



University of
Strathclyde
Engineering

BALANCING ENERGY- EFFICIENCY AND HEALTH **ACHIEVING OPTIMAL INDOOR AIR QUALITY IN NET ZERO HOMES**

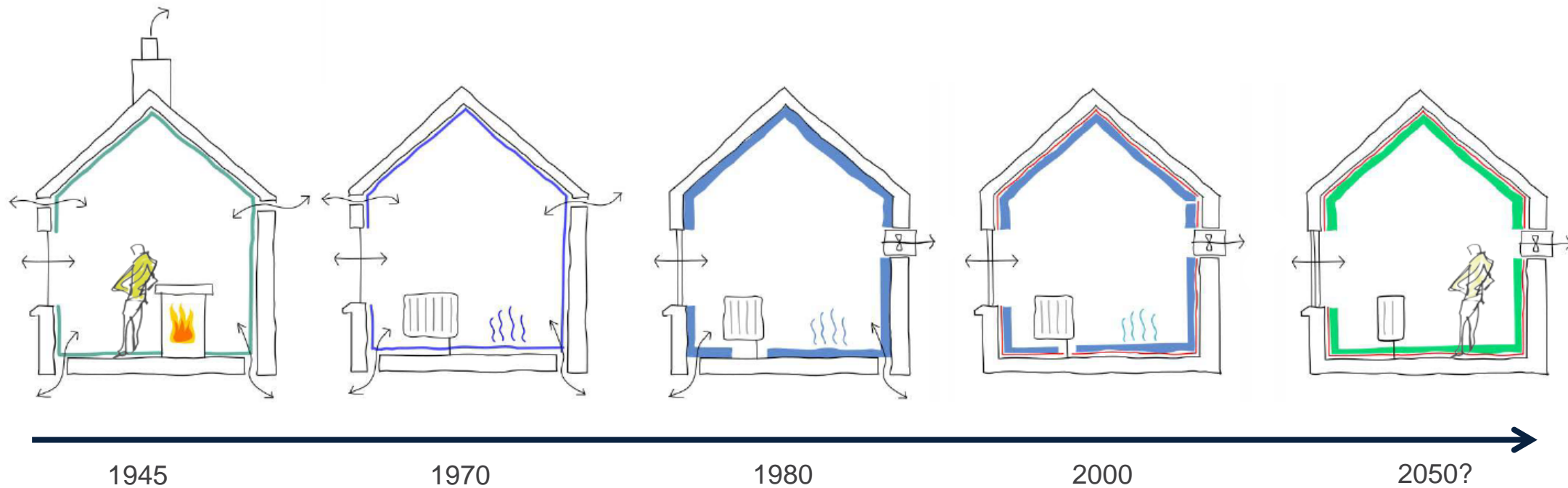
Dr Alejandro Moreno-Rangel



ENVIRONMENTAL IMPACT



EVOLUTION OF THE HOME



NET ZERO POLICY AND HOUSING [ENGLAND]

- Announced first in 2019 and is set to be in place by 2025.
- The government has introduced major changes to the Building Regs [Parts F, L, O and S]
- Seeks to reduce carbon emissions from new homes between 75% to 80%.
- Gas boilers banned and promotion low-carbon heating strategies (i.e., air source heat pump).
- Changes to ventilation and airtightness.



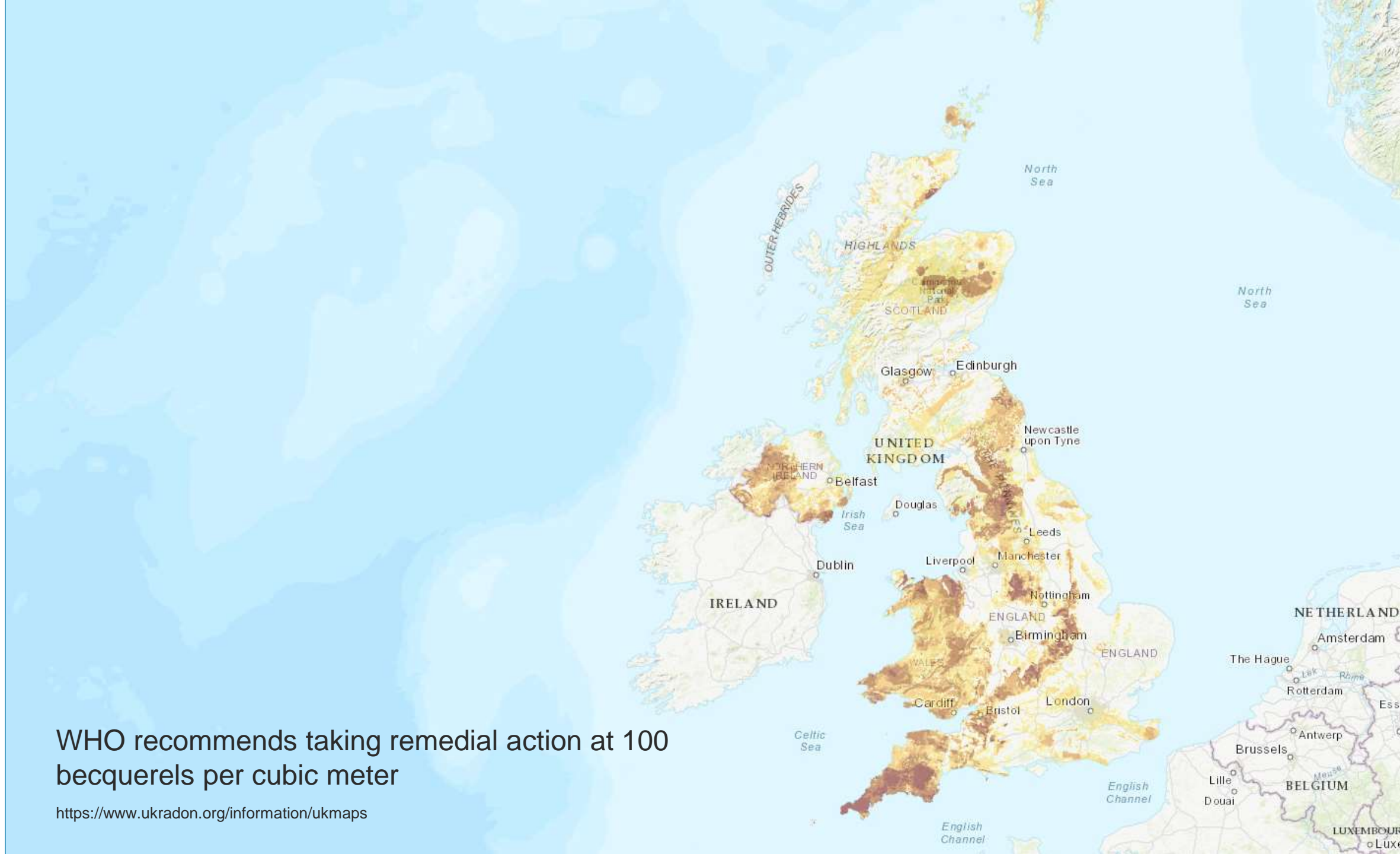
CHANGES IN U-VALUES [SCOTLAND]

Thermal Element	Scottish Regs Section 6 (2015) U-values (W/m ² K)	Scottish Regs Section 6 (2020) U-Value (W/m ² K)	Scottish Regs Section 6 (2025) U-Value (W/m ² K)	Passivhaus
Wall	0.17	0.15	0.13	0.10 – 0.15
Roof	0.11	0.09	0.09	0.10 – 0.15
Floor	0.15	0.12	0.10	0.10 – 0.15
Windows	1.4	1.2	0.8 – 1.0	0.8
Doors	1.4	1.2	0.8 – 1.0	0.8
Air Permeability	7m ³ /(h·m ²) at 50 Pa	5.0 m ³ /(h·m ²) at 50 Pa	3.0 m ³ /(h·m ²) at 50 Pa	0.6 m ³ /(h·m ²) at 50 Pa

WHAT DOES SCIENCE TELL US?







WHO recommends taking remedial action at 100 becquerels per cubic meter

<https://www.ukradon.org/information/ukmaps>

IAQ OF SCOTTISH HOMES WITH DIFFERENT BUILDING FABRICS.



Article

Indoor Air Quality and Thermal Environment Assessment of Scottish Homes with Different Building Fabrics

Alejandro Moreno-Rangel ^{1,2,*}, Tim Sharpe ^{1,2}, Gráinne McGill ^{1,2} and Filbert Musau ¹

¹ Mackintosh Environmental Architecture Research Unit, The Glasgow School of Art, 167 Renfrew Street, Glasgow G3 6RQ, UK

² Department of Architecture, University of Strathclyde, 75 Montrose Street, Glasgow G1 1XJ, UK

* Correspondence: alejandro.moreno-rangel@strath.ac.uk; Tel.: +44-(0)-141-548-3995

Abstract: The ongoing climate change and policies around it are changing how we design and build homes to meet national carbon emission targets. Some countries such as Scotland are adopting higher-energy-efficient buildings as minimum requirements in the building regulations. While net zero homes might be more energy-efficient and emit fewer operational carbon emissions, we have yet to fully understand the influence on the indoor environment, particularly on indoor air quality (IAQ) and thermal comfort. This study compares the IAQ of three homes in Scotland with equal internal layouts and designs but different building fabrics. The homes represent the minimum Scottish building regulations (2015), the Passivhaus standard and the Scottish 'Gold Standard'. Temperature, relative humidity, PM_{2.5} and total volatile organic compounds (TVOC) were measured at five-minute intervals for seven months and compared to occupants' subjective responses to the IAQ. All three homes had temperatures above the recommended thresholds for overheating. Measured hygrothermal conditions were within the ideal range 66.4% of the time in the Passivhaus, 56.4% in the Gold Standard home and 62.7% in the control home. Measured IAQ was better in homes with higher energy efficiency, particularly TVOC. For instance, indoor PM_{2.5} in the Passivhaus were 78.0% of the time below the threshold, while in the standard home the figure was 51.5%, with a weak correlation with outdoor PM_{2.5} (Passivhaus: $B r_s = 0.167$, $K r_s = 0.306$ and $L r_s = 0.163$ ($p < 0.001$); Gold: $B r_s = -0.157$, $K r_s = 0.322$ and $L r_s = 0.340$ ($p < 0.001$); Control: $B r_s = -0.111$, $K r_s = 0.235$ and

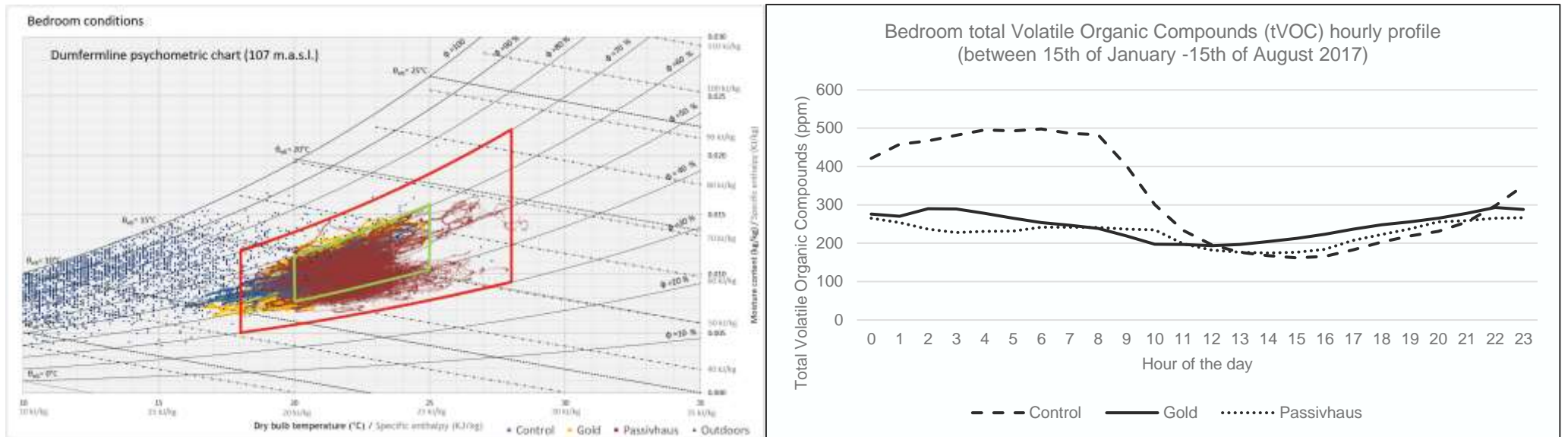


GROUND FLOOR

FIRST FLOOR



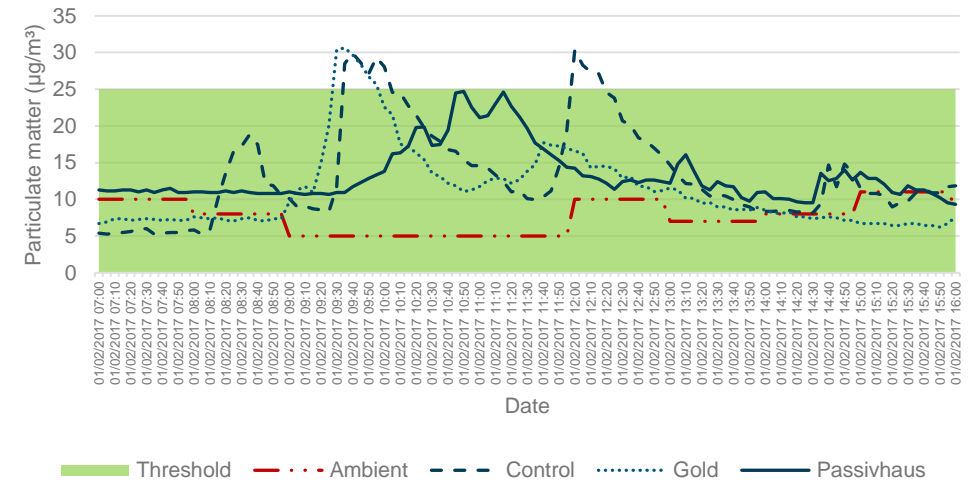
IAQ OF SCOTTISH HOMES WITH DIFFERENT BUILDING FABRICS.



IAQ OF SCOTTISH HOMES WITH DIFFERENT BUILDING FABRICS.

		Ambient																											
		Hour	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Hour		
February	Ambient	7.2	7.1	7.3	7.3	7.6	7.9	8.1	8.0	7.3	7.1	7.6	7.2	7.7	7.5	8.0	7.9	8.7	9.6	9.2	8.0	7.6	7.8	7.9	7.5	Ambient	February		
March	Ambient	6.5	6.0	5.7	5.5	5.7	7.1	7.5	7.5	7.1	6.7	6.3	6.4	6.1	6.1	6.6	7.1	7.7	8.3	9.2	8.3	8.0	7.5	7.1	6.8	Ambient	March		
April	Ambient	3.7	3.7	3.9	4.3	4.8	5.2	5.5	5.5	5.0	5.0	5.0	4.9	4.5	4.5	4.6	4.3	4.3	4.1	4.6	4.8	4.6	5.2	4.9	4.1	Ambient	April		
May	Ambient	7.3	7.5	7.7	8.0	8.3	8.6	8.6	8.2	7.9	7.8	7.4	7.6	7.6	7.3	7.4	7.3	7.4	7.5	7.5	7.6	7.4	7.3	7.0	Ambient	May			
June	Ambient	4.1	4.1	3.8	3.9	3.8	3.7	3.7	3.7	3.5	3.2	3.2	3.4	3.0	2.9	3.0	3.0	3.2	3.3	3.2	3.5	4.1	4.0	3.9	4.1	Ambient	June		
July	Ambient	4.4	4.3	4.8	4.6	4.6	4.5	4.4	3.9	3.9	3.9	3.9	4.0	4.2	4.3	4.1	4.1	4.1	4.3	4.1	4.0	4.1	4.1	4.0	4.1	Ambient	July		
August	Ambient	3.2	3.4	3.3	3.0	2.9	2.6	2.5	2.7	2.5	2.4	2.2	2.7	3.0	2.8	2.9	2.9	2.8	2.8	2.9	2.9	2.8	3.1	2.9	3.1	Ambient	August		
		Bedroom																											
		Hour	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Hour		
February	Control	11.2	12.8	10.6	9.2	8.5	8.0	7.4	7.1	8.7	10.2	11.5	11.0	11.8	12.2	12.7	9.4	10.8	31.6	37.2	24.8	20.1	20.3	15.5	12.6	Control	February		
	Gold	8.3	7.7	7.2	7.0	6.9	6.7	6.7	7.6	10.9	16.6	16.0	13.7	10.7	8.5	8.0	8.3	10.4	10.8	9.1	9.7	12.0	12.2	9.5	9.1	Gold			
	Passivhaus	12.2	8.4	7.5	7.1	6.9	7.1	6.9	20.2	20.0	64.5	77.5	18.8	12.6	8.8	7.6	11.8	23.4	34.6	16.6	14.0	11.1	10.6	8.9	9.0	Passivhaus			
March	Control	12.8	11.5	10.2	9.2	8.4	8.0	7.6	7.6	10.3	13.7	13.4	13.8	13.3	11.8	11.0	11.5	10.5	11.9	21.8	25.4	19.5	19.5	16.5	14.2	Control	March		
	Gold	9.3	8.9	8.9	8.6	8.3	8.1	8.0	8.8	12.7	16.0	14.5	13.2	11.9	10.1	9.2	9.6	10.1	11.0	12.1	10.4	9.6	10.9	11.7	10.5	Gold			
	Passivhaus	10.2	6.4	5.5	5.2	5.0	6.4	8.9	5.3	5.2	63.0	73.9	11.5	6.0	8.5	6.3	13.1	13.2	22.3	10.9	15.3	10.5	7.6	8.5	15.8	Passivhaus			
April	Control	6.4	5.5	5.0	4.7	4.6	4.5	4.5	4.6	5.1	6.6	7.0	8.6	7.8	8.3	7.6	6.6	6.1	6.7	6.9	7.4	6.8	7.1	7.5	7.2	Control	April		
	Gold	10.1	9.6	9.5	9.5	9.5	9.6	9.6	10.5	13.0	16.9	18.5	16.9	15.0	14.0	13.6	12.5	12.0	12.3	12.2	11.7	11.3	11.2	10.6	10.4	Gold			
	Passivhaus	12.4	5.4	4.2	3.9	3.8	5.7	19.9	7.7	8.2	26.8	61.6	18.1	8.4	8.0	12.5	15.1	15.4	14.4	14.1	13.1	10.7	11.6	6.3	17.8	Passivhaus			
May	Control	9.0	8.1	7.5	7.3	7.3	7.4	7.2	8.9	13.4	12.2	13.9	12.5	14.2	9.6	9.6	8.3	8.2	11.9	11.8	10.6	10.8	11.0	10.1	Control	May			
	Gold	9.9	9.7	9.5	9.6	9.9	10.1	10.2	10.4	12.9	15.0	15.5	15.5	12.1	11.0	11.0	11.3	11.5	11.7	13.3	11.3	10.2	10.4	10.2	10.1		Gold		
	Passivhaus	12.2	9.7	9.0	9.7	10.9	15.4	22.7	10.8	15.4	45.5	39.9	22.4	11.5	15.5	15.4	15.2	12.6	22.3	16.9	18.8	13.6	10.7	10.0	11.8		Passivhaus		
June	Control	8.3	6.9	6.3	6.0	5.9	5.7	5.5	5.4	5.8	7.2	7.7	8.1	7.4	7.8	6.0	5.7	5.7	6.0	6.3	6.2	6.2	7.0	7.5	8.2	Control	June		
	Gold	11.0	13.9	14.0	13.8	13.7	13.8	13.8	13.8	16.3	21.2	20.4	19.8	16.6	15.8	14.5	14.4	14.6	15.4	14.4	14.0	14.0	13.8	14.0	14.4	Gold			
	Passivhaus	11.3	9.5	9.4	9.3	9.8	11.1	13.0	12.5	13.8	33.5	71.3	15.6	10.7	9.6	14.2	8.7	10.5	10.5	17.5	14.2	10.9	10.4	9.8	11.6	Passivhaus			
July	Control	12.5	12.6	11.4	10.8	10.2	9.9	9.7	9.9	10.0	10.1	10.2	10.8	11.4	11.9	11.0	10.6	10.0	9.7	10.5	10.7	11.1	11.0	12.0	12.3	Control	July		
	Gold	20.3	20.4	20.5	20.5	20.5	20.6	20.5	20.8	21.7	22.8	23.4	22.6	23.1	22.5	21.6	21.3	21.0	20.9	20.9	20.5	20.5	20.4	20.4	20.3	Gold			
	Passivhaus	10.1	9.5	9.5	9.6	10.0	12.6	18.1	21.8	13.4	25.6	34.7	12.9	10.5	13.9	12.3	10.2	12.4	16.4	11.2	16.0	11.0	12.4	14.1	15.7	Passivhaus			
August	Control	19.0	18.5	19.3	19.2	19.0	19.0	19.5	19.7	19.7	19.8	20.2	20.6	22.9	22.3	21.0	19.9	19.5	19.5	20.9	20.5	19.5	20.1	20.6	20.1	Control	August		
	Gold	19.7	20.1	20.0	19.9	20.0	20.3	20.4	20.8	21.4	24.1	25.3	25.5	24.4	24.9	21.6	20.6	19.9	19.9	19.7	19.8	19.9	20.5	20.1	20.3	Gold			
	Passivhaus	8.1	8.3	7.7	7.4	7.7	8.8	12.3	9.7	8.7	10.4	63.4	33.5	13.3	24.8	11.9	7.2	7.0	8.1	10.8	10.9	13.7	12.6	8.8	9.2	Passivhaus			
PM2.5 (µg/m³) scale		0	3	7	10	14	17	21	24	28	31	35	38	42	45	49	52	56	59	63	66	70	73	77	80	PM2.5 (µg/m³) scale			

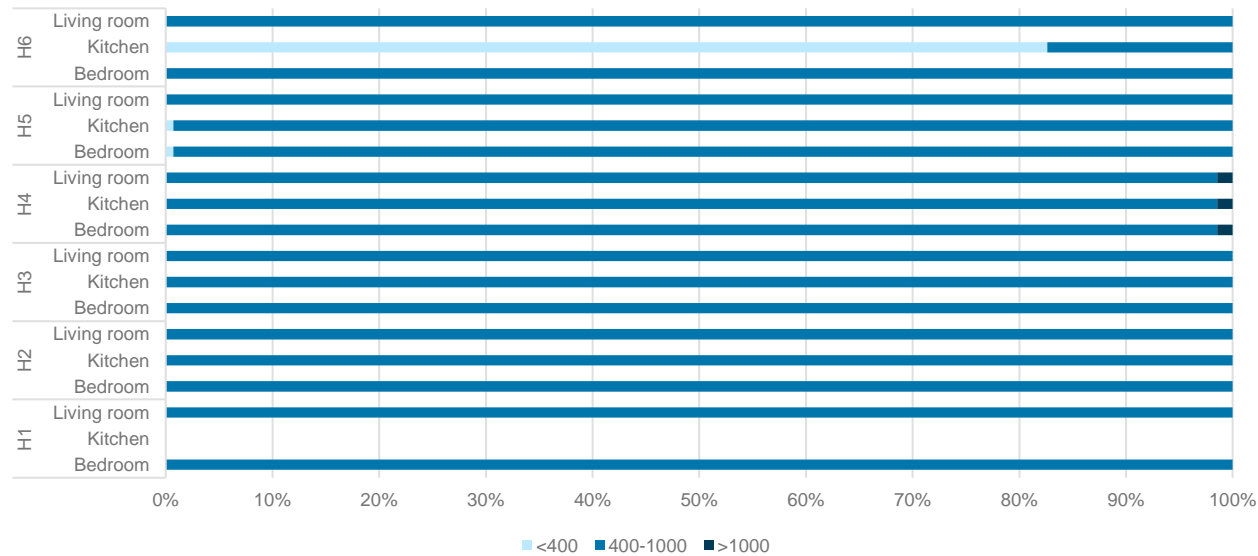
Living room PM2.5 of the different during winter



RETROFITTED NET ZERO HOMES

The environmental analysis suggests that the temperature (67% of the time), relative humidity (75% of the time) and CO2 (100% of the time) were within the recommended parameters.

Carbon dioxide ranges (ppm - 27/01/2023 - 26/06/2023)





University of
Strathclyde
Engineering