Warm Homes Fund evaluation:

Indoor environmental monitoring report

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Newcastle University

NEA
Action for Warm Homes

Introduction

The Innovation and Technical Evaluation team within NEA have compiled this report following a monitoring campaign with project partners, which aimed to collect data from homes that received interventions through the Warm Homes Fund (WHF). With the assistance of project partners, data loggers were deployed to collect temperature, relative humidity (RH) and carbon monoxide (CO) data from beneficiary properties. The purpose of this work was to complement the wider WHF programme evaluation and assess the impact of interventions on internal living conditions and other risk factors. These factors are associated with fuel poverty risk or poor energy efficiency; for example, low temperatures can expose households to cold-related ill health, while high humidity can lead to mould growth and increased indoor pollutants. Both of these can affect or trigger respiratory conditions, or damage building fabric or interior fittings, thus leading to additional maintenance and household expenditure from treating and/or repair work.[1]

Recent developments relating to regulation and practice in the housing sector, particularly in social housing, have underlined the need to include indoor environmental monitoring within the scope of evaluation[2]. In particular, social and private landlords are increasingly required to monitor and address damp and mould growth in their properties, as well as to ensure that tenants can be warm and safe in their homes. The installation of first-time central heating systems forms part of this work, as it affects the temperature and RH that are observed in beneficiary homes. Beyond this, CO remains a critical aspect of wider safety practices in domestic housing. Accordingly, it is important for the evaluation to consider the impact of first-time central heating interventions on the factors most closely related to indoor air quality and safety; specifically temperature, RH, and CO.

Information contained within this report is integrated within the main evaluation report where appropriate. However, this report has been prepared to provide the WHF with a full analysis and breakdown of the indoor environmental monitoring analysis.

Methodology

Monitoring was undertaken using temperature and humidity, and Lascar[3] CO data loggers. To gather temperature and humidity data, two loggers were deployed in the monitored households via project partners: one in the primary living area (typically the living room), and another in a secondary living area (typically a bedroom). For carbon monoxide monitoring (Category 1 households only) a single CO-sensitive data logger was supplied, to be situated appropriately. In total, 192 loggers were supplied to be installed in people's homes through 2020 and 2021.

The loggers were collected by project partners and returned to NEA in spring and summer 2022. The data gathered, along with the installation date of the intervention, gives an opportunity to monitor the temperature, RH and CO levels before and after the heating change. Households' heating requirement varies throughout the year, so in order to compare pre- and post-intervention, a period of time with similar heating need is required to conduct a fair comparison of how the two heating systems performed.

1. Children's Society and NEA (2015) Making a House a Home. Research for National Grid Affordable Warmth Solutions.

2. See, for example, the findings of the Housing Ombudsman's report into mould and damp growth in social housing, and the findings of the Better Social Housing Review.

3. Logger specifications and information can be found here.

Heating Degree Days (HDD) are an accepted measure of how much (in degrees), and for how long (in days), the outside air temperature drops below a certain level; they are commonly used in calculations relating to the energy consumption required to heat buildings. An external temperature of 15.5˚C is the usual base temperature below which heating is normally required inside a building, and above which no heating is normally needed. Degree days are a measure of heating demand of a building relative to the external weather, i.e. the number of degrees below 15.5˚C that the average temperature falls, for each day. For example, if the average outside temperature is 14.5˚C, this is recorded as 1 degree-day. Using the locally appropriate weather data[4], a comparable heating period pre- and post-intervention was selected for comparison. Temperatures of homes in the evening between 6pm and 9pm were chosen, as well as 24-hour average temperatures; the results are integrated where appropriate throughout the full report and this additional report has been prepared by the evaluation team, to expand on the results of the environmental monitoring analysis.

Results

The Warm Homes Fund was divided into four categories of funding, three of which were concerned primarily with heating system installation. These were broadly categorised into the following three tranches of funding:

- Category 1, which was focused on urban homes and communities. Interventions delivered through Category 1 were primarily first-time gas central heating system installations, although a small number of alternative solutions were also delivered in urban homes.
- Category 2, which was focused on rural homes and off-gas communities. Interventions delivered through Category 2 were primarily air source heat pumps (ASHPs), and a smaller number of alternative solutions, especially oil and LPG, were delivered in the earlier phases of the programme.
- Category 3 (Park Homes), which focused on the extension of mains gas to Park Homes sites.

In total, 69 temperature and humidity loggers were returned from households that received interventions, during the monitoring period; the results are analysed below according to category of intervention.

Temperature

This report analyses temperature, humidity and carbon monoxide data taken from hourly readings by the Lascar data loggers. These metrics are indicative of thermal comfort, indoor air quality, and safety within the home.

Temperature analysis can confirm whether the installation of a new heating system enabled the household to achieve the recommended temperatures for health of 18˚C–21˚C in living rooms and 18˚C in bedrooms.

Humidity

Water vapour in the air is measured as relative humidity (RH), which is the percentage of water vapour held by the air compared to its saturation level (the highest quantity of water able to be supported by the air at that temperature). The saturation amount is dependent on temperature, as warmer air can hold more moisture; thus, relative humidity is a function of both moisture content and temperature. Humidity is not usually considered to be an indoor contaminant or a cause of health problems. In fact, some level of humidity is necessary for comfort. However, the relative humidity of indoor

4. See: www.degreedays.net/#generate

environments (over the range of normal indoor temperatures of 19°C to 27°C), has both direct and indirect effects on health and comfort. The direct effects of relative humidity are seen in physiological processes, whereas the indirect effects concern the impact on pathogenic organisms or chemicals, which may affect health. High values of RH are problematic because they can cause damage to building fabric and furnishings, and encourage mould growth and associated health problems. From the Building Regulations Part F, the suggested average monthly maximum humidity for domestic dwellings during the heating season is 65%; weekly, it is 75%, and daily, 85%.[5]

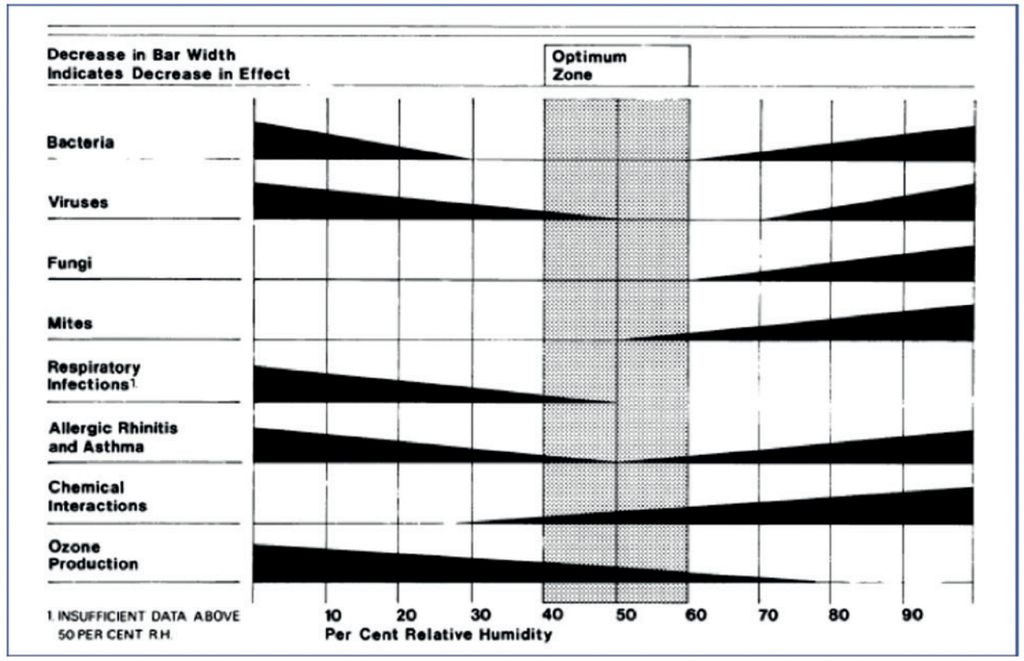

Figure 1: Optimum humidity levels to reduce indirect effects from pathogenic organisms or chemicals.

The figure above illustrates the optimum humidity levels as cited by Arundel et al[6]. The study concluded that maintaining relative humidity levels between 40% and 60% would minimise adverse health effects from relative humidity.

5. UK Government (2022) Ventilation: Approved Document F.

6. Arundel, A.V., Sterling, E.M., Biggin, J.H. and Sterling, T.D. (1986) Indirect Health Effects of Relative Humidity in Indoor Environments, Environ Health Perspect 65: 351–361.

Category 1 Properties

A total of 41 loggers were returned from Category 1 properties, which are listed in Table 1 below.

Logger Ref	Category	Heating System Change
W-165b	1	Electric storage heaters to GCH
W-173l	1	Electric storage heaters to GCH
W-156b	1	Electric storage heaters to GCH
W-170l	**1**	Electric storage heaters to GCH
W-163b	**1**	Electric storage heaters to GCH
W-159l	**1**	Electric storage heaters to GCH
W-168b	**1**	Electric storage heaters to GCH
W-161l	**1**	Electric storage heaters to GCH
W-157b	**1**	Electric storage heaters to GCH
W-154l	**1**	Electric storage heaters to GCH
W-004l	**1**	Electric storage heaters to GCH
W-002b	**1**	Electric storage heaters to GCH
W-211b	**1**	Electric storage heaters to GCH
W-209l	**1**	Electric storage heaters to GCH
W-166b	**1**	Electric storage heaters to GCH
W-162l	**1**	Electric storage heaters to GCH
W-155b	**1**	Electric storage heaters to GCH
W-172l	**1**	Electric storage heaters to GCH
W-160b	**1**	Electric storage heaters to GCH
W-167l	**1**	Electric storage heaters to GCH
ES-013b	**1**	Gas fire to GCH
WF-008	**1**	Solid fuel to GCH
ES-086b	**1**	Gas fire to GCH
ES-020b	**1**	Gas fire to GCH
NPT-125b	**1**	Solid fuel to GCH
NPT-126l	**1**	Solid fuel to GCH

NPT-127b	1	Solid fuel to GCH
NPT-128l	1	Solid fuel to GCH
NPT-129l	1	Solid fuel to GCH
NPT-131b	1	Solid fuel to GCH
NPT-132b	1	Solid fuel to GCH
NPT-133b	1	Solid fuel to GCH
NPT-134l	1	Solid fuel to GCH
NPT-135b	1	Solid fuel to GCH
NPT-143b	1	Solid fuel to GCH
NPT-145b	1	Solid fuel to GCH
NPT-146l	1	Solid fuel to GCH
NPT-147b	1	Solid fuel to GCH
NPT-203l	1	Solid fuel to GCH
NPT-149l	1	Solid fuel to GCH

Table 1: Category 1 loggers.

Temperature

In order to understand how the heating system change affected thermal comfort, the average temperature during an evening period of 6pm to 9pm was compared pre- and post-intervention.

The evening period was chosen as it is a useful indicator of indoor temperature, as this is reliably a time of day when people occupy their dwelling regardless of working status, and feel it important to be comfortable.

Temperature (°C)			
Logger Ref	**Pre evening 6–9pm**	**Post evening 6–9pm**	**Difference**
W-165b	18.0	22.5	4.6
W-173l	23.8	23.5	-0.3
W-156b	24.7	24.7	0.0
W-170l	25.0	25.2	0.3
W-163b	23.4	22.9	-0.6
W-159l	27.0	21.3	-5.7
W-168b	21.6	20.4	-1.2
W-161l	22.1	21.4	-0.7
W-157b	20.9	23.4	2.6
W-154l	24.5	25.9	1.4
W-004l	19.9	19.6	-0.3
W-002b	18.9	19.3	0.4
W-211b	18.7	20.9	2.2
W-209l	18.3	21.6	3.3
W-166b	22.6	22.6	0.0
W-162l	24.8	21.6	-3.2
W-155b	21.7	21.8	0.1
W-172l	23.6	22.7	-0.9
W-160b	21.3	21.6	0.3
W-167l	22.6	21.7	-0.9
ES-013b	21.2	19.7	-1.5
WF-008	23.9	26.1	2.2
ES-086b	14.6	24.0	9.4
ES-020b	20.3	26.1	5.8

NPT-124l	20.7	17.8	-2.9
NPT-125b	21.2	21.2	0.0
NPT-126l	21.7	24.7	3.0
NPT-127b	15.8	18.8	3.0
NPT-128l	22.9	25.2	2.2
NPT-129l	23.5	24.7	1.3
NPT-131b	21.1	25.4	4.3
NPT-132b	21.3	18.8	-2.5
NPT-133b	21.3	20.4	-0.8
NPT-134l	22.6	21.6	-0.9
NPT-135b	23.1	19.2	-4.0
NPT-143b	17.9	16.9	-0.9
NPT-145b	20.1	17.2	-2.9
NPT-146l	20.5	20.1	-0.4
NPT-147b	10.3	15.4	5.1
NPT-203l	18.4	18.8	0.4
NPT-149l	12.3	15.3	2.9
Count	41.0	41.0	0.0
Maximum	27.0	26.1	-1.0
Minimum	10.3	15.3	5.0
Average	20.9	21.5	0.6
Median	21.3	21.6	0.3
Std Dev	3.3	2.9	-0.5

Table 2: Pre- and post-intervention comparison of temperatures, 6–9pm.

When averaging the temperature across the entire 24 hours of the monitoring period, the following results were observed, as shown in Table 3.

Temperature (°C)			
Logger Ref	**Pre 24hr Avg.**	**Post 24hr Avg.**	**Difference**
W-165b	18.9	22.7	3.8
W-173l	21.5	22.4	0.9
W-156b	24.2	24.1	-0.1
W-170l	24.2	24.4	0.2
W-163b	22.7	22.3	-0.4
W-159l	25.0	20.5	-4.5
W-168b	19.8	18.9	-0.9
W-161l	20.1	19.6	-0.4
W-157b	18.6	21.6	3.0
W-154l	21.6	23.2	1.6
W-004l	19.2	19.1	-0.1
W-002b	18.3	19.0	0.6
W-211b	18.1	20.2	2.1
W-209l	18.0	20.8	2.8
W-166b	20.7	22.6	1.9
W-162l	24.2	20.5	-3.7
W-155b	19.4	19.5	0.1
W-172l	19.0	18.8	-0.2
W-160b	19.1	19.4	0.3
W-167l	19.6	19.5	-0.1
ES-013b	20.1	19.6	-0.5
WF-008	23.6	25.0	1.4
ES-086b	14.4	17.9	3.5
ES-020b	19.3	18.9	-0.4
NPT-124l	20.2	17.6	-2.7
NPT-125b	21.2	20.7	-0.4
NPT-126l	21.4	23.9	2.5
NPT-127b	15.8	18.7	2.9
NPT-128l	22.5	24.7	2.2
NPT-129l	22.3	22.8	0.5
NPT-131b	20.9	25.0	4.1
NPT-132b	21.3	18.3	-3.0
NPT-133b	20.3	19.9	-0.4

NPT-134l	21.8	20.9	-0.9
NPT-135b	23.2	19.5	-3.7
NPT-143b	17.9	16.4	-1.4
NPT-145b	19.5	16.8	-2.7
NPT-146l	20.2	20.0	-0.3
NPT-147b	10.1	15.4	5.3
NPT-203l	17.8	18.3	0.5
NPT-149l	11.3	15.3	4.0
Count	41.0	41.0	0.0
Maximum	25.0	25.0	0.1
Minimum	10.1	15.3	5.2
Average	19.9	20.4	0.4
Median	20.1	19.9	-0.2
Std Dev	3.1	2.5	-0.6

Table 3: Pre- and post-intervention comparison of temperatures averaged across a 24hr period.

During the evening period, 22 properties out of 41 saw an increase in average evening temperature, and 19 stayed the same or decreased. Overall, there was a 0.6˚C increase in temperature during the 6–9pm evening period. Across the whole day this pattern was also observed, with a 0.4˚C rise in average temperature.

As shown in the main evaluation report, storage heaters are used in a variety of ways by households; typically, a large temperature variation is seen these homes, as some householders use 'boost' functions during the evening, and some use supplementary heating alongside storage heaters. An example of this may be Logger Ref W-159, where the average pre-intervention evening temperature of 27.2˚C was found. This could be due to the logger being placed in an inappropriate place too close to a heat source, or to the use of a supplementary heating source. If this is the case, then the reduction in average temperature could indicate improved controllability of the heating system by bringing the temperature into the comfortable range of near 21˚C.

Due to the uncontrollable heat output of storage heaters, and the variety of ways that householders use them, the installation of a central heating system is consistent with improved control. This pattern is also typically seen for households using solid fuel systems, whereby there is little ability to control temperature output, as shown in the main evaluation report. These findings therefore support the overall evaluation finding that replacing storage heaters and solid fuel systems has led to greater heating system controllability for beneficiaries of Category 1 interventions.

This is further supported in the standard deviation analysis, which shows that the variation around the mean reduced following installation of gas central heating. This indicates a heating system with higher controllability: the standard deviation fell from 3.3 (pre) to 2.9 (post), a reduction of 0.4

Relative Humidity

The loggers collected data on RH across the same periods, as shown in Table 4 below. The readings in green indicate they are within the recommended threshold of 40%–60% RH, with the red shaded ones lying outside this threshold.

Relative Humidity (%)			
Logger Ref	**Pre evening 3–9pm**	**Post evening 3–9pm**	**Difference**
W-165b	49.84	36.79	-13.0
W-173l	38.62	37.35	-1.3
W-156b	35.75	30.81	-4.9
W-170l	45.29	38.45	-6.8
W-163b	38.04	36.24	-1.8
W-159l	34.45	41.27	6.8
W-168b	44.95	44.32	-0.6
W-161l	45.65	42.15	-3.5
W-157b	58.58	37.56	-21.0
W-154l	48.63	34.50	-14.1
W-004l	68.03	65.19	-2.8
W-002b	60.83	60.44	-0.4
W-211b	56.15	54.50	-1.7
W-209l	57.08	53.49	-3.6
W-166b	59.09	62.31	3.2
W-162l	52.69	63.80	11.1
W-155b	55.10	57.86	2.8
W-172l	54.17	58.25	4.1
W-160b	52.50	58.85	6.4
W-167l	49.01	58.35	9.3
ES-013b	46.02	49.24	3.2
W-167l	46.02	34.74	-11.3
ES-086b	54.53	46.06	-8.5
ES-020b	47.28	47.91	0.6
NPT-124l	56.4	61.3	5.0
NPT-125b	41.9	41.9	0.0

NPT-126l	53.1	44.2	-8.9
NPT-127b	67.3	58.3	-9.0
NPT-128l	47.2	40.2	-7.0
NPT-129l	47.5	50.9	3.4
NPT-131b	45.7	37.2	-8.5
NPT-132b	52.6	51.7	-0.9
NPT-133b	42.2	52.2	10.0
NPT-134l	52.7	54.1	1.4
NPT-135b	47.5	52.2	4.6
NPT-143b	52.7	59.7	7.0
NPT-145b	42.5	64.8	22.3
NPT-146l	55.9	62.0	6.1
NPT-147b	81.8	73.6	-8.2
NPT-203l	60.1	56.8	-3.3
NPT-149l	78.1	74.0	-4.1
Count	41.0	41.0	0.0
Maximum	81.8	74.0	-7.8
Minimum	34.4	30.8	-3.6
Average	51.8	50.9	-0.9
Median	52.5	52.2	-0.3
Std Dev	10.0	11.2	1.2

Table 4: Pre- and post-intervention comparison of RH, 6–9pm.

The average RH across the whole day is given in Table 5 below.

Relative Humidity (%)			
Logger Ref	**Pre 24hr Avg.**	**Post 24hr Avg.**	**Difference**
W-165b	50.04	37.21	-12.8
W-173l	41.18	37.09	-4.1
W-156b	35.94	30.79	-5.2
W-170l	45.20	38.27	-6.9
W-163b	39.20	37.35	-1.8
W-159l	34.77	40.82	6.0
W-168b	46.44	45.48	-1.0
W-161l	46.58	41.28	-5.3
W-157b	58.43	37.79	-20.6
W-154l	49.42	34.94	-14.5
W-004l	65.97	63.98	-2.0
W-002b	62.41	61.23	-1.2
W-211b	56.91	56.07	-0.8
W-209l	57.31	52.85	-4.5
W-166b	60.24	62.32	2.1
W-162l	54.42	63.89	9.5
W-155b	55.31	58.25	2.9
W-172l	56.35	59.72	3.4
W-160b	54.22	60.79	6.6
W-167l	52.27	59.84	7.6
ES-013b	43.98	46.32	2.3
W-167l	42.91	36.17	-6.7
ES-086b	53.79	45.83	-8.0
ES-020b	46.54	47.83	1.3
NPT-124l	55.0	58.8	3.7
NPT-125b	41.8	42.0	0.2
NPT-126l	52.4	43.4	-9.0
NPT-127b	67.2	57.7	-9.5
NPT-128l	46.5	39.7	-6.8
NPT-129l	43.2	50.4	7.2
NPT-131b	46.2	37.0	-9.2
NPT-132b	53.9	54.5	0.6
NPT-133b	42.3	53.2	10.9

NPT-134l	50.1	52.3	2.2
NPT-135b	47.2	50.7	3.5
NPT-143b	53.7	61.1	7.4
NPT-145b	42.9	65.5	22.7
NPT-146l	58.3	63.3	5.0
NPT-147b	80.6	73.3	-7.3
NPT-203l	60.8	57.5	-3.2
NPT-149l	79.6	73.8	-5.8
Count	41.0	41.0	0.0
Maximum	80.6	73.8	-6.8
Minimum	34.8	30.8	-4.0
Average	52.0	51.0	-1.0
Median	52.3	52.3	0.0
Std Dev	10.0	11.3	1.2

Table 5: Pre- and post-intervention comparison of RH averaged across a 24hr period.

There was a large variation in changes to indoor humidity levels following the installation of gas central heating for Category 1 properties, ranging from an increase of 22% to a reduction of 21%. This is somewhat surprising, as storage heaters do not require in-room ventilation; thus, large changes to ventilation and therefore humidity levels are unanticipated from the switch to gas central heating.

During the recorded whole-day averaged RH levels, there were 19 logged areas that saw an increase in RH levels, and 22 that saw a decrease. Across the whole of Category 1 there was an overall reduction in RH levels of 1%.

Category 2 Properties

A total of 15 loggers were returned from Category 2 properties, shown in Table 6.

Logger Ref	Category	Heating System Change
ACHA-104b	2	Solid fuel to ASHP
ACHA-113b	2	Solid fuel to ASHP
ACHA-114l	2	Solid fuel to ASHP
ACHA-117b	2	Solid fuel to ASHP
ACHA-119l	2	Solid fuel to ASHP
ACHA-105b	2	Solid fuel to ASHP
ACHA-106l	2	Solid fuel to ASHP
Eden-094	2	Electric storage heaters to ASHP
Eden-195b	2	Electric storage heaters to ASHP
Eden-096	2	Electric storage heaters to ASHP
Eden-097	2	Electric storage heaters to ASHP
Eden-098l	2	Electric storage heaters to ASHP
Eden-099b	2	Electric storage heaters to ASHP
Eden-100l	2	Electric storage heaters to ASHP
Eden-101b	2	Electric storage heaters to ASHP

Table 6: Category 2 loggers.

Temperature

The temperature data is presented in Table 7 below for the 6–9pm evening period.

Temperature (°C)			
Property	**Pre evening 6–9pm**	**Post evening 6–9pm**	**Difference**
ACHA-104b	16.6	17.6	1.0
ACHA-113b	17.6	17.8	0.2
ACHA-114l	17.9	18.7	0.8
ACHA-117b	18.5	17.7	-0.7
ACHA-119l	17.7	19.8	2.1
ACHA-105b	15.1	16.8	1.7
ACHA-106l	20.9	19.9	-1.0
Eden-094	12.7	18.8	6.0
Eden-095b	20.8	15.2	-5.6
Eden-096	21.4	21.4	0.0
Eden-097	19.1	18.7	-0.4
Eden-098l	24.4	24.5	0.0
Eden-099b	20.1	22.4	2.3
Eden-100l	19.3	21.2	1.9
Eden-101b	17.8	21.5	3.7
Count	15	15	0.0
Maximum	24.4	24.5	0.0
Minimum	12.7	15.2	2.5
Average	18.7	19.5	0.8
Median	18.5	18.8	0.3
Std Dev	2.8	2.4	-0.4

Table 7: Pre- and post-intervention comparison of temperatures, 6–9pm.

When averaging the temperature across the entire 24 hours of the monitoring period the following was found:

Temperature (°C)			
Property	**Pre whole day**	**Post whole day**	**Difference**
ACHA-104b	16.7	17.9	1.3
ACHA-113b	17.7	18.0	0.3
ACHA-114l	17.5	18.7	1.2
ACHA-117b	16.4	16.9	0.5
ACHA-119l	16.9	20.1	3.1
ACHA-105b	15.4	16.7	1.3
ACHA-106l	20.0	19.3	-0.7
Eden-094	14.9	17.3	2.3
Eden-195b	18.4	14.4	-4.0
Eden-094	21.0	20.7	-0.3
Eden-095b	18.8	18.4	-0.4
Eden-096	23.8	24.1	0.3
Eden-097	19.8	22.4	2.6
Eden-098l	19.0	20.2	1.2
Eden-099b	17.9	20.9	3.1
Count	15	15	0.0
Maximum	23.8	24.1	0.3
Minimum	14.9	14.4	-0.5
Average	18.3	19.1	0.8
Median	17.9	18.7	0.8
Std Dev	2.3	2.4	0.2

Table 8: Pre- and post-intervention comparison of temperatures averaged across a 24hr period.

Solid fuel for space-heating is generally found to be poorly controlled, and temperature profiles from homes using solid fuel for heating will experience high temperature fluctuations. Solid fuel is also highly dependent on the householder's usage patterns; for example, a wood-burning stove can only heat a space when in use and manual input from the householder is available; it is non-programmable, and cannot be thermostatically controlled. Therefore, by moving from solid fuel to an ASHP, a more constant temperature profile would be expected.

In this case, 10 of the 15 logged areas recorded an increase in average temperatures across the evening, and 11 of the 15 increased their average temperature across the 24-hour period when using an ASHP rather than solid fuel or storage heaters.

As the original heating systems were storage heaters and solid fuel, which are difficult to control, a reduction in standard variation would be expected with the installation of an ASHP, and this was seen in a reduction from 2.8 to 2.4 during the evening period.

Relative Humidity

The loggers' collected data on RH across the same periods is shown in Table 9.

Relative Humidity (%)			
Property	**6–9pm**	**6–9pm**	**Difference**
ACHA-104b	55.0	54.5	-0.5
ACHA-113b	60.8	65.1	4.3
ACHA-114l	71.4	74.9	3.5
ACHA-117b	64.8	65.8	1.0
ACHA-119l	53.7	51.2	-2.5
ACHA-105b	63.7	57.0	-6.7
ACHA-106l	48.3	48.2	-0.1
Eden-094	61.3	48.4	-12.9
Eden-195b	39.4	60.8	21.4
Eden-094	60.9	58.6	-2.3
Eden-095b	54.5	58.2	3.7
Eden-096	47.3	45.9	-1.4
Eden-097	59.0	51.5	-7.5
Eden-098l	47.7	41.0	-6.6
Eden-099b	51.9	39.8	-12.1
Count	15	15	0.0
Maximum	71.4	74.9	3.5
Minimum	39.4	39.8	0.4
Average	56.0	54.7	-1.2
Median	55.0	54.5	-0.5
Std Dev	8.3	9.6	1.3

Table 9: Pre- and post-intervention comparison of RH, 6–9pm.

The RH averaged across the whole 24-hour period is shown in Table 10.

Relative Humidity (%)			
Property	**24hr Avg.**	**24hr Avg.**	**Difference**
ACHA-104b	53.6	52.3	-1.3
ACHA-113b	60.6	65.4	4.8
ACHA-114l	66.7	70.3	3.6
ACHA-117b	68.5	67.8	-0.7
ACHA-119l	51.1	49.2	-1.9
ACHA-105b	63.5	57.9	-5.6
ACHA-106l	47.6	47.8	0.2
Eden-094	63.7	48.8	-14.9
Eden-195b	42.4	63.9	21.5
Eden-094	59.5	58.5	-1.0
Eden-095b	54.2	58.2	4.0
Eden-096	48.2	45.7	-2.4
Eden-097	59.4	51.3	-8.1
Eden-098l	47.1	40.5	-6.6
Eden-099b	53.2	41.3	-11.9
Count	15	15	0.0
Maximum	68.5	70.3	1.8
Minimum	42.4	40.5	-1.9
Average	55.9	54.6	-1.3
Median	54.2	52.3	-1.9
Std Dev	7.9	9.4	1.5

Table 10: Pre- and post-intervention comparison of RH averaged across a 24hr period.

In some logged areas, humidity levels increased, while others decreased, both during the evening period and across the whole day. One logged area, ACHA-114l, rose slightly from 71.4 to 74.9% during the evening period, and was the most humid area before and after installation of the ASHP. This is higher than the recommended average monthly maximum humidity of 65% for domestic dwellings during the heating season; however, this was higher both pre- and post-intervention. Across all 15 of the logged areas there was an overall decrease of 1.3% in RH levels across the 24-hour monitored period.

Solid fuel requires high levels of ventilation to supply fresh air for combustion, which can mean elevated humidity in the home. As the average RH has decreased across the 24-hour monitoring period for the ACHA properties, this indicates that using the ASHP has not increased indoor humidity levels.

Category 3 (Park Homes) Properties

A total of 19 loggers were returned from Category 3 properties. These were all Park Homes that switched from a liquid petroleum gas central heating system to a mains gas system.

Temperature

The temperature data is presented here in Tables 11 and 12 below.

Property	Pre evening 6–9pm	Post evening 6–9pm	Difference
C-083b	19.43	18.69	-0.7
C-067l	21.92	20.20	-1.7
C-077b	20.41	18.57	-1.8
C-082l	21.08	20.06	-1.0
C-066b	14.53	14.07	-0.5
C-075l	16.62	15.66	-1.0
C-071l	22.47	21.88	-0.6
C-072b	22.69	20.73	-2.0
C-073l	21.55	20.70	-0.8
C-069l	21.05	22.07	1.0
C-079b	20.31	18.22	-2.1
C-085l	20.84	21.52	0.7
C-068b	17.54	17.24	-0.3
W-155b	21.75	21.83	0.1
W-172l	23.60	22.70	-0.9
W-166b	22.57	22.60	0.0
W-162l	24.77	21.59	-3.2
W-160b	21.26	21.56	0.3
W-167l	22.58	21.66	-0.9
Count	19.00	19.00	0.00
Maximum	24.77	22.70	-2.08
Minimum	14.53	14.07	-0.46
Average	20.89	20.08	-0.81
Median	21.26	20.73	-0.53
Std Dev	2.46	2.41	-0.05

Table 11: Pre- and post-intervention comparison of temperatures, 6–9pm.

Property	Pre Whole Day	Post Whole Day	Difference
C-083b	17.2	16.9	-0.3
C-067l	19.2	17.9	-1.3
C-077b	18.5	17.4	-1.1
C-082l	19.1	18.1	-1.0
C-066b	12.9	13.0	0.1
C-075l	14.2	13.8	-0.5
C-071l	19.6	19.4	-0.2
C-072b	21.0	19.5	-1.5
C-073l	20.2	19.6	-0.6
C-069l	20.3	19.6	-0.7
C-079b	19.8	17.7	-2.2
C-085l	20.5	21.7	1.2
W-068b	16.1	16.1	0.1
W-155b	19.4	19.5	0.1
W-172l	19.0	18.8	-0.2
W-166b	20.7	22.6	1.9
W-162l	24.2	20.5	-3.7

W-160b	19.1	19.4	0.3
W-167l	19.6	19.5	-0.1
Count	19.0	19.0	0.0
Maximum	24.2	22.6	-1.6
Minimum	12.9	13.0	0.1
Average	19.0	18.5	-0.5
Median	19.4	19.4	0.0
Std Dev	2.5	2.4	-0.1

Table 12: Pre- and post-intervention comparison of temperatures averaged across a 24hr period.

Out of the 19 monitored areas, 14 saw a decrease in average temperature across the full day following the new heating system installation. Of note is the small variation across all the logged areas, pre- and post-heating system change. This minor difference indicates that the previous system was similarly controlled, and it appears that simply moving to natural gas had little impact on temperature within the home, thus supporting the findings of the main evaluation report. A switch to gas will have a positive impact on cost – again mirroring the findings of the main report – and insulation will also lower the energy requirement for the home, which will help bring down costs further for the householder.

Relative Humidity

The loggers' collected data on RH across the same periods is presented in Table 13 below.

Relative Humidity (%)			
Property	**Pre evening 6–9pm**	**Post evening 6–9pm**	**Difference**
C-083b	58.61	66.43	7.82
C-067l	51.56	56.88	5.32
C-077b	55.86	63.29	7.43
C-082l	53.05	60.54	7.49
C-066b	68.80	73.64	4.84
C-075l	60.15	65.49	5.34
C-071l	46.66	54.47	7.81
C-072b	45.15	56.20	11.05
C-073l	51.52	54.91	3.40
C-069l	46.80	45.95	-0.86
C-079b	56.92	51.77	-5.14
C-085l	47.76	47.93	0.17
W-068b	61.97	66.33	4.36
W-155b	55.10	57.86	2.76
W-172l	54.17	58.25	4.08
W-166b	59.09	62.31	3.22
W-162l	52.69	63.80	11.11
W-160b	52.50	58.85	6.35
W-167l	49.01	58.35	9.34
Count	19.0	19.0	0.0
Maximum	68.8	73.6	4.8
Minimum	45.1	45.9	0.8
Average	54.1	59.1	5.1
Median	53.0	58.4	5.3
Std Dev	6.0	6.7	0.7

Table 13: Pre- and post-intervention comparison of RH, 6–9pm.

There was, on average, an increase in relative humidity levels of during the period. This is an expected trend in line with installing insulation across most of the properties, as this will generally increase the airtightness – thereby reducing the ventilation, which helps to lower indoor humidity produced by household activities such as breathing, cooking or bathing.

Air quality: carbon monoxide levels

Carbon monoxide (CO) is the toxic product of incomplete combustion of carbon-containing fuels. This can occur where appliances such as gas, oil or multi-fuel stoves, ovens, water heaters and boilers, malfunction; or if they are inadequately ventilated, so that insufficient oxygen reaches them (e.g. due to blocked flues). The health effects of different levels of CO are shown in Table 14 below.

Level of CO	Health Effects and Other Information
0.1 PPM	Natural atmospheric levels in normal, fresh air.
0.5-5 PPM	Average level in homes without indoor sources.
5-15 PPM	Near properly adjusted gas stoves in the home.
9 PPM	Maximum recommended prolonged indoor CO level (ASHRAE).
10-24 PPM	Possible health effects with long-term exposure.
25 PPM	Max TWA Exposure for 8 hour work day (ACGIH).
50 PPM	Maximum permissible exposure in workplace (OSAH) and safety level specified by HSE in the UK.
100 PPM	Slight headache after 1-2 hours.
200 PPM	Dizziness, nausea, fatigue, headache after 2-3 hours of exposure.
400 PPM	Headache and nausea after 1-2 hours of exposure. **Life threatening in 3 hours.**
800 PPM	Headache and nausea after 45 minutes of exposure; collapse and unconsciousness after 1 hour of exposure. **Death within 2-3 hours.**
1000 PPM	Loss of consciousness after 1 hour of exposure.
1600 PPM	Headache, nausea and dizziness after 20 minutes of exposure. **Death within 1-2 hours.**
3200 PPM	Headache, nausea and dizziness after 5-10 minutes; collapse and unconsciousness after 30 minutes of exposure. **Death within 1 hour.**
6400 PPM	**Death within 30 minutes.**
12,800 PPM	Immediate physiological effects, unconsciousness. **Death within 1-3 minutes of exposure.**

Table 14: Health effects of various concentrations of carbon monoxide.

As draughts provide uncontrolled ventilation, which could reduce the danger should high carbon monoxide levels be present, it is important to verify that reducing such ventilation by applying airtightness measures or changing the heating system did not exacerbate any problems.

The CO loggers recorded carbon monoxide concentrations at 1 hour intervals. A total of 41 loggers were deployed and returned for analysis.

As shown in Table 14, there are various levels of CO which may cause concern: both individual spikes of high CO concentrations over 50 ppm, and long-term average exposure of above 10 ppm.

Logger Reference	No. of samples over 9 ppm (1 hour reading)	Comments	No. of samples over 50 ppm
P69-230	52	0.16% of time readings were above 9 ppm.	0
P47-182	21	0.065% of the time at sporadic intervals	0

Table 15: Frequency of CO levels above 9 ppm and 50 ppm.

Table 15 above presents numbers of incidences of concentrations over 9 ppm and 50 ppm, in the homes monitored for CO. This shows that no sustained levels of CO were recorded that would have an impact on health. There were momentary instances of levels reaching higher than 9 ppm, and two specific loggers of interest, which are explored below.

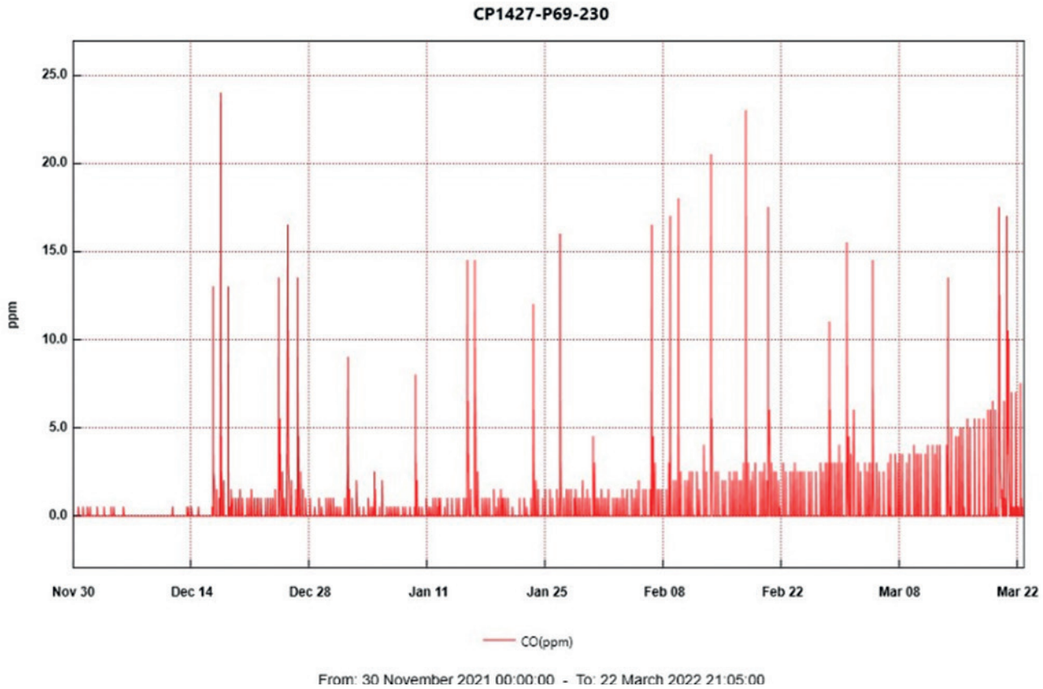

Figure 2: Logger P69-230 CO monitoring results.

Logger P69-230 reported on an LPG system switched to gas central heating on 16 August 2021, so the new heating system was in place for the total monitoring period. Figure 2 above shows a sustained and increasing level of CO in this location[7]. Across the rest of the homes that underwent the same heating system change, no instances of CO levels above 9 ppm were found, which may indicate that a supplementary combustive heating source was in use in this home.

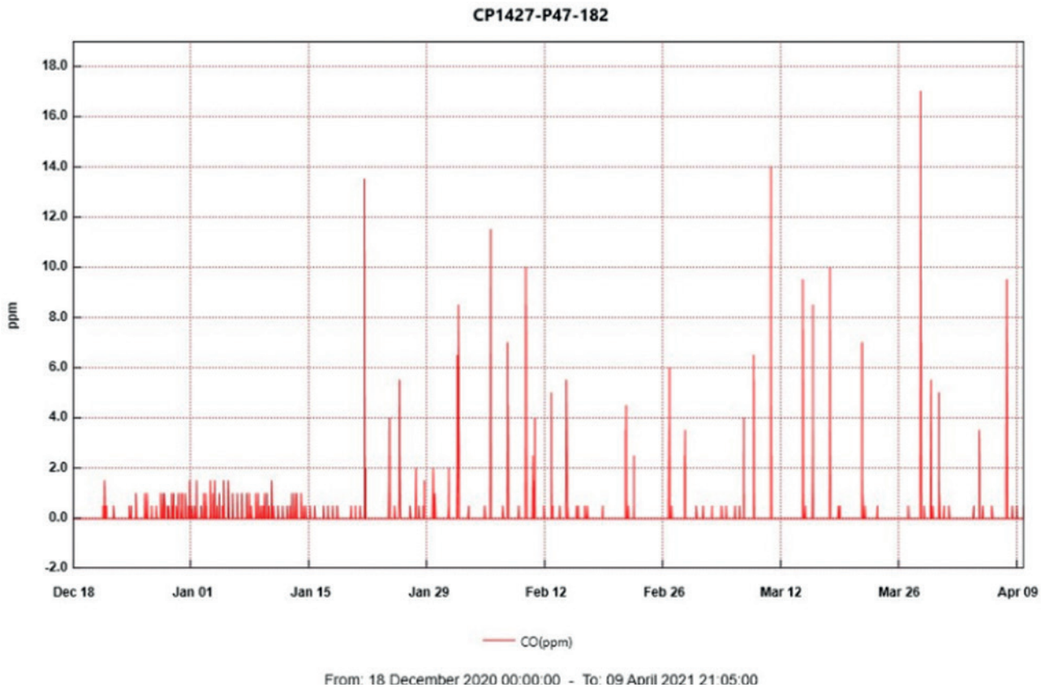

Figure 3: Logger P47-182 CO monitoring results.

Logger P47-182 reported on a solid fuel heating system switched to gas central heating on 3 March 2021, so the new heating system was in place for the last month of the monitoring period shown in the graph above. Across the rest of the homes that underwent the same heating system change, no instances of CO levels above 9 ppm were found; this may indicate that a supplementary combustive heating source was in use in this home, particularly as similar spikes occur pre- and post-heating system change.

No trends in CO levels across the whole project, or types of measures, have been identified from the data. The CO concentrations recorded are at levels which do not arouse concern.

7. NEA notified the relevant WHF project of this concern, for investigation and follow-up.