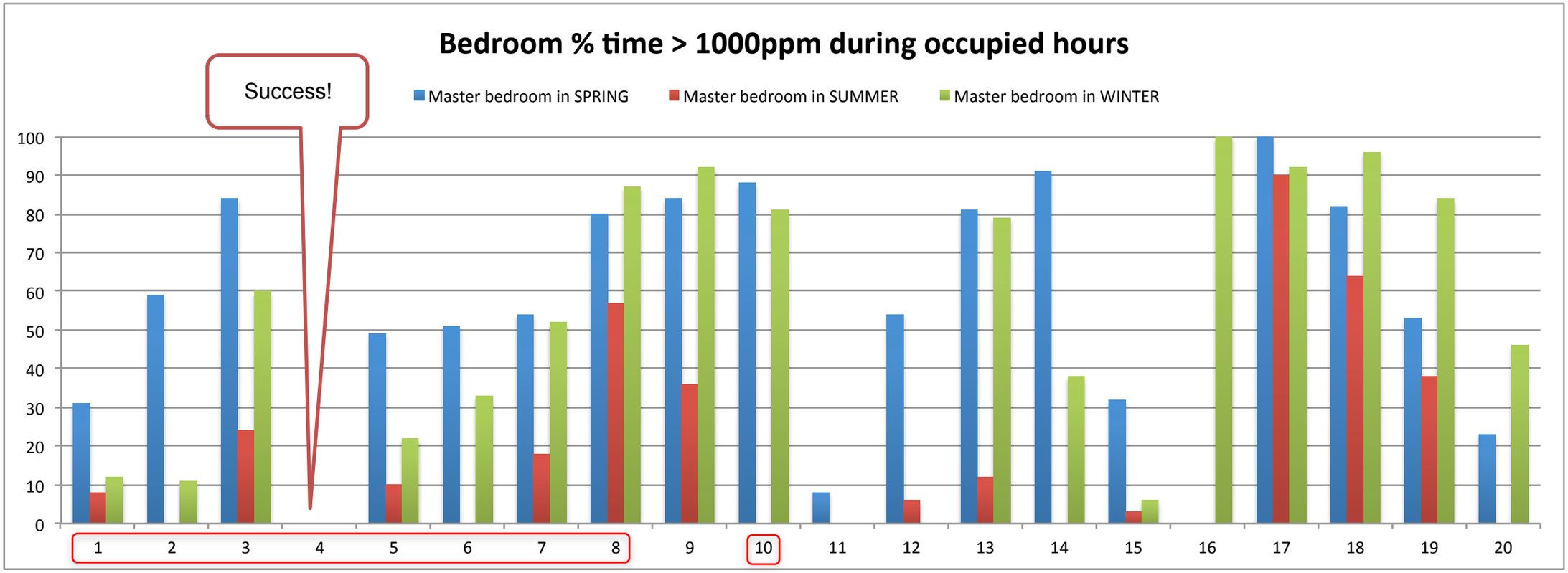
- % time over 1000ppm
- Bedrooms
- Worse overnight



MVHR issues

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- Design intentions
- Design integration
- Ducts type and size

- Missing vents in bedrooms
- Unbalanced systems
- Unit location for filter cleaning
- Construction debris

- Noise
- Occupant understanding
- Lack of maintenance strategy

Air Quality in airtight homes

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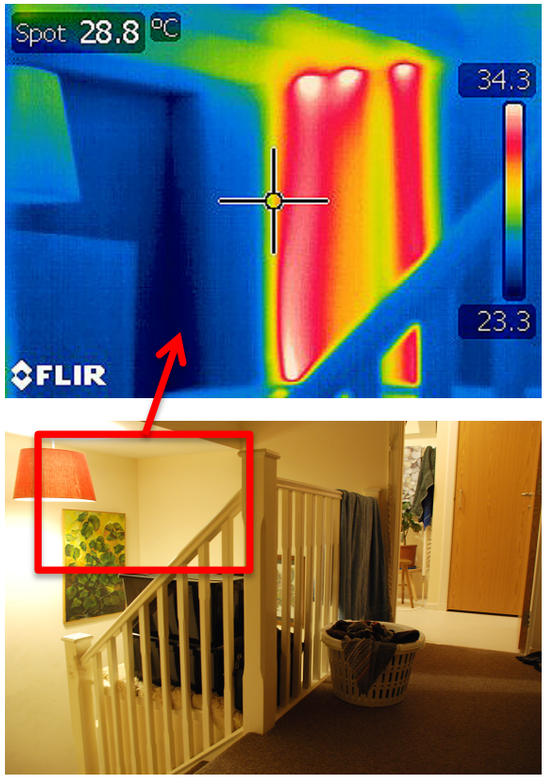
- Airborne Bacteria and Fungi Concentrations in Airtight Contemporary Dwellings

House No.	Occupancy A=Adult, C=Child	Reported presence of mould	Monitored bedroom conditions	Main heating fuel
No.1	2A, 1C	Yes	Spare room	Natural gas (fire)
No.2	2A, 1C	No	Playroom	Natural gas (fire)
No.3	2A, 2C	Yes	Childs bedroom	Natural gas (fire)
No.4	2A, 1C	No	Childs bedroom	Electric (fire)
No.5	2A	No	Spare room	Electric (fire)
No.6	4A, 1C	Yes	Teenagers bedroom	Natural gas (fire)



McGill, Grainne, Sharpe, Tim, Oyedele, Lukumon, Keeffe, Greg and McAllister, Keith (2015) An Investigation of indoor air quality in UK Passivhaus dwellings. In: Smart Energy Systems and Buildings for a Sustainable Future. Springer.

McGill, Grainne, Oyedele, Lukumon, Keeffe, Greg, McAllister, Keith and Sharpe, Tim (2015) Bedroom environmental conditions in airtight mechanically ventilated dwellings. In: Healthy Buildings Conference, Europe, 18-20th May, Eindhoven.

McGill, Grainne, Moore, John, Sharpe, Tim, Downey, Damian and Oyedele, Lukumon (2015) Airborne bacteria and fungi concentrations in airtight contemporary dwellings. In: Healthy Buildings America.

Sharpe, Tim and Morgan, Chris (2014) TOWARDS LOW CARBON HOMES – MEASURED PERFORMANCE OF FOUR PASSIVHAUS PROJECTS IN SCOTLAND. In: Eurosun 2014, 16 - 19 September 2014, Aix-les-bains, France.

Conclusions

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- Energy only strategies
- Ventilation is not being designed
- Compliance is prescriptive and achieved at design stages - no verification
- The process and the product is fragmented
- No-one has an overview of the whole process

- **Design should include performance**
- **Evaluation of performance not intention**
- **Building Performance Evaluation must be mainstream**

- **What is good ventilation?**
- **What are the health consequences?**

Health effects of modern airtight construction

- AHRC Network Funding
- With medical researchers University of Aberdeen
- Investigating health effects

- 3 networking events in the next 12 months
- Multidisciplinary

- http://hemacnetwork.com

- Symposium Sept
  - platform for participants to present their research findings
- Workshop Nov/Dec
  - develop research and output ideas
- Sandpit Mar/Apr
  - Further refine and peer review
  - Develop network outputs

Progress

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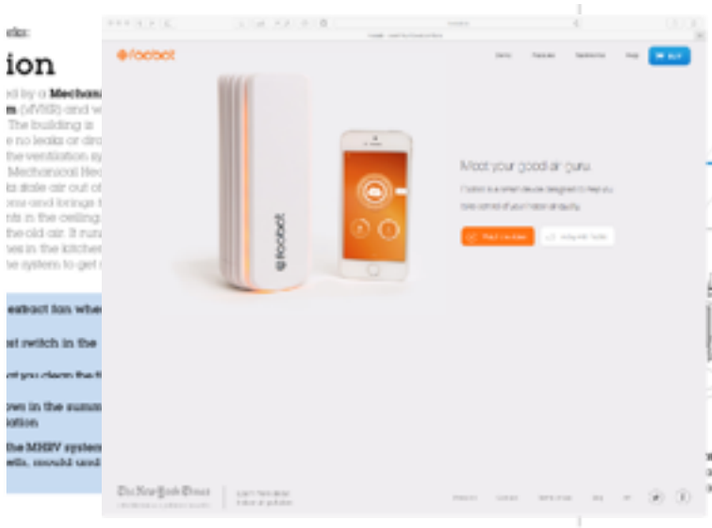
- Simple guidance for occupants of low energy homes for Scottish Building Standards
- http://www.gov.scot/resource/doc/217736/0116377.pdf
- CO_2 awareness raising

3.14.2 Ventilation awareness in dwellings

Carbon dioxide (CO_2) is present in the external air we breathe at concentration levels of around 400 parts per million and is not harmful to health at low concentration levels. However, as people release CO_2 into the air when they exhale, increased levels of CO_2 in occupied buildings can occur. This s generally accepted as being a reasonable indication that ventilation action is necessary.

CO_2 monitoring equipment should be provided in the apartment expected to be the main or principal bedroom in a dweling where infiltrating air rates are less than $15m^3/hr/m^2$ @ 50 Pa. This should raise occupant awareness of CO_2 levels (and therefore other pollutants) present in their homes and of the need for them to take proactive measures to increase the ventilation. Guidance on the operation of the monitoring equipment, including options for improving ventilation when indicated as necessary by the monitor, should be provided to the occupant. For more detailed information on the provision of guidance to occupants, reference may be made to "*Domestic Ventilation*" Scottish Government 2015 http://www.gov.scot/Resource/0040/00409104.pdf.



Conclusions

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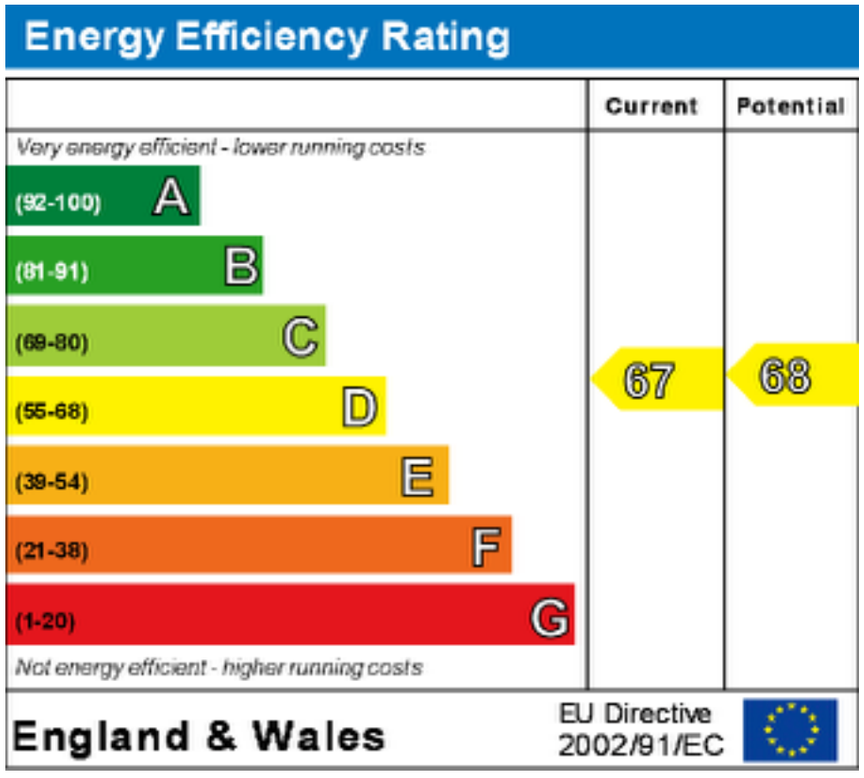

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Thank you

- http://tinyurl.com/qzrbumo

- Tim Sharpe t.sharpe@gsa.ac.uk 0141 353 4658

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- http://www.gsa.ac.uk/study/graduate-degrees/environmental-architecture/

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Environmental Architecture

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