UK Government

Homes for Net Zero

Findings from Summer 2025

Department for Energy Security and Net Zero (2025)

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Executive Summary

This is the second report to describe findings from the Homes for Net Zero (HfNZ) project. The findings are largely based upon activities undertaken and analyses of data collected over the summer of 2025. These activities include installing reversible air-to-air heat pumps (RAAHP) in trial participants' homes, analysing quantitative data collected from sensors and equipment installed in homes in the trial, and analysing data from surveys and interviews with trial participants.

Over the summer and early autumn, 31 RAAHPs were installed. Future reports will more fully assess the performance of the RAAHPs for providing space heating and cooling, and hot water to trial participants; a small number of case studies provide an initial assessment of their performance and show their ability to rapidly reduce internal temperatures in hot weather.

Several barriers were faced that either slowed down or prevented installations, including requirements for planning permission related to noise assessments, and requirements for permissions from building owners when trial participants only had a leasehold for their home. These challenges are not unique to installations of RAAHPs and would have been faced for installations of other types of heat pumps. Many homes would have benefitted from a 'multi-plus' RAAHP that provides hot water as well as space heating and cooling; however, at the outset of installations multi-plus systems had a maximum hot water tank size of 120 litres, too small for households with two or more people (larger systems are now available, 180 and 230 litres). The trial also wanted to investigate a range of system types, and so many installations were instead single- or multi-split.

The summer of 2025 in the UK was the hottest on record. Quantified measurements of overheating from temperature sensors in trial participants' homes, and participant perceptions of comfort in survey responses both reflected this. Overheating was more pronounced overnight, particularly on nights following days classified as a heatwave day, with homes being above a threshold of 26°C on average for nearly 5 hours per night, reducing to nearly an hour per night when averaged across the whole summer period. More than half of respondents found it difficult to be comfortable overnight during a heatwave.

The performance and occupant experiences of heat batteries is assessed. Running costs were influenced more by how the system was set up and operated than by the heat battery itself and tended to fall or remain stable when households removed the gas standing charge and shifted most charging to off-peak periods. Costs tended to rise when peak-time boosts were frequently used or when the battery was also used to heat domestic hot water. A heat battery tended to cost more to run than an air-source heat pump, oil boiler, or gas boilers, but was cheaper than electric resistive heaters; however, many factors and assumptions affect running costs for all systems. Installation costs were generally higher than an equivalent gas boiler installation, and higher still if households opted for upgrades (e.g., new cylinders or smart controls).

Householders with heat batteries reported the technology served as a practical alternative when heat pumps felt too costly, complex, or space constrained, and installations were fast (typically 1-2 days) and rated as low disruption. Operating the system was rated as familiar and simple by most users. After installation, 91% of households reported being always or mostly warm enough. Comfort was reported most consistently in small to medium-sized homes, while some larger or multi-storey properties ran short of heat during cold spells. The placement of the heat battery in a central location improved comfort, whereas enclosed or peripheral locations (e.g., garages, sealed cupboards) reduced this benefit. Supplementary heaters were seldom required for comfort.

An initial assessment of air quality is provided. Assessments for two months, April and August, have enabled a seasonal comparison to be made, and assessments of sampled individual days have allowed for comparisons to WHO limits. For some pollutants, such as $PM_{2.5}$, the WHO limits were exceeded, and this was by higher amounts for April than August (suggesting warmer weather and increased ventilation reduced exceedance). The next report will include more analysis of data from IAQ sensors, repeat what has been provided in this report and provide further breakdowns across seasons.

Some householders had their heating system serviced, and in some cases upgrade with the flow temperature reduced, along with other complimentary measures (referred to as a MOT or MOT+) in order to move them towards being ‘heat-pump-ready’. While the mean inferred flow temperatures reported for both MOT (65.3°C) and MOT+ (57.3°C) homes provide encouragement that homes in the trial that had these measures are more likely to be considered ‘heat pump ready’, the maximum flow temperatures were still very high (85.7°C and 79.4°C respectively).

Respondents in the core trial reported on their satisfaction with the measure they received. The Boiler MOT+ was well received, delivering relatively high impact (e.g., higher comfort and warmth consistency) and any disruption being considered worth the outcome. Tado smart TRVs increased the impact of the heating MOT+ measure and provided the ability for respondents to target energy use, be more economical with energy use, and perceive a saving of money on bills. Of the few interventions (11) that carried out draught proofing, they were felt to be the least effective measure, with least impact and satisfaction with the outcome due to the small difference. Loft insulation encouraged more stated comfort taking from participants, and most respondents were quite satisfied with the measure.

The majority of participants in the trial experience problems with condensation, damp or mould, especially for those without measures. However, this could be partly to do with people answering this survey after a period of wetter and colder weather. Control group respondents indicated a reduced ability to keep comfortably warm in living rooms during the day, compared with their baseline measurements. Those with measures showed an improvement in comfort in their bedrooms during the night.

Most participants reported that they joined the project because of their interest in Net Zero. Overall, participants were satisfied with the trial.

1. Introduction

1.1. Scope of this report

This report is the second to report progress being made in Homes for Net Zero (HfNZ). The first report, ‘Homes for Net Zero: Project Summary and Initial Findings from Winter 2024/25’ is published alongside this report[1], and details the work undertaken to set up the trials and reports findings from an initial analysis of some of the data collected. This second report provides a description of further work undertaken to manage the trials and provides analyses of more data collected in the project. Specifically, it covers:

- A description of challenges faced when installing reversible air-to-air heat pumps (RAAHPs).
- An analysis of overheating in trial homes, using both data from temperature sensors and from surveys with householders.
- An overview of the characteristics of homes in the alternative electric heating trial.
- An analysis of data collected from homes in the alternative electric heating trial that have a heat battery installed.
- An assessment of heat pump readiness for homes in the core trial.
- An assessment of indoor air quality.

1.2. The Challenge

The UK Government has set a challenging target of meeting Net Zero emissions by 2050, that will mean decarbonising all sectors of the UK economy. Providing space heating and hot water to the UK’s nearly 30 million dwellings contributed 18% of the UK’s greenhouse gas emissions in 2021[2].

Decarbonising domestic space heating and hot water has been recognised as one of the most difficult challenges on the pathway to Net Zero (National Audit Office, 2024[3]). Replacing gas or oil boilers is often not a simple and straightforward heating source swap to a zero direct emissions alternative. For example, additional changes may be required to ensure that the householders are comfortable and can afford their energy bills. These additional changes may entail changes to other aspects of the heating system, such as

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[1] Homes for Net Zero: Project Summary and Winter 2024-25 Findings (https://www.gov.uk/government/publications/homes-for-net-zero-research-programme)

[2] Decarbonising Home Heating, 2024, National Audit Office (https://www.nao.org.uk/reports/decarbonising-home-heating/).

[3] Decarbonising Home Heating, 2024, National Audit Office (https://www.nao.org.uk/reports/decarbonising-home-heating/).

pipework and radiators, or changes to the fabric of the dwelling, such as insulation and draught proofing.

Dwellings that already have a ‘zero direct emissions’ space heating and hot water system will most likely have something that can be replaced with a more efficient alternative. Older systems such as storage heaters are at best 100% efficient and can be replaced with alternatives that are at least 200-300% efficient, if not more. Making these changes reduces running costs for householders and frees up capacity that could allow more low carbon technologies to connect to the electricity network.

A small number of dwellings in the UK have already made the transition to high efficiency and zero direct emissions heating systems, such as air source heat pumps[4].

1.3. Homes for Net Zero

The purpose of the Homes for Net Zero (HfNZ) project is therefore to better understand the heat decarbonisation challenges for householders. HfNZ is a project designed and funded by the Department for Energy Security and Net Zero (DESNZ) and delivered by the Energy Systems Catapult (hereafter referred to as *the Catapult*). HfNZ has the following objectives:

1. Develop a flexible home monitoring trial for a range of research priorities,
2. Better understand the opportunities and barriers for homeowners to transition to a Net Zero ready home,
3. Explore the role of alternative electric heating technologies to decarbonise heating in homes,
4. Explore the emerging issues and potential solutions to adapt homes to a changing climate.

Two types of home and heating system are of interest in HfNZ and meeting the project’s objectives is therefore through two trials:

1. A ‘core trial’ focussing on solid wall homes with a gas combi-boiler,
2. An ‘alternative electric heating trial’ focussing on two types of electrically heated homes: direct electric heated flats and houses, and those with a heat battery.

Solid wall homes with gas boilers are of interest to DESNZ because they may be challenging to decarbonise due to their unique characteristics (solid walls can be

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[4] Those supported by funding from Government schemes total just less than 125,000 over the period Q1 2018 - Q2 2024, around 0.5% of the UK housing stock. The English Housing Survey 2023-24 low carbon technologies fact sheet reports a figure of 276,000 in England, around 1% (https://www.gov.uk/government/statistics/english-housing-survey-2023-to-2024-low-carbon-technologies-in-english-homes-fact-sheet/english-housing-survey-2023-to-2024-low-carbon-technologies-in-english-homes-fact-sheet#low-carbon-technologies)

expensive to insulate, combi-boilers provide hot water directly and therefore do not need to be paired with a hot water tank). Flats provide unique challenges as they typically have limited space and therefore reduced options for decarbonisation or energy efficiency, likewise, houses with direct electric heating may not choose an ASHP as it would entail installation of a full ‘wet’ heating system. Homes with heat batteries are of interest to DESNZ because they are already electrically heated and have a ‘wet’ heating system; DESNZ is interested to understand how these technologies perform.

To understand these challenges and meet the project’s objectives, ~1,250 homes have been recruited to HfNZ. All homes are having their energy use and internal temperatures monitored to provide a detailed understanding of their heating use.

From the cohort of ~1,250 homes, several hundred homes were selected to have measures installed to better understand the opportunities and barriers for homeowners transitioning to Net Zero. These measures included changes to building fabric such as loft insulation refreshes and changes to heating systems such as radiator upgrades, or entirely new systems such as reversible air-to-air heat pumps (RAAHPs) that can provide cooling as well as heating. Some homes already have alternative electric heating technologies installed and are providing data on their performance.

Homes that were having measures installed also had additional and more advanced monitoring installed, such as a heat meter or room-by-room temperature controls, to better understand how these changes have affected their heating use. Approximately a third of the homes had their internal air quality monitored. All monitoring is managed through the Energy Systems Catapult’s Living Lab[5].

Up to 250 householders received different types of information about how they can get their home ready for Net Zero in the form of a Roadmap or reduce their energy use through behaviour change. Roadmaps included detailed and tailored information about their home, including suggested measures to get their home ready for Net Zero. Behaviour change measures were easy-to-make low or zero cost changes that householders can adopt immediately, that both reduce their energy use and bills, and prepare a household for how their heating system may work in the future (e.g., reducing flow temperature). Some surveys were undertaken after extreme weather events, such as a heatwave to understand how householders coped.

The intended outcome from HfNZ is therefore a robust evidence base built on the back of the data collected and analysed in the project, that answers the project’s research questions (see Appendix 1). This project summary and initial findings report describes the progress made to date and the methods and approaches adopted and provides an initial analysis of some data.

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[5] https://www.livinglab.energy/home

1.4. Overview of project approach

In both trials, householders volunteered to participate. The recruitment process required householders to sign up to the trials, agree to the project's terms and conditions, provide access to their smart meter data and set up temperature and humidity monitoring equipment that was provided free of charge to them. Hundreds of homes were surveyed, with those meeting a project's requirements then selected to receive a 'measure'. A measure was a change to the dwelling that will progress the householder's transition to being a 'Net Zero ready' home. These measures varied from a low level of disruption such as improving the draught proofing of a dwelling to much more complex measures such as replacing the heating system. Some measures were paired with additional monitoring equipment to provide specific data streams. Some householders were provided with advice and information on how they may get their home ready for Net Zero.

In the core trial, the target was to recruit a cohort of 1,000 homes. As noted, these dwellings were built with solid external walls and have a gas combi-boiler. Decarbonising this type of dwelling is of particular interest due to it having solid walls and not having a hot water tank. Solid walls can only be insulated internally or externally (because there is no cavity to be insulted); internal insulation is very disruptive, reduces room sizes and requires redecoration whereas external insulation is comparatively expensive, requires rendering and changes the look of the building. Having insulated external walls reduces heat loss and therefore makes providing space heating more efficient and affordable and increases occupant comfort, however Homes for Net Zero is seeking to understand how these homes can transition to being Net Zero ready without insulating external walls. The absence of a hot water tank introduces a further challenge (although one not addressed in HfNZ so far); a home that transitions to being Net Zero ready will likely install a heat pump and therefore will need to find space to accommodate a hot water tank, space it may have previously had before a gas combi-boiler was installed, but has since been utilised for another purpose.

In the alternative electric heating (AEH) trial, the target was to recruit a cohort of ~250 homes. These dwellings were electrically heated and will be a mix of flats and houses. Approximately 200 of these will be electrically heated flats and houses without a 'wet' heating system; this type of dwelling is of particular interest due to the potential for it to benefit from a significantly more efficient heating system that does not require installation of 'wet' central heating plumbing and can also provide space cooling to prevent over-heating. The remaining 50 recruited were homes that do have a 'wet' heating system powered by an already installed heat battery.

2. Analysis and findings

This section of the report covers several aspects of analysis and findings from continued delivery of HfNZ. Most analysis and findings relate to the project's research questions, with some providing anecdotal evidence from experiences during delivery.

2.1. RAAHPs - installation challenges

Once participants had been successfully recruited and offered the installation of an RAAHP in the alternative electric heating trial, several hurdles were encountered preventing or slowing down progress with installations. Thirty-one RAAHP installs have been delivered to date; the fastest of which took 20 calendar days from design visit to installation completion, and the longest of which took 190 days, with the mean being 91 days. Of the 31 installations, six didn't meet the requirements of permitted development and required planning permission, which took an average of 49 days from application to approval.

The breakdown of system types installed is as follows:

- 18 homes received a single-split system, with a single indoor unit providing heating and cooling to one room
- 11 homes received a multi-split system, with up to 5 indoor units heating and cooling up to 5 rooms
- 2 homes received a multi-plus system, with up to four indoor units heating and cooling rooms and domestic hot water provided by the heat pump.

2.1.1. Planning Permission

An update to *The Town and Country Planning (General Permitted Development) (England) Order 2015* in May 2025 made it possible to install RAAHPs under permitted development if the conditions can be met. Nevertheless, a significant number of installation surveys revealed that it would not be possible to meet the noise requirement for permitted development, as set out in Microgeneration Certification Scheme (MCS) standard MCS020a. This standard requires the noise level created by the installation to be less than 37 decibels, measured at a distance of 1 meter from the window or door of the nearest habitable room of a neighbouring property.

This noise limit is particularly challenging for flats, terraces, and otherwise dense housing types, especially where neighbours' windows can belong to the same building as the proposed installation. Where it is necessary to position the outdoor unit of the heat pump close to a neighbour's window or door in a design, it's common for the calculated noise level to exceed the limit set by the MCS standard.

Where the noise limit for permitted development is exceeded, a full planning permission application can be submitted, though the calculated noise level exceeding a defined limit weakens the application, giving grounds for rejection.

Twelve homes in England which had installation surveys carried out were found to have calculated noise levels above the limit, ranging from 38 to 48.5 dB. Of these, five homes received approval for planning permission with calculated noise levels ranging from 38 to 42 dB. Two homes were refused planning permission, with both citing noise as a reason, having noise levels of 41 and 46.5 dB.

Where noise was a concern, planning authorities often requested noise impact assessments to be carried out. A noise impact assessment involves a survey of the background noise (both daytime and nighttime) at the location of the proposed installation, along with a calculation of the noise created by the heat pump at neighbouring windows or doors, in accordance with BS7445. If the heat pump would raise the noise level at neighbouring properties' facades by less than 5 dB above measured background levels, this is classed as "low impact". While this method will give a more specific understanding of the noise impact in the environment of the proposed installation, it will often lead to a similar conclusion as MCS020a, being based on similar principles.

In some cases, planning authorities requested the use of acoustic enclosures for the heat pump outdoor units to mitigate noise impact (see Figure 1 for an example). The Catapult explored options for procuring enclosure products from Environ and Daikin. Costs and lead times were found to be significant, posing problems for accommodating enclosures within trial timelines and budget. There was uncertainty around the compatibility of the Daikin enclosure with the specific heat pump models being installed in the trial. Enclosures also add to the size and visual impact of the heat pump outdoor units.

Figure 1: Image of Environ acoustic enclosure

Planning approvals which were conditional upon noise abatement by means of an acoustic enclosure revealed a limitation in the MCS020a calculation method: there is no facility in the calculation to account for acoustic enclosures. The Catapult was advised by MCS that the heat pump sound power level input to the calculation should not be modified to account for the effect of the enclosure, and doing so would invalidate the calculation. Whether the planning authority is prepared to accept an enclosure as a mitigation measure without a valid MCS noise calculation showing noise levels to be below the limit may vary by local authority. In the Catapult's experience during this trial, the local authority may be satisfied with the technical specifications of the acoustic enclosure, or an MCS calculation modified to account for the enclosure, even though this would not be considered valid by MCS.

The update to *The Town and Country Planning Order* applied only in England, meaning participants in Wales and Scotland were still required to submit planning applications in all cases. At the time of writing, three homes remain on the installation journey in Wales and Scotland, all of which had planning permission approved. A further one home was advised by planning that a noise impact assessment would be required to proceed.

2.1.2. System Type Suitability

The target for the trial is to install twenty single-split RAAHPs (which provide heating and cooling to a single room of the home), five multi-splits (covering up to four rooms) and five multi-plus systems (covering up to three rooms and providing hot water from the heat pump). Home requirements and occupant preferences have made it challenging to prescribe this ratio of system types; in the majority of homes, multi-split systems would have been selected by the installer so that coverage of as many of the habitable rooms as possible by the heat pump could have been achieved. Even the smallest flats typically have two habitable rooms; no studio flats embarked on the installation journey. In several cases, participants expressed dissatisfaction or confusion with the proposal to cover single rooms with the installation.

When the trial was planned, and contract agreed with the installer, only one hot water cylinder size option was available with the multi-plus system – 120 litres – and only three indoor units for heating and cooling of rooms could be connected to a multi-plus system. Industry guidance recommends allowing 45 litres of hot water storage per household occupant (or bedroom), plus an additional 45 litres. According to this formula, the multi-plus system would be slightly undersized for households of two people, and unsuitable for three or more. Additionally, many homes were found to have electric showers which are fed from a cold-water supply, meaning the benefit of a replacement hot water system would be diminished, as it would not be used for showers. For these reasons, the multi-plus system was not found to be suitable for many homes in the trial, making the target of five installations difficult to achieve. During the trial, however, Daikin has announced a new version of the multi-plus system with a 230-litre hot water cylinder, and the ability to connect up to four indoor units. This system would have been suitable for a greater proportion of the homes in the trial, had it been available earlier. For one home, it was possible within project timelines to design a system utilising this larger tank and four indoor units.

The 120-litre hot water cylinder for the multi-plus system must be wall-mounted, and for one home this meant that there was insufficient headroom in the location of the cylinder, so the existing hot water system had to be retained. Wall-mounting of cylinders is uncommon in the UK. The 230-litre cylinder for the multi-plus system can be floor-standing.

Some homes were found to have alternative hot water systems in place, including solar thermal and even a distributed micro-server (see Figure 2), which transfers waste heat from a cloud computing device into the hot water cylinder. In these cases, integrating the heat pump hot water system would be difficult or impossible, as well as having diminished energy saving benefits.

Figure 2: Photo from site showing micro-server attached to hot water cylinder

2.1.3. Existing Heating System Eligibility

The intention of the trial is to replace or supplement “dry” electric heating systems, meaning systems which do not use water to distribute heat to emitters in rooms. Typically, this means resistive heaters located in each room, which may work primarily by convection or radiation, and can either be direct-acting or use thermal storage to utilise off-peak electricity tariffs. Electric underfloor heating is eligible, and electric warm-air systems are also a form of dry electric heating, albeit more centralised than individual room heaters. Homes with electric boilers supplying hydronic central heating are not eligible for the trial, despite having electric heating.

Some difficulty with recruitment was caused by the inconsistent terminology used by industry and householders to identify heating system types. For example, direct electric room heaters may be referred to as “radiators” or “panel heaters”, and occupants may think of them as “central heating” despite their decentralised operation. Some direct resistive heaters are oil-filled but electrically powered, which could lead participants to report that they have “oil heating” and being incorrectly excluded from the trial.

In one case, a home was believed to have storage heaters, as stated on the home’s energy performance certificate (EPC), when in fact it had direct electric heaters featuring the brand name “Heatstore” (as a result the home has a significantly more favourable EPC rating than it ought to). Participants with gas-fired central heating or log burners may report that they have electric heating, due to some reliance on plug-in supplementary heaters.

Hot water cylinders, present in the majority of homes with dry electric heating, may be referred to as “boilers”, which was particularly troublesome for efforts to exclude homes with hydronic central heating boilers (in fact the term “boiler” is a misnomer in all cases, as water for domestic heating and hot water is not heated to 100°C, except in historic steam systems).

Some participants may not be aware of whether their shower is electric (i.e., heats its own water from a cold supply) or is supplied by the central hot water system. “Power showers” take hot water from the central system and use an electric pump to increase water pressure, which can easily be confused with an electric shower. Efforts were made to cross-check participant responses to heating system questions in the screener with phone calls and data available from EPCs, but many of these ambiguities were only resolved by the installer’s site survey, resulting in numerous surveys failing to lead to an installation.

2.1.4. Other barriers to installation

As well as the barriers already identified in this section of the report, participants initially identified as suitable for RAAHP installations faced a variety of other blockers which caused dropouts during the installation journey. These included multiple instances of freeholder objections (where the homeowner was not the property freeholder, so required permission from another party), multiple instances of a lack of a suitable location for the outdoor unit (including some flats with balconies which were surveyed for suitability), a single instance of flood risks (whereby the unit could only be ground mounted in a place that had flooded regularly), a single instance of unconventional home construction that made wall mounting dangerous and a single instance of coordination complexities with major changes to the building taking place that encompassed significant renovations and extensions.

The geographical location of some homes stretched the capabilities of the installation contractor, with the offer of installations for some participants in remote conditions, such as the Western Isles, being revoked, despite meeting the geographical criteria for the trial. In hindsight, a more limited geographical range for trial eligibility was needed to match the contractor’s capabilities.

2.1.5. Key findings and future plans

This section has highlighted some of the technical and non-technical challenges associated with installation of RAAHPs, based upon the Catapult’s experience across 31 homes.

- Requirements for planning approval remain a barrier; whilst permitted development removed a barrier for many installations (in England only), it remained an issue for several others. In particular, the noise restrictions can be insurmountable for high density dwellings such as flats where distances to neighbours are small.
- Many householders needed permission from their building owner, as they have a leasehold on their dwelling and must ask for permission from the freeholder to make changes to the outside of the building. In several cases this was ignored, refused or was chargeable, preventing many installations from progressing (however, these householders may have been refused planning permission given the above point).
- It should be noted that both the planning and freeholder permission findings are not unique to installations of RAAHP; they apply equally to householders seeking permissions for installations of air-to-water heat pumps.
- Recent technological developments in RAAHP systems have meant a larger hot water tank can now be served, meaning a ‘multi-plus’ RAAHP system is likely to be suitable for many more households; previously, a multi-plus system was limited to being paired with a 120 litre hot water cylinder, too small for households of two or more people.
- Most householders needed to retain some of their existing heating system; limitations on the project’s budget to support a greater number of multi or multi-plus systems, plus the limitations of the system (RAAHPs should not be installed in bathrooms) meant that most installations covered only a proportion of a householders space and hot water needs, and mean they retained some of their existing set up.

In the next report, installation challenges will not be discussed again. However, many other aspects of the RAAHP installations will be, including their performance, their ability to keep householders comfortable, and their costs.

2.2. Overheating

This section of the report covers overheating during summer months, both from an analysis of quantitative data from temperature and humidity sensors in trial participants' homes, as well as insights from surveying participants to understand their behaviours during heatwaves. The quantitative data covers both summer 2024 and summer 2025, allowing a comparison between the years.

2.2.1. Temperatures in summer 2024 and 2025

Levels of overheating are strongly related to weather conditions; Figure 7 shows mean daily external temperatures for HfNZ project homes in both summer 2024 and 2025. The summer period is taken as 1 June to 31 August, following the definition of cooling requirements in SAP[6]. The local external temperatures derived from weather station data for each individual HfNZ dwelling were used to calculate an average across all the homes that also have internal temperature data available for the summer in question. Temperatures were noticeably higher in the second year; the orange-red line denoting 2025 is almost always above the blue line denoting 2024, and often by several degrees Celsius. Summer 2025 was the warmest summer on record for the UK[7].

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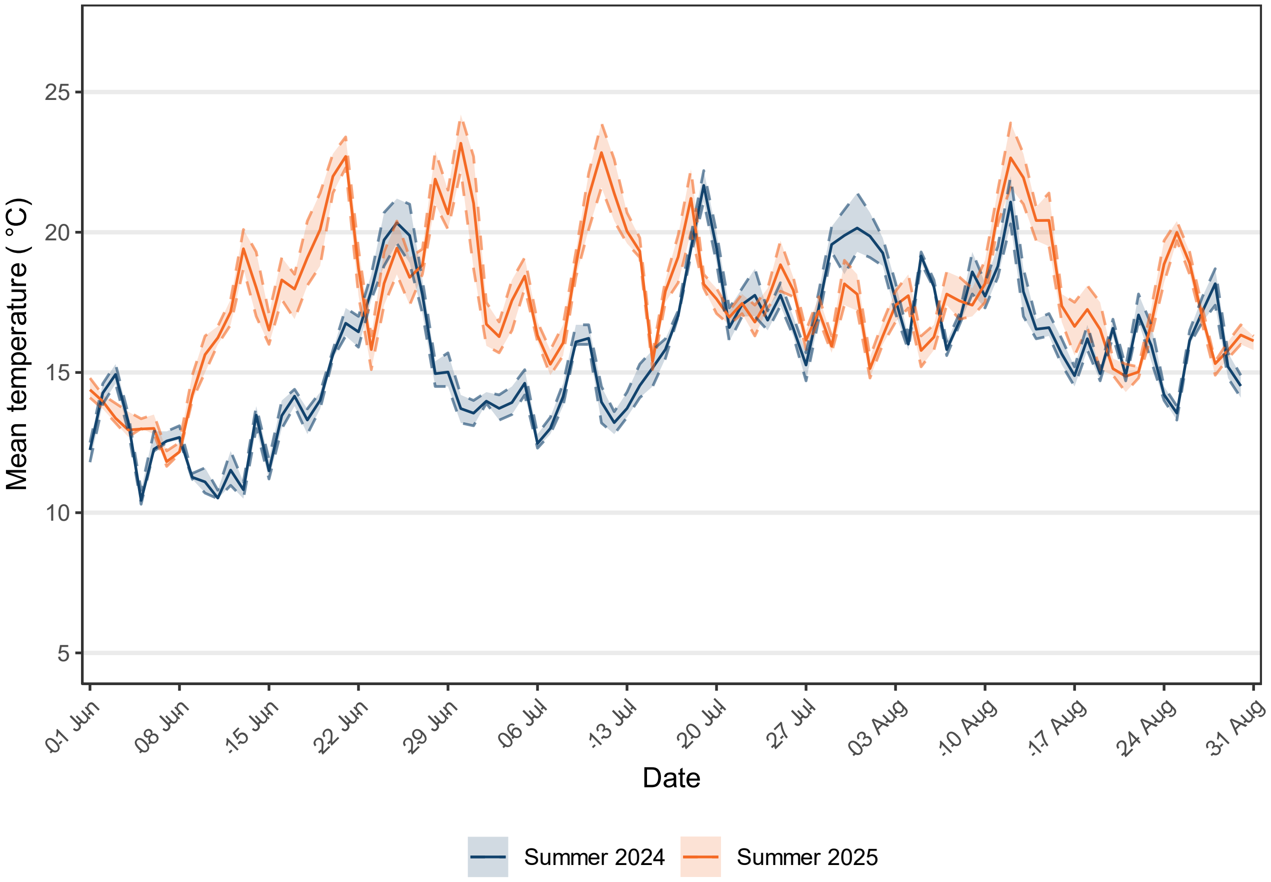
[6] SAP documentation

[7] https://www.metoffice.gov.uk/about-us/news-and-media/media-centre/weather-and-climate-news/2025/summer-2025-is-the-warmest-on-record-for-the-uk

Figure 3: Mean external temperatures across 584 core project homes (June-August 2024) and 803 core project and electrically heated homes (June-August 2025). Dotted lines show 25th and 75th percentile temperatures.



2.2.2. Method for assessing overheating

Overheating was assessed using temperature data from the tado° temperature and humidity sensors (typically three sensors in each home). The data were filtered so that only days or nights with >90% data completeness, and only rooms with at least 80 days of data in the 92-day summer period were included. Sufficient data was available for 1,726 rooms in 588 core project homes in Summer 2024 and 2,775 rooms in 895 homes in core project and electrically heated homes in Summer 2025 (including the original core project homes monitored in 2024). Overheating at nighttime (22:00 to 07:00) in bedrooms was analysed separately from overheating in rooms used during the day (rooms classified as[8] lounge, dining, kitchen, kitchen-diner, office, centralised device or family room, from 07:00 to 22:00).

The analysis follows the overheating thresholds defined in British Standard EN 16798 (BSI 2019) (also discussed in in CIBSE TM 52[9]). At night two fixed thresholds of 26°C and 28°C were investigated. The daytime threshold was an adaptive threshold that varies according

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[8] Sensors were self-installed, with householders following instructions provided to them by the Catapult.

[9] Nicol, F., Spires, B., & Chartered Institution of Building Services Engineers. (2013). *The limits of thermal comfort : avoiding overheating in European buildings.* Chartered Institution of Building Services Engineers.

to the running mean of the external temperature, considering that perception of overheating varies with outside temperature. The running mean T_{rm} was calculated from previous daily mean external temperature for the i-th previous day T_{e-i} using the CIBSE TM 52 recommended value of α=0.8.

$$T_{rm} = (1 - \alpha)(T_{ed-1} + \alpha\ T_{ed-2} + \alpha^2 T_{ed-3})$$

The threshold value for each day T_{th} was calculated using:

$$T_{th} = 0.33\ T_{rm} + 18.8 + 3$$

This is the equation set out in BS EN 16798 for the Category II "normal expectation" upper temperature limit. A Category I level (for "spaces occupied by very sensitive and fragile persons") would have set an upper limit one degree lower.

The analysis also follows the definitions of '*frequency of exceedance*' and '*intensity of exceedance*' used in a Department for Energy Security and Net Zero (DESNZ) report[10]. They are defined as follows:

- Frequency of **exceedance** is defined as the percentage of the relevant time period at which temperatures exceed the threshold. For example, a bedroom where the temperature was above the threshold for 30 minutes out of the 9-hour nighttime period would have an exceedance of 5.6% for that night.
- The **intensity** of exceedance combines the temperature above the threshold with time, to give a value in °C hours – for example a temperature that was 2 degrees above the threshold for one hour and one degree above for a subsequent hour would have an intensity of 3°C hours. Intensity is summed over 10-minute intervals.

Historical weather data for each participant was obtained from Visual Crossing[11], using a weighted average of measurements from multiple weather stations based on the participant's postcode. This local weather data was used to identify "**heatwave days**" for each home. A heatwave was defined as '*three or more consecutive days with peak temperature above 27°C*'. This threshold is based on the Met Office's definition[12] but differs in that a single threshold temperature is used across the whole of England and Wales rather than using different temperatures by country. The outside air temperatures at each HfNZ home are inferred by interpolation from readings taken at nearby weather stations. These inferences do not consider local factors such as orientation and shading which may lead to a difference in the actual temperatures immediately outside the house and subsequently overheating.

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[10] *The effect of energy efficiency measures on summertime overheating in English Homes: Summary* (2024), M Li, P Drury, S Watson, K Lomas https://assets.publishing.service.gov.uk/media/6723b01d59832068128c1e24/energy-follow-up-survey-summary.pdf

[11] www.visualcrossing.com

[12] https://weather.metoffice.gov.uk/learn-about/weather/types-of-weather/temperature/heatwave

Data from sensors for which the location was given as ‘bathroom’, ‘corridor’, ‘garage’, ‘toilet’ or ‘utility room’ was not included in the analysis (248 sensors from a total of 2,318). There are fewer homes included in the nighttime than the daytime statistics because not all homes had temperature measurement in a bedroom; of those that did, for some there were insufficient data (minimum 80 days required) to be included.

2.2.3. Mean and peak temperatures

Before detailed analysis of overheating, a basic understanding of temperature data from the tado° sensors is provided. Figure 8 shows a plot of mean temperatures across all the homes with data available in Summer 2025, with bedrooms and living rooms shown separately. Bedrooms are, on average, consistently warmer than living rooms and the time of the temperature peak is slightly later.

Figure 4: Mean temperature for 797 homes during Summer 2025, across the day in bedrooms and living rooms (25th and 75th percentile shown as dotted lines)

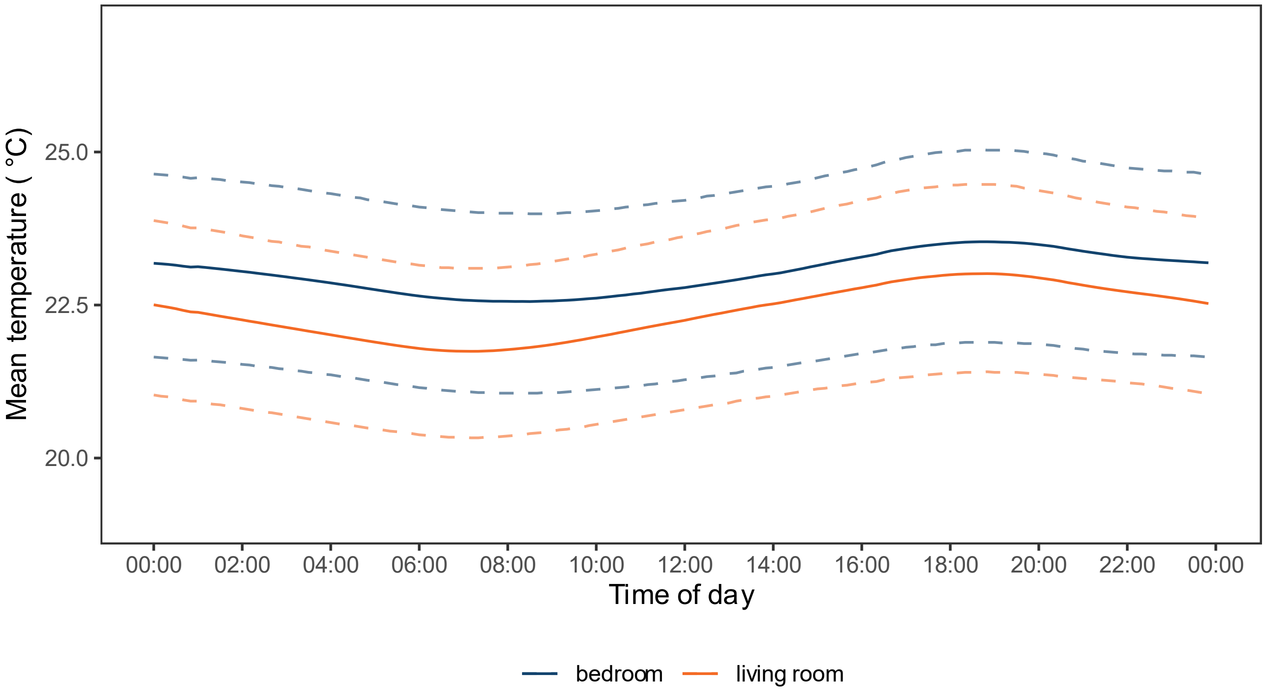
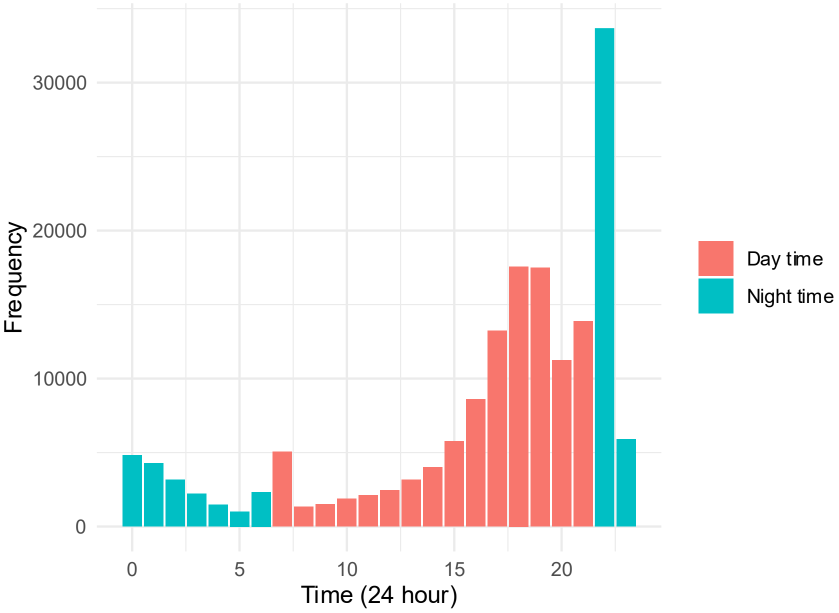


Figure 9 shows a plot of the frequency distribution of the hour during which the peak temperature was recorded, for each home on each day in Summer 2025. The peak nighttime temperature in bedrooms is generally experienced at the start night period (22:00-23:00). This is as expected, with temperatures falling away after sunset and bedrooms cooling. There are two peaks in the distribution of peak living room temperatures in the day, one at 18:00-19:00 and one later in the evening at 21:00 to 22:00. The explanation of peak day time temperatures is less obvious and will depend on orientation of windows, heat retention in building fabric, and occupant behaviours and ventilation practices, among other factors.

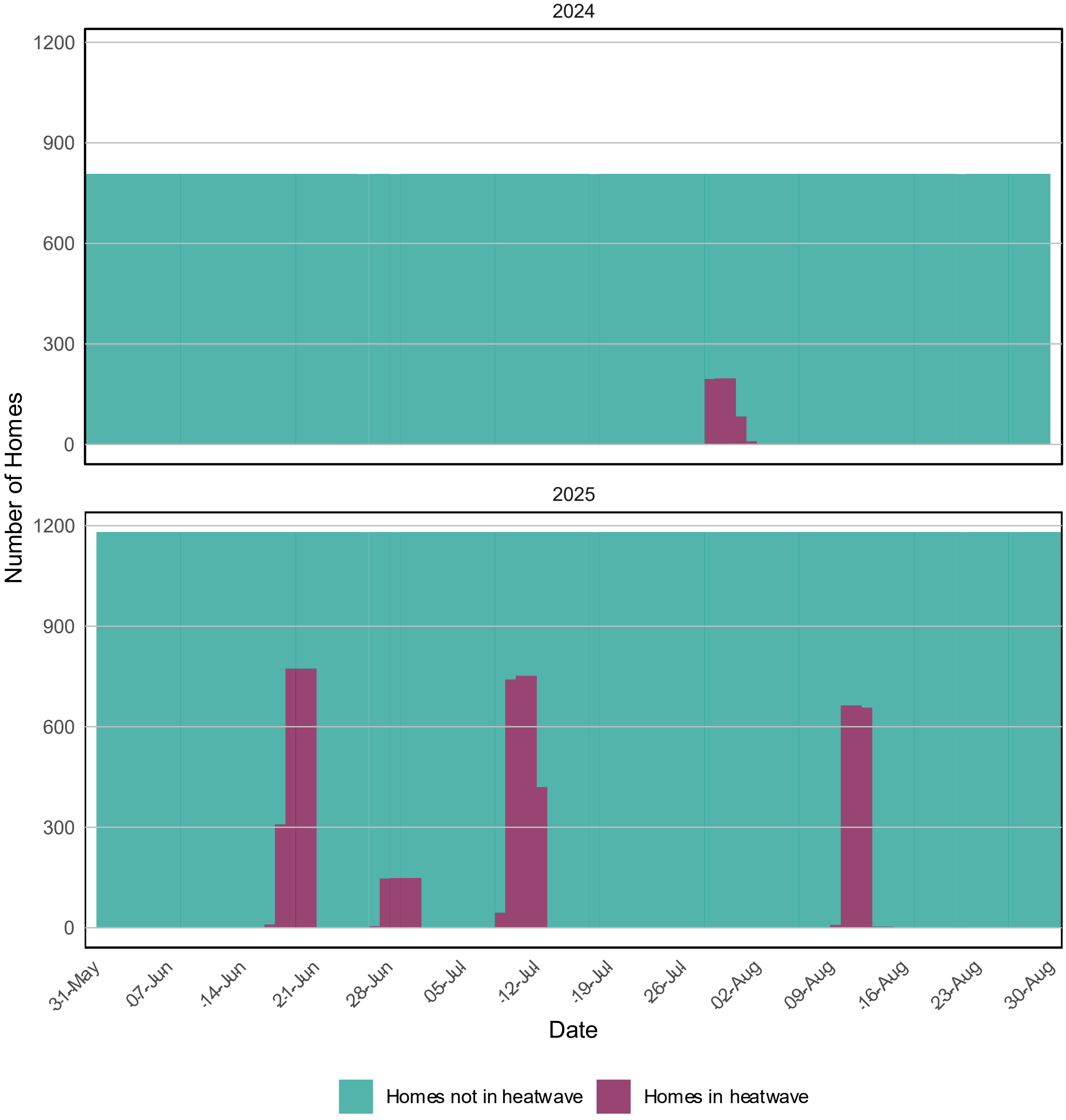
Figure 5: Time of peak temperature in 797 homes in summer 2025 (data from sensors in bedrooms at night, and living rooms in the daytime)



2.2.4. Heatwaves

Figure 10 shows how many individual homes experienced heatwaves on each day through the two summers. Additional homes had been recruited to the trial in 2025, so the columns (y-axis) are higher than for 2024. As would be expected from the higher external temperatures, the incidence of heatwaves is much higher in 2025. The main heatwave periods are consistent across the majority of homes in each year, however there is some variation that may be explained by geographic location with some homes not experiencing a heatwave whilst others are, and some homes experiencing heatwaves earlier than others.

Figure 6: Heatwaves as experienced by 799 homes in 2024 and 1,118 homes in 2025



2.3. Results - overheating

2.3.1. Nighttime overheating

The frequency and intensity of exceedance were calculated for three periods for both the 26°C and 28°C thresholds[13]:

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[13] Only rooms with at least 80 days' complete temperature data during the 92-day summer period were included in the analysis.

- Summer 2024 (June, July and August),
- Summer 2025 (June, July and August),
- Heatwave nights only, 2025 (assessing data only for days for which the heatwave threshold was met)

A large increase in overheating was experienced in 2025 compared to 2024, as would be expected given the higher mean temperatures and much longer periods of heatwaves. Both the proportion of rooms over the threshold and the frequency and intensity of exceedance were higher in 2025 than 2024. The temperature in bedrooms was over 26°C for an average of 0.90 hours or 54 mins per day in summer 2025 compared to 0.38 hours (23 mins) per day in 2024. For nights following days classified as heatwave days in 2025, the proportion of bedrooms overheating was similar to the proportion over the whole summer, but the length of time and intensity of the overheating was greater in these periods. Bedrooms were over 26°C on average for more than half the night following a heatwave day at 4.70 hours (282 mins) per day (see Table 1). When a threshold of 28°C was used, as might be expected the exceedance statistics are much lower and very low apart from the 2025 heatwave days when the temperature was over this threshold for an average of 1.26 hours (76 mins) per day (see Table 2).

The nighttime analysis is for all operational temperature sensors in bedrooms; some homes in the trial did not place a sensor in a bedroom and some did but data collection failed. As a result, there are more homes with daytime living room temperatures included in the statistics than homes with nighttime bedroom statistics. Some homes had temperature sensors in more than one bedroom, in which case the mean exceedance and intensity across the bedrooms was calculated for that home.

Table 1: Nighttime (22:00 to 07:00) exceedance and intensity in bedrooms, 26°C threshold

Nighttime overheating (26°C threshold)	Summer 2024	Summer 2025	Summer 2025 heatwave only
Number of homes in sample	200	449	350
Number of homes exceeding threshold	133 (67%)	403 (90%)	322 (92%)
Number of bedrooms in sample	239	537	423
Number of bedrooms exceeding threshold	160 (67%)	481 (90%)	386 (91%)
Mean exceedance (hrs)	0.38hrs	0.90hrs	4.70 hrs
Mean exceedance (%)	4.2%	10.0%	52.2%
Mean intensity of exceedance (°C hrs)	0.06	0.182	1.159

Table 2: Nighttime (22:00 to 07:00) exceedance and intensity for 28°C threshold

Nighttime overheating (28°C threshold)	Summer 2024	Summer 2025	Summer 2025 heatwave only
Number of homes in sample	200	449	350
Number of homes exceeding threshold	44 (22%)	249 (55%)	198 (56%)
Number of bedrooms in sample	239	537	423
Number of bedrooms exceeding threshold	52 (22%)	288 (54%)	229 (54%)
Mean exceedance (hrs)	0.04hrs	0.18hrs	1.26hrs
Mean exceedance (%)	0.5%	2.0%	14.0%
Mean intensity of exceedance (°C hrs)	0.004	0.026	0.23

2.3.2. Daytime overheating

The same pattern observed when assessing nighttime overheating - of higher mean exceedance in Summer 2025 than Summer 2024 and even higher mean exceedance when only heatwave days in Summer 2025 are considered - is seen for overheating in living rooms during the day (see Table 3). The proportion of living rooms overheating is lower than the proportion of homes; this is because many homes placed sensors in two (or more) ‘living rooms’ and one showed overheating whereas another did not.

Table 3: Day time exceedance and intensity in living rooms, adaptive threshold

Daytime overheating (adaptive threshold)	Summer 2024	Summer 2025	Summer 2025 heatwave only
Number of homes in sample	268	618	531
Number of homes exceeding threshold	97 (36%)	302 (49%)	251 (47%)
Number of living rooms in sample	442	1026	910
Number of living rooms exceeding threshold	107 (24%)	390 (38%)	335 (37%)

Mean exceedance (hrs)	0.04 hrs	0.11 hrs	0.65 hrs
Mean exceedance (%)	0.5%	1.2%	7.2%
Mean intensity of exceedance (°C hrs)	0.011	0.034	0.23

2.3.3. Overheating by dwelling type

Previous studies have shown variation in level of overheating by building type[14]. The Li et al. analysis of Energy Follow Up Survey (EFUS)[15] data for 2018 showed higher levels of overheating in flats than in houses in what was, at the time, the joint hottest summer on record in England[16]. HfNZ data was used to assess how overheating varied by building type for Summer 2025, which, as noted, is now the hottest on record.

Figure 11 shows the difference by type of building in core project and electrically heated homes in mean exceedance at night over 26°C for the whole of summer 2025 and heatwave only days in summer 2025.

When the standard error of the mean (shown by the error bar[17]) is considered there is very little difference between types of dwelling apart from two small samples of electrically heated terrace houses which have higher mean exceedance than the rest of the sample during heatwaves, and the core project flats which have very low exceedance for the whole summer. The mean night exceedance for flats and maisonettes is similar to houses. This is unexpected as this building type has been shown as most prone to overheating in other studies[5,6]. The selection of flats for HfNZ, with a focus on electrically heated dwellings, may mean that this group is not representative of the stock as a whole; this also holds for the core project homes which are older, solid wall construction.

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[14] Beizaee, A., Lomas, K. J., & Firth, S. K. (2013). National survey of summertime temperatures and overheating risk in English homes. *Building and Environment*, *65*, 1–17. https://doi.org/10.1016/j.buildenv.2013.03.011

[15] https://www.gov.uk/government/publications/energy-follow-up-survey-efus-2017-reports

[16] *The effect of energy efficiency measures on summertime overheating in English Homes: Summary* (2024), M Li, P Drury, S Watson, K Lomas https://assets.publishing.service.gov.uk/media/6723b01d59832068128c1e24/energy-follow-up-survey-summary.pdf

[17] Standard error of the mean is a measure to indicate how likely a sample mean is likely to diverge from the population mean. It is calculated from the standard deviation of the variable divided by the square root of the number of homes in the sample

Figure 7: Variation in mean exceedance (night > 26°C) across different types of building (error bar indicates confidence interval of +/- standard error of mean). Data analysed for 'All Summer' (2025) and 'Heatwave days only' (2025).

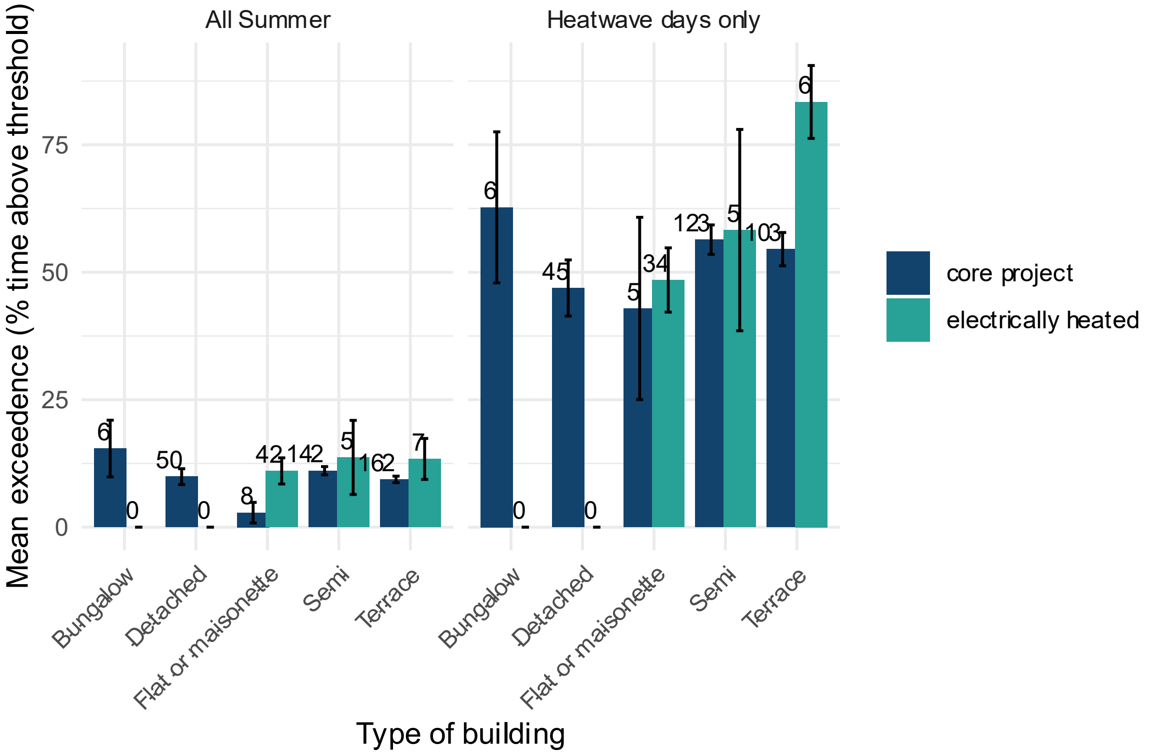
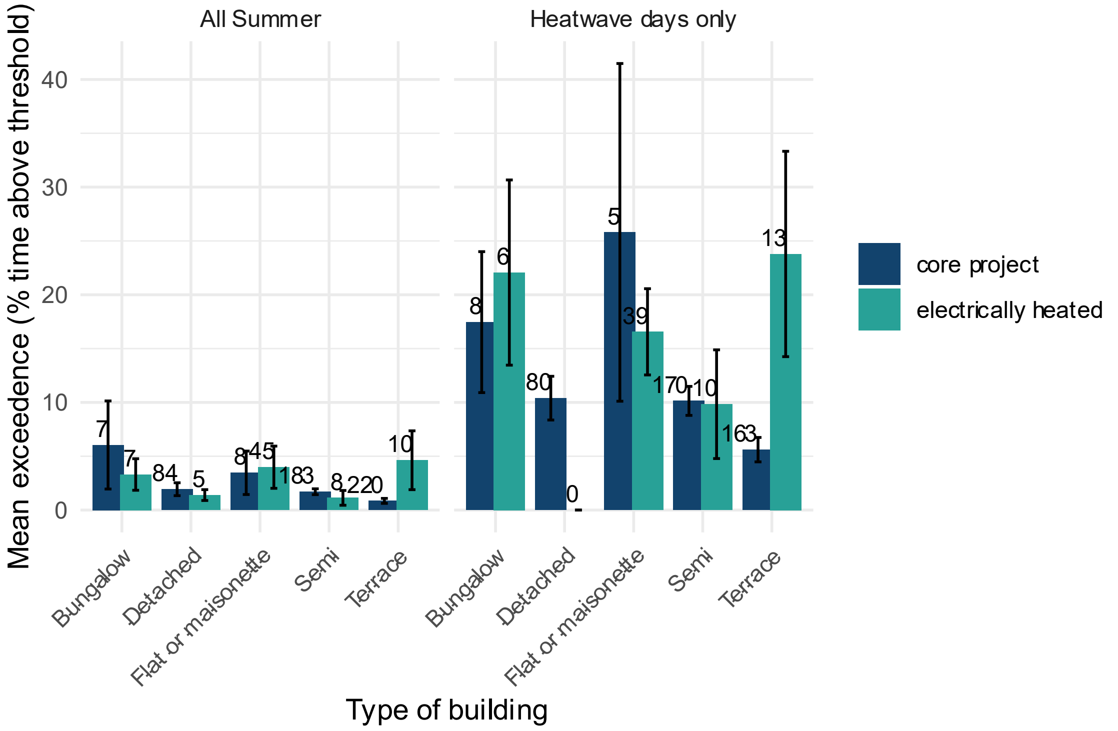


Figure 8: Variation in mean exceedance in daytime (adaptive threshold) across different types of building (error bar indicates confidence interval of +/- standard error of mean). Data analysed for 'All Summer' (2025) and 'Heatwave days only' (2025).



2.3.4. Heat wave survey findings (RQ 4.2 and 4.3)

To understand perceptions of overheating, a survey was sent to trial participants shortly after a heat wave in July 2025. The survey was sent out to 1,214 participants from across all three cohorts of the HfNZ trial via email (*n*=591). Participants were asked about their experience with the heatwave at home between the 10th and 13th of July 2025. They were given approximately one week to complete the survey, with a reminder issued a couple days before the deadline. Completed responses were received from 591 participants. Participants who completed the survey by the given deadline were then given the chance to win one of ten £50 vouchers.

The following sections provide an overview of findings from analysing responses.

2.3.4.1. Perceptions of overheating compared with temperature measurements

The mean calculated exceedance levels were compared with reported perception of overheating, using survey answers to the following questions:

- “During the heat wave, how often were you able to maintain a comfortable temperature in your bedroom during the night?”
- “During the heat wave, how often were you able to maintain a comfortable temperature in your living room during the day?”

There were five possible responses to report frequency: ‘*Never*’, ‘*Rarely*’, ‘*Occasionally*’, ‘*Often*’, and ‘*Always*’. The 26°C nighttime exceedance figures were compared with the question about bedroom comfort, and the daytime exceedance figures were compared with the question about living room comfort.

As might be anticipated, those who reported never being able to maintain a comfortable temperature in the bedroom at night during heatwaves had the highest mean exceedance level; the exceedance level progressively decreased to the lowest value for those who said they were always comfortable (see Figure 13). The relationship between reported comfort and exceedance in living rooms was not so clear. While those who reported always being able to maintain comfortable temperature in the day had lower mean exceedance than those who said they never did, the similarity of overheating levels between those who said ‘*never*’ and those who said ‘*often*’ suggests that perception of overheating during the day can be affected by other factors as well as measured temperature (e.g., ventilation levels). An assessment that included only those days classified as heat wave days shows a similar pattern (see Figure 14).

There are fewer homes included in the nighttime than the daytime statistics because not all homes had temperature measurement in a bedroom; of those that did, for some there were insufficient data (minimum 80 days required) to be included.

Figure 9: Overheating perceptions versus exceedance statistics (percentage of total answers for each sample shown on bar) Summer 2025

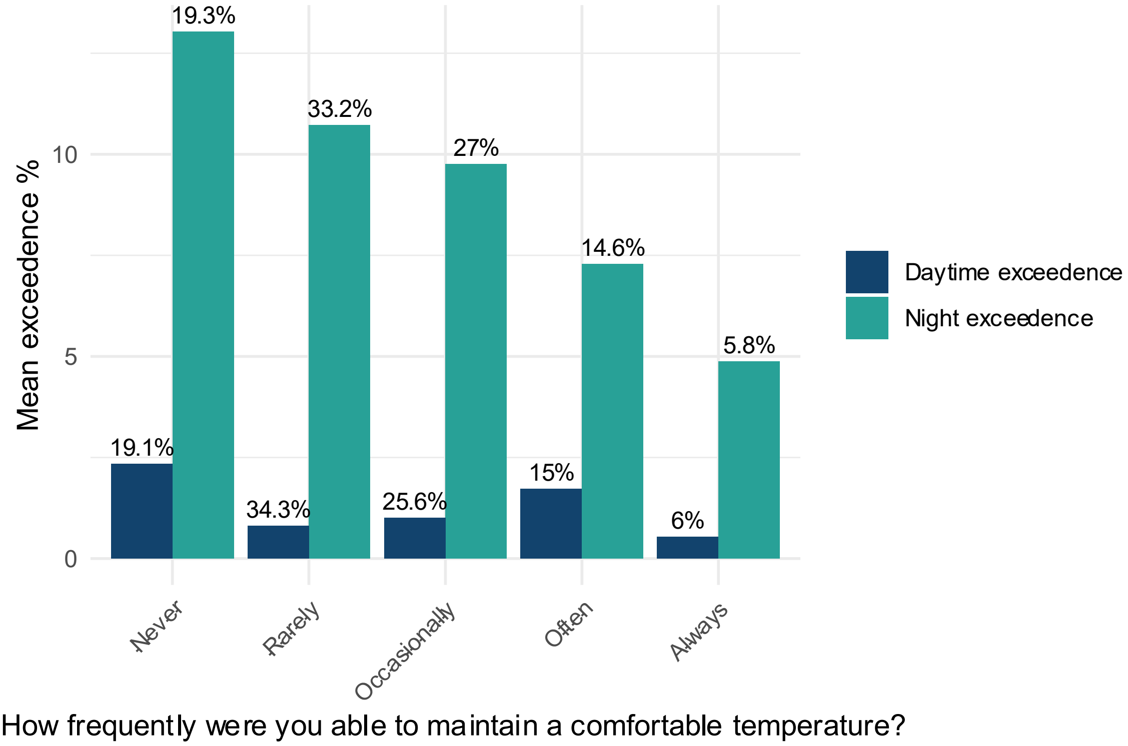
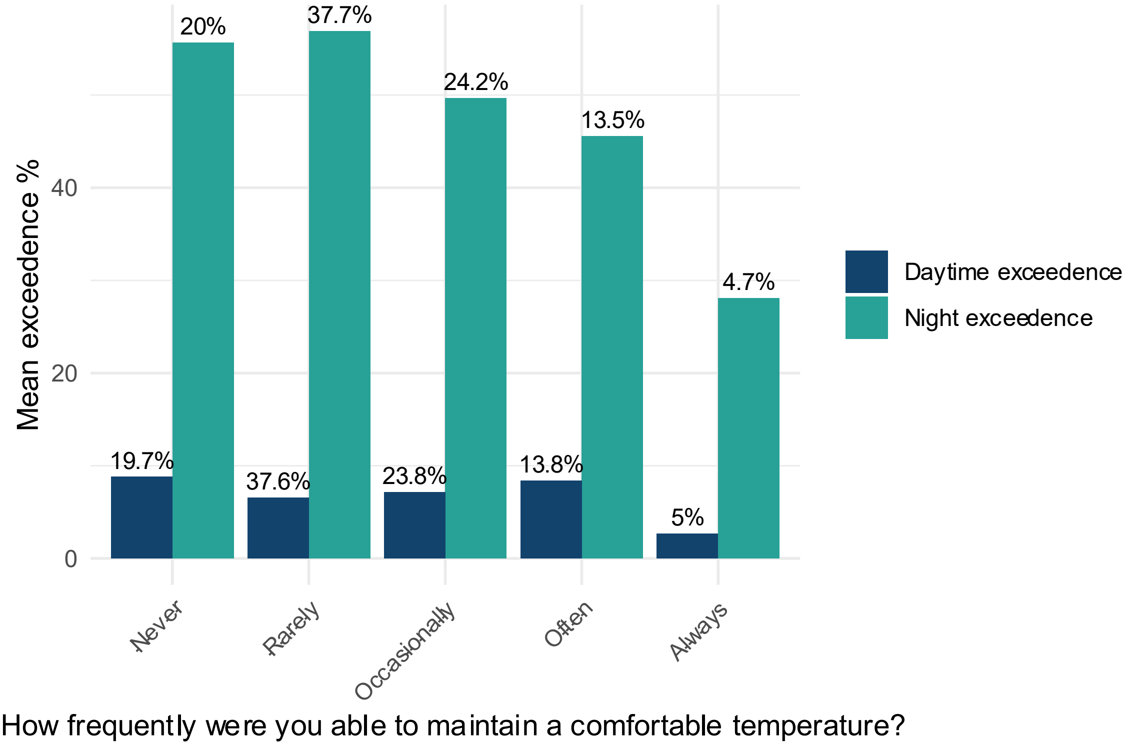


Figure 10: Overheating perceptions versus exceedance statistics (percentage of total answers shown on bar) Summer 2025 heat wave days only



The survey also included questions about coping mechanisms and their effectiveness. Two questions were asked:

- “During the heat wave, how often did you attempt to reduce the temperature in your home?” and,
- “During the heat wave, how often were you successfully able to reduce the temperature of your home?”.

The mean exceedance statistics for those who answered ‘*always’* or ‘*often’* to *attempting to reduce the temperature in their home*, and who also reported ‘*always’* or ‘*often’ successfully being able to reduce the temperature*, did experience lower overheating both during the night and during the day, compared to those who answered ‘*never’* or ‘*rarely’* to being successful.

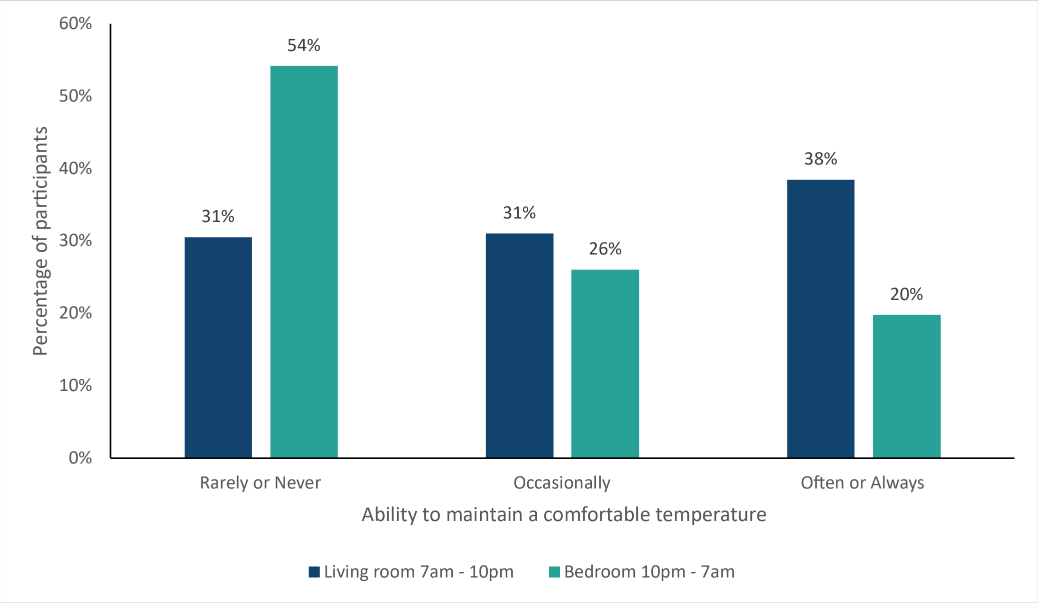
Table 4: Exceedance statistics for survey respondents who reported attempting to reduce temperature.

	Mean night exceedance (>26°C) %	Mean day exceedance %
Tried and succeeded in reducing temperature	8.8 +/- 1.1%	1.1+/-0.3 %
Tried and did not succeed in reducing temperature	11.8+/- 1.9%	2.2+/- 1.1 %

2.3.4.2. During the heatwave, participants were more able to stay comfortable in the day than at night

More than half (54%) reported that they were ‘*rarely’* or ‘*never’* able to maintain a comfortable temperature in their bedroom at nighttime, while only 1 in 5 (20%) were ‘*often*’ or ‘*always*’ comfortable (see Figure 15). In contrast, 31% of respondents were ‘*rarely*’ or ‘*never*’ able to maintain a comfortable temperature in their living room in the daytime, compared to 38% that were ‘*often’* or *‘always*’ comfortable. A Wilcoxon signed-rank test confirmed that there was a significant difference (W = 12036.5, $P < 0.001$) between comfort in the day vs at night, indicating that during a heatwave, participants were more comfortable in the living room during the day than in their bedroom at night. This mirrors the findings from quantitative analysis of temperature sensor data (see 2.2.4).

Figure 11: "During the heat wave, how often were you able to maintain a comfortable temperature in your living room during the day/bedroom during the night?"



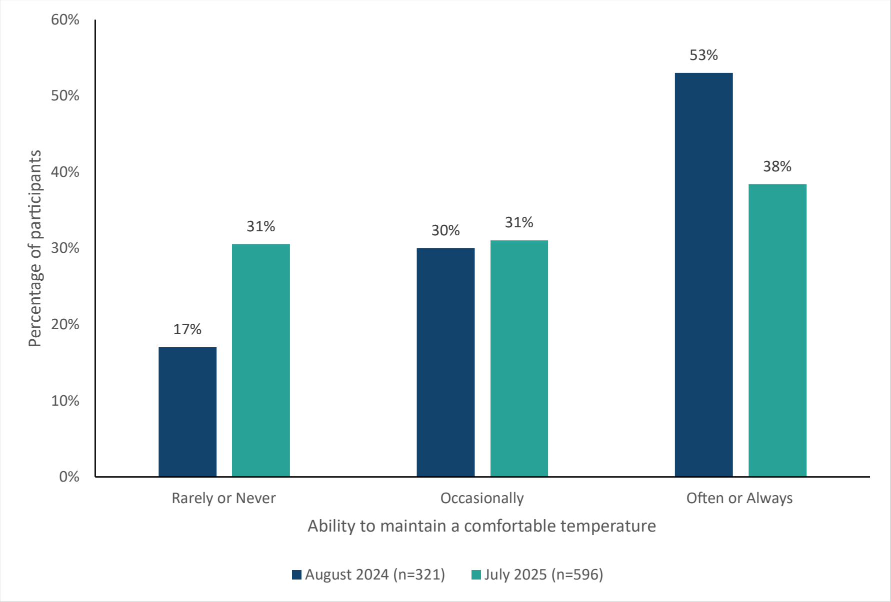
2.3.4.3. Participants were less comfortable during the day during the heatwave this summer (2025) than last summer (2024).

A comparison was made between participants' comfort between this year's heatwave (2025) and last year's (2024) to identify any similarities or differences in comfort between the responses for each heatwave, as shown in Figure 16. This highlighted any variability or inconsistency for participants' reported comfort levels during heatwaves. As there was natural variability in the conditions and temperature of each heatwave, particularly in how strongly they are felt across the country and thus the participants' households, they cannot be viewed as a perfect comparison. Even so, this could be useful in signifying a temperature threshold for greater reported discomfort levels.

Significant difference was found between participants' ability to maintain a comfortable temperature in their living rooms in the day during the heatwave of 2025 compared to the heatwave of 2024. While more than half (54%) agreed that they were '*often*' or '*always*' comfortable during the heatwave of August 2024, only 38% felt they were able to be during the July 2025 heatwave. Participants were significantly less comfortable during the heatwave this summer, as 31% were '*rarely*' or '*never*' comfortable, almost twice as many as last summer's heatwave (16%).

A Chi-square test of independence revealed that there was a statistically significant shift ($x^2(2) = 24.72$, $p<0.001$) in the response distributions between comfort across the two heatwaves. Further post-hoc tests revealed that the proportion of the *'never*' or *'rarely'* responses increased from 2024 (17.1%) to 2025 (30.5%), while the proportion of *'often'* or *'always'* responses decreased from 2024 (53%) to 2025 (38.4%). This supports the finding that participants were significantly less comfortable during the day in the 2025 heatwave than the 2024 heatwave. This mirrors the findings from quantitative analysis of temperature sensor data.

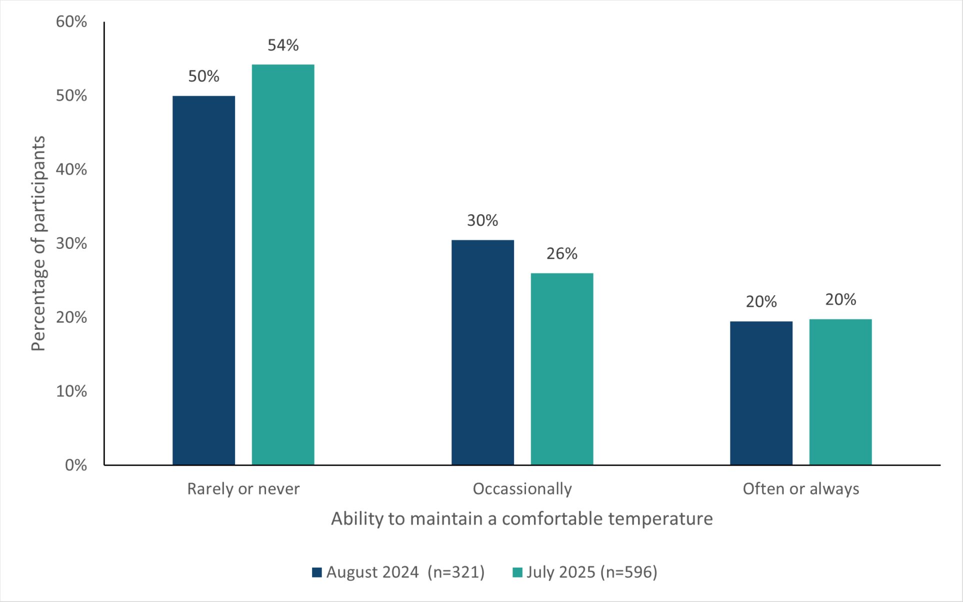
Figure 12: Respondent ability to maintain a comfortable temperature in the living room during the day during the August 2024 heatwave compared against ability to maintain a comfortable temperature in their living room during the day during the July 2025 heatwave (*n*=596)



Despite the significant difference in comfort of participants during the day, comfort during the night was very similar for both heatwaves, as shown in Figure 17. Around half (50%) of participants last year expressed discomfort in the night during the heatwave, as did just over half (54%) of participants this year. Similarly, only one fifth (20%) of participants were '*often*' or '*always*' comfortable in the night during both heatwaves. A Chi-square test of independence confirmed that there was no statistically significant difference ($x^2(2) = 1.54$, p=0.4641) between the level of comfort responses between each heatwave at night. This implies that participants experienced a relatively similar level of discomfort during both heatwaves at night.

These findings align with quantitative measurements of exceedance in participants' homes during the heatwaves, with exceedance in bedrooms similar during both summers, and exceedance during the daytime in living rooms being considerably higher in summer 2025.

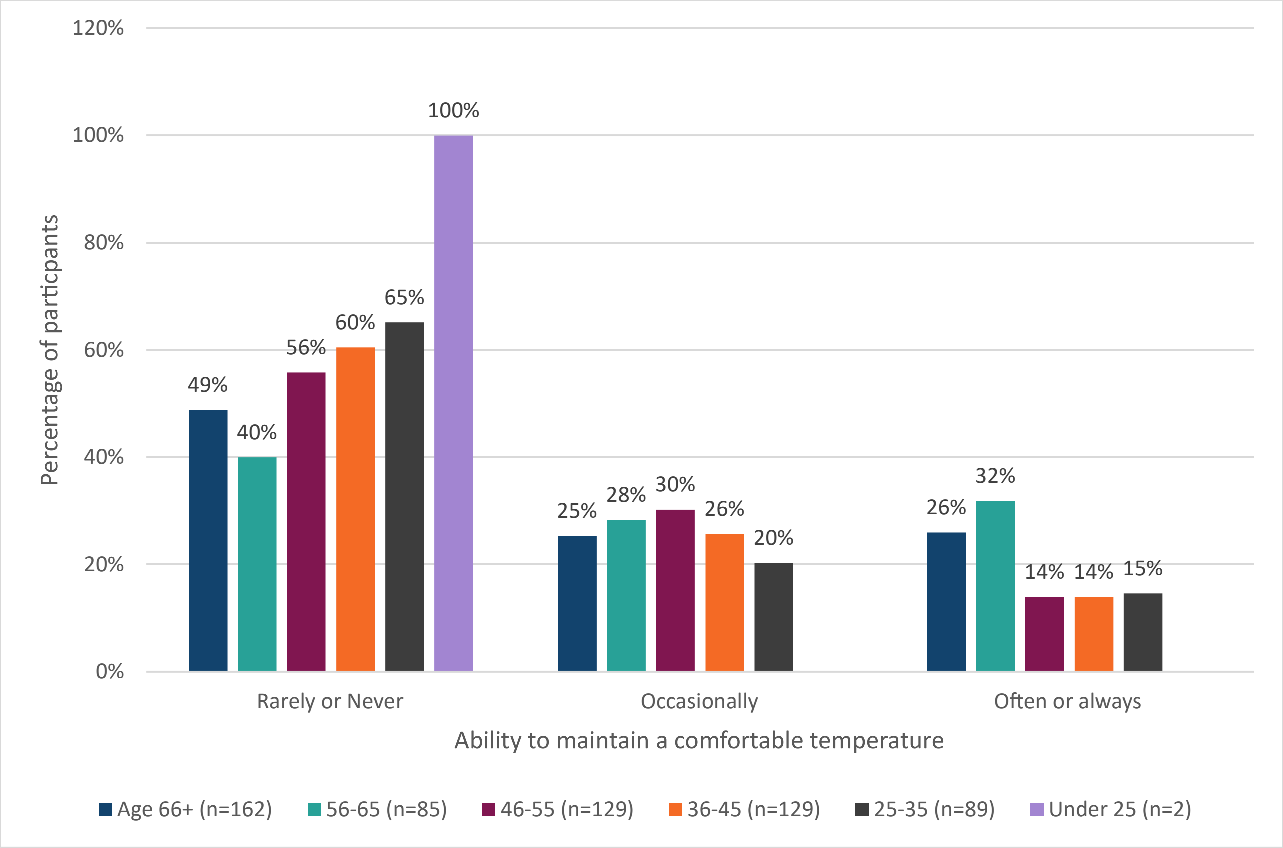
Figure 13: Respondent ability to maintain a comfortable temperature in their bedroom in the night during the August 2024 heatwave compared against ability to maintain a comfortable temperature in their bedroom in the night during the July 2025 heatwave (*n*=596).



2.3.4.4. Respondents aged 56+ more frequently reported to be comfortable than younger participants

Further analysis investigated how reported comfort varies by age during the heatwave to understand whether certain age groups were more impacted by the warmer temperatures. This could indicate whether there is a need for more targeted measures to support cooling for certain age groups. Figure 18 indicates how respondents of all ages were more likely to report that they struggled to maintain a comfortable temperature in their bedrooms at night. Older respondents (those older than 56), however, more often reported to be *'often'* or *'always'* comfortable (28%) than younger respondents (14%). Notably, more than half (60%) of those younger than 56 felt '*rarely*' or '*never*' comfortable.

Figure 14: Respondent age compared against reported ability to maintain a comfortable temperature in the bedroom during the night (*n*=596).

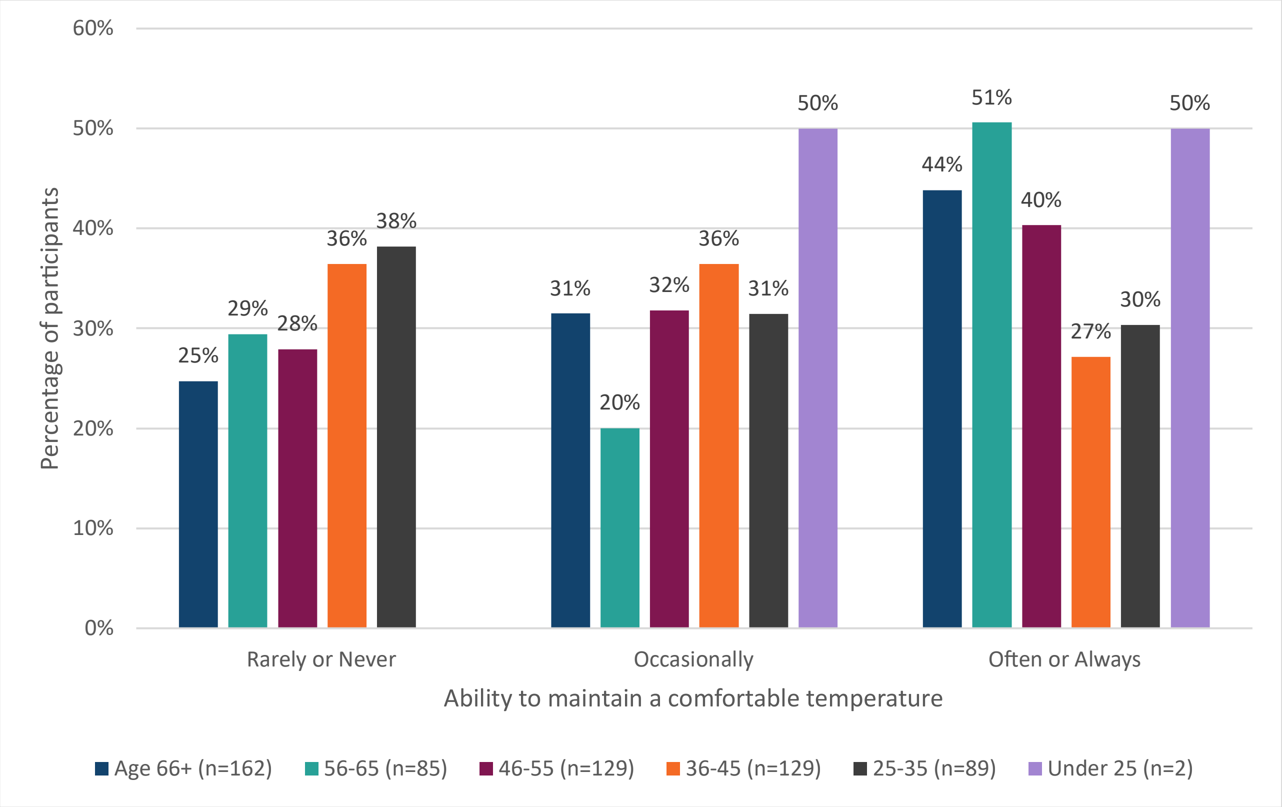


2.3.4.5. Around half of those who were older than 56 were able to maintain a comfortable temperature in their living rooms during the day

In contrast, comfort during the day was more variable amongst the age groups. Even so, as shown in Figure 19, respondents in the category ‘aged 56 and over’ were still more likely to report being comfortable, with around half (46%) saying they were able to maintain a comfortable temperature in their living rooms during the day. Younger adults, aged 25 to 55, tended to struggle more, with around one third (33%) reporting ‘*rarely*’ or ‘*never*’ maintaining a comfortable temperature.

Further research is needed to understand the cause of the reported differences in comfort between age groups; for example, whether it suggests greater tolerance or preference for warmer room temperatures as people age. Other dependencies, like reported vs actual comfort, use of cooling measures, and insulation or ventilation of the home could also influence this result. As the sample size for respondents under 25 was too small (*n*=2) to reflect a representative sample, insight about this age group could not be inferred from this survey alone.

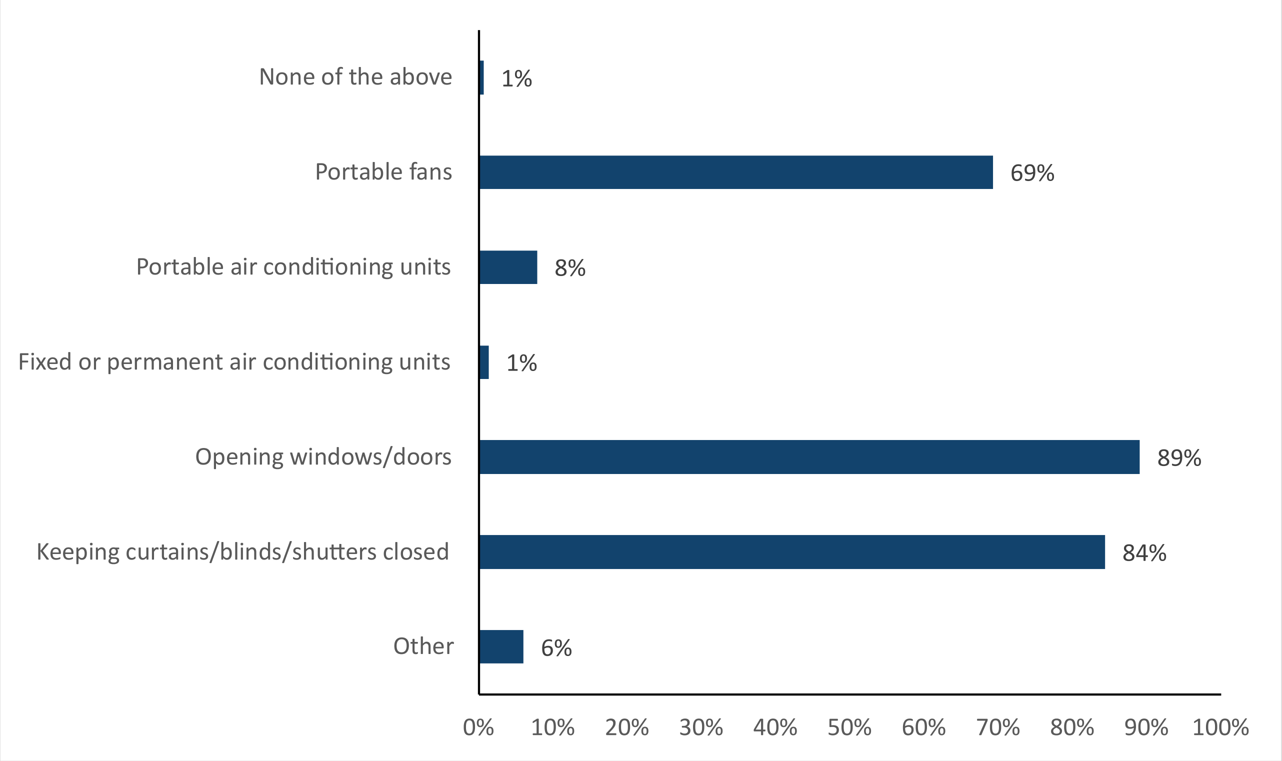
Figure 15: Respondent age compared against reported ability to maintain a comfortable temperature in the living room during the day (*n*=596).



2.3.4.6. Passive cooling measures were more commonly used, with fewer participants using active cooling measures and very low levels of air conditioning unit use

The kind of measures that households use to keep cool in their homes helps identify which methods are most effective when combined with an assessment of perception of success. It can be useful to monitor measures used over time to understand changes in household behaviour in a changing climate. As shown in Figure 20, passive cooling measures, such as opening windows and doors (89%), and keeping the sun from heating up rooms through keeping curtains/blinds/shutters closed (84%) were the most commonly used methods. While the majority of participants used portable fans (69%), fewer participants used other types of active cooling measures during the heatwave, with only 8% using portable air conditioning and very low levels of fixed air conditioning unit usage (1%). Of the 6% that reported using other ways to keep cool, just over half (54%) of those used other passive methods such as only using north facing rooms or using special glazing to reduce UV rays, as well as water-based cooling methods. The others used active methods such as fixed ceiling fans, evaporative fans / coolers, air coolers, extractor fans or even dehumidifiers.

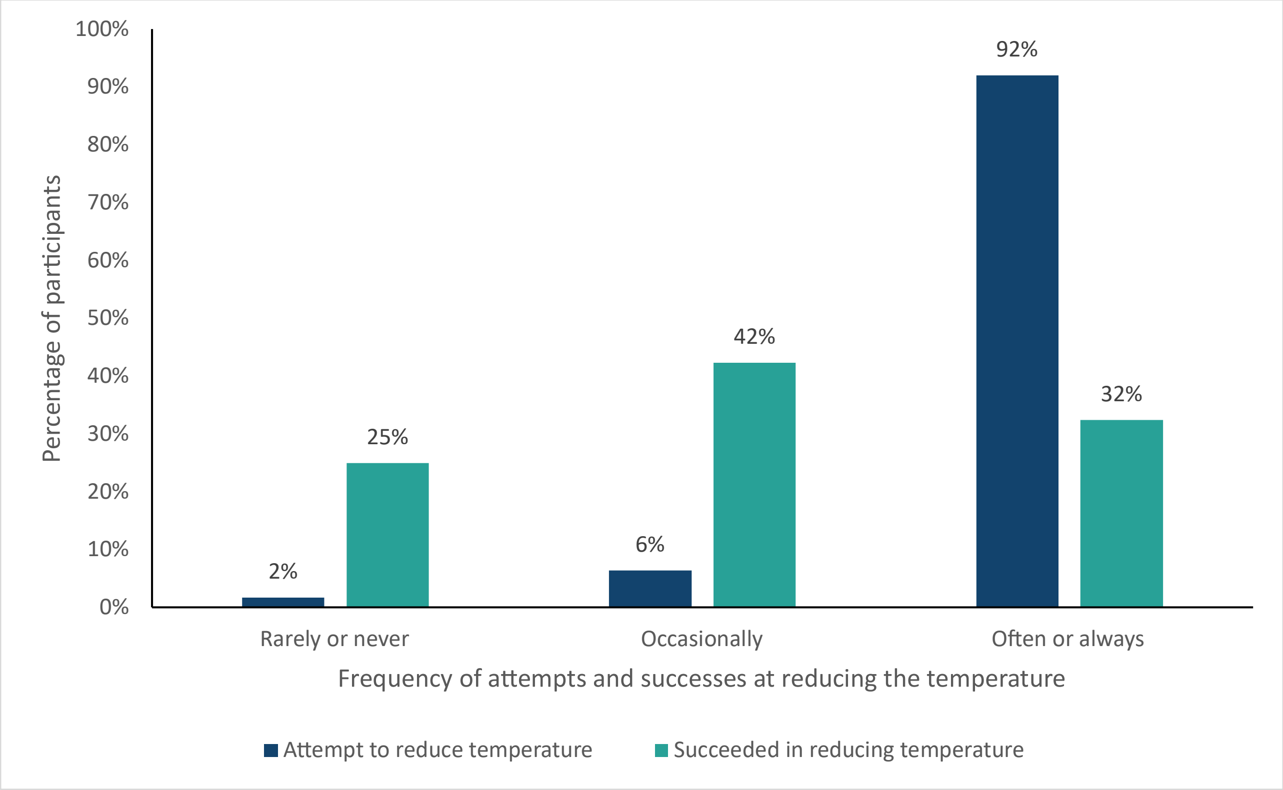
Figure 16: “What methods, if any, did you use to help cool your home during the heatwave?”.



2.3.4.7. Most participants attempted to reduce the temperature during the heatwave; however, many were unsuccessful

In addition to the types of measures they use to cool their home, participants were also asked how often they attempted and succeeded to reduce the temperature during the heatwave, to examine the effectiveness of their attempts. As shown in Figure 21, the majority (92%) of participants ‘*often*’ or ‘*always*’ attempted to reduce the temperature in their home during the heatwave, yet only 32% were successful. Of the 6% that ‘*occasionally*’ made attempts, less than half (42%) were successful. This suggests that while many residents want to try to reduce the temperature, either the measures they take, or the effectiveness of these measures, is often not satisfactory. This helps to identify a need for better temperature management during a heatwave, and potential demand for alternative cooling solutions. Electrical cooling measures like portable fans and air conditioning units may be considered by households to be expensive to purchase and operate, which may be perceived to outweigh the benefits of keeping a home cool, hence their low usage. Increasing frequency of extreme weather events like heatwaves may increase their uptake in the future.

Figure 17: "During the heat wave, how often did you attempt to and succeed in reducing the temperature in your home e.g. by opening windows or using a fan?" (*n*=596)



2.3.4.8. Across trials, respondents mostly used active and passive cooling measures during the heatwave in a similar way.

Methods that participants used to keep cool during the heatwave across trials were compared to determine whether the type of heating system a household uses influences cooling measure usage (see Figure 22). Across the projects, it was found that the majority of respondents used passive cooling measures during the heatwave in a similar way, with over 80% of participants opening windows/doors and keeping curtains/blinds/shutters closed, and over 70% opening windows and doors. Likewise for active cooling measures, usage across the project cohorts was somewhat similar. There was low usage of portable air conditioning across all groups, with only 7-8% using this method[18]. Those on the core trial, however, more frequently reported using portable fans (74%), while around half (52%) of participants from the AEH trial (both RAAHP and heat battery) used this method. As these project groups represent a relatively smaller sample compared to the core trial cohort, this may account for some discrepancy. When viewed collectively, the results suggest that the heating system type does not substantially influence cooling methods used. However, further research into motivations for cooling methods chosen and a larger sample size across all projects would be needed to support or confirm this hypothesis.

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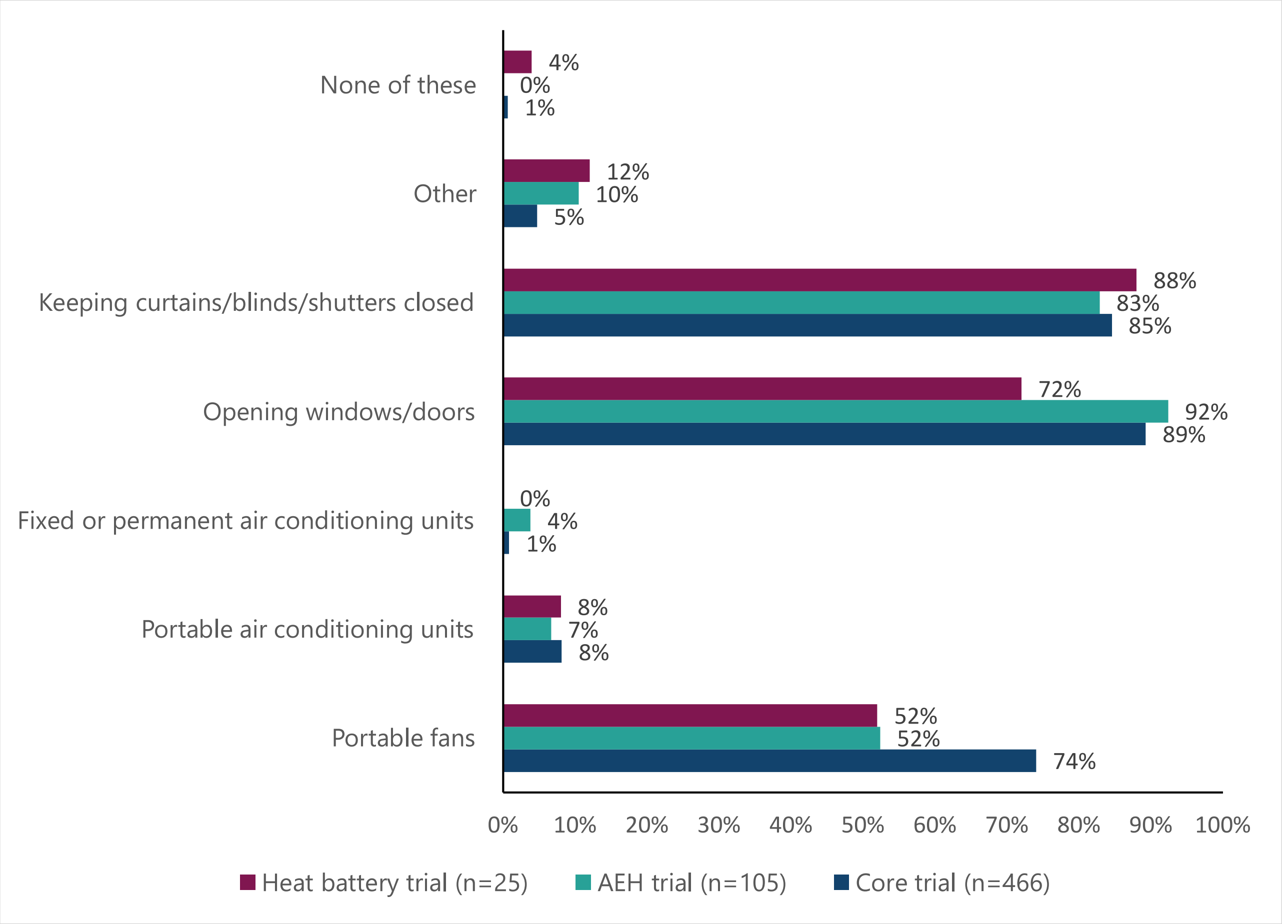
[18] At this stage, none of the RAAHP installs were complete

Figure 18: Participant trial cohort compared by methods taken to keep cool during the heatwave.



2.3.5. Key findings and future plans

This section has covered overheating in participant homes. It has covered both quantified measurements of overheating using data from temperature sensors, as well as householder experiences of overheating shortly after a heatwave. In summary:

- 2025 was the hottest summer on record, and both quantified measurements of overheating and participant perceptions of comfort reflected this in comparisons to 2024.
- Overnight, most homes exceeded the 26°C threshold during the summer months and averaged nearly an hour per day above the threshold. On nights following days classified as heatwave days, this increased to nearly five hours per night.
- Findings from analysis of daytime overheating were less pronounced, with fewer homes meeting the overheating threshold and for shorter periods. However, this could be because the industry standard for analysis of daytime temperatures is against an adaptive threshold that changes according to outside temperature, and so is not an absolute measure.
- The type of dwelling did not statistically significantly affect overheating; however, dwelling types in the trials are not representative of the UK housing stock and instead are specific dwelling archetypes according to trial eligibility criteria.

- Households who exceeded thresholds for the longest periods or by the largest margin more frequently reported finding difficulty being comfortable.
- During a heatwave, more than half of respondents reported finding it difficult to be comfortable overnight, dropping to around a third during the day.
- Younger householders reported finding it harder to be comfortable than older.
- During a heatwave, householders typically relied upon ‘passive’ technologies, such as closing curtains or opening windows, to reduce internal temperatures, and ‘typical’ active measures such as portable fans rather than active such as air-conditioning (the heatwave was before RAAHPs were installed).

At the time of writing, the remainder of the project includes only winter months, and so no further analysis of overheating is planned.

2.4. Cold snap survey findings

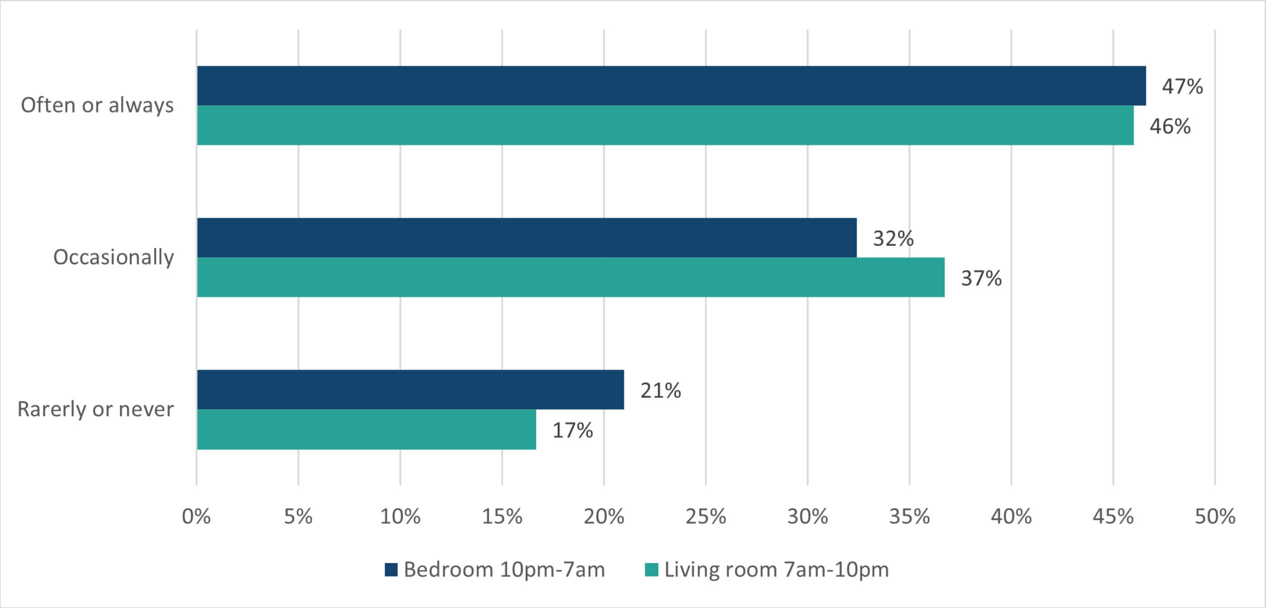
To understand perceptions of coping during a period of cold weather, a survey was sent to trial participants shortly after a cold snap in November 2024. The survey was sent out to 751 participants from across two cohorts of the HfNZ trial via email. Participants were asked about their experience with the cold snap at home between the 18th and 22nd of November 2024. They were given approximately one week to complete the survey, with a reminder issued a couple days before the deadline. Completed responses were received from 322 participants. Participants who completed the survey by the given deadline were then given the chance to win one of ten £50 vouchers.

The following sections provide an overview of findings from analysing responses.

2.4.1.1. During a cold snap, fewer than half of the participants are able to maintain a comfortable temperature in their homes

Based on the answers to the survey, overall fewer than 50% of participants reported being often or always able to maintain a comfortable temperature in their living room during the day and/or their bedroom during the night during a cold snap. No significant difference was found between respondents’ reported ability to stay comfortable during the day or during the night (as seen in Figure 23).

Figure 19: "How often were you able to maintain a comfortable temperature in your living room during the day" (*n*=321)



2.4.1.2. Exploratory analysis shows potential indication of greater comfort for certain age groups during a cold snap

No significant difference was found between age and comfort at home, but exploratory analysis suggests that comfort during the night seems to increase with age, where adults of 56+ years self-report being able to maintain a comfortable temperature during the day and night most often. Those between 36-45 years old self-reported least often being able to maintain a comfortable temperature on both occasions. As the sample sizes of the age groups are too small to derive any robust conclusions, further investigation is needed to understand if the increase in reported comfort from older residents is because they are able to keep their bedrooms warmer, or they are used to or prefer cooler overnight temperatures.

2.4.1.3. Most participants always managed the cold weather by layering on more clothes and using central heating

Nearly half of the respondents said they '*always'* layered on more clothes (44% of respondents) or used their central heating (44% of respondents) to keep warm during the cold snap. Around a third (28%) '*always'* took other behavioural measures such as using blankets and hot water bottles. Some used other forms of heating and insulation (18%). However, only 35% of participants reported ever using electric heating devices such as portable heaters or electric blankets, lower than any other method.

Overall, respondents felt they were mostly successful in *'often'* or *'always'* maintaining a comfortable temperature in their home through using central heating and other methods of heating, as well as layering on more clothes and using blankets and hot water bottles. However, only 40% of the 107 participants who said they used electrical heating devices felt they were successful in staying comfortable this way.

2.4.1.4. Participants’ concerns about the cost of heating their home influenced how they heated it

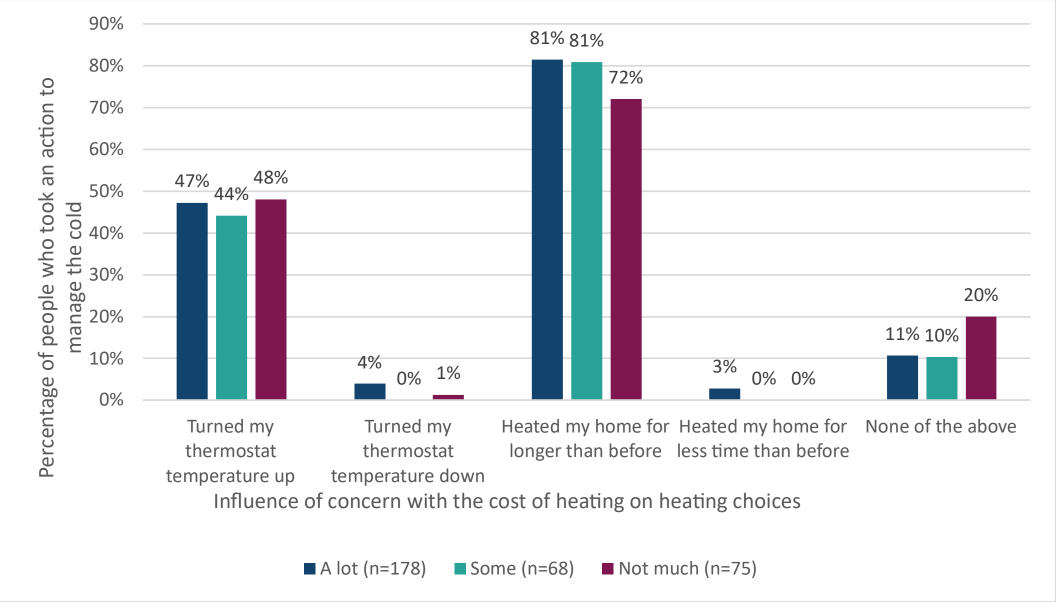
Participants were asked what actions they took to heat their home during the cold snap.

- 3 in 4 respondents felt their concern about the cost of heating their home influenced their heating choices during the cold snap.
- 79% of respondents said they heated their home for longer than before during the cold snap, which is supported by the actions that people took to manage their comfort at home.
- Almost half (47%) of respondents turned their thermostat temperature up to manage the cold.
- 13% did not change how they were heating their home, with some heating less (4%).

2.4.1.5. Those least influenced by the cost of heating in managing comfort took less action and were more comfortable

Although the relationship between the actions taken by respondents to manage the temperature and the impact of their concern for cost looks broadly similar across groups (noting there was a strong skew to towards those who’s heating actions were influenced *‘a lot’* by cost), a chi-square test of independence indicated a statistically significant difference ($\chi^2(8) = 76.12$, $p = 0.001$) in heating actions taken during the cold snap and how their concern for cost influenced heating choices. Further post-hoc tests revealed that those who took ‘None of the above’ actions during cold weather were significantly more likely to report being less influenced by their concern for the cost of heating, of which 20% were not very concerned, compared to only 11% that were very concerned ($p<0.05$).

Figure 20: "To what extent has concern about the cost of your heating over the recent cold weather influenced how you've been heating your home?"



A chi square test of independence also revealed a significant relationship between reported comfort and concern about heating costs ($\chi^2(4) = 13.28$, $p < .001$). Post-hoc tests indicated that participants who reported being "not very influenced by the cost" were significantly more likely to be *'often'* or *'always'* comfortable in the night (81% vs. 28% $p<0.05$) and day (79% vs. 25% $p<0.05$) than those who said they were very concerned. Therefore, those who were most influenced by the cost of heating when making heating choices were less likely to feel comfortable during the cold snap, indicating that concern for cost may be undermining their comfort.

Figure 21: Respondent ability to maintain a comfortable temperature in the living room during the day compared against their level of concern with the cost of heating their home. (*n*=321). Q: "How often were you able to maintain a comfortable temperature in your living room during the day" Q: "To what extent has concern about the cost of your heating over the recent cold weather influenced how you've been heating your home?"

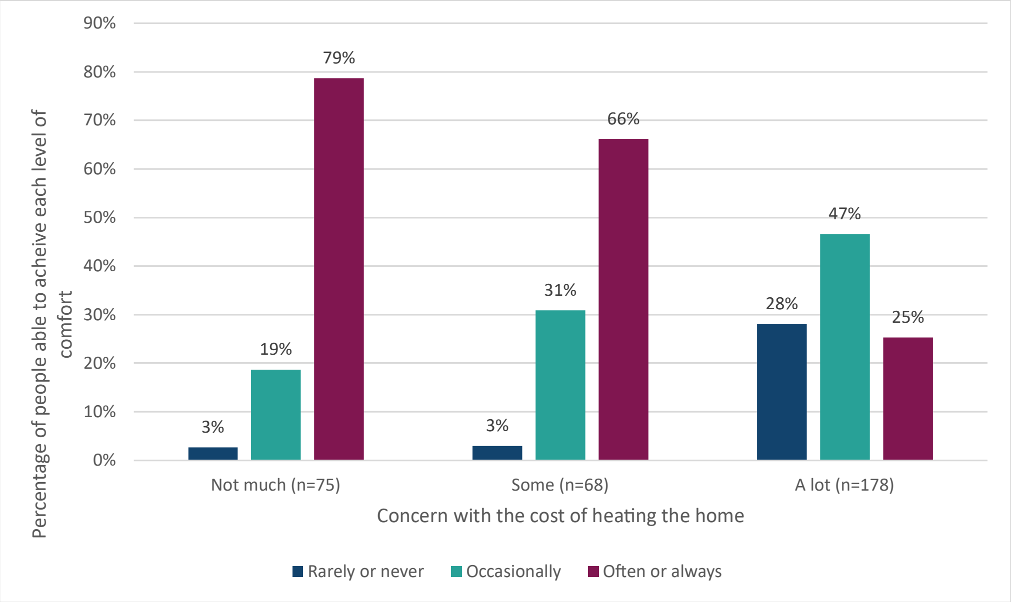
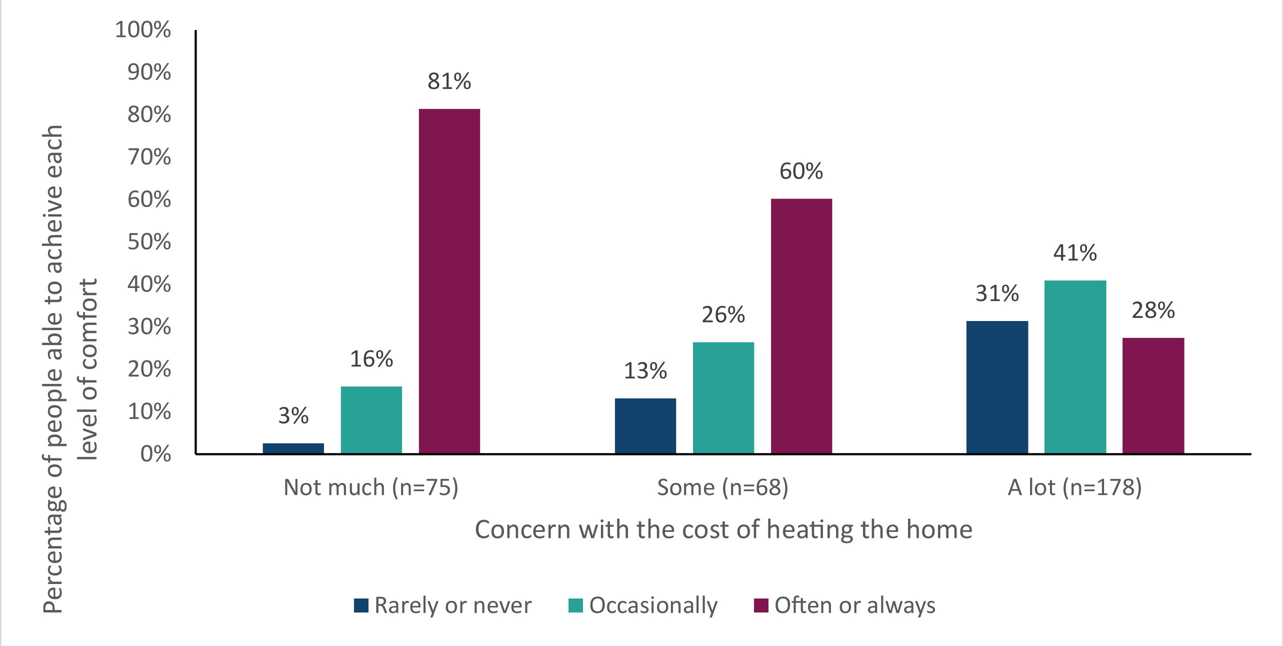


Figure 22: Respondent ability to maintain a comfortable temperature in the bedroom during the night compared against their level of concern with the cost of heating their home. (*n*=321). Q: "How often were you able to maintain a comfortable temperature in your bedroom during the night" Q: "To what extent has concern about the cost of your heating over the recent cold weather influenced how you've been heating your home?"



Analysis of internal temperature data by different levels of influence of concern about energy affordability on heating choices shows that those reporting they were more influenced by the concern, on average, kept both their living and bedrooms at a lower temperature. This effect is less present in bedrooms, and more prominent in living spaces. This effect is true for the cold snap in mid-November 2024, as well as during the cold snap in early January 2025. Therefore, people who let concern about the cost of energy impact how they heat their home both feel less comfortable and have cooler homes than those who are not during a cold snap.

Figure 23: Mean internal temperature (°C) in the living room (November 3rd, 2024, to January 5th, 2025). Temperature is shown for three groups with different levels of influence of their concern about energy affordability on how they heat their home. "To what extent has concern about the cost of your heating over the recent cold weather influenced how you've been heating your home?"

Figure 24: Mean internal temperature (°C) in the bedroom (November 3rd, 2024, to January 5th, 2025). Temperature is shown for three groups with different levels of influence of their concern about energy affordability on how they heat their home. Q: "To what extent has concern about the cost of your heating over the recent cold weather influenced how you've been heating your home?"

2.4.2. Key findings and future plans

This section has reported upon findings from questionnaire data collected shortly after a cold snap, that sought to understand participant comfort in prolonged periods of cold weather.

- Fewer than half of respondents reported being able to maintain a comfortable temperature during the cold snap;
- The most popular methods for dealing with cold weather included wearing more clothing and using the central heating, as well as blankets and hot water bottles.
- Cost was a factor in how participants reacted to the cold weather; participants least concerned with cost took the least action and were most comfortable, whereas those most concerned had lower temperatures in living spaces and bedrooms.

The cold snap survey will again be fielded during the winter of 2025/26, providing a sufficiently long spell of cold weather occurs. The analysis presented here will be repeated in future reports.

2.5. Electrically heated homes

In the previous HfNZ report, a basic statistical analysis of the characteristics of the core project homes was conducted. This analysis is repeated here but instead covers the homes of the participants in the alternative electric heating trial (not those with a heat battery). Analysis of this cohort was not possible previously as they were still being recruited.

2.5.1. Representativeness of HfNZ electrically heated homes

The alternative electric heating trial sought to recruit electrically heated homes or flats. This section provides an overview of the characteristics of the homes and flats in the trial.

The most common type of heater was electric panel heaters, found in 45% of the HfNZ electrically heated homes. Of 196 homes recruited for which the heating type was recorded, 57 (29%) have storage heaters, very similar to the proportion of electrically heated homes in the SERL Observatory with storage heaters (27%)[19]. The distribution of number of occupants is shown in Figure 29. Many of the electrically heated homes (42%) are single person households and the mean number of occupants (2.0) is lower than the national average household occupancy of 2.4[20]. In the alternative electric heating trial, there is a much higher proportion of flats and maisonettes than in the general housing stock, which is expected, given the recruitment criterion for electric heating and prevalence

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[19] SERL Observatory data does not distinguish between panel heaters and other types of electrical radiator.

[20] https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/families/bulletins/familiesandhouseholds/2023

of electrical heating in high rise flats[21] (see Figure 30 for a comparison with the English Housing Survey (EHS)).

Figure 25: Distribution of number of occupants across electrically heated homes in alternative electric heating trial

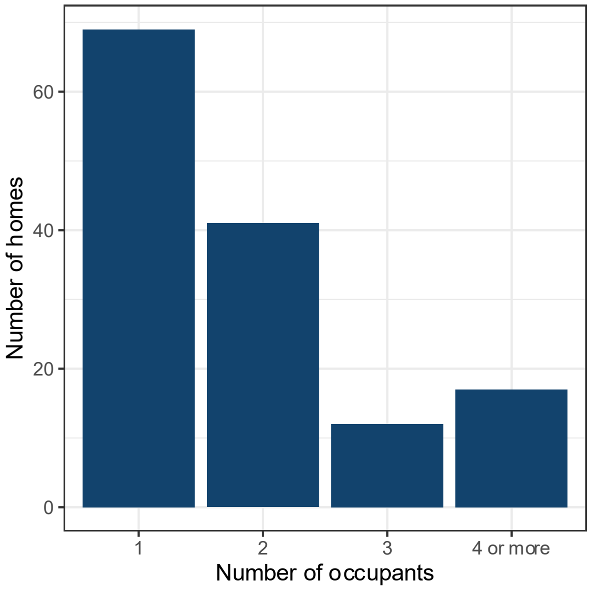
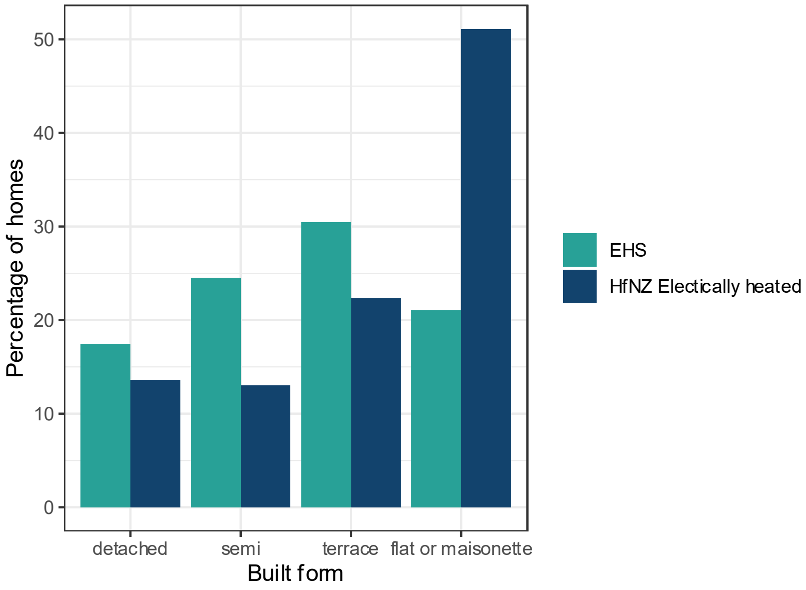


Figure 26: Distribution of built form in electrically heated homes compared with EHS 2023



2.5.2. Energy use in winter

Homes in the alternative electric heating trial connect their electricity smart meter upon joining allowing an assessment of the profile of their electricity use. The distribution of mean daily electricity consumption in January 2025 is shown in Figure 31 (January is

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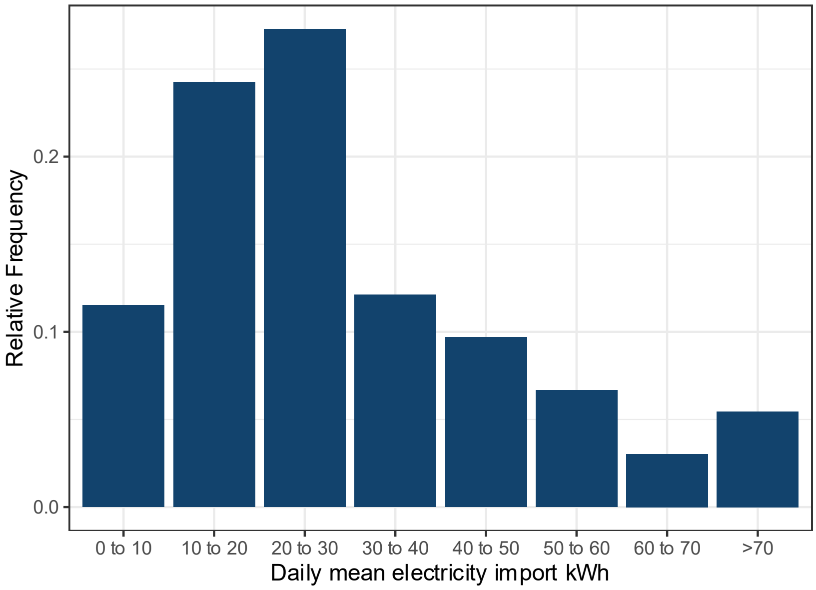
[21] https://www.gov.uk/government/statistics/english-housing-survey-2021-to-2022-energy/english-housing-survey-2021-to-2022-energy

chosen as the month with the highest heating energy demand and compatible with the results quoted in the first HfNZ report). The overall mean is about 10% higher (33.5kWh/day) for homes with storage heaters when compared to homes with other forms of electric heating (28.3kWh/day).

Figure 27: Distribution of daily energy consumption for January 2025 in HfNZ electrically heated homes (*N*=165)



2.5.3. Energy use when cooling

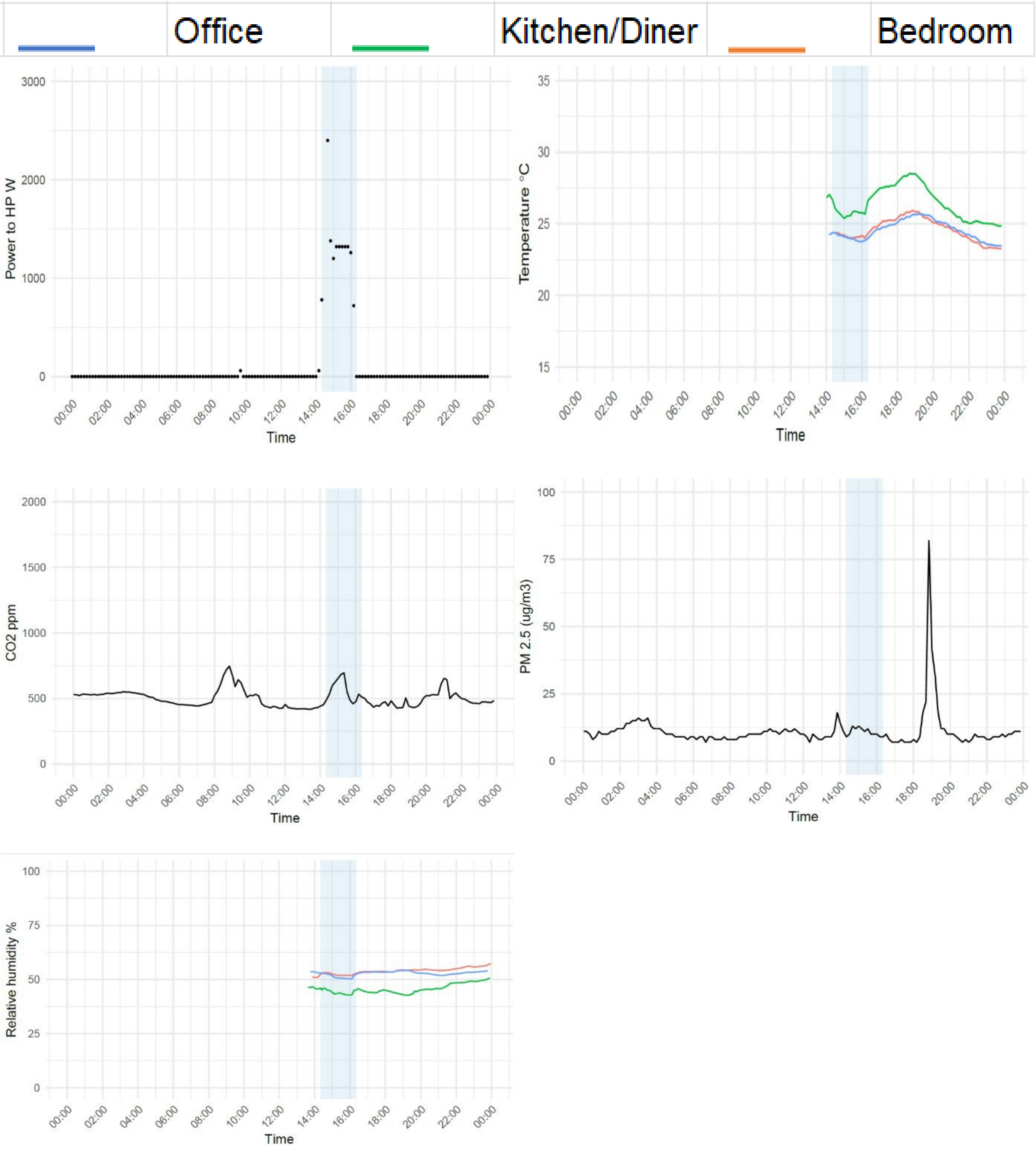
RAAHPs also provide cooling as well as heating. The purpose of this section is to begin to understand how householders use the cooling function provided by their RAAHP, and to understand the potential effect it may have on their comfort. Some installations were completed before or during the summer of 2025 allowing an initial assessment using case studies of energy used by households for cooling. Future reports - after summer 2026 - will enable a quantitative analysis of cooling energy use. Three homes are selected for use for case studies as they had a RAAHP installed for which submeter and temperature data showed cooling took place during August 2025. The case studies illustrate patterns of cooling operation, showing temperature (°C), relative humidity (%), CO_2 (parts-per-million) and PM2.5 (ug/m^3) from rooms in or adjacent to the room with the RAAHP, as well as power (W) to the RAAHP.

Case Study 1

In Case Study 1, the heat pump is a single split unit installed in the lounge. The rooms with tado° temperature and humidity sensors are identified as 'office'(blue trace), 'kitchen-diner' (green trace) and 'bedroom' (red trace). The sensor measuring particulates and CO_2 is in the bedroom. The building is a bungalow with an open plan living area.

On the single day that is used for the case study, the heat pump submeter registered 2.4kWh of electricity use out of a total daily import for the bungalow of 12.8 kWh. There is a clear drop in temperature in all three rooms when the heat pump is operating, particularly in the kitchen-diner where the temperature drops by around 2°C in under 60 mins just after 2pm. The PM2.5 readings are also shown; there is no visible impact of cooling on the particulate level, but there is a peak around 19:00 which could be associated with the cooking of an evening meal. CO_2 levels have three peaks during the day, including when cooling is being used, possibly indicating occupancy. Relative humidity measurements are unchanged during the cooling period. Figure 32 shows several plots for Case Study 1.

Figure 28: Power, temperature, CO_2, P.M 2.5 and relative humidity for Case study 1

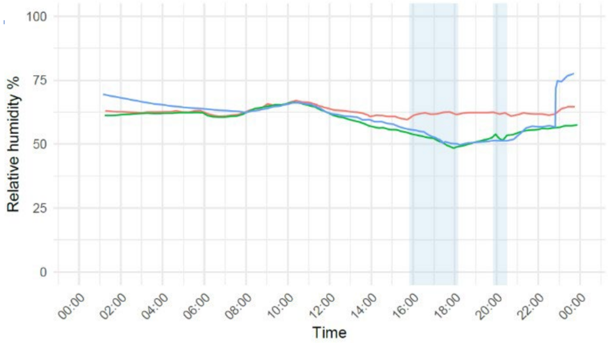


Case Study 2

In case study 2, the semi-detached house has a single split unit installed in the dining room. Tado° temperature and humidity sensors are identified as ‘family room’ (green trace), ‘kitchen’ (blue trace), and ‘corridor’ (red trace). The location of the IAQ sensor is not provided by the householders.

On the single day that is used for the case study, the heat pump submeter registered 1.7kWh of electricity use out of a total daily import for the house of 10.4kWh. There is a clear drop in the temperature in the family room (green line) by 2°C over the course of two hours, but not in the other two rooms. The rising CO_2 readings in the afternoon suggests occupied rooms with limited ventilation, possibly linked to windows being closed when the cooling started. There do not appear to be changes in relative humidity or particulate (PM2.5) level associated with the cooling periods. Figure 33 shows several plots for Case Study 2.

Figure 29: Power, temperature, CO_2, P.M 2.5 and relative humidity for Case study 2



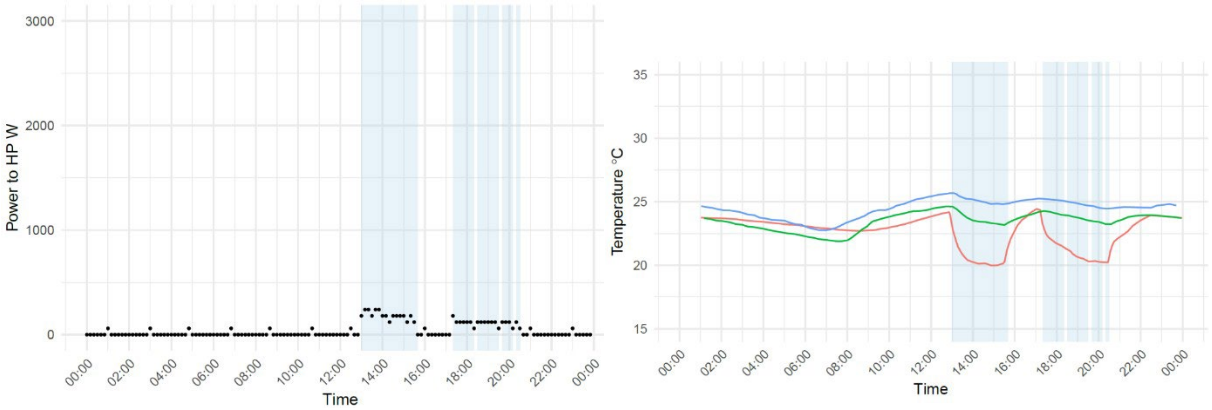
Case Study 3

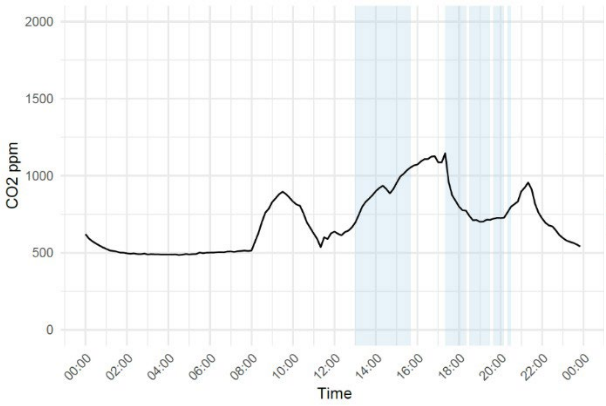
The third case study shows a mid-terrace house with single split unit to the lounge. The temperature sensors are in rooms described as office (red trace) lounge (blue trace), and bedroom (green trace). The indoor air quality sensor is located in the office.

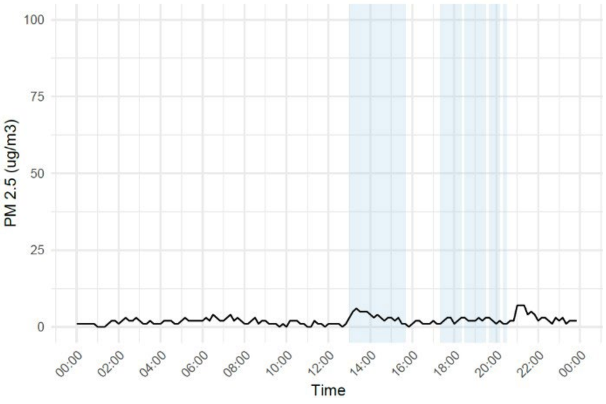
The total power in the day to the heat pump is 1.7kWh out of a daily total of 3.1kWh. The office shows a rapid drop of around 4°C when the heat pump is running, while the temperature drop in the other two rooms is slower. CO_2 peaks at over 1000ppm between 17:00 and 18:00. There are clearly changes over time in relative humidity, although it is not possible to relate these directly to heat pump operation and actions by occupants without more information on ventilation and occupancy. Figure 34 shows several plots for Case Study 3.

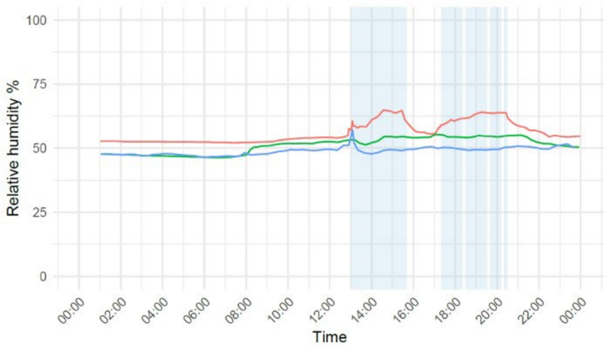
Figure 30: Power, temperature, CO_2, P.M 2.5 and relative humidity for Case study 3

🟦	Lounge	🟩	Bedroom	🟧	Office









2.5.4. Key findings and future plans

This section of the report has provided an insight into homes in the alternative electric heating trial, assessing their representativeness and providing an initial analysis using case studies of the use of RAAHPs for cooling.

The case studies show steep decreases in temperatures when the RAAHPs are used for cooling. This observation is clearly present in the room with the heat pump internal unit whereas other rooms appear to remain stable. It is hoped that the project will extend to cover another period of summer months, to allow for collection of more data on the performance of RAAHPs when used for cooling, and to provide greater insight into their effect on indoor air quality and occupant comfort.

2.6. Alternative electric heating trial - analysis of heat battery data

The following sections provide an analysis of data from homes in the alternative electric heating trial who have a heat battery. Fifty homes in the trial have a heat battery and are providing granular data on their use of the heat battery for space heating, and in some instances using the heat battery to provide hot water. The data used for assessments covers a full calendar year.

2.6.1. Heat battery home characteristics

All of the 50 participants in the trial provided information about their house type.

The two most common house types are 4-bedroom detached (28%), and 3-bedroom semi-detached (22%). Nearly half, 48% live in detached houses, and nearly a third (32%) live in semi-detached homes. Almost half (46%) of homes in the survey have 3 bedrooms, and 42% of homes have at least four bedrooms. On this basis, homes in the trial tend to be bigger than typical homes[22] in England or Wales.

2.6.2. Costs analysis

Operating costs are a key factor in assessing heating technologies. In this section the ZEB's heating costs, based on usage data from 50 homes provided by tepeo are quantified. The trial started in December 2023, and this analysis uses data up until August 2025. Only operating costs are assessed; other costs, such as lifetime, capital, or maintenance, are not assessed.

Costs are compared with counterfactual costs for the same households using oil boilers, gas boilers, electric resistive heaters and heat pumps, and instances when ZEBs can be cost competitive to gas boilers are highlighted. The Catapult does not have information on which heating systems were used before the heat batteries were installed; the counterfactual costs are estimated based on the heat batteries' operational data. The key results are presented in plots where each dot represents a cost for a specific household in a specific month (e.g., household 43, October 2024) with months grouped into seasons and coloured as follows:

Table 5: Colours used to denote seasons and associated months

Months	Season	Colour
March, April, May	Spring	Light green
June, July, August	Summer	Orange
September, October, November	Autumn	Purple
December, January, February	Winter	Light blue
Annual	All	Dark blue

In addition to the dots themselves, the median for each category, as well as a box around the median which extends to the first and third quartile (i.e., "the middle 50%" of the data) is presented.

2.6.2.1. Method for calculating ZEBs operating costs

tepeo provided two sets of data sheets for each ZEB in the trial.

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[22] In England and Wales, about 40% of homes have 3-bedrooms, and 21% have at least 4 according to the - 2021 Census (https://www.ons.gov.uk/datasets/TS050/editions/2021/versions/4). In England, 17.4% are detached, and 24.5% are semi-detached, according to the English Housing Survey 2022/3 (https://www.gov.uk/government/statistics/annex-tables-for-english-housing-survey-headline-report-2022-to-2023).

- **5-min interval readings**: These readings are from various sensors inside the ZEB and are used to optimize its operation. The most important values for this analysis are:
    - Electricity consumption of the ZEB's heating elements
    - Heat output, determined by the flow rate and temperature difference between flow and return water
- **Monthly summary**: The ZEB stores aggregates for incoming and outgoing energy internally, which are reported for each month, together with the number of measurements successfully submitted.

The ZEB's monthly operating costs are computed by multiplying its electricity consumption by the electricity rate in each time slice and summing that value over all 5-min periods within that month.

When there are data missing because of a transmission problem, the sum of all 5-min period readings might not be identical to the total energy consumption in the monthly summary. In that case, the monthly operating costs are corrected by multiplying it by the ratio of these two values. The operating costs reported might differ from the costs consumers actually paid for the following reasons.

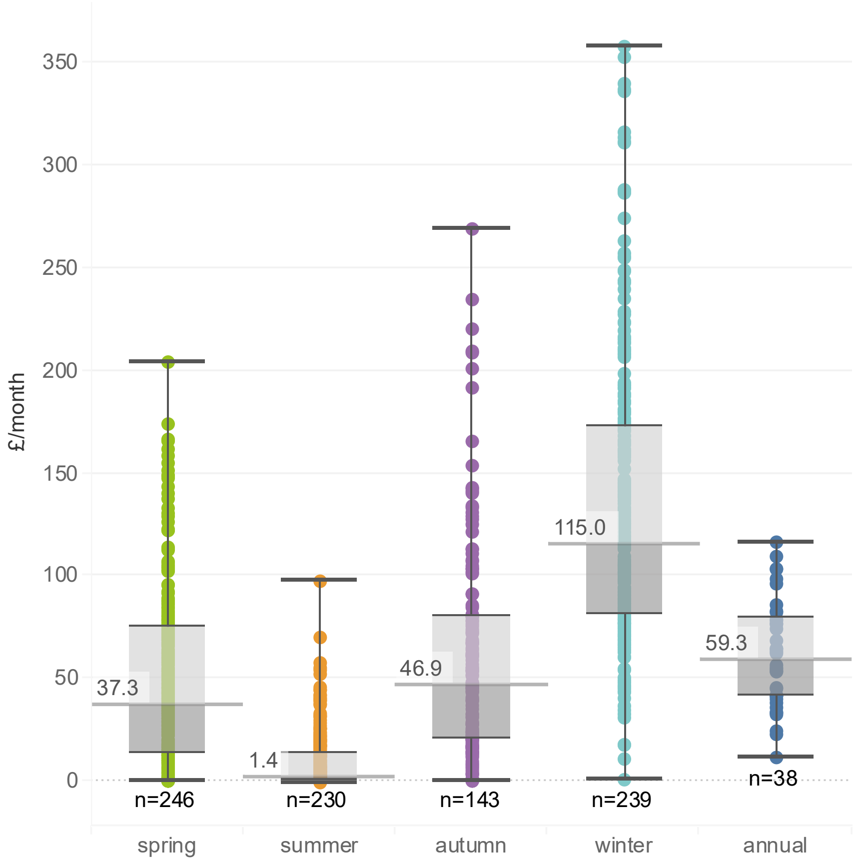
- **Additional hot water costs**: the ZEB unit is designed as a "heat only" boiler and so tepeo advises that it should be installed in combination with a hot water cylinder. Some consumers on the trial used the ZEB to heat their hot water cylinder, while others used a separate means to heat their hot water. To make costs of both groups comparable, we added costs based on typical hot water consumption for households. Details on how hot water costs were estimated can be found in Appendix 2.
- **Export vs import rates:** the electricity rate is assumed to be metered imported grid electricity based on the household's tariff (see 2.6.2.4 for assumptions around household tariffs). However, when the ZEB consumes electricity generated by a solar PV system, the effective cost of any self-consumed electricity is the supplier's export electricity price - representing the export revenue forgone by the household. Export rates vary by supplier but are always substantially lower than import rates.
- **Additional free/off-peak charging periods**: Octopus offers free or off-peak electricity periods that aren't reflected in the import rates. Customers are notified a few hours or days in advance, so they may use the boosting function during those windows. We do not, however, have data on exactly when this occurs.

In conclusion, the costs reported here are not always identical to the costs paid by the consumer. They are the costs a consumer would have paid for space heating, if they had used the ZEB for hot water, and if the electricity consumed by the ZEB were always charged at the supplier's import rate. To simplify the terminology, costs are referred to as the "ZEB's operating costs" nevertheless.

2.6.2.2. What are the costs of operating a ZEB?

Figure 35 shows the monthly operating cost for all ZEBs in the trial sample.

Figure 31: The ZEB's operating costs by season, showing median and inter-quartile range. "Annual" column shows average monthly costs based on overall annual values if 12 months of data are available.



The median annual cost to operate a ZEB is £711, or £59 per month on average.[23] The costs not only vary strongly by season, but also by household within the same season.

There are a few stark outliers. One consumer pays about £100 per month in the hottest months of the year. These excessive costs are caused by suboptimal operation of the ZEB. There are a few examples where ZEBs were charged in the summer but never discharged. The annual figures have fewer extreme outliers but a wide IQR. The top 25% of households with the highest cost pay at least £79 per month, while the bottom 25% pay no more than £41 per month.

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[23] Note that the yearly median differs from the sum of the monthly medians ((£37.3+£1.4+£46.9+£115)x3 equals £601.8, not £711) for two reasons: yearly values include only homes with data in every month, and the median of a sum generally does not equal the sum of medians.

2.6.2.3. In the median, ZEBs are slightly more expensive to run than gas boilers or heat pumps

The Catapult compared the operating costs of the ZEB system against counterfactual costs for the same households using electric resistive heaters, gas boilers, oil boilers, and heat pumps. To calculate the operating cost differences, we calculated how much consumers would have paid if they had used one of these alternative heating systems instead of the ZEB. We assume that the p/kWh for electricity used by heat pumps and electric resistive heaters is at the Ofgem price cap for the appropriate month of operation (recognising that the price cap changes quarterly, and the data analysed covers several quarters). The estimated operating costs of these electric heating technologies could potentially be lower if we assumed a time of use tariff, like Cosy, instead.

To determine the operating costs of counterfactual heating technologies, we assumed they would provide the same amount of “useful” heat as the ZEB. As in the interim presentation, we distinguish between the following accounting methods for determining useful heat:

- In the "heat generation" basis, the counterfactual heating technology is required to provide heat output corresponding to all the electrical energy that enters the ZEB. (i.e. this basis assumes that all the energy that enters the ZEB remains within the thermal envelope of the home and contributes to thermal comfort.)
- In the "heat delivery" basis, it is assumed that the heating technology is only required to provide the heat that the ZEB outputs and enters the heat distribution system (radiator circuit). The ZEB's heat output is measured as the flowrate times the temperature difference of outgoing and return water.

So, the counterfactual costs will always be higher using the "heat generation" basis. Which of the two accounting methods is more appropriate depends on where the ZEB is located. In fact, consumers reported that centrally located units contribute more to thermal comfort than those in enclosed or less central locations. The exact difference between the two methods depends on usage patterns and the alternative heating technology. It typically ranges from £10 per month for oil boilers to £43 per month for electric resistive heaters, as seen in Figure 36.

Figure 32: The operating costs of alternative heating technologies minus the ZEB's costs. Values are average monthly costs based on overall annual values.

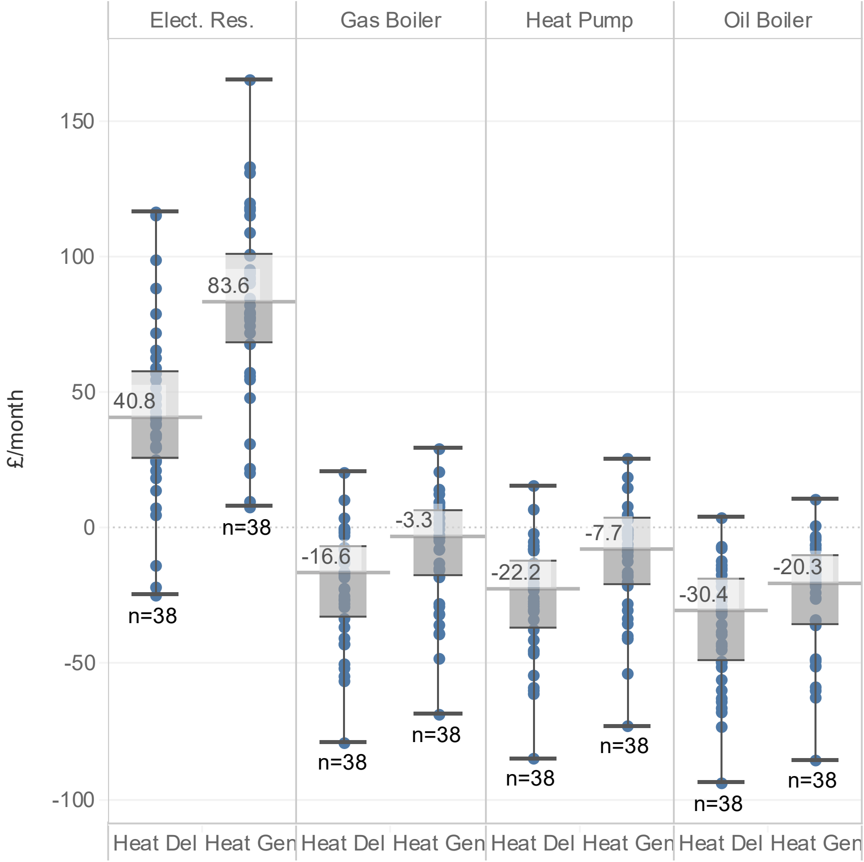


Figure 36 shows that the ZEB's ability to store heat makes it a much cheaper option to heat a home than electric resistive heaters, typically by between £40-83/month. It is no surprise that electric resistive heating is by far the most expensive heating technology. But it might be a surprise that oil boilers are cheaper than gas boilers. The reason is that heating oil has been consistently cheaper than gas since the start of this trial in winter 2023. Furthermore, we assume that consumers using a gas boiler would pay the gas standing charge of about £10 per month in addition to the per-kWh cost of gas.

The result is that oil boilers are also significantly cheaper to run than ZEBs, about £20-£30/month, depending on the accounting method. The ZEB is also more costly to run than heat pumps or gas boilers, but only slightly so in the heat generation accounting method. In that case, the ZEB is cheaper than a gas boiler in 39% of the months. To understand when ZEBs can be cost competitive to gas boilers, the most common alternative heating system in the UK, we look at the impact of the following variables on costs:

- Electricity Tariffs
- Seasons
- Whether the ZEB supplies hot water as well as space heating
- Whether households own a solar PV installation

2.6.2.4. Only EV-tariff consumers achieve gas-boiler like costs

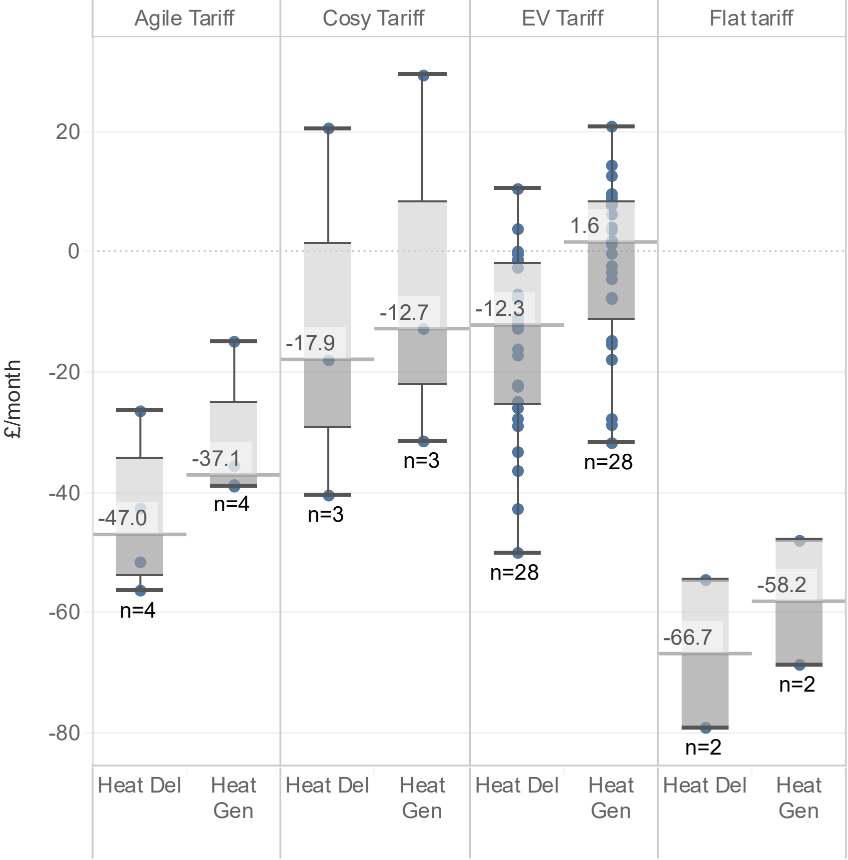
Many ZEB customers are on Time-of-Use electricity tariffs, where the price per kWh varies on a half-hourly basis. Different tariff structures exist, and in some cases may only be available to households that own a specific asset (e.g., an EV).

Tepeo provided the price per kWh for each 5-minute interval but not the type of electricity tariffs the consumers are on. We inferred the type of tariff from the timeseries data, out of the following 5 categories:

- Flat tariff: the electricity price is constant throughout the day.
- EV tariff: there is one peak period and one off-peak period, and the average between peak and off-peak rate is below 23 p/kWh.
- Other overnight tariff: there is one peak period and one off-peak period, and the average between peak and off-peak rate is at least 23 p/kWh.
- Cosy: there are at least 3 but fewer than 8 different price bands in the day, similar to the Octopus Cosy electric heating tariff.
- Agile: There are at least 8 different price bands in the day.

It turns out that many consumers changed their tariff type throughout the year. In Figure 37, each household is mapped to the most frequent tariff type within the 12 months.

Figure 33: The gas boiler's operating costs minus the ZEB's operating costs, based on overall annual values, split by tariff type.



There is no column for "other overnight tariff" in Figure 37, even though that was part of our classification. Interestingly, while some consumers were on such tariffs for a few months, they did not stay on it for most of the year. Instead, they all switched to different tariff types, usually an EV tariff.

As expected, consumers on flat electricity tariffs have the highest costs (i.e., the most negative difference between ZEB and gas boiler running costs). After all, there is no cost advantage of a heat battery over an instant electric heater without variability in costs.

In months where renewable generation is particularly high compared to demand, consumers on agile tariffs have the lowest costs. However, in the annual aggregate, their cost increment over gas boilers is the second highest.

The only consumer group that can achieve cost parity to gas boilers is the cohort on EV tariffs, because of the low overnight rate used to 'charge' the heat battery**.** The EV tariff is also the most popular option amongst consumers in the trial. There are only 2-4 consumers in each of the other tariff groups, which means those costs have a higher uncertainty.

If an EV tariff is not available, since such tariffs are normally restricted to those that own EVs, Cosy-type tariffs are the cheapest way to operate a ZEB, with a cost increment over gas boilers between £13-£18/month. Future tariffs and their effect on running costs are unknown at this stage but will play an important factor in any assessment of costs.

2.6.2.5. The cost increment over gas boilers is highest in winter

Figure 34: The gas boiler's operating costs minus the ZEB's operating costs, split by season. "Annual" column shows average monthly costs based on overall annual values if 12 months of data are available.

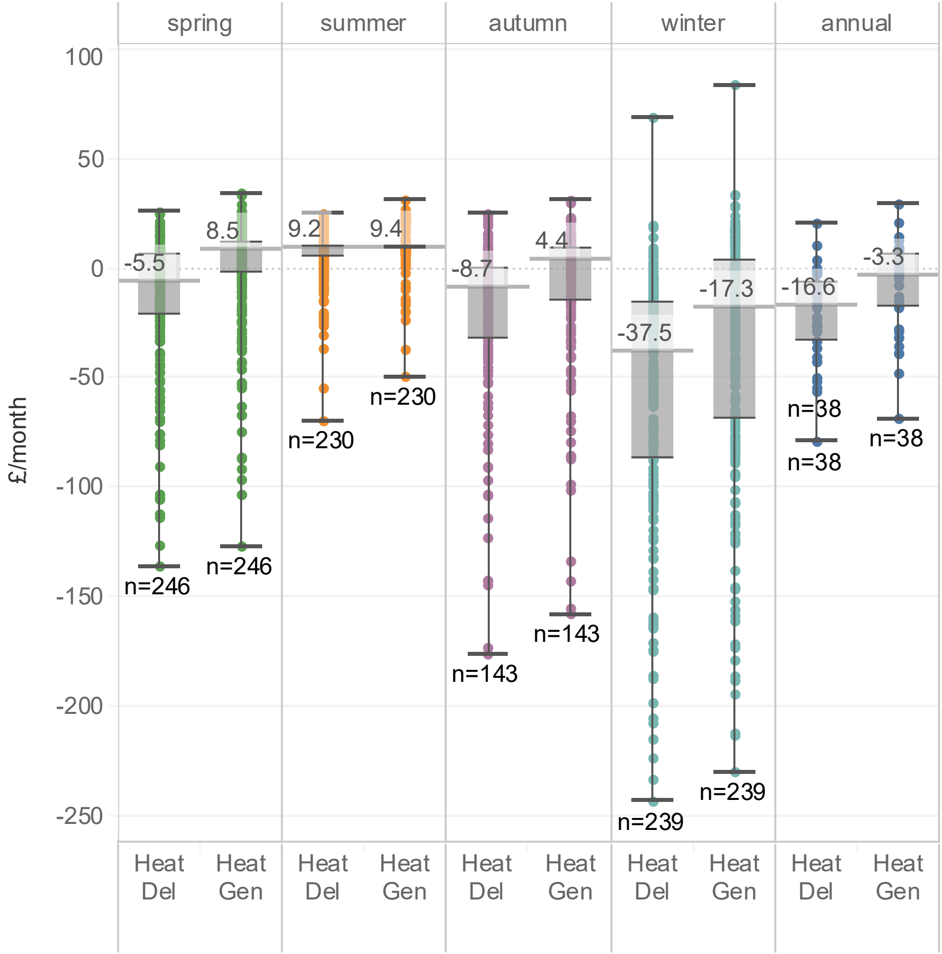


Figure 38 reveals that:

- In winter, gas boilers are cheaper to operate than ZEBs by about £17-£37/month:
- In spring and autumn, the costs of both heating technologies are comparable;
- Cost savings over gas boilers are modest at best, but cost increments over gas boilers can potentially be quite extreme (i.e. the downward tail of the distributions is relatively long). For example, in spring, autumn and winter, there are outliers with cost increments of more than £100, whereas the highest savings are always below £35 (except for one consumer on an agile tariff in one month in winter).
- In summer, the ZEB is typically cheaper to operate, thanks to low heat demand and avoiding the standing charge for a gas connection.

A key question is whether the high extra costs in winter are just a result of the high energy consumption. Looking at the ZEB's average price per kWh, that is its operating costs divided by its energy consumption, helps answer that question.

Figure 35: The ZEB's operating cost divided by electricity consumption, split by season. The annual value is the household's total annual cost divided by its total annual energy consumption.

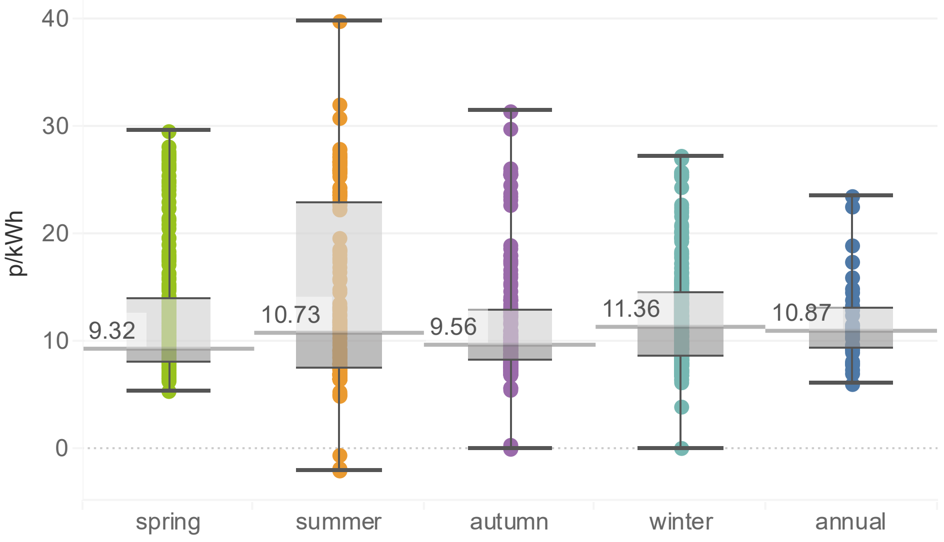


Figure 39 shows that consumers pay the highest price per kWh in winter months. A likely reason is that ZEBs need more boosting in winter, using peak-rate electricity. Indeed, boosting was mentioned to happen on cold days in the interviews (see 2.5.2).

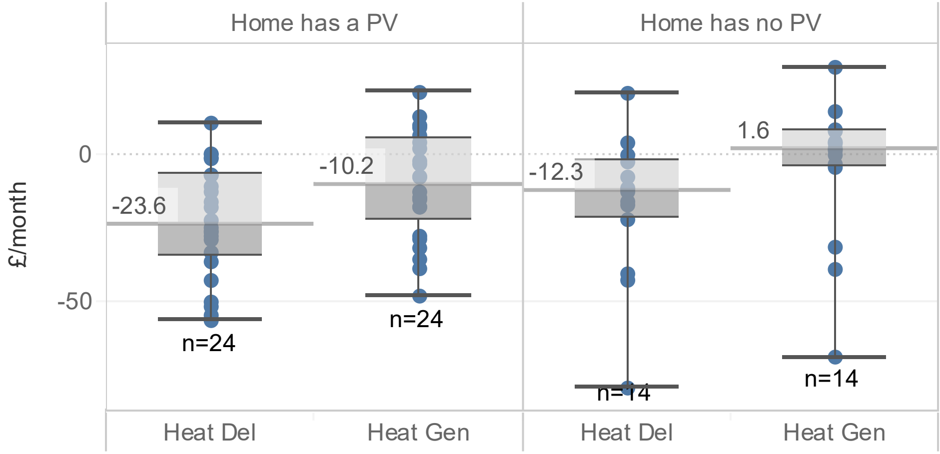
As the total energy consumption for heating in summer is very low, the spread of costs is the highest in that season. It is remarkable that there are two installations with minimal negative costs. This is not a computation error - both datapoints are associated with a consumer on an agile tariff who exploited negative electricity costs. The month with the highest cost per kWh is also in the summer. The corresponding householder owns a solar PV system.

2.6.2.6. Possible overestimate of ZEB costs for solar-PV consumers

As explained in section 2.5.1.1, the ZEBs operating costs are based on the electricity suppliers import rates. This leads to errors in the cost calculation when the ZEB consumes electricity generated by a solar PV system. While the ZEB does not have the feature to react to a solar PV system's output automatically, the consumers might do so by using the boost feature when the sun is shining.

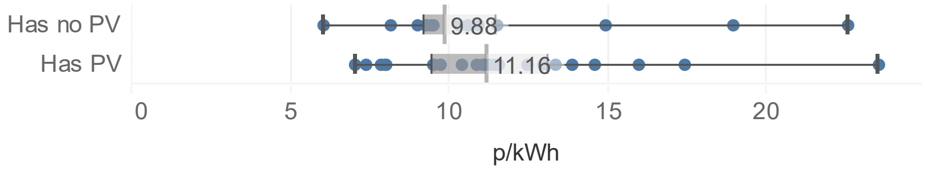
Figure 40 gives an indication that for households with solar PV systems we might be overestimating ZEB costs compared to gas boilers. From the 38 homes for which we have annual data, 24 own a solar PV system and typically have an increment of at least £10/month in reported costs over a gas boiler. Meanwhile, the remaining 14 homes without a PV come close to cost parity with gas boilers.

Figure 36: The gas boiler's operating costs minus the ZEB's operating costs, based on annual values and split by whether or not the household has a solar PV system installed.



Looking at the price per kWh in Figure 41 confirms that this difference is not just due to different heat demands. Reported prices per kWh for consumers with solar PV systems are 1.3p/kWh higher than those without a PV system. A likely reason is that PV self-consumption is priced at electricity import rates.

Figure 37: The ZEB's operating cost divided by its electricity consumption. Based on annual values and split by whether or not the household has a solar PV installed.

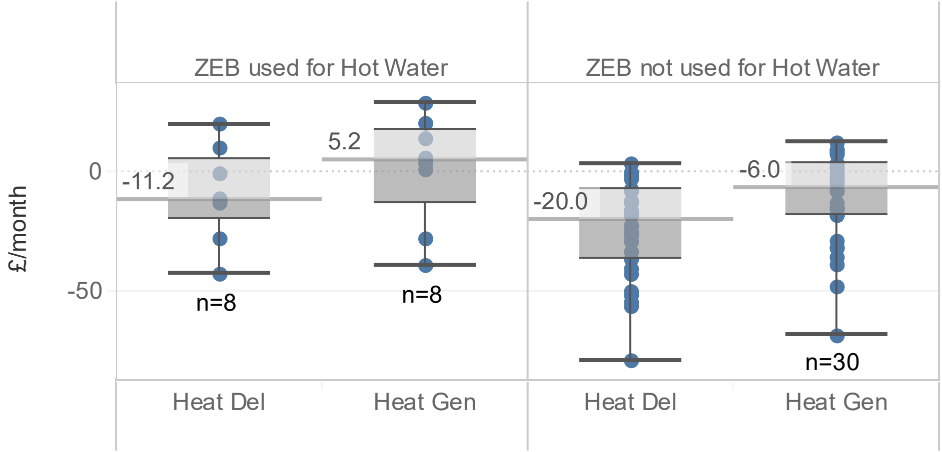


In the upcoming winter 2025/26 report, we will include an extra piece of analysis to estimate the energy that the ZEBs consume directly from the Solar PV system.

2.6.2.7. Hot Water provision doesn't affect average costs per kWh

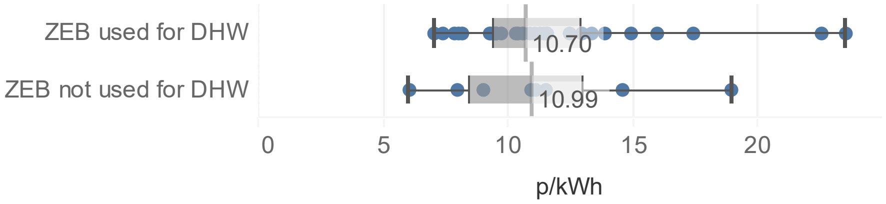
Using the ZEB for hot water adds to the total heat it must provide, raising the question whether this increases the need for boosting and with it the ZEB's running costs. Figure 42 shows that the opposite is the case: When a separate source is used for hot water, the ZEB is between £6-£20/month more expensive to run than a gas boiler. But, when the ZEB itself provides hot water, the costs become comparable.

Figure 38: The gas boiler's operating costs minus the ZEB's operating costs, based on annual values and split by whether or not the ZEB provides domestic hot water.



A likely reason is that homes where the ZEB provides hot water tend to be smaller and have lower heat demand. Indeed, in the per-kWh price there is no significant difference between both groups.

Figure 39: The ZEB's operating cost divided by electricity consumption, split by whether or not the ZEB provides domestic hot water.



2.6.2.8. Key findings and future plans

Based on historical energy unit prices from winter 2023, ZEBs are about £20-£30/month more expensive to run than oil boilers, which were the cheapest counterfactual heating technology analysed.

However, assuming that gas standing charges are avoided, ZEBs are only slightly more expensive to run than gas boilers, between £3 and £17 per month. The extra costs are highest in winter, when ZEBs are occasionally required to use peak-rate electricity for boosting. However, those consumers who have access to EV tariffs and place the ZEB centrally in the house have costs comparable to gas boilers. Any future changes made to electricity and/or gas prices that reduce the (more than[24]) 4:1 ratio may mean ZEBs become cheaper to run than gas and/or oil boilers.

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[24] Based on October 2025 Ofgem Price Cap figures (https://www.ofgem.gov.uk/information-consumers/energy-advice-households/energy-price-cap-explained)

As a result of limitations in the analysis possible, there are suggestions ZEBs' running costs are overestimated; these will be addressed in the next report.

2.6.3. Lived experiences with heat batteries

This section presents findings from surveys and in-depth interviews with participants who have a heat battery. This research explores the lived experience of households using heat batteries, with a focus on whether, and to what extent, they can provide a viable alternative to other heating systems such as gas boilers and heat pumps.

Two research questions guided this work:

- How effective are heat batteries at storing and discharging heat to meet household demand?
- What is the lived experience of residents using heat batteries in their homes? Do they deliver the required levels of comfort, and are they straightforward to operate and control?

The study explored several additional areas to provide a full understanding of household experiences:

- Which heating systems were replaced by heat batteries, and how to heat batteries compare in performance?
- What motivates households to install a heat battery?
- How disruptive is the installation process?
- How do heat batteries influence comfort in the home?
- To what extent is supplementary heating required in homes using heat batteries?
- How user friendly are heat battery systems?
- How does maintenance compare with previous systems in terms of ease and disruption?
- Overall, how satisfied are consumers with their heat batteries?

Both qualitative interviews and quantitative questionnaires were used to gather insights from participants. Thirteen participants took part in interviews. A purposive sample of households living in two- to five-bedroom homes (1 x two-bedrooms, 8 x three-bedrooms, 3 x four-bedrooms and 1 x five-bedrooms), most of which previously heated with gas (10 previously heated by gas, one by oil, one by log burner and one by a previous heat battery) were selected from the full cohort of trial participants. Forty-three trial participants responded to the survey.

2.6.4. Findings

2.6.4.1. Drivers of adoption: cost, space, timing — and the case for heat batteries

Participants were asked about their reasons for choosing to install a heat battery.

For many households, the choice of a heat battery came after looking into heat pumps and stepping back.. Several mentioned the high upfront cost of an ASHP, not just of the unit itself, but also of replacing radiators, upgrading pipework, or digging for ground source systems.

> *"I kept looking at heat pumps… the more I found out, the more complicated it became" (P2)*

> *"Air source looked expensive to run… friends removed one… and we didn't like the look of them." (P13)*

Some were also influenced by stories from friends and neighbours about disappointing performance or high running costs.

Heat batteries provided a good alternative for people who did not have space for outdoor units or ground works. Heat pumps were not an option in some homes because of space. In interviews, four participants stated said that limited outdoor space or unsuitable ground conditions made a battery the only practical choice.

> "*We went for the ZEB because we could install it inside the house.*" (P1)

> "Don't have a huge amount of outside space… heat pump would have to be mounted to a wall… not ideal." (P14)

Heat batteries offer a quick switch which appeals to people in urgent need of a new heating solution. In the survey, 24 of 43 households (56%) reported that their old heating system was more than 10 years old, and a further 10 households (23%) had systems between 5–10 years old.

Several households acted when their boiler was already failing, condemned, or simply old enough to worry about. For these users, switching was less about early adoption and more about seizing the opportunity to choose a lower-carbon alternative.

> *"My boiler was dying to death… it had been about a year of looking." (P3)*

> *"Boiler was installed 20+ years ago… we wanted to replace it as soon as possible"(P12).*

Ease of installation reinforced these decisions. Unlike heat pumps, which often required radiator changes or major re-plumbing, the ZEB could often be fitted as a “straight swap.” Homes with existing hot-water cylinders, microbore pipework, or site constraints also found the ZEB easier to integrate than alternatives.

> *“We already had a hot water cylinder… so it was easy.”(P4)*

> *“Zeb can go in the kitchen… no need to replace radiators.” (P5)*
> *The survey shows 4 in 5 rated installation disruption as “not at all” or “slightly disruptive.” Participants summed it up as a simpler, lower-cost swap compared with other low-carbon technologies.*

> *“Gas boiler out, heat battery in.” (P12)*

For some households, emissions reductions were central. In the survey, nine households (21%) said their main reason for adopting a heat battery was to help the environment. Interviewees described how they valued moving away from fossil fuels and embracing clean technologies.

> *“Desperately wanted a sustainable option… I’m very much for the planet.” (P5)*
> *“The green credentials… we wanted to move to a green energy heating system.” (P10)*

Cost was important— households looked for ways to save money on running costs and upfront installation.. In the survey, 17 of 43 respondents (40%) said reducing bills was their main reason for choosing a heat battery. Several interview participants (five of 13) said charging on off-peak tariffs made the system affordable.

> *“We’ve got two EVs… nighttime tariff… we’ve made savings.”(P6)*

Two participants mentioned linking the heat battery to solar generation, either now or in future, because this would let them use free electricity from their panels instead of buying from the grid. Two participants said they could only adopt because grants or trial schemes covered the upfront cost.

> *“Lloyds Banking Group had a competition… I actually won… I wouldn’t have been able to afford it.” (P9)*

Together, these examples highlight that while heat batteries appealed for environmental or practical reasons, cost remained the decisive factor. Some households looked to maximise savings through flexible tariffs and future solar, while others needed direct financial support to overcome upfront costs.

2.6.4.2. Installation experience: fast, low-disruption, boiler-like

Installation of heat batteries was described by 80% of survey respondents as “not at all” or only “slightly” disruptive. Interviews explored their installation experience further, and found that it was simpler and faster and comparable to previous experiences of replacing their gas boiler.

The installation felt easy because the system was designed to work with what participants already had. The indoor-only placement and compatibility with existing cylinders meant there was little need for major changes, making the process straightforward. As one participant explained:

> *“It fitted in with our existing pipework”. (P7)*

Some also highlighted the professionalism of installers, describing the work as tidy and well managed. A 4-bed, detached, gas household reflected:

> *“Installers were great – very tidy, explained everything.” (P9)*

Some compared it to a boiler install. One described it as:

> *“Just the same as putting in a new boiler,”*

While another reflected that it was:

> “*Not much more inconvenient than a standard boiler replacement.”*

Planning and timing reduced disruption. Households who scheduled their installation outside the heating season or alongside other renovation works described it as almost seamless.

> *“We timed it for summer, so even when the hot water was off for a bit, it didn’t really affect us.” (P8)*

> *“It was no inconvenience at all—we already had planned trades on site.” (P14)*

Minor system adjustments were manageable. Over half of the interviewees required small electrical or plumbing changes as part of their installation, but these were seen as routine rather than disruptive. The most common adjustments included running a dedicated cable from the heat battery, upgrading a fuse, or re-routing sections of pipework. Importantly, participants emphasised that these tasks were handled quickly and folded into the normal installation process, so they did not feel like major obstacles.

> *“They had to run a heavy-duty cable during the install, but it was done quickly and didn’t really get in the way.” (P7)*

> *“They drilled the cable straight from the garage to the unit—it was straightforward.” (P8)*

> *“We upgraded the fuse and added extra pipework to future-proof the connection.” (P5)*

2.6.4.3. Living with a heat battery

Participants were also asked about their experience of living with a heat battery in terms of how well it provided comfort. In particular, interviews explored the reasons why participants still used additional heating alongside their heat batteries, as revealed in the survey. Interviews explored more about the heating experience of people in larger homes who reported slightly less satisfaction with their heating than others in the survey.

Nearly all (91%) of homeowners reported enjoying comfortable warmth throughout their homes, and more (93%) said they could access comfort on demand. Importantly, while a small minority had previously reported “never feeling warm,” after installation no participants experienced this level of discomfort. These findings were reinforced in interviews, where households consistently described the system as delivering steady warmth and reliability:

> *“The house has felt warmer since we had the Zeb." (P1)*

> *"We were warm when we needed to be. No extra heating was needed anywhere in the house." (P6)*

Location of the heat battery significantly affected comfort. Centrally located units — in kitchens, hallways, or under-stairs cupboards — gave off steady background heat that spread into adjacent rooms and, in some cases, replaced the need for a radiator.

> *“I just leave the kitchen open, and it warms the front of the house with the sun and the heater.” (P12)*

> *“You walk in and it hits you as warm — it’s perfect there. It saves having a radiator in the hallway.” (P6)*

By contrast, when batteries were enclosed or positioned in less central locations, households said that some of this benefit was lost. Many compensated by opening cupboard doors or adding vents to distribute the heat.

> *“We open the cupboard door to let the heat out… Otherwise a lot of it probably goes into the thermal mass of the cupboard.” (P5)*

> “I leave the door open and there’s a reasonable heat that comes out. I’ll probably add more vent holes to make use of it.” (P10)

Half of survey respondents said the heat battery improved comfort specifically because of its ambient warmth, with many highlighting benefits such as drying clothes indoors or removing radiators in utility spaces.

Larger and multi-storey homes sometimes experienced uneven heat distribution. Tepeo’s marketing position presents heat batteries as most suitable for small to medium-sized homes rather than large, multi-storey properties. The survey found that satisfaction with heating was not always as high among homeowners in larger properties, particularly in four-bedroom houses. Some participants in larger homes noted that warmth was not always evenly spread and some rooms heated up more slowly or felt cooler than others. To manage this, households used radiator zoning or relied on residual heat from centrally placed batteries. While most interviewees did not see this as a major issue, they acknowledged it as a limitation to be aware of. One owner of a four-bedroom property explained:

> *"It's a three-storey house… the battery's in a stair cupboard in the core of the home. The heat spreads into the walls and helps warm the house."*
>
> *"It struggled a little during extended cold periods." (detached house)*

2.6.4.4. Heat demand from secondary sources

Of those surveyed, 63% reported they used extra heating alongside heat batteries during the winter. The living room was the most common room where extra heating was used. Half of those who used extra devices said they used a wood stove. However, most of those interviewed stated that the heat battery kept them warn enough without needing supplementary heating, and where devices such as wood burners were recorded they were typically used for ambience rather than comfort.

> *"There was never any time that I thought, 'Oh, I need to get another heater. I don't use any extra heaters in other rooms." (P1)*
>
> *"No, I didn't feel cold at all… no need for additional heating."(P4)*
>
> *"No extra heating sources were needed anywhere in the house."(P8)*
>
> *"We still use oil-filled radiators during the day to avoid running the central heating… It's easier to just heat one room." (P6)*
>
> *"We used the log burner occasionally for ambience, not necessity" (P10)*

2.6.4.5. Comparisons to the previous heating system

Reliability and peace of mind were improved with the heat battery — especially in homes with prior system failures. Knowing the system wouldn't break down (especially in winter), and didn't need frequent repairs, led to greater confidence in home heating:

> *"The boiler was worse — it was on its way out. The new system is much better." (P2)*
> *"The old one would break down every year… sometimes we waited three weeks for a fix in November. Now we feel we can rely on it." (P11)*

With smart radiator valves, custom schedules, and zoning, some users achieved more targeted and efficient heating than they had with older gas systems. This was particularly helpful for homes with variable schedules or multiple occupants.

> *“We heat different parts of the house at different times — kitchen at 4pm, lounge at 6pm, bedrooms at 9pm.” (P9)*

A fifth of survey respondents reported that environmental reasons were their main motivation for adopting the heat battery. In interviews, some spoke about cleaner air, reduced pollution, and the satisfaction of moving away from fossil fuels:

> *“I don’t think there is any difference apart from the feeling that you’re not polluting the atmosphere.” (P3, replacing gas fired heating system)*
> *“The environmental impact … I can’t state how important it was to get rid of the fumes… then you literally could go outside and smell and taste it. Was so [nice] not to have that..” (P7, replacing oil fired heating system)(*

In comparison to their previous heating, a few were actually less happy with the heat they got from their heat battery. This concern was concentrated in larger or multi-storey properties, where the 40-kWh unit could be fully used before the end of the day during very cold weather. Participants in these homes said they would prefer a higher-capacity model (or an additional unit).

An owner of a 3-bedroom detached house stated:

> *“I wish the heat battery came in different sizes… in a bigger house, you might need two.”*

The owner of the 4-bedroom detached house stated:

> *“There are moments when it’s 8:00 pm, we still need heat, and it’s nearly depleted. That’s when I have to decide whether to boost or wait.”*

Some interviewees noted that gas boilers required less hands-on management. In contrast, the battery sometimes required checking charge levels, adjusting schedules, or using the boost. This again was more something participants in larger homes commented on.

> *“It does the job, but I have to manage it more than with the traditional boiler… With gas, it was ‘set and forget.’ Now I have to check it and maybe top it up.”(P12, 4-bedroom home)*
> *“You do have to work quite hard to make it work for you… to keep the price down. I’ve maybe become borderline obsessive.” (P11, 4-bedroom home)*

One interviewee highlighted the contrast between the quick, on-demand heat provided by gas boilers and the slower, less immediate experience of alternatives such as heat batteries.

> *“No question — the gas was better in terms of immediacy. Instantaneous heat. You turn it on, and you get it. The heat battery isn’t quite the same.”(P9)*

2.6.4.6. Charging routines and everyday use: the lived experience of operating a heat battery

Survey results showed that 94% of respondents reported the system was straightforward to use. Once initial configuration was complete — often with support from installers — most households said they rarely needed to adjust settings again. Several people noted the heat battery app is easy to navigate for setting charge limits and times:

> *"I've got the tepeo app — it's straightforward."(P6)*
> *"Literally fractions of seconds to do custom changes." (P13)*
>
> *"I set the controls up on my wife's phone… Once it's been set up, it's straightforward." (P7)*

Many reported that their battery charges overnight, typically between 11:30pm and 5:30am, aligning with off-peak tariffs like Octopus Go, Cosy, or other custom night-time schedules. A few occasionally charged during the day when free electricity was available:

> *"We always charge overnight on off-peak. If it runs out on a cold day, we boost — but aim to get back to 0% before midnight for 100% off-peak charging." (P5)*
>
> *"We used to be on Octopus Go — that's purely off-peak at night. We charged overnight unless it was exceptionally cold." (P12)*

Some valued being able to tailor their heat battery settings — such as setting charge percentages, managing schedules, or adjusting to weather and routine changes.

> *"I've chosen to do it manually… I tell it to charge 100% rather than use their automatic probably AI-type of thing… I think I can do a good enough job of it." (P1)*
>
> *"I made my own custom schedule."(P13)*
>
> *"Because I've got it on manual charging rather than automatic, I have to manage it more now… but that gives me more control over how and when it runs." (P14)*

While some users liked manual control, others valued automation. They appreciated that the heat battery could operate quietly in the background, charging automatically during off-peak times and heating the home without frequent input. For these users, the goal was convenience, minimal fuss, and consistent warmth — without needing to check apps or change settings often.

> *"It doesn't involve much… I just let it get on with it. I might tweak it occasionally, but it only takes a few seconds." (P8)*

> *"It's very seamless. Once I put the charge settings in the Tepio app, it just does it all itself." (P6)*

A small number – particularly larger homes facing extended cold spells- reported that the heat battery could run out before the evening. In these cases, households often relied on the boost function to top up, which sometimes meant paying peak electricity prices. This was described as occasional rather than routine, but it highlighted how limitations in capacity could create additional costs in winter. The owner of a 4-bed, mid-terrace said:

> *"On the coldest days we will run out. So, I use a half-hour boost and keep an eye — if it's still cold, we just leave it and let it do 100% off-peak."*

The owner of a 3-bedroom detached house stated*:*

> "*On a cold day, I'll run the heating early and then boost after to get an extra cycle in."*

Others boost tactically— either to take advantage of cheap tariffs or in response to specific life events and unusual circumstances. A few use it tactically to align with low or free electricity periods, manually watching the clock, battery level, or tariff windows.

> *"I boost because I know the best tariff times and plan around them." (P2)*

> *"If I spot a cheap period in the evening or morning, I'll shove the boost on for half an hour — just in case." (P4)*

Others boost reactively when unusual situations arise — such as accommodating guests, coping with construction, or maintaining comfort during life stages like caring for a baby.

> *"When we had a baby, we needed to keep the house warmer 24/7 — we tried to avoid peak charging by holding a 5% buffer." (P9)*

> *"We've boosted when my mum visits — she likes it warmer. We don't use apps — just boost when we need it." (P10)*

In the survey, 80% reported that servicing was straightforward. During the trial, participants were enrolled on a maintenance plan at no cost; outside the trial, many paid around £10 per month for an equivalent plan. In both cases, engineers proactively responded to minor alerts or faults, often before users noticed an issue.

Interviewees said the system required very little day-to-day maintenance. Unlike gas or oil boilers, there are no combustion components or filters to manage, and routine interaction is minimal.

> *"There's no maintenance, really… They come out and do a few tests and off you go." (P2)*

> *“They have been quite proactive if they’ve noticed any alerts. Sometimes they call or send a text to check.” (P13)*

> *“tepeo noticed a sensor wasn’t working and came to fix it without any involvement from me. I didn’t even notice it.” (P14)*

Some users had minor issues (e.g., heating cores or sensors), but these were resolved quickly under the maintenance agreement — often with same-day or next-day visits.

> *“Two heating cores stopped working in the first two winters… but they came and replaced them quickly under the service plan.” (P6)*

2.6.4.7. Comparisons to the previous heating system

In the survey, 94% of respondents said the heat battery was straightforward to use. Interviews reinforced this, with participants highlighting that app-based control, remote access, and clear visibility of energy use made the system more convenient and flexible than their previous heating setup.

For many households, day-to-day operation of the heating system felt familiar because the controls for warmth inside the home did not change. Thermostats and radiator valves continued to work in the same way as with their previous gas or oil systems, meaning that users could adjust room temperatures in the same manner they always had. This integration meant that learning to operate the new system was largely focused on scheduling the heat battery to charge, rather than re-learning how to heat the home. As a result, households often described the transition as smooth, with the ZEB slotting into existing routines rather than requiring entirely new behaviours.

> *“Heat battery run on room thermostats, the same ones that were there before… I can change the temperature of 1 radiator with just a touch of the finger.” (P3)*

> *“There is no change… thermostats are the same… only difference is scheduling the Zeb to charge.”(P4)*

Being able to adjust heating or charging settings remotely (e.g., while away or from a different room) was a noticeable improvement over traditional boiler setups for some users. As one participant put it:

> *“If I’m away, my sister will be in the house… she’ll say, ‘can you do this?’ and I can do it for her. It’s amazing.” (P7)*

Compared to their older gas or oil systems — which many interviewees told us often just had basic manual timers or wall thermostats — the heat battery setup allows them to see real-time energy levels, adjust charge cycles, and monitor performance remotely. This was appreciated by those interviewed who enjoy control over their system or want more transparency over energy use.

> *"It gives you that option [to be more involved], which is helpful." (P7)*
>
> *"With the Zeb… you have got the extra of setting up the charge cycles, which you didn't have before… I like to have control over that bit." (P11)*

Annual servicing is included in a care plan and is typically preventative rather than reactive. The ZEB's design was seen as simpler and more reliable, providing reassurance during winter.

> *"Maintaining it is a lot easier than maintaining a gas boiler… they come out to service it every year as part of the care plan, but it really is just an inspection." (P5)*
> *"It just works… compared to a gas boiler where you're checking pilot lights or things like that." (P12)*

2.6.4.8. Space Heating vs hot water: where heat batteries are most used

Those interviewed feel that systems like immersion heaters, solar thermal setups, or thermodynamic panels provide faster, more direct, or more cost-effective hot water, especially for their household size or usage pattern. In contrast, the heat battery is sometimes viewed as inefficient or unnecessary for water heating.

> *"I have thermodynamic hot water… 24/7 water all the time. The immersion heater is immersed in the tank… there's no way the heat battery can be as efficient.". (P13)*
>
> *"For most of the summer, the hot water is heated from the sun by the solar thermal system… I spent about 80p on hot water last month." (P10)*

Some felt that, with gas boilers, having hot water when you needed it was much simpler - they did not need to manage off-peak electricity or plan charging windows. For some, this simplicity is missed, even if they value the environmental or cost benefits of newer systems. As one explained:

> "With gas you don't have peak and off-peak — you just use more gas if needed… If it's daytime and you run out of hot water, you're paying peak electricity with the Zeb." (P7)
>
> "The Zeb doesn't provide hot water… the gas boiler used to heat the hot water tank directly." (P9)

2.6.4.9. Real-World Costs

Costs mattered greatly in shaping household experiences with the heat battery. Upfront installation was usually straightforward, with most households avoiding major extra expenses unless they opted for upgrades such as new cylinders or smart controls.

Day-to-day running costs were more variable. Some households saw bills fall when they shifted charging to cheaper night-time rates, while others reported higher costs when peak-time boosts or hot water demand stretched the system. Others found it difficult to isolate the battery's effect on bills because other changes — from new tariffs and solar panels to fluctuating wholesale prices — blurred the picture.

Installation costs

Most households did not face significant 'extra' costs for installation (as may be required when installing an ASHP, for example radiator and pipework upgrades), aside from optional upgrades they chose themselves. Common add-ons — such as running a larger electricity supply cable, upgrading a fuse, or re-routing short sections of pipe — were handled quickly and usually included in the job or timed with other works, so they did not add significant cost. Moving the unit to a different spot could increase costs, but this was a user choice.

> *"Fuse upgrade needed… added pipework during home renovation to make final connection easier." (P1)*

> *"We chose to move the unit, which added more pipework. But it was our choice." (P2)*

When the existing hot water cylinder was suitable, households avoided the large expense of buying and fitting a new tank — often a four-figure item including labour. As one noted:

> *"No hot water cylinder was installed — I already had one. So, no extra costs."*

By contrast, households that upgraded or replaced a cylinder saw their installation costs rise, sometimes by over £1,000. One explained:

> *"I replaced mine with a Mixergy tank… cost over £1,000 — a choice, not a necessity." (P6)*

> *"Included a new Mixergy hot water cylinder in the £10,000 install cost." (13)*

Some people bought a single, "all-in" package that covered the kit and the install. Others bought the battery and then paid an installer separately. A small number got theirs through a free trial or promotion. In all cases, the pricing was transparent.

> *"Package price… no unexpected cost." (P4)*

> *"Paid fixed price. Installation was not included". (P7)*

Day to day running costs

Seventeen out of 43 households (40%) said that a hope for “lower bills” was a key reason they adopted a heat battery. Households who shifted most charging into off-peak windows often kept bills steady or lower, while costs rose when frequent peak-time boosts or hot water demand were added. Many also found it difficult to separate the impact of the battery from other changes, such as new tariffs, solar panels, or wider shifts in energy prices.

Running costs depended on charging patterns. Costs tended to fall or stay steady when households fully shifted most charging to off-peak.

> *“Our off-peak rate is 8 or 9 pence a unit… that brings our overall electricity cost down as well.” (P1)*
>
> *“I think our bills are less because of the efficiency… and the EV tariff gives us cheaper peak and off-peak rates." (P11)*

As already noted, costs tended to rise when peak-time boosts were frequent or when the battery also heated hot water. Interviewees told us that sometimes they had to boost at expensive times either later in the day or during the cold snaps.

Sometimes it was hard to attribute bill changes to the heat battery alone because households made multiple changes. Households often adopted the Zeb alongside other shifts—new time-of-use tariffs, added PV or a house battery, smart radiator valves, or insulation upgrades—while wholesale prices and standing charges moved in the background. Winters also varied in severity, and several people changed comfort targets, so demand wasn’t constant.

On top of that, bills typically show whole-home electricity, not a clean breakdown for the heat battery, and export credits from solar can net off consumption in ways that mask the Zeb’s share. Finally, early months involved a learning curve (tweaking charge limits, switching smart/ manual modes), so “before vs after” periods weren’t like-for-like. As one participant put it:

> *“Very hard to compare because energy prices have changed so much.”*
>
> *“Other changes going on at the same time… so I cannot tell you the difference in numbers.” (P7)*

2.6.4.10. Barriers to adoption

As already noted, for some households, the first hurdles were affordability and upfront costs could have put heat batteries out of reach for some without the support they received. Others struggled with the practicalities of siting.

Some participants received a heat battery through a grant or trial. The financial assistance made the heat battery a realistic option when otherwise it would not have been affordable.

> *"The battery itself was supplied and installed for free. Otherwise, the cost is the biggest hindrance… if the ZEB could be part of the Boiler Upgrade Scheme… people could effectively get it for free." (P8)*

Finding a suitable location can be challenging for some households. Units generally require ground-level, load-bearing floor space and clear access for delivery and installation.

> *"It takes up quite a bit of indoor space… we had to put it in a garage" (P6)*

> *"It weighs so much it can't go upstairs… would break the floorboards." (P4)*

2.6.4.11. Key findings

This section summarises the key takeaways from the latest interview and survey findings with participants with heat batteries.

- Heat batteries served as a practical alternative when heat pumps felt too costly, complex, or space constrained. Some households considered heat pumps but stepped back due to radiator upgrades, pipework changes, or outdoor unit requirements. An indoor, boiler-like install made heat batteries a credible option at boiler end-of-life.
- Heat battery installation was fast and low-disruption for most households. Most installs completed in 1–2 days and were rated "not at all" or "slightly" disruptive. Minor works such as heavier-duty cabling, fuse upgrades, short pipe reroutes were routine and often folded into the job.
- Heat battery comfort outcomes were generally strong, especially in small–medium homes. After installation, 91% of households reported being always or mostly warm enough. Comfort was reported most consistently in small to medium-sized homes, while some larger or multi-storey properties ran short of heat during cold spells.
- Heat battery placement in a central location improved comfort in Winter. Siting in hallways, kitchens, or under-stairs cupboards provided ambient warmth to adjacent rooms, whereas enclosed or peripheral locations (e.g., garages, sealed cupboards) reduced this benefit.
- Supplementary heaters were seldom required for comfort. Interviewees typically did not need extra heat; where used (e.g., log burners), it was usually for ambience or targeted daytime warmth in a single room.
- Operating heat batteries felt familiar and simple for most users. 94% of respondents said the system was easy to operate. Existing thermostats and TRVs still worked as before, and the only new task—scheduling charging—was easy to do in the app.
- Charging routines centred on off-peak periods, with tactical boosts used by some. Overnight charging on time-of-use tariffs was standard. Some households used short boosts during cold spells or specific circumstances (guests, works, care needs), with preferences split between manual control and automation.

- Domestic hot water was often kept separate from the heat battery. Many households used separate hot-water solutions—such as immersion heaters, smart cylinders, or solar thermal—because they were simpler to run and easier to control costs.
- Running costs were influenced more by how the system was set up and operated than by the heat battery itself. Installation costs were generally higher than an equivalent gas boiler installation, and higher still if households opted for upgrades (e.g., new cylinders or smart controls). Heat battery running costs tended to fall or remain stable when households removed the gas standing charge and shifted most charging to off-peak periods. Costs tended to rise when peak-time boosts were frequent or when the battery was also used to heat domestic hot water. Attributing bill changes to the battery alone was often difficult because other changes occurred at the same time (e.g., tariffs, solar PV/home batteries, insulation improvements, energy prices, and weather). A few participants in larger (4 bedroom) homes, did comment that keeping costs down required manual effort to charge batteries enough whilst avoiding peak electricity charges.
- Servicing was straightforward and proactive for most participants. 80% of the surveyed reported straightforward servicing. Maintenance plans enabled remote alerts and proactive fixes. The absence of combustion and fewer moving parts reduced routine maintenance.
- For some households, affordability and siting/access were the main barriers they had to overcome before adoption. Upfront cost could have put systems out of reach without grants or trials. Besides the costs, the units require ground-level, load-bearing space and clear access, so smaller homes sometimes placed them in garages or peripheral rooms.

2.7. Heat pump readiness

This section reports additional analysis of data from core project homes over the winter of 2024 – 2025. The focus is on the homes that received the MOT (maintenance check of boiler and heating system with improvements and adjustments to optimise efficiency while retaining original boiler controls) and MOT+ (same as MOT but with radiators changed to larger emitters) interventions. All homes that had a MOT/MOT+ had a heat meter fitted to the boiler space heating circuit on the flow pipe. The heat meters provide data for flow temperature and volume; the flow temperature data was used to infer the flow temperature set at the boiler controller, and to investigate any changes over time. The aim of the analysis was to explore whether the householders maintained the flow temperature set at during the MOT/MOT+. If the set point is changed after the MOT/MOT+, it may suggest the householders were not happy with the heat being delivered by their radiators.

2.7.1. Concerns when assessing inferred boiler flow setpoint temperature

A number of considerations are described relating to analysing flow meter data and inferring set point:

- The flow temperature as measured by the heat meter is very ‘noisy’ and shows considerable variation. Subsequently, the flow temperature was inferred by calculating the 95th percentile of the distribution of flow temperatures on a particular day and therefore may not accurately reflect the actual setting.
- Both interventions did not involve the fitting of new boiler controls. Existing controls were used to set the flow temperature to an appropriate, low value. Often this is done by turning a dial that does not show flow temperatures in degrees Celsius but instead has values 1 (lower flow temperature) to 5 (higher flow temperature). Some boilers may have weather compensation or other smart controls operational, in which case the original installation settings may have been changed as a result of the control algorithm, not because of householder behaviours. HfNZ is a multi-year project, and it is therefore possible that an annual boiler service may have led to the flow temperature being reset at some point after the MOT/MOT+ intervention.
- The flow temperature may not settle at the desired setpoint. For example, in late March -when temperatures are warmer - the case studies show shorter space heating periods not allowing for the flow temperature to reach or ‘settle’ at a consistent value. If, for example, the heating only runs for a short time in the morning and not at all in the evening, the 95th percentile temperature may not accurately reflect the flow temperature setting.
- The first temperature reading from the flow meter may be some time after the date of the MOT/MOT+ intervention, so this should not be interpreted as the temperature setpoint at the time of the intervention.

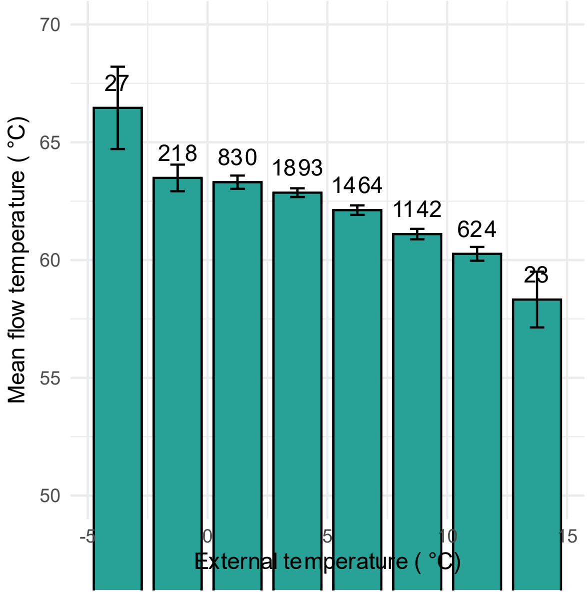
The MOT+ intervention included replacement of radiators with larger emitters designed to provide the same amount of heat as the removed radiators but at lower flow temperatures. This is an intervention that may be required to support the transition to air source heat pumps, that work most efficiently at lower flow temperatures and therefore may require larger radiators to maintain comfort. Table 6 shows that the mean inferred flow temperature set point in the MOT+ homes was lower than in MOT homes, that did not have changes to emitters. Maximum flow temperatures for both intervention groups were much higher than would be desirable for efficient heat pump operation.

Table 6: Statistics for inferred flow temperatures winter 2024-25

Measure	Number of homes	Mean inferred flow temperature setpoint (°C)	Maximum inferred flow temperature setpoint (°C)
MOT	49	65.3	85.7
MOT+	23	57.3	79.4

Figure 44 shows the results for inferred temperature by external temperature, with external temperature shown in columns of 2.5°C. The mean flow temperature is typically higher at lower external temperature, although error bars often overlap indicating no statistically significant difference. Differences suggest weather compensation control or occupant action to increase flow temperature when the weather is colder.

Figure 40: Variation in inferred boiler flow set temperature with external temperature (N for each bin labelled). Error bars at +/- standard error of the mean.



- Visual inspection of trends for individual homes do not show clear indications of points when the flow temperature increased or decreased in reaction to changes to the external temperature. Four plots are shown to indicate the variety of patterns of inferred temperature in different homes, with some changes to setpoints: Figure 45 shows an MOT home where the initial flow temperature was below 60°C but increased in mid-January to about 80°C and remained at this level for the rest of the heating season.
- Figure 46 shows an MOT home where the flow temperature appears to have been reduced in late February, possible related to warming external temperatures
- Figure 47 shows an MOT+ home with an increase in flow temperature from about 50°C to around 60°C in late December.
- Figure 48 shows an MOT home with several changes to flow temperature, including an increase in January and a drop at the start of February.

Figure 41: Case study 1 Inferred flow temperature setpoint over time in MOT home A

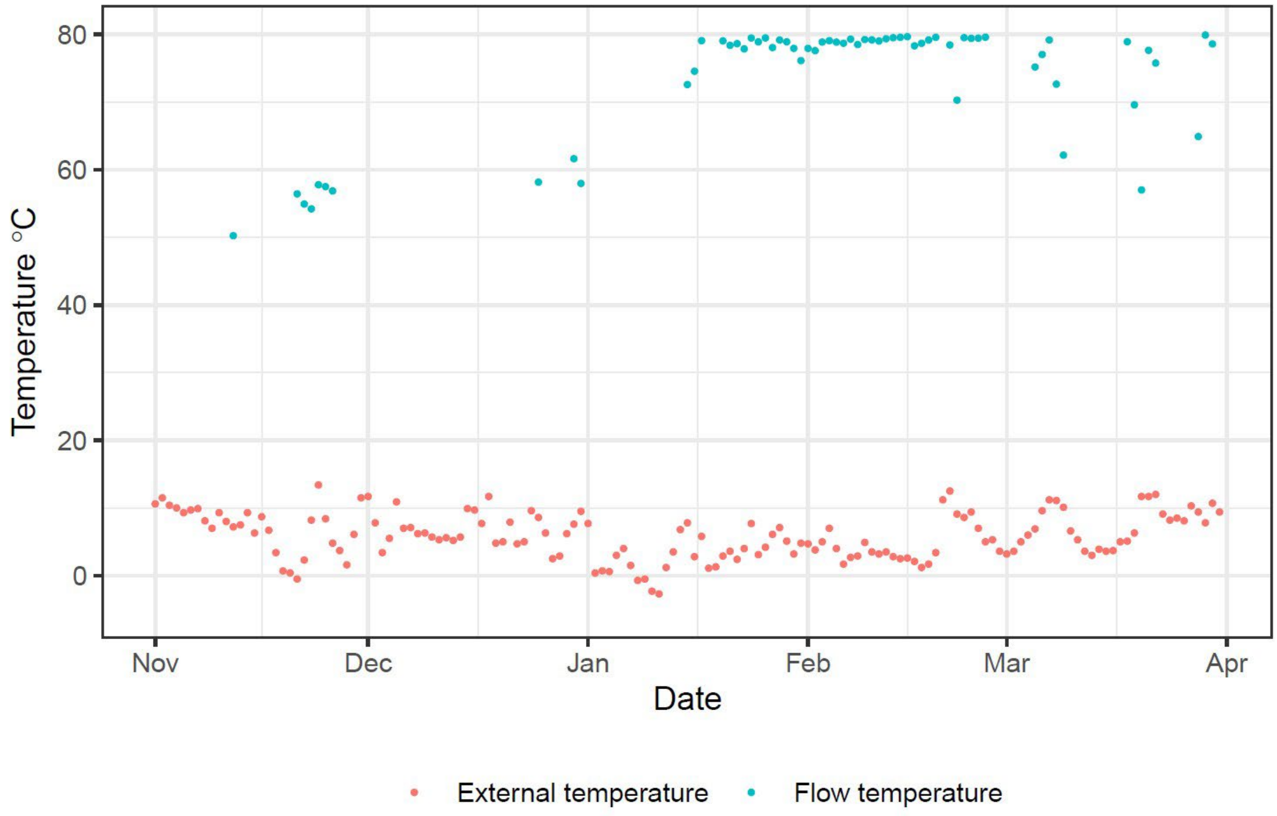


Figure 42: Case study 2 Inferred flow temperature setpoint over time in MOT home B

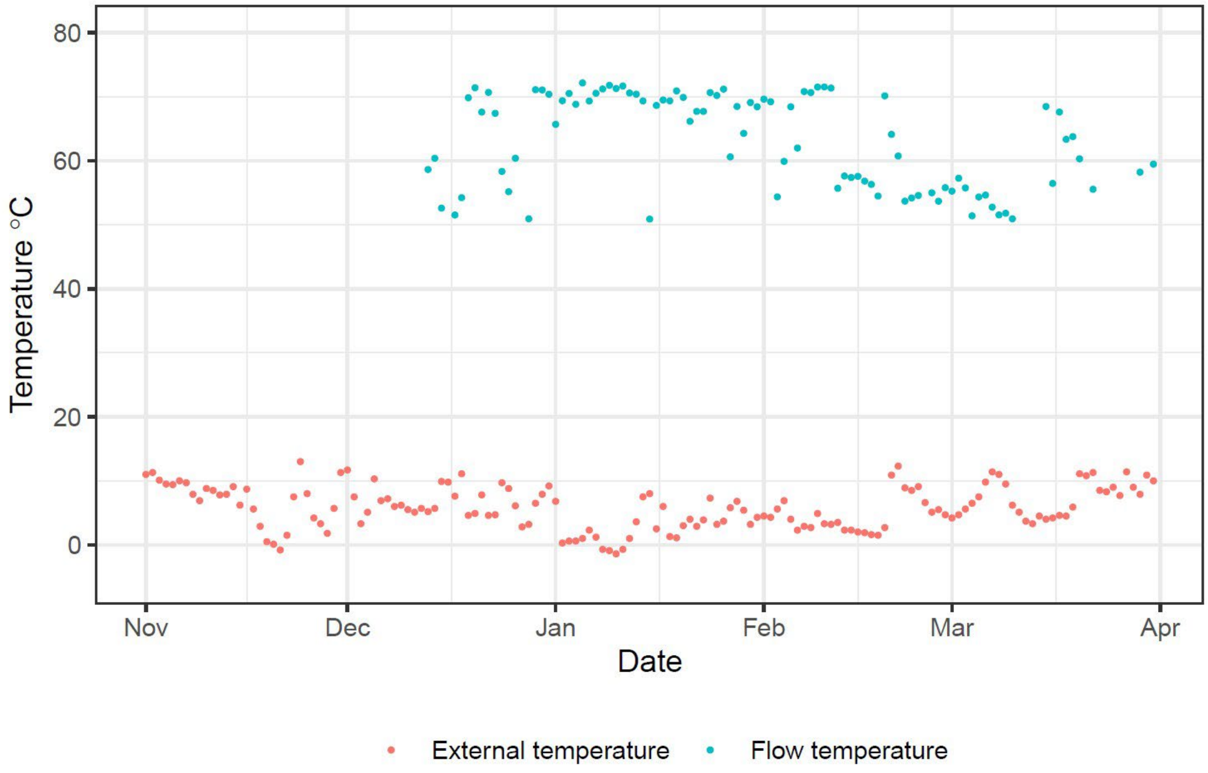


Figure 43: Inferred flow temperature setpoint over time in MOT+ home C

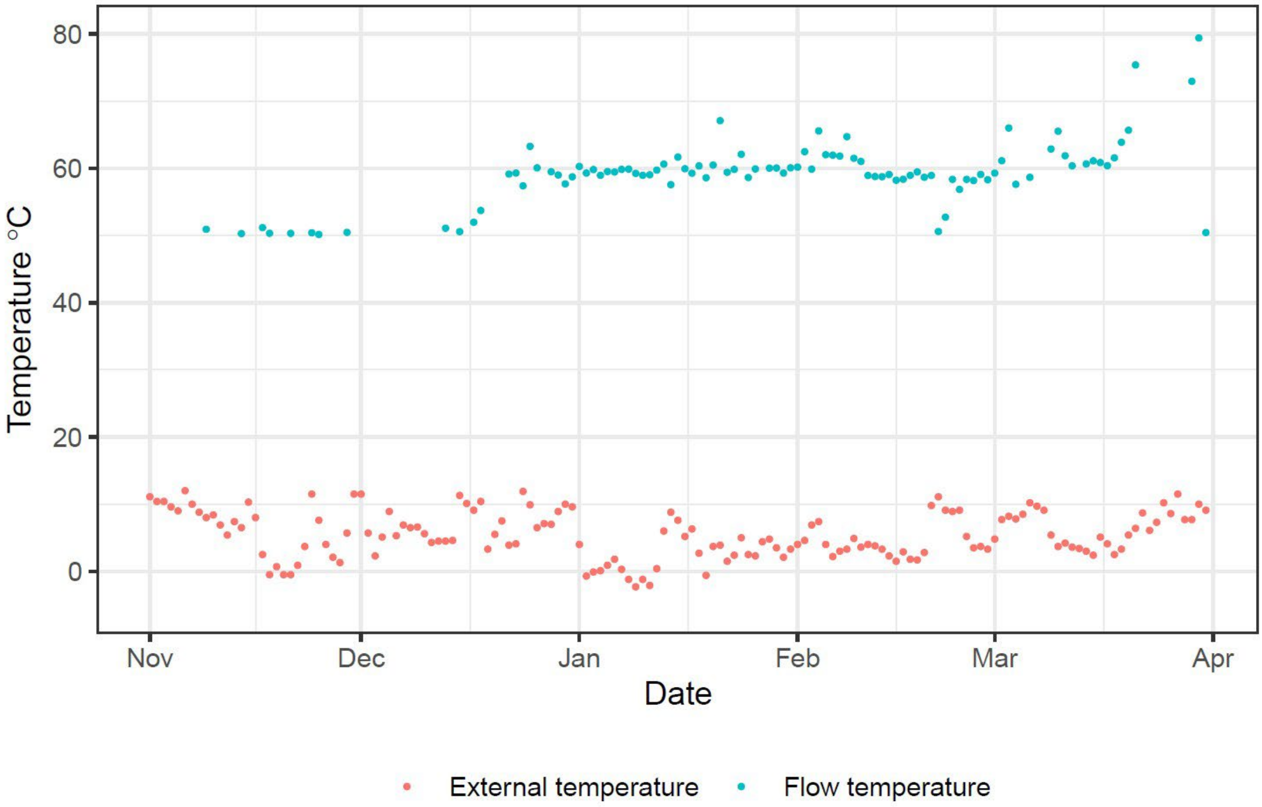
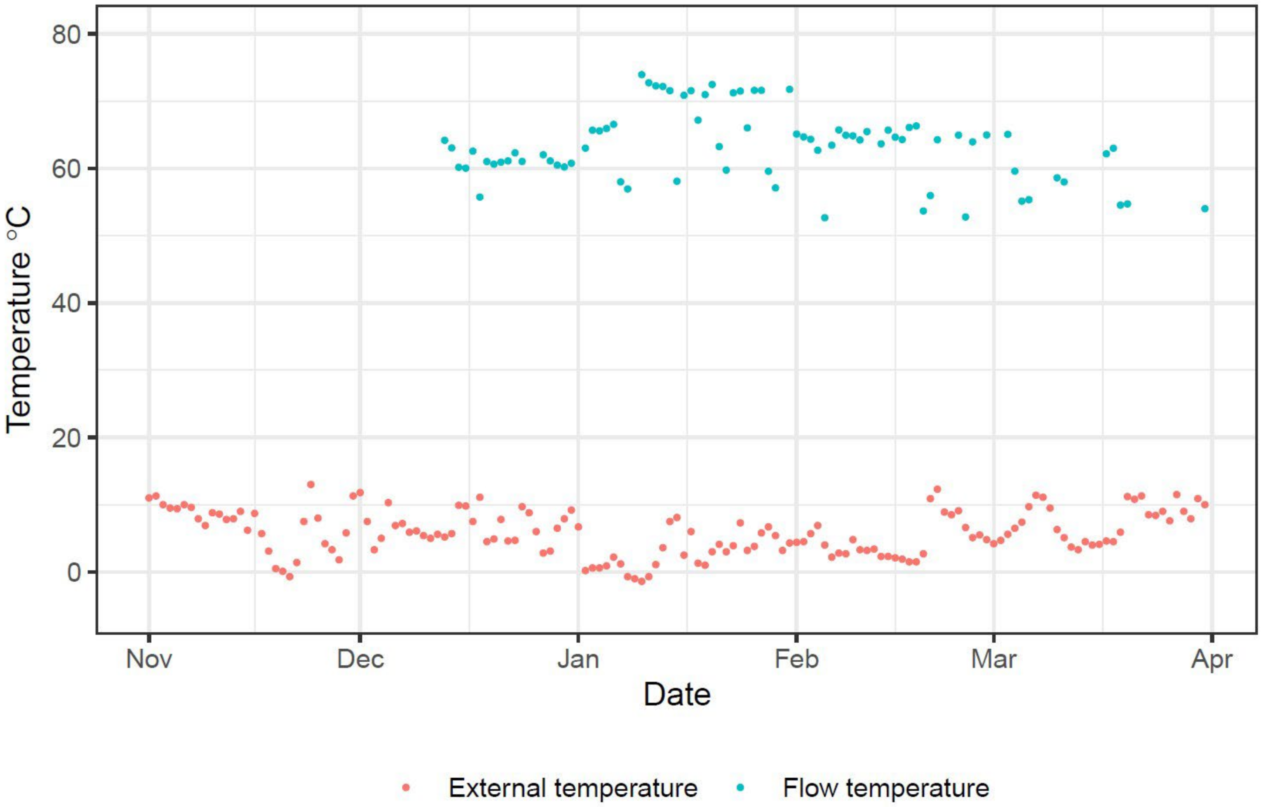


Figure 44: Inferred flow temperature setpoint over time in MOT home D



2.7.2. Key findings and future plans

This section has provided an analysis of ‘heat pump readiness’ inferred from an assessment of boiler flow temperatures. While the mean flow temperatures reported for both MOT and MOT+ homes provide encouragement that homes in the trial that had these measures are more likely to be considered ‘heat pump ready’, the maximum flow temperatures suggest more work may be required. The analysis presented here will be repeated in the next report using data from the winter of 2025/26. It will be interesting to see whether flow temperatures have remained in line with the findings presented here or not, given the longer time since intervention and therefore increased likelihood of settings being altered, either by householders or annual servicing and maintenance engineers.

2.8. Indoor Air Quality

The assessment of indoor air quality (IAQ) in HfNZ encompasses deployment to approximately 500 UK dwellings, each of which is instrumented with a single Lascar WEM+ monitor for indoor air quality (IAQ) parameters, alongside three Tado° sensors for temperature and relative humidity monitoring. This scale of deployment is an important step in developing a substantial evidence base for characterising indoor air quality in UK homes. The monitored properties are predominantly solid walled with gas heating (~400 homes), complemented by ~100 electrically heated properties of which ~30 will undergo installation of a RAAHP. Of the 194 P1 homes with IAQ measurement that answered the April survey 42% have gas hobs, 11% have a wood burner used a few or more than a few times a week and 18% have a wood burner used less frequently.

The IAQ monitors have been distributed to trial participants, who have self-installed them and reported the location of the monitor in the dwelling to HfNZ. This means that some dwellings have monitors in the kitchens, others will have monitors in living rooms, offices, or bedrooms and these samples do not overlap.

This analysis presents indoor air quality measurements collected using the Lascar Easylog WEM+ monitors. Prior to presenting the substantive findings, it is essential to characterise the performance and limitations of the sensors deployed, because understanding measurement uncertainty is critical for appropriate interpretation of the results.

2.8.1. Introduction to HfNZ IAQ measurement

2.8.1.1. Monitor accuracy

The Lascar data sheet[25] specifies the measurement range, precision, and accuracy for several of the parameters. Through calibration exercises and comparison with reference instruments, we have established that certain pollutant measurements are more reliable than others. This section details the sensor characteristics, assessment procedures, and data cleaning approaches applied, and aims to contextualise the ‘in home’ data.

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[25] IAQ Lascar technical specification

Assessment of the monitors was performed through two approaches. First, co-location of the five monitors with a reference grade instrument; a Palas Fidas 200[26] (which covered a subset of the Lascar measurands) at UCL, and second on evaluating the degree of consensus between five monitors, both at UCL and under normal domestic occupancy conditions. This consensus-based approach provided insights into measurement variability and reliability, which informed the data cleaning protocols. However, given the small number of monitors assessed, no drift corrections, offset adjustments, or other mathematical corrections have been applied to the in-home monitoring data. This is because the drift and offset characteristics are not identical for all monitors, and by applying these corrections there is a risk of implying a greater accuracy than possible. Furthermore, it is possible that the inter sensor performance may not be consistent throughout the deployment period. All values presented therefore represent raw sensor outputs after quality control cleaning only, which is viewed to be a conservative but the most transparent approach.

Final measures of consensus between the sensors, for the period 7th August 2025 to 10th September 2025 under normal occupancy conditions are provided in Table 7. The sensors were co-located on a low table in a living room corner and were left undisturbed and plugged in for the full monitoring period. Note that these statistics are calculated on data which has had the final cleaning procedure applied; hence, these statistics are intended to provide an insight as to the behaviour of the monitors installed in occupants' homes.

In home and calibration data cleaning involved the following actions:

- Removal of clearly erroneous values (loggers near to radiators for example)
- Down sampling PMs to 20 minutes
- Sensor faults (oscillating between maximum and minimum values)
- Interpolation of missing data for gaps of less than one day

Statistics have been calculated using the median at each time point as a measure of the "consensus value", and the data for key variables is summarised in Table 7. The median Coefficient of Variation (CV) describes typical relative disagreement between the five sensors, calculated as the standard deviation divided by the mean at each timestep. Lower CV values indicate better sensor agreement. The 95th percentile range indicates the maximum typical disagreement between sensors (in other words, 95% of the time sensors agreed within this range). Range stability measures whether the level of disagreement between sensors stayed constant over time (low values) or fluctuated significantly (high values), with high values suggesting sensor drift or concentration dependent performance. Finally, any home with more than a day of missing data was excluded from the sample.

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[26] https://www.palas.de/en/product/fidas200

Table 7: Consensus between IAQ sensors

Measurand	Median CV	95th percentile range	Coverage (%)	Range Stability
Temperature (°C)	1.04%	±0.45°C	100	0.14°C
Relative Humidity (%RH)	2.34%	±2.0% RH	100	0.61%
Particulates: (PM_{10}) (µg/m^3)	26.23%	±2.7 µg/m^3	100	7.81 µg/m^3
Particulates: ($PM_{2.5}$) (µg/m^3)	26.21%	±2.3 µg/m^3	100	6.79 µg/m^3
Particulates: ($PM_{1.0}$) (µg/m^3)	35.60%	±1.9 µg/m^3	100	5.57 µg/m^3
Carbon Dioxide (ppm)	2.00%	±75 ppm	100	53.2 ppm

The assessment revealed a clear distinction in sensor performance between measurements. Temperature, relative humidity, and CO_2 sensors demonstrated the precision and stability expected of consumer environmental monitors, with inter-sensor variability below 3% and consistent performance over time. Particulate matter sensors showed high variability (26-36%CV) coupled with temporal instability, indicating that both the magnitude and consistency of measurements varied between individual sensors. This combination of high variability and instability indicates that sensor-specific drift or concentration dependent performance characteristics preclude the application of simple offset corrections to improve accuracy.

However, although the level of disagreement between the particulate matter sensors is higher than would be ideal, this is not completely outside expected performance for this class of sensor, and it is still of value to include results with appropriate caveats. For example, in lab experiments the Alphasense OPC-N3 and Plantower PMS5003 and PMS6003 were found to have coefficients of variation (for particle size) of 19.5 % for 2 µm to 34.2 % for 10 µm (Kaur and Kelly (2023)[27], reported in Sharma et al., 2025[28]).

It should also be noted that although the sensors are located in an occupied dwelling (living room) during this co-location experiment, the ventilation conditions may be atypical, which would mean that PM concentrations may not exhibit such large peaks as they might under different occupancy conditions, and may be on the whole less variable that might otherwise be expected. This low variability in background concentration means that the CV might be inflated due to the low signal to noise ratio. However, readers should interpret

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[27] Kaur, K. and Kelly, K.E. (2023) 'Laboratory evaluation of the Alphasense OPC-N3, and the Plantower PMS5003 and PMS6003 sensors', Journal of Aerosol Science, 171, 106181. https://doi.org/10.1016/j.jaerosci.2023.106181

[28] Sharma, R., Razakamanantsoa, A., Kumar, A., Thajudeen, T. and Jullien, A. (2025) 'Performance and applicability of low-cost PM sensors to assess global pollution variability through machine learning techniques', Atmospheric Environment: X, 26, 100331. Available at: https://doi.org/10.1016/j.aeaoa.2025.100331

absolute values with caution and instead focus on the temporal pattern of peaks and relative comparisons between spaces.

Although the Lascar sensors are capable of measuring temperature and relative humidity, both have been monitored already in HfNZ for longer periods using tado° sensors, and so analysis of Lascar captured temperature and relative humidity data is not provided.

2.8.1.2. Note on VOCs

VOC measurements have been excluded from this analysis. The Lascar EL-WEM+ monitors utilize a metal-oxide (MOX) sensor that is calibrated for breath VOCs - a subset of biogenic VOCs - rather than the volatile organic compounds typically of interest in indoor air quality assessments, such as those emitted from cleaning products, air fresheners, and other household sources. Consequently, these measurements cannot be compared to regulatory standards (e.g., Building Regulations Part F) which reference total VOCs (TVOC) from different compound sources. The sensor's response is primarily indicative of occupancy and ventilation rather than exposure to potentially harmful VOCs. Assessment during co-location revealed additional concerns including sensor saturation, strong cross-sensitivities to humidity and temperature, and poor inter-sensor agreement. Although these issues are not atypical for sensors of this type, given these limitations, including these data as "VOC measurements" would risk misrepresenting the nature of volatile organic compound exposure in the study homes and would not address the study objectives regarding common household VOC sources.

2.8.1.3. Note on Statistical Disclosure Control (SDC)

Protecting participant data is of utmost importance, and rigorous SDC procedures have been applied to all data in order to ensure that no individual participant data point is released. This requires that all statistics are calculated for a minimum of five data points. For example, sample medians and percentiles are calculated as the mean of the nearest five rather than the true median or percentile, which could relate to an individual dwelling.

2.8.2. Aggregated data analysis

Table 8 describes aggregated data across all available sensors and room types that have passed initial data quality checks. While this provides a very high-level overview, it is important to note that the more disaggregated, room specific, analyses presented in subsequent sections offers substantial interpretive advantages for indoor air quality analysis and therefore enable much stronger and more policy relevant insights.

Each dwelling is monitored by a single sensor, which may be located in any room type (for example kitchens, living rooms, bedrooms, hallways, home offices, or others). Many sensor locations are unlabelled, and the distribution of room types within the sample is therefore unknown. This means that the aggregated sample may over or underrepresent certain rooms and related occupant activities.

Table 8: Aggregated data across all sensors, for both seasons[29]

Variable	Trial	Month	N	Mean	SD	Median	IQR
CO_2 (ppm)	Core	April	199	687	178	587	457
	Both	August	191	593	121	516	297
Relative Humidity (%)	Core	April	201	49.6	5.8	50	12
	Both	August	191	53.2	5.0	53	12
PM_1 (µg/m³)	Core	April	201	5.86	8.46	1.73	5.74
	Both	August	190	8.40	55.2	0.8	4.27
PM_{10} (µg/m³)	Core	April	201	8.22	10.9	2.75	7.70
	Both	August	188	3.81	8.7	1.49	4.43
$PM_{2.5}$ (µg/m³)	Core	April	201	7.53	9.7	2.75	7.13
	Both	August	189	5.42	8.3	1.75	5.69
Temperature (°C)	Core	April	201	19.3	1.60	19.2	1.66
	Both	August	191	23.2	1.29	23	3.46

Due to the high heterogeneity of pollutant concentrations within dwellings, restricting analysis to specific, labelled room types (living rooms only, kitchens only) provides the most physically interpretable exposure metrics. Living room statistics can arguably represent typical occupied space conditions, while kitchen statistics capture cooking related exposure. These are each meaningful for different aspects of health impact assessment.

2.8.3. Analysis of individual pollutants

The next section describes the initial data analysis performed, with emphasis on inter-seasonal comparisons made between data for April and August (spring and summer), and using data from both kitchens and living rooms. At this point in the project, only data from core trial homes with IAQ monitors is assessed due to the small sample sizes for homes from other trials in HfNZ. This is intended to assess whether or not a seasonal effect can be observed, and accounts for the different pollutant profiles in kitchens and living rooms (see IAQ Review in Table 7 for further details). Following data cleaning, the numbers of homes in each group is as follows (Table 9).

Table 9: Number of homes in each sample

	April (N)	**August (N)**	**Homes in both months post cleaning**
Pre Cleaning			
Living Rooms	84	85	--
Kitchens	14	14	--
Post Cleaning			
Living Rooms	69	52	40
Kitchens	14	11	11

It is important to note that living room and kitchen samples do not overlap, as each home has only one sensor. Furthermore, the nature of the deployment of IAQ sensors coupled

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[29] Comparisons to WHO limits are made in latter sections

with some sensors being represented during some months but not others means that the August data is not for the same homes as the April data. This is because there has been some degree of churn throughout the campaign, with loggers coming on and offline. Furthermore, application of data cleaning protocols has resulted in retention of different homes in each time period. The decision to include all dwellings with valid data, rather than restrict the analysis to those with valid data across both months (i.e., matched pairs analysis) was made in order to maximise the sample size and representativeness while maintaining data quality standards. Imposing a matched pair analysis would have meant eliminating nearly 40% of homes. The trade-off results in maximum data retention and representativeness but means that the data presented is not a truly longitudinal sample.

To aid interpretation of the gathered data, some reference standards are shown in Table 10.

Table 10: Reference Standards and general guidance for key pollutants.

Pollutant	Period	Limit	Standard or Guideline	Reference
$PM_{2.5}$	24-hour average	15 µg/m³	WHO Air Quality Guidelines 2021 (40% reduction from 2005 limit)	World Health Organization (WHO) (2021) WHO Global Air Quality Guidelines: Particulate Matter (PM2.5 and PM10), Ozone, Nitrogen Dioxide, Sulfur Dioxide and Carbon Monoxide. Geneva: World Health Organization.
$PM_{2.5}$	Annual average	5 µg/m³	WHO Air Quality Guidelines 2021 (50% reduction from 2005 limit)	World Health Organization (WHO) (2021) WHO Global Air Quality Guidelines: Particulate Matter (PM2.5 and PM10), Ozone, Nitrogen Dioxide, Sulfur Dioxide and Carbon Monoxide. Geneva: World Health Organization.
PM_{10}	24-hour average	45 µg/m³	WHO Air Quality Guidelines 2021	World Health Organization (WHO) (2021) WHO Global Air Quality Guidelines: Particulate Matter (PM2.5 and PM10), Ozone, Nitrogen Dioxide, Sulfur Dioxide and Carbon Monoxide. Geneva: World Health Organization.
PM_{10}	Annual Average	15 µg/m³	WHO Air Quality Guidelines 2021	World Health Organization (WHO) (2021) WHO Global Air Quality Guidelines: Particulate Matter (PM2.5 and PM10), Ozone, Nitrogen Dioxide, Sulfur Dioxide and Carbon Monoxide. Geneva: World Health Organization.
$PM_{1.0}$	No explicit guidance presently			
CO_2	Maximum duration	Should not exceed 1500 ppm for >20 min/day	Building Bulletin 101 (UK Schools)	Department for Education (2018) Building Bulletin 101: Ventilation, thermal comfort and indoor air quality. London: Department for Education. Available at: https://www.gov.uk/government/publications/building-bulletin-101-ventilation-for-school-buildings (Accessed: 10 July 2025)

Relative Humidity	Mould growth threshold	>80% for >1 month	Literature (Note that there are complicated interactions between building fabric, temperature, and RH that are difficult to capture using a simple threshold.)	Vereecken, E. and Roels, S. (2012) Review of mould prediction models and their influence on mould risk evaluation, Building and Environment, 51, pp. 296-310. https://doi.org/10.1016/j.buildenv.2011.11.003 Menneer, T., Mueller, M., Sharpe, R.A. and Townley, S. (2022) Modelling mould growth in domestic environments using relative humidity and temperature, Building and Environment, 208, 108583. https://doi.org/10.1016/j.buildenv.2021.108583
Relative Humidity	Comfort range	30-60% RH	General guidance	ASHRAE (2024) ASHRAE Handbook - Fundamentals. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

2.8.3.1. Room-wise statistical tables for measured data

This section presents summary statistics for gathered air quality data for the months of April and August, noting seasonal differences and overall data characteristics (Table 11). Many of the reference standards and guidelines are over either 24-hour or annual time periods. IAQ data has not been collected long enough to assess annual values; values over 24-hour periods are covered in latter sections, per pollutant.

Table 11: Summary statistics for several air quality measurements, by season and room

Variable	Sensor location	Month	N	Mean	SD	Median	IQR
CO_2 (ppm)	Kitchen	April	14	678	181	540	348
		August	11	555	74.6	489	199
	Living Room	April	69	655	129	576	423
		August	53	579	97	511	282
Relative Humidity (%)	Kitchen	April	14	48.8	5.11	48.6	13.8
		August	11	51.3	4.17	52	10.2
	Living Room	April	69	50.3	6.84	50.2	12.87
		August	53	54.4	5.01	55	49.8
PM_1 (µg/m³)	Kitchen	April	14	5.45	6.09	2.08	5.11
		August	11	2.79	0.99	0.46	4.21
	Living Room	April	69	5.31	5.03	1.45	5.77
		August	52	3.02	1.76	0.75	3.87
PM_{10} (µg/m³)	Kitchen	April	14	7.82	8.29	3.11	6.59
		August	11	4.25	1.39	1.52	5.53
	Living Room	April	69	7.72	6.98	2.46	7.82
		August	52	4.56	2.42	1.73	4.89
$PM_{2.5}$ (µg/m³)	Kitchen	April	14	7.30	7.51	3.11	6.20
		August	11	3.98	1.24	1.52	5.47
	Living Room	April	69	7.08	6.19	2.45	6.83
		August	52	4.26	2.18	1.71	4.84
Temperature	Kitchen	April	14	19.8	1.10	19.82	3.10

(°C)		August	11	23.72	1.07	23.82	2.98
	Living Room	April	69	19.06	1.63	19.02	3.84
		August	53	23.01	1.29	22.98	3.58

Measurements from kitchens (*n*=14 April, *n*=11 August) and living rooms (*n*=69 April, *n*=53 August) reveal potentially variable indoor air quality conditions across both seasons and room types, along with expected seasonal variations.

The August data reveals a possible seasonal ventilation effect, with both CO_2 and particulate matter concentrations significantly lower than in April. August living rooms showed median CO_2 of 511 ppm compared to 576 ppm in April (11% reduction), while median $PM_{2.5}$ decreased from 2.45 µg/m³ in April to 1.71 µg/m³ in August (30% reduction). This pattern is consistent across both means and medians, and across both kitchens and living rooms, which suggests increased natural ventilation during warmer months, potentially due to open windows or other ventilation activities.

Indoor particulate matter has distributions characterised by low baseline concentrations for extended periods, punctuated by episodic emission events such as cooking, cleaning, or other particle generating activities that create short lived concentration spikes.

As expected from this episodic pattern then, the data are right skewed with means consistently exceeding medians by factors of 2 or 3 for most datasets. For example, April living room $PM_{2.5}$ showed a mean of 7.08µg/m³ but a median of only 2.45µg/m³, indicating that most measurements were at very low concentrations with occasional elevated values pulling the mean upward. The large standard deviations relative to means further confirm this episodic exposure pattern. In contrast, CO_2, temperature, and humidity show more symmetric distributions with means and medians in closer agreement, reflecting their gradual changes and continuous nature rather than event driven variability (although CO_2 tends to follow a lognormal distribution).

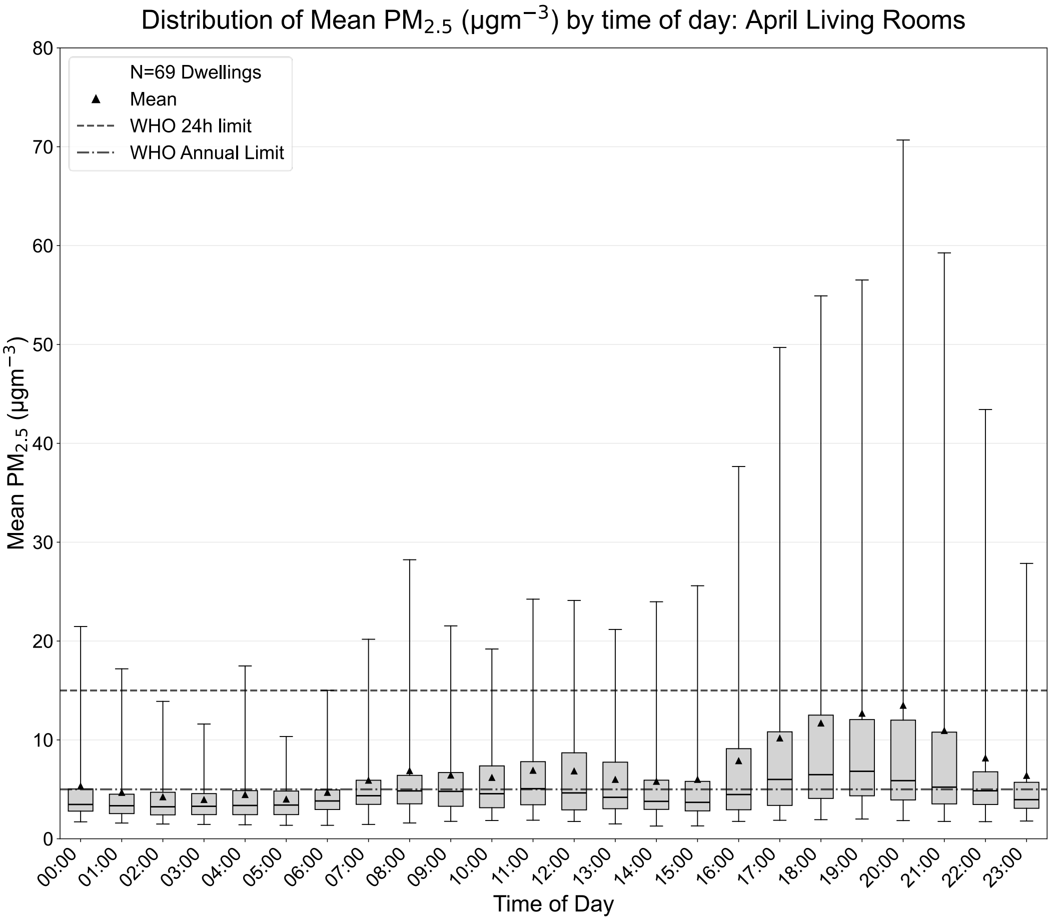
2.8.4. $PM_{2.5}$

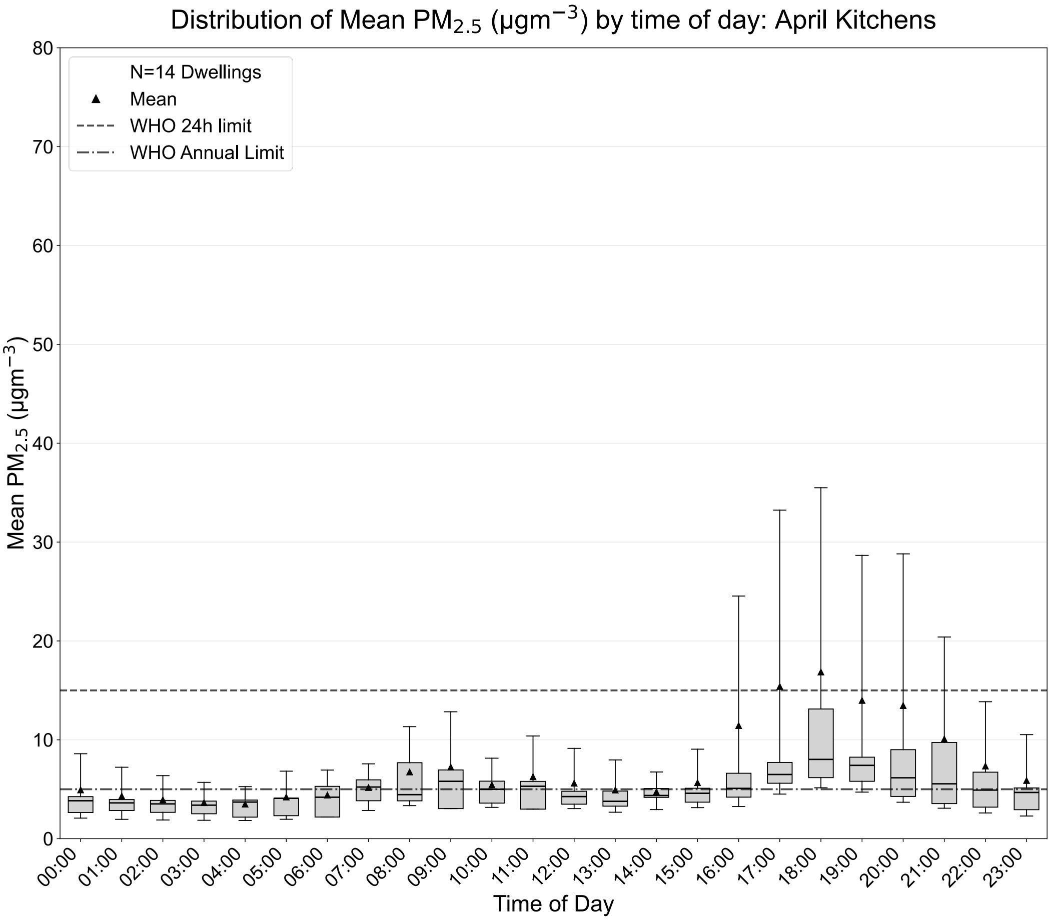
$PM_{2.5}$ exposure is associated with significant adverse health outcomes, including cardiovascular mortality, respiratory disease, and systemic inflammation. The WHO guidelines (2021) recommend 24-hour mean concentrations do not exceed 15 µg/m³, with an annual mean of 5 µg/m³. This section examines $PM_{2.5}$ concentrations in participant dwellings during April and August 2025. Analysis includes hourly diurnal profiles to identify activity related patterns and 24-hour rolling mean distributions to assess WHO guideline exceedances. Given the sensor variability (see Section 2.7.1.1), interpretation is best focussed on temporal patterns, seasonal differences, and relative comparisons between room types and time periods. Sources of $PM_{2.5}$ include cooking (especially with gas), combustion-based heating, as well as ingress from outdoor sources such as traffic.

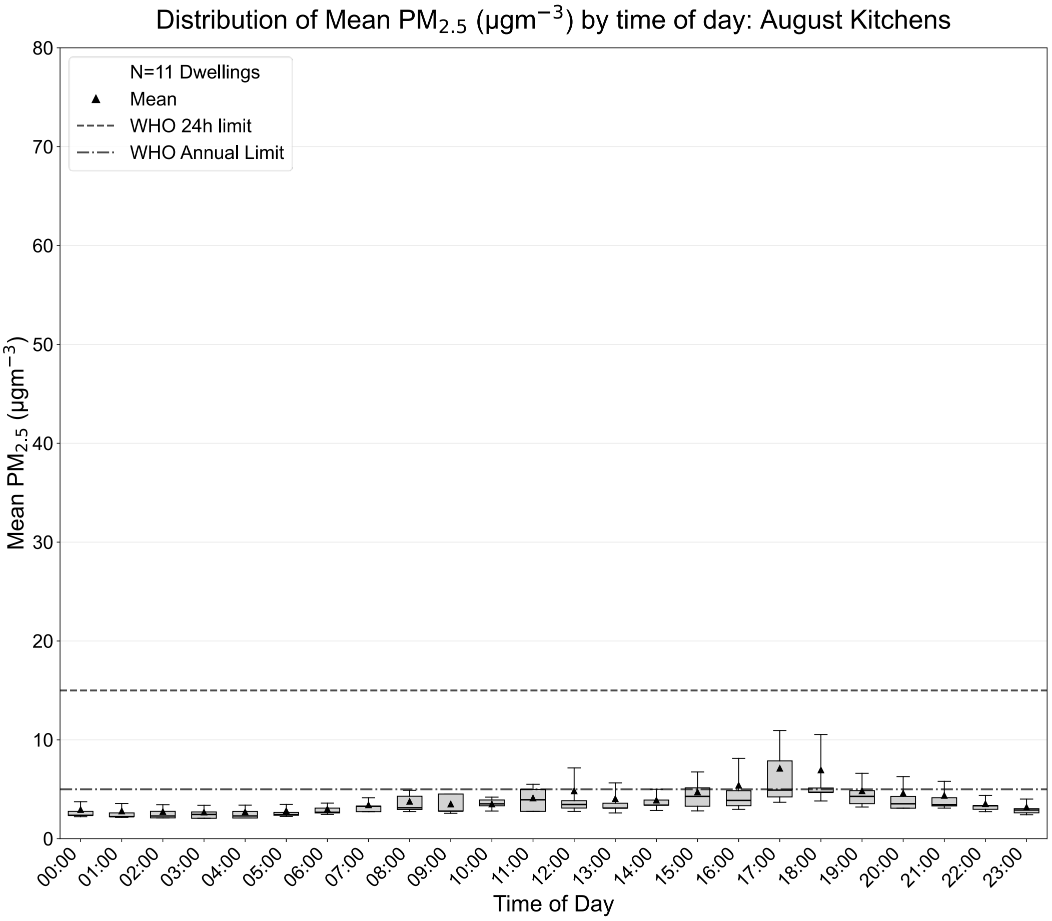
Figure 49 shows the hourly mean $PM_{2.5}$ profiles for each dwelling in April and August 2025, for kitchens and living rooms. They show distinct diurnal patterns in $PM_{2.5}$ concentrations. Both rooms exhibit clear evening peaks between 16:00-21:00 in April; and living rooms show particularly pronounced elevations in April. August measurements show quite different PM2.5 patterns compared to April. Both kitchens (*n*=11) and living rooms (*n*=52) showed much flatter diurnal profiles (Figure 49), with consistently low concentrations throughout the day. Evening peaks, while still present around 17:00-19:00, are attenuated, with mean concentrations reaching approximately half the April levels. This flattening suggests higher levels of ventilation during warmer months, plausibly due to increased window opening.

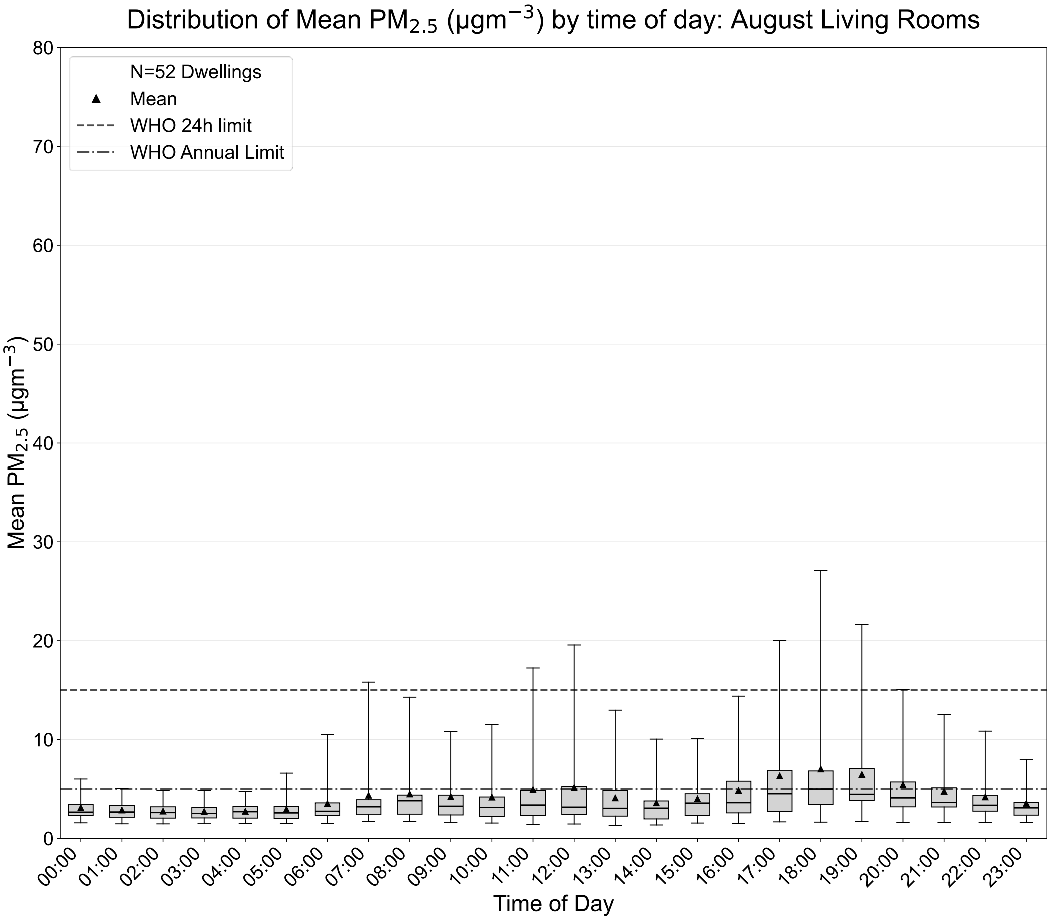
The large interquartile ranges and extensive upper whiskers during evening periods indicate considerable variability between dwellings, which suggests that while some homes exhibit minimal PM2.5 elevation, others had substantial peaks, plausibly as a result of activities such as gas cooking, or using supplementary heating such as a wood burner.

Figure 45: Hourly box plot showing the daily variation of $PM_{2.5}$ for 69 Living Rooms and 14 kitchens in April 2025, and 52 Living Rooms and 11 kitchens in August 2025




Distribution of Mean $PM_{2.5}$ (μgm^{-3}) by time of day: April Kitchens


Distribution of Mean $PM_{2.5}$ (μgm^{-3}) by time of day: August Kitchens



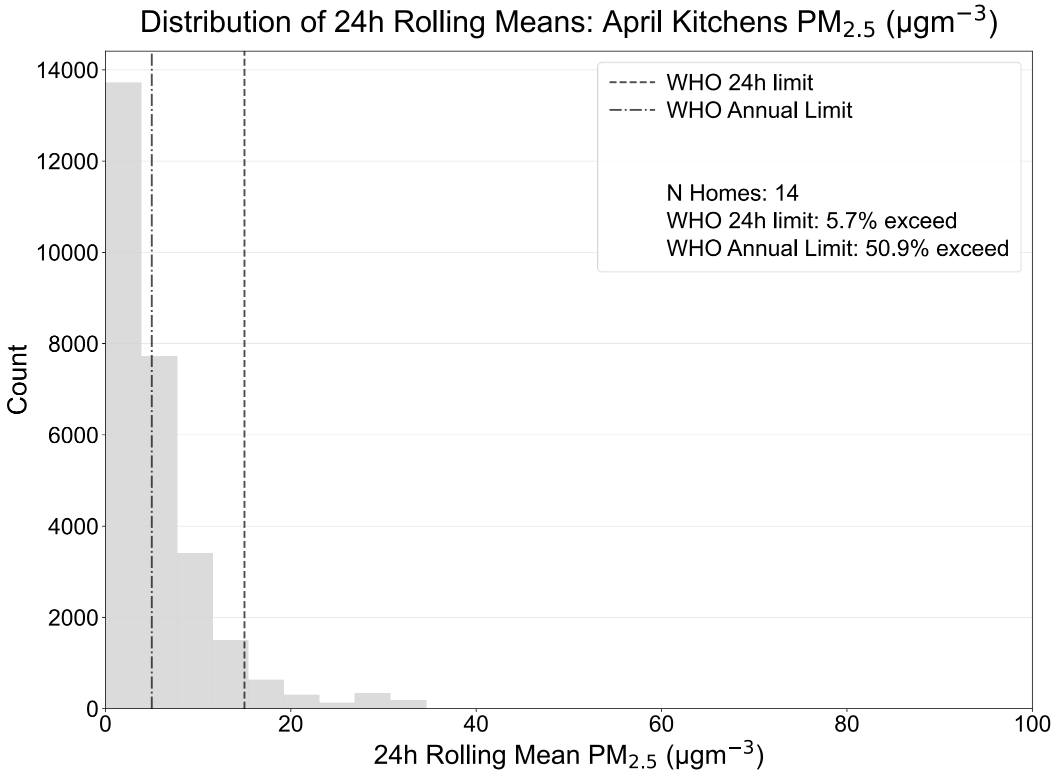
Counter-intuitively, living rooms demonstrate slightly higher 24-hour rolling mean exceedances (6.16%) compared to kitchens (5.71%) despite kitchens being the primary source of cooking emissions (Figure 50). This unexpected finding plausibly reflects migration and accumulation of particles from kitchens into living spaces, where they may persist due to longer occupancy periods and potentially lower ventilation rates. Histograms (Figure 50) confirm strongly right-skewed distributions for both room types, with the vast majority of 24-hour periods below 10 µg/m³ but with long tails.

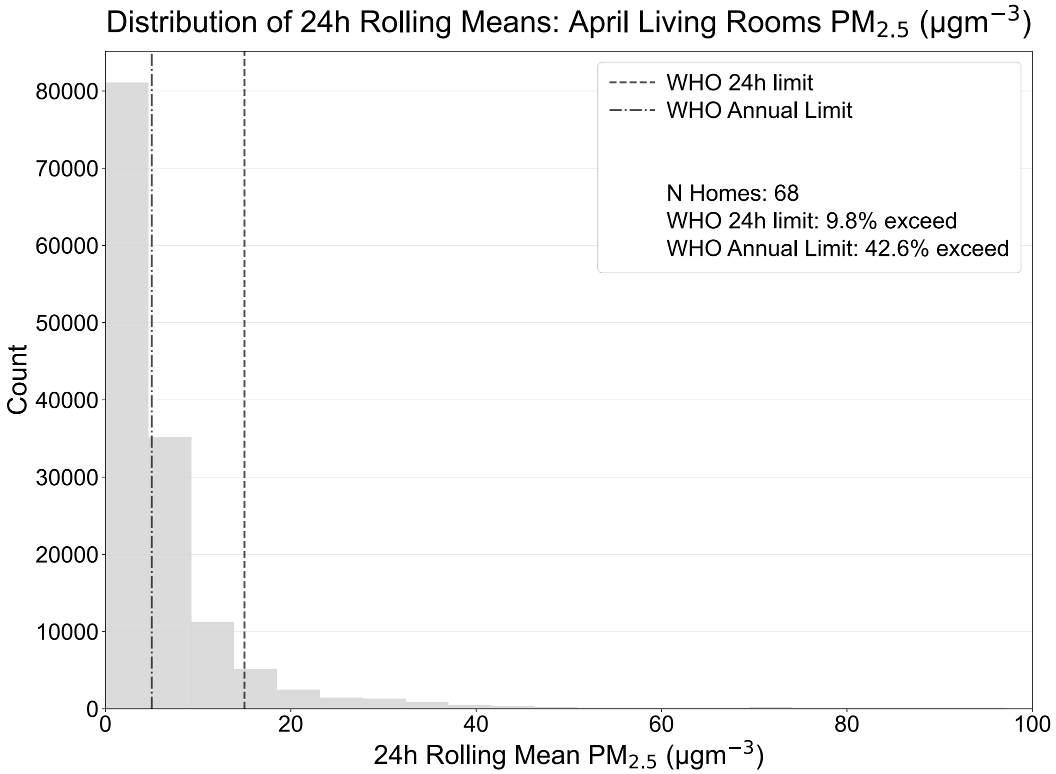
There appears to be a seasonal impact on $PM_{2.5}$ exceedances, with living room exceedances decreasing from 6.16% to 2.58%, and kitchen exceedances from 5.71% to 1.32% (Figure 50). The August histograms show tighter distributions with shorter right tails, which indicates not only lower typical concentrations but also less severe episodic events. Notably, kitchens in August showed the lowest exceedance rate of all scenarios (1.32%), which could indicate window opening during cooking.

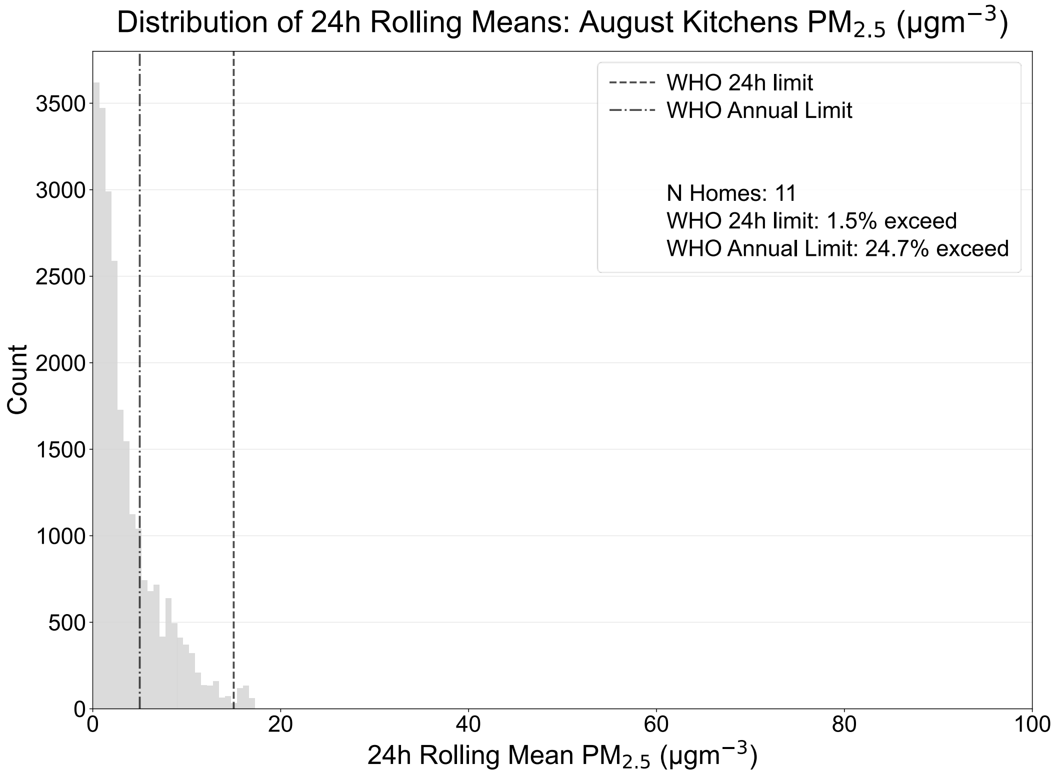
However, it is important to note that in the context of high sensor uncertainty, the absolute values in all plots should be interpreted with caution, with the most salient finding being the seasonal differences and the lack of extreme outliers in August, suggesting the impact of ventilation on $PM_{2.5}$ concentrations.

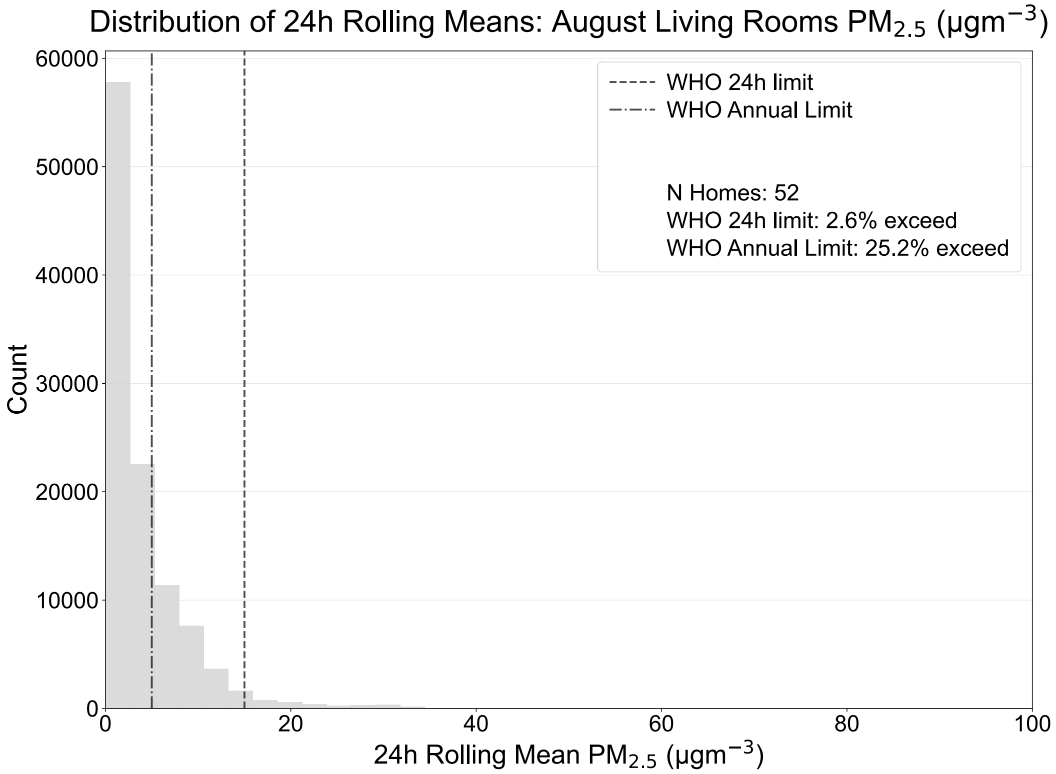
Figure 46: Distribution of 24h rolling mean $PM_{2.5}$, for living rooms (LR) and kitchens (K) in April and August 2025. Exceedance was 6.16% (LR) and 5.71% (K) in April, falling to

2.58% and 1.32% respectively in August. Exceedance indicates proportion of 24h periods exceeded the WHO24h limit.









2.8.4.1. Survey Questions: PM2.5 and Gas Cooking

Although multiple dwelling characteristics were investigated, including rurality, built form, and temporal patterns (e.g., morning vs. evening periods), only monthly aggregate $PM_{2.5}$ concentrations stratified by cooking fuel type (gas vs. electric) are presented. Small sample sizes within subgroups limit statistical power for detecting differences between dwelling categories. Further analysis using alternative aggregation methods (e.g., hourly or event-based comparisons) or data from subsequent monitoring periods with larger samples may reveal significant associations not detectable in the current analysis.

To test whether or not gas cooking could be plausibly associated with elevated $PM_{2.5}$, Kruskal-Wallis tests were performed between monthly mean dwelling values for kitchens (Table 12). Although the testing performed did not reveal statistical significance, the power of this test is limited by the small sample sizes. In April, kitchens with gas cookers do have a higher mean level of $PM_{2.5}$ than those that don’t, suggesting again strong episodic peaks. Further analysis could provide greater insights.

Table 12: Kruskal Wallis test results and dwelling PM2.5 statistics for presence of gas cooking in August and April in Kitchens

		N	Mean	Median	Standard Deviation	H statistic	P-value	Effect Size	Significant
April	No gas (cooker/hob)	10	5.05	5.2	1.96				
	Gas cooker/hob	5	10.29	5.83	10.08	0.817	0.6	-0.011	No
August	No gas (cooker/hob)	5	3.72	3.42	0.93				
	Gas cooker/hob	5	4.3	4.3	1.36	0.133	0.715	-0.096	No

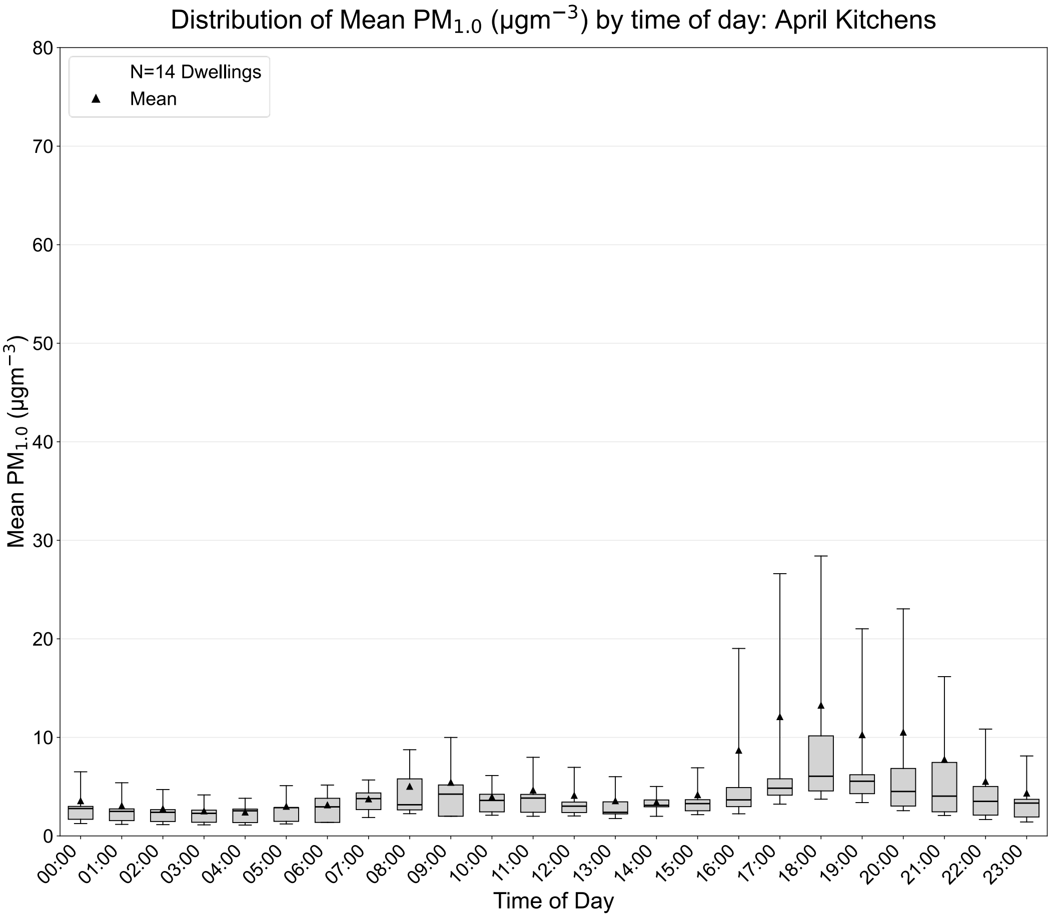
2.8.5. $PM_{1.0}$

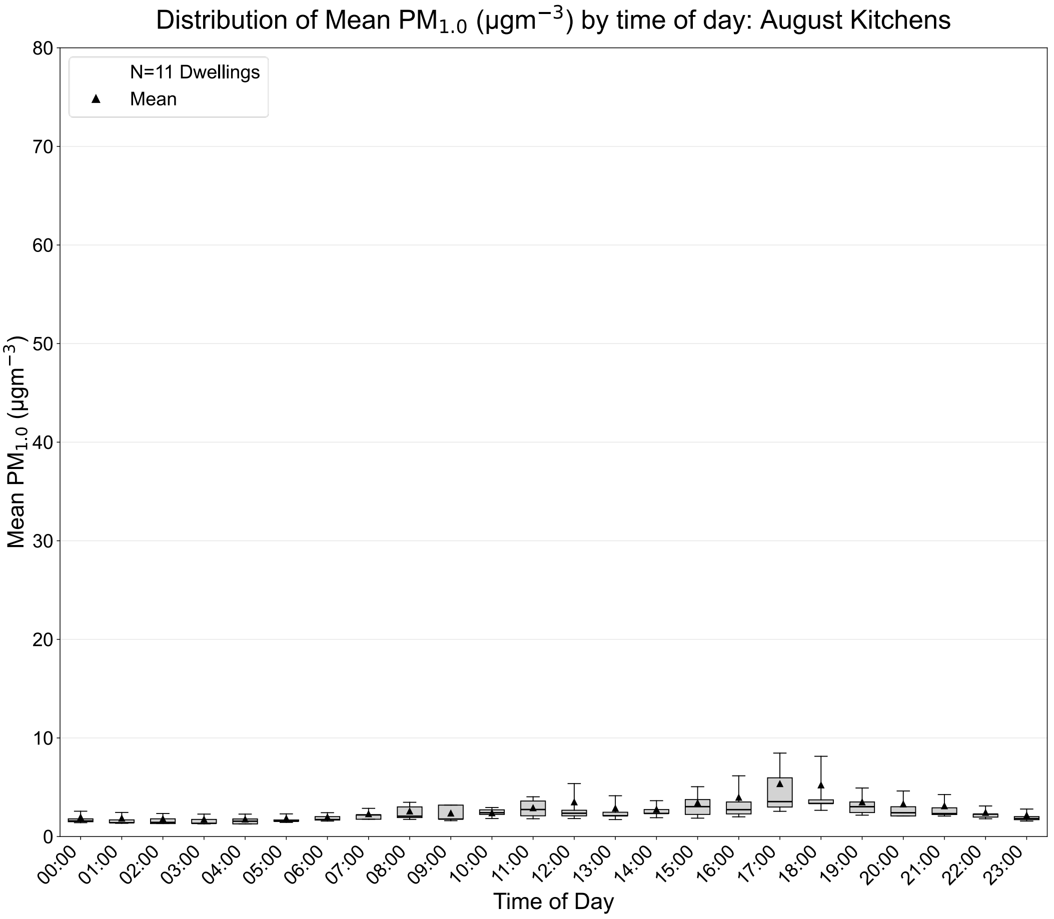
$PM_{1.0}$ represents the ultrafine particle fraction, predominantly generated by combustion processes including cooking, candles, and infiltration of outdoor traffic fumes. $PM_{1.0}$ poses health concerns due to its ability to penetrate deeply into the lungs and cardiovascular system. Unlike $PM_{2.5}$ and PM_{10}, no international guidelines currently exist for $PM_{1.0}$, though it is increasingly recognised as a marker of combustion related air quality. This section examines $PM_{1.0}$ temporal patterns across kitchens and living rooms during April and August 2025.

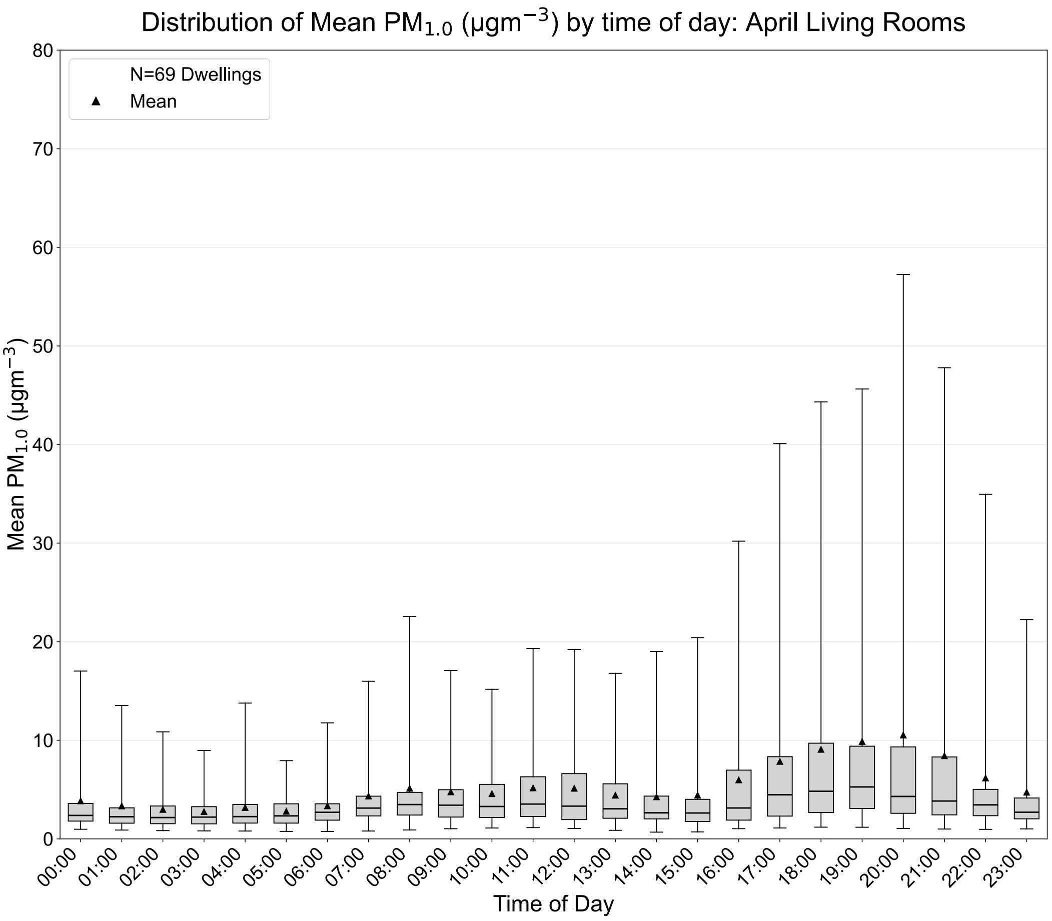
It should be noted that $PM_{1.0}$ sensors exhibited the highest measurement variability during assessment (Section 2.7.3.1), which means interpretation of absolute values should be done with high caution, but still permits analysis of temporal and seasonal patterns.

$PM_{1.0}$ measurements show similar patterns to $PM_{2.5}$ during April and August, with evening peaks between 17:00 and 21:00 in both living rooms and kitchens (Figure 51). Median hourly concentrations remain consistently low throughout most of the day, but increase substantially during evening hours, with mean concentrations reaching 5-10 µg/m³ in living rooms and 5-13 µg/m³ in kitchens. The evening peak timing aligns closely with $PM_{2.5}$ patterns, which suggests that the sources are likely the same.

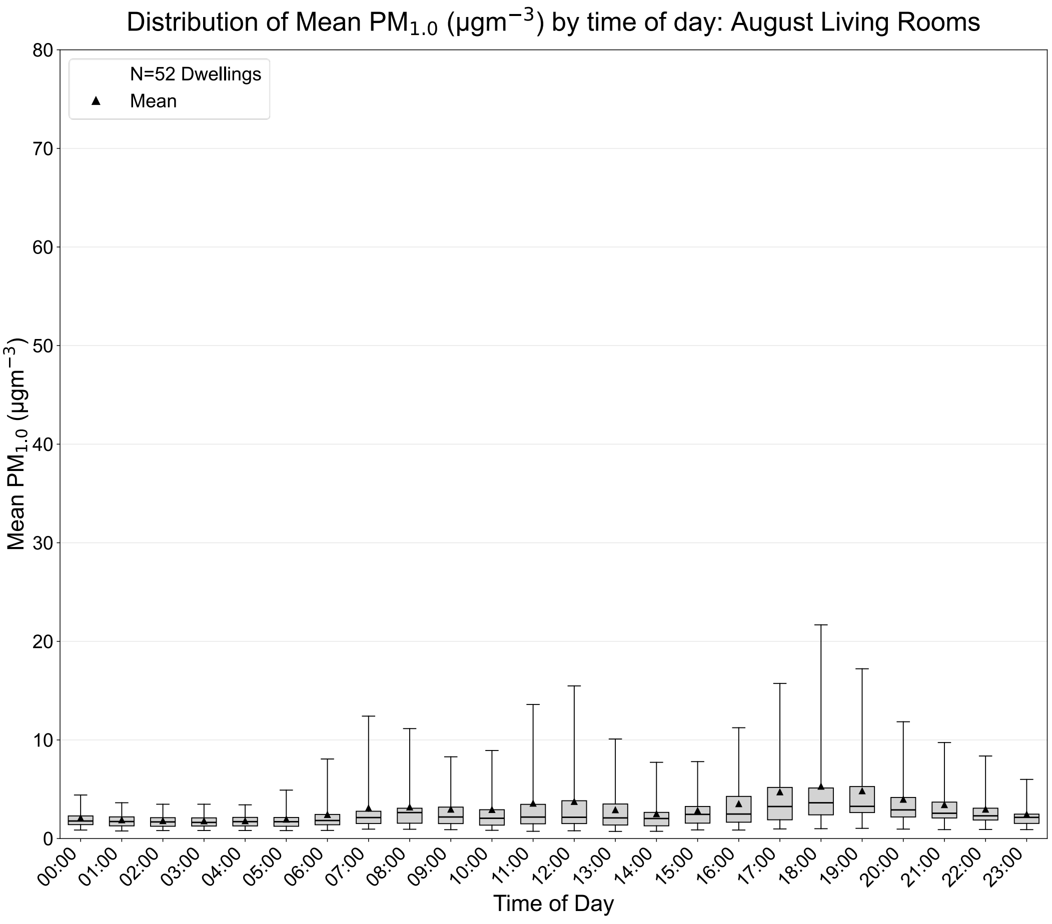
Figure 47: Hourly box plots showing the daily variation of PM1.0 for Living Rooms and Kitchens in April and August 2025


Distribution of Mean $PM_{1.0}$ (μgm^{-3}) by time of day: April Kitchens
N=14 Dwellings
Mean
Mean $PM_{1.0}$ (μgm^{-3})
0
10
20
30
40
50
60
70
80
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time of Day


Distribution of Mean $PM_{1.0}$ (μgm^{-3}) by time of day: August Kitchens
N=11 Dwellings
Mean
Mean $PM_{1.0}$ (μgm^{-3})
0
10
20
30
40
50
60
70
80
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time of Day



Distribution of Mean $PM_{1.0}$ (μgm^{-3}) by time of day: April Living Rooms



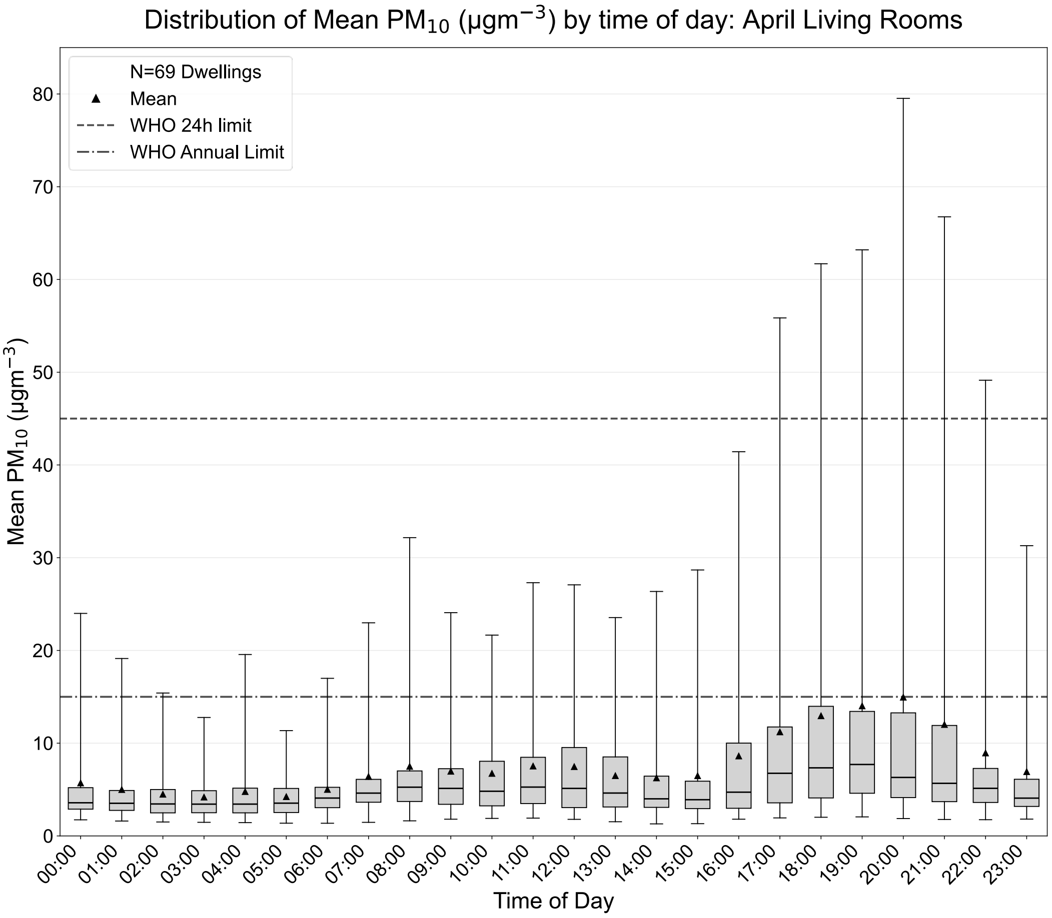
Distribution of Mean $PM_{1.0}$ (μgm^{-3}) by time of day: August Living Rooms

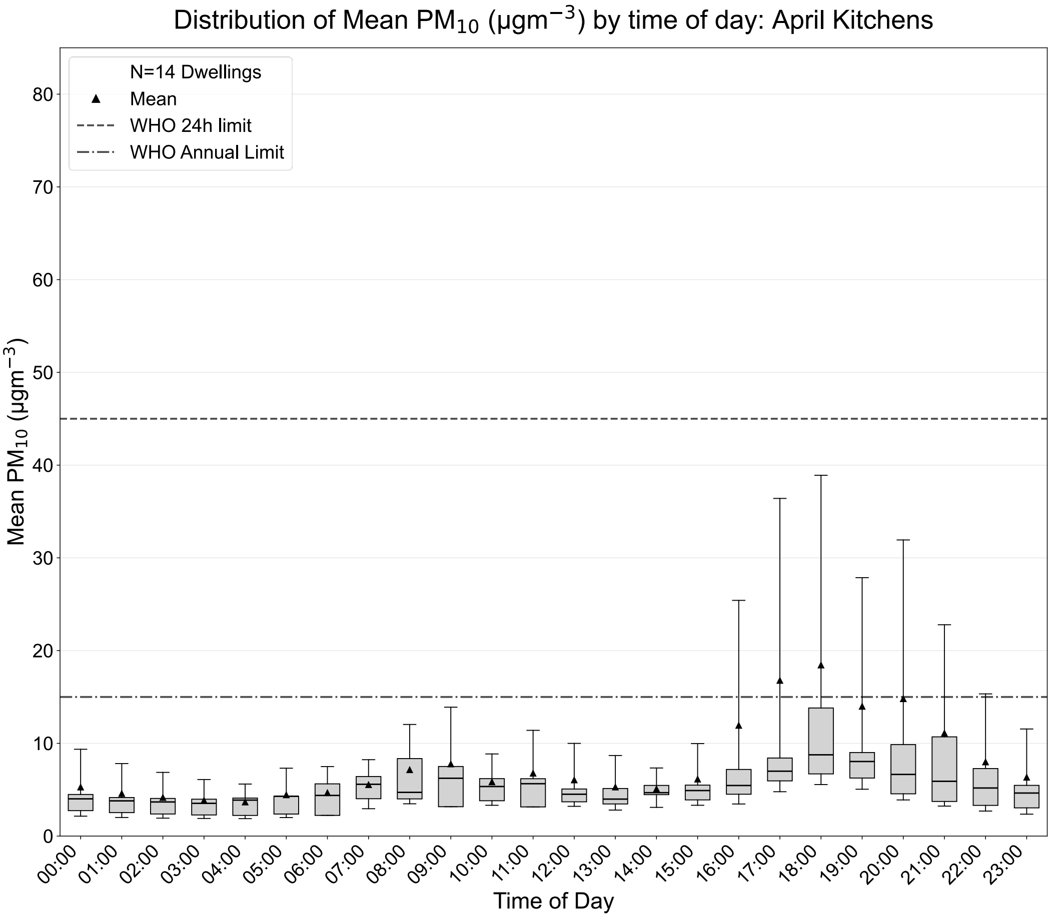
2.8.6. PM_{10}

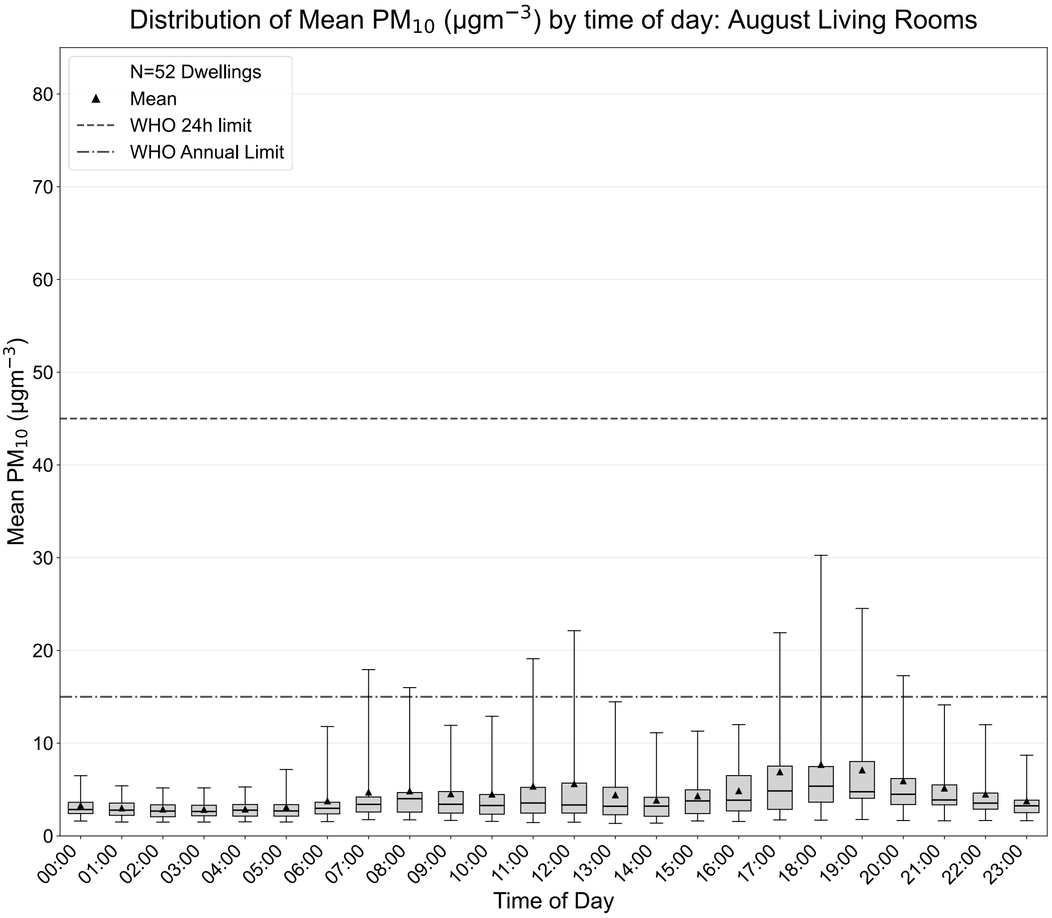
PM_{10} includes all particles smaller than 10 micrometres, including the $PM_{2.5}$ and $PM_{1.0}$ fractions plus coarser particles such as dust, textile fibres, and skin flakes. The WHO 2021 guidelines specify a 24-hour mean of 45 µg/m³ and an annual mean of 15 µg/m³ for PM_{10}. This section examines PM_{10} temporal patterns across Kitchens and Living Rooms in April and August 2025.

PM_{10} measurements show similar patterns to $PM_{2.5}$ during April, with (slightly smaller) evening peaks between 17:00 and 21:00 in both living rooms and kitchens (Figure 52). Median hourly concentrations also remain consistently low throughout most of the day, but increase during evening hours, with mean concentrations increasing in both living rooms and kitchens. Similarly to $PM_{1.0}$, the evening peak timing aligns with $PM_{2.5}$ patterns, which suggests that the sources are likely the same.

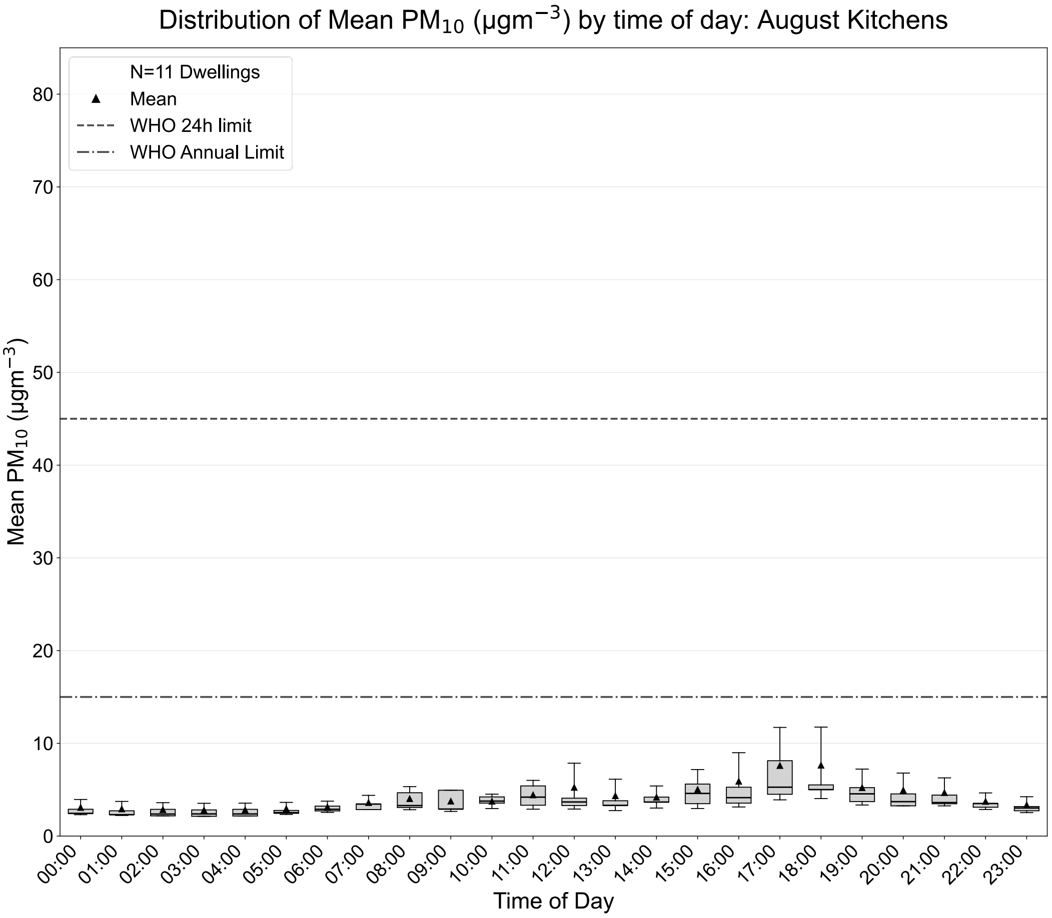
Figure 48: Hourly box plots showing the daily variation of PM_{10} for Living Rooms and Kitchens in April and August 2025


Distribution of Mean PM_{10} (μgm^{-3}) by time of day: April Living Rooms


Distribution of Mean PM_{10} (μgm^{-3}) by time of day: April Kitchens



Distribution of Mean PM_{10} (μgm^{-3}) by time of day: August Living Rooms



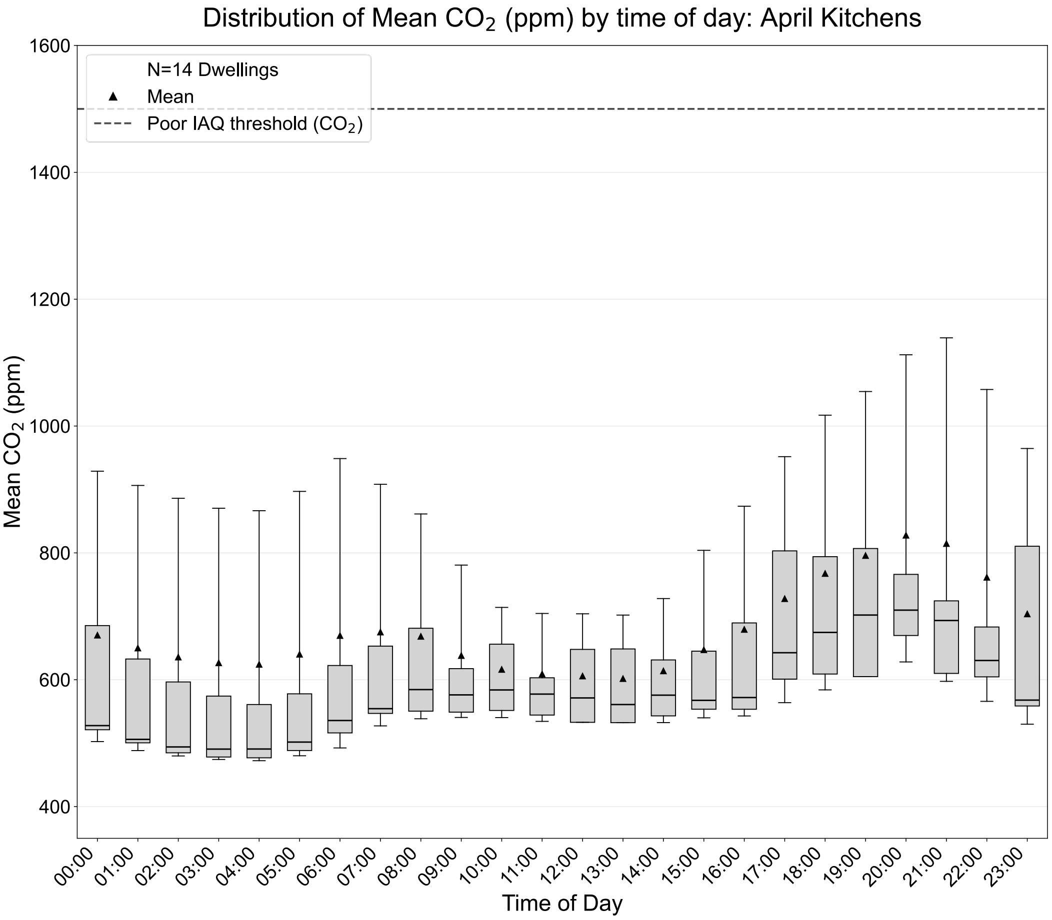
Distribution of Mean PM_{10} (μgm^{-3}) by time of day: August Kitchens

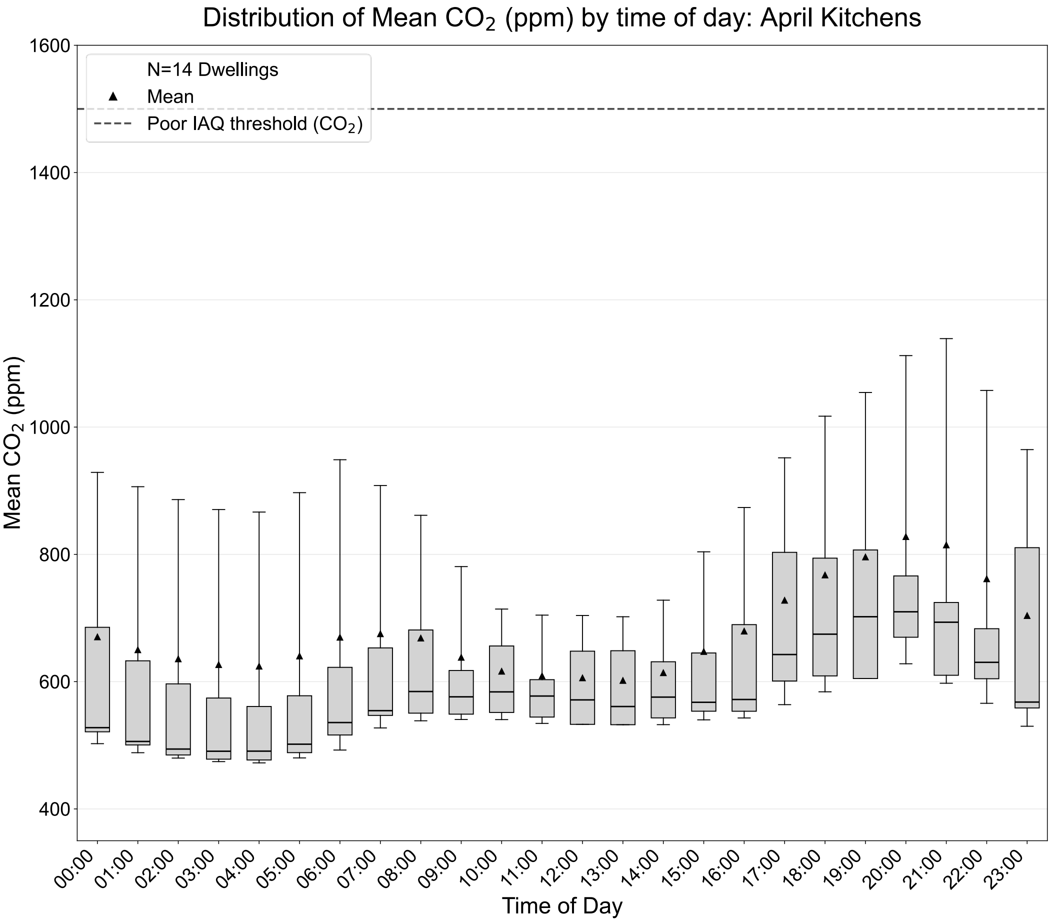
2.8.7. CO_2

Indoor CO_2 concentration is sometimes used as an indicator of ventilation adequacy, however, should be treated with caution as different levels of ventilation are needed for different levels of occupancy. CO_2 does not generally pose a direct health risk at typical indoor levels but has been associated with poor perceived air quality, reduced cognitive performance, and inadequate fresh air supply.

Building Bulletin 101 (see Table 10) denotes a threshold of 1500ppm to denote poor IAQ, which is shown on each plot. Hourly boxplots (Figure 53) summarise the distribution of CO_2 concentrations across dwellings for each hour of the day. The most striking feature of the CO_2 data is the seasonal variation, which is indicative of greater ventilation in August than in April. Peaks are higher in April, and in Living rooms, and are slightly temporally shifted compared to the PM data (they occur from 19:00 – 22:00 rather than 17:00 – 20:00). This suggests again that ventilation may be playing a greater role in summertime air quality than during the heating season, and that there may be additional ventilation occurring in kitchens compared to living rooms. The temporal shift is a plausible indication that occupants are spending time in their living rooms post cooking activities.

Figure 49: Hourly box plots showing the daily variation of CO_2 for Kitchens and Living Rooms in April and August 2025.


Distribution of Mean CO_2 (ppm) by time of day: April Kitchens
N=14 Dwellings
▲ Mean
---- Poor IAQ threshold (CO_2)
Mean CO_2 (ppm)
1600
1400
1200
1000
800
600
400
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time of Day


Distribution of Mean CO_2 (ppm) by time of day: April Kitchens
N=14 Dwellings
▲ Mean
---- Poor IAQ threshold (CO_2)
Mean CO_2 (ppm)
1600
1400
1200
1000
800
600
400
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
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18:00
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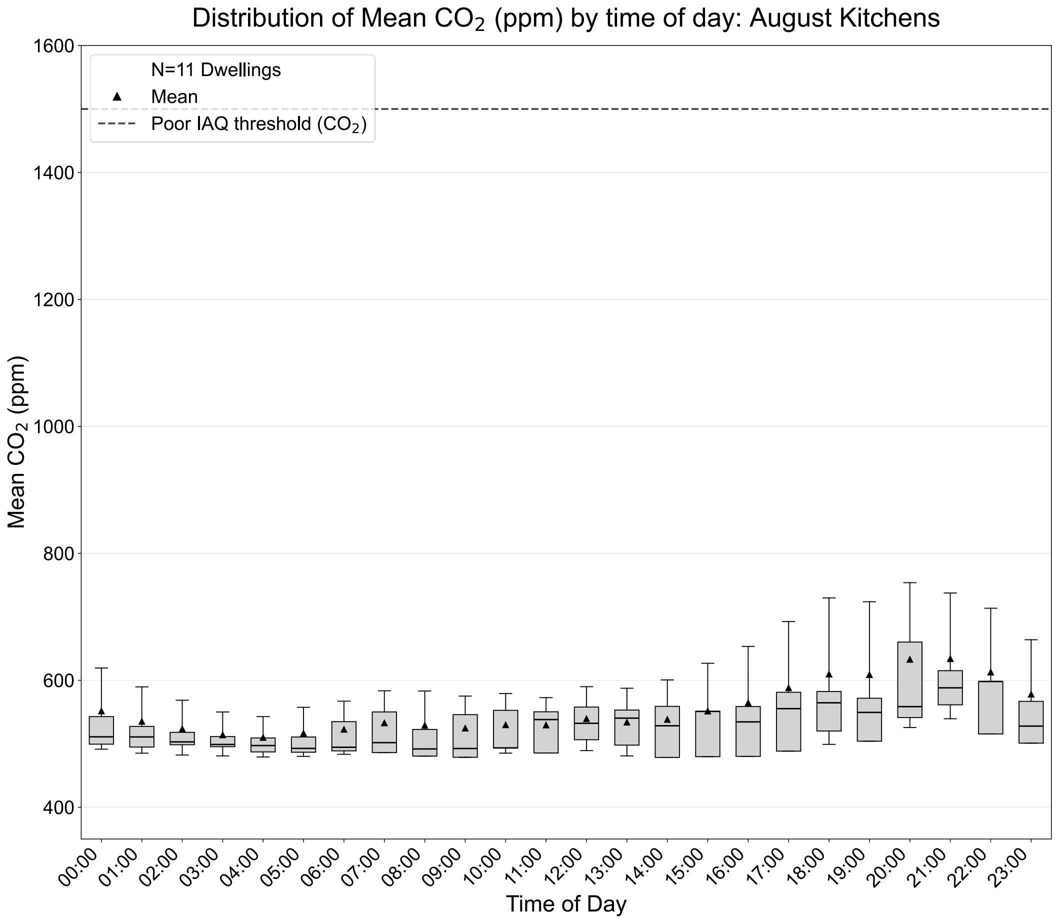
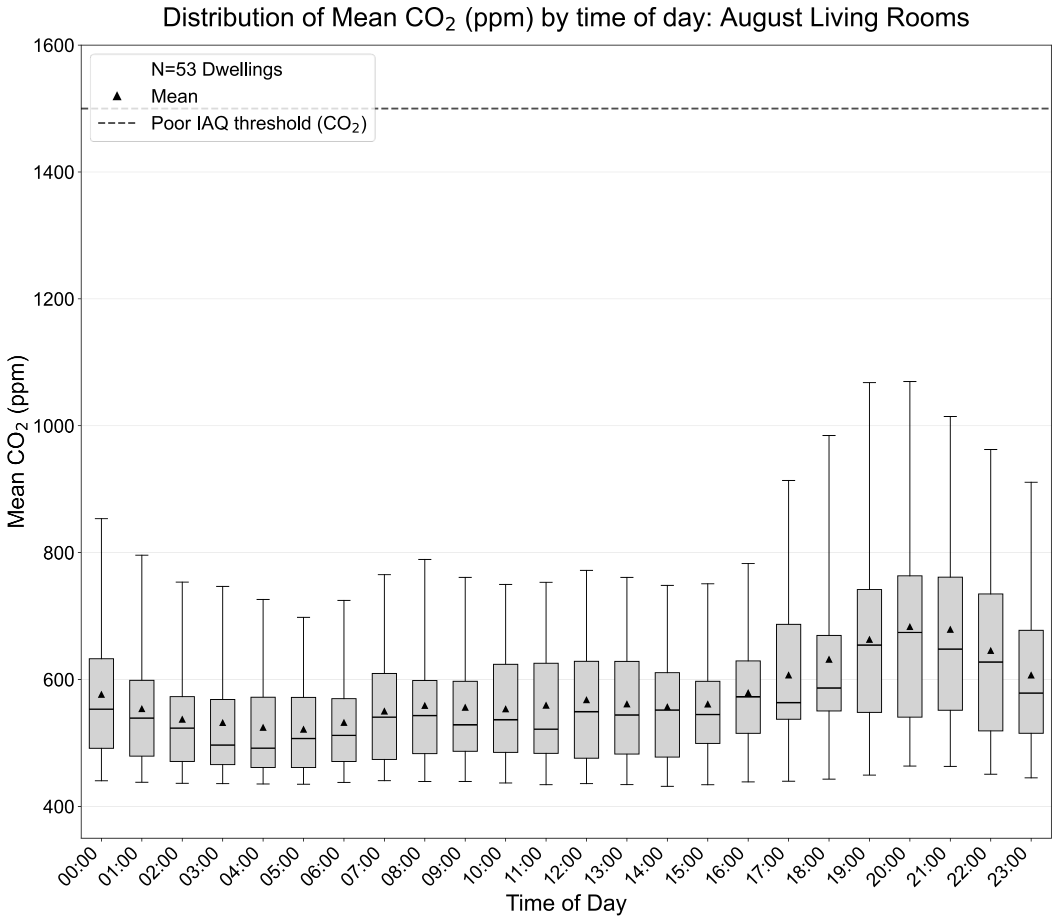
21:00
22:00
23:00
Time of Day



Distribution of Mean CO_2 (ppm) by time of day: August Kitchens



Distribution of Mean CO_2 (ppm) by time of day: August Living Rooms

2.8.8. Key findings and future plans

The analysis presented here provides an initial assessment of indoor air quality in some homes from the trials. Assessments for two months, April and August, have enabled a seasonal comparison to be made, and assessments of sampled individual days have allowed for comparisons to WHO limits.

The next HfNZ report will include more analysis of data from IAQ sensors. This analysis will repeat what has been provided in this report and provide further breakdowns across seasons; it will also make assessments of air quality in homes with and without a RAAHP to understand the effect of the technology.

2.9. Trial participant surveys

This section reports findings from several surveys with participants in HfNZ trials.

2.9.1. Core trial survey

The survey sent out to core trial participants in April 2025 aimed to capture a snapshot of participant experiences and comfort following winter 2024/25, as well as the experiences of those who received measures. Many of the questions in the survey were also used in a ‘baseline’ survey at the outset of HfNZ to allow for longitudinal analysis. All 900+ core trial participants were sent the survey, along with two reminders. Of these, 197 had physical measures installed (e.g., loft insulation refresh, heating system MOT, draught proofing, or combinations of measures) as part of the core trial between August 2024 and February 2025.

The survey received 566 responses; 137 were from those who received physical measures, 65 from those who had received behavioural measures, and 56 from those who had received roadmaps.

The survey covered:

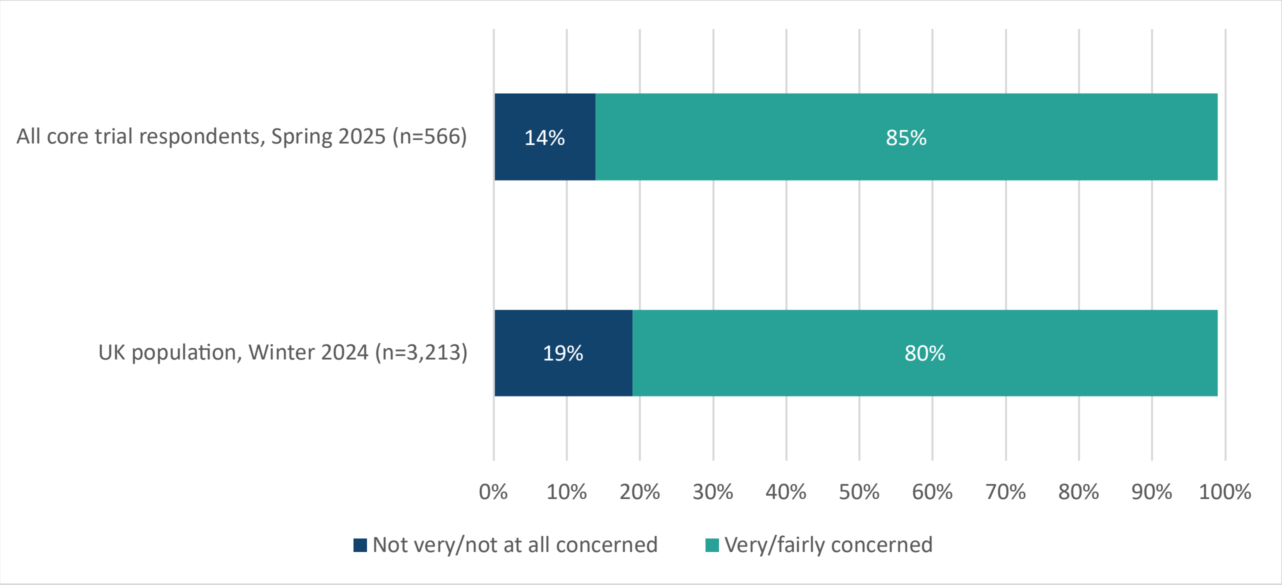
- Net zero awareness and climate change
- General experience and comfort questions
- Feedback on installed measures
- Measure preferences
- Use of behavioural measures at home

2.9.2. Net zero awareness and climate change

To understand how trial participants’ awareness of Net Zero compared to the UK population, two questions were asked from the DESNZ Public Attitudes tracker in the April survey. These asked about their level of concern about climate change and their awareness of Net Zero. Compared to the UK population, trial participants were more concerned and had greater awareness of Net Zero.

The trial sample was significantly more likely to be very or fairly concerned about climate change. The level of concern of the UK population has consistently decreased from 85% in Autumn 2021 to the Winter 2024 figure (80%)[30]. Test statistics for independent percentages (Z score = 2.78, $p < 0.05$) indicated that trial sample was significantly more likely to be very or fairly concerned about climate change (85%) compared to the UK population (80%), as shown in Figure 54. This could be due to various reasons, such as those who are more concerned about climate change may be more inclined to take part in this kind of research, or participation in the trial itself raises awareness of the issues.

Figure 50: How concerned, if at all, are you about climate change, sometimes referred to as 'global warming'? (Note: The chart does not equate to 100% as those who selected 'Don't know' were excluded from this comparison).



The trial sample had a significantly higher awareness of Net Zero than the UK population. Comparing the awareness of the concept of 'Net Zero' of core trial participants in April 2025 and the general population in Winter 2024, test statistics for independent percentages (Z score= 5.73, $p <0.05$) indicated that the trial cohort had a significantly higher awareness of Net Zero than the UK population (see Figure 55).

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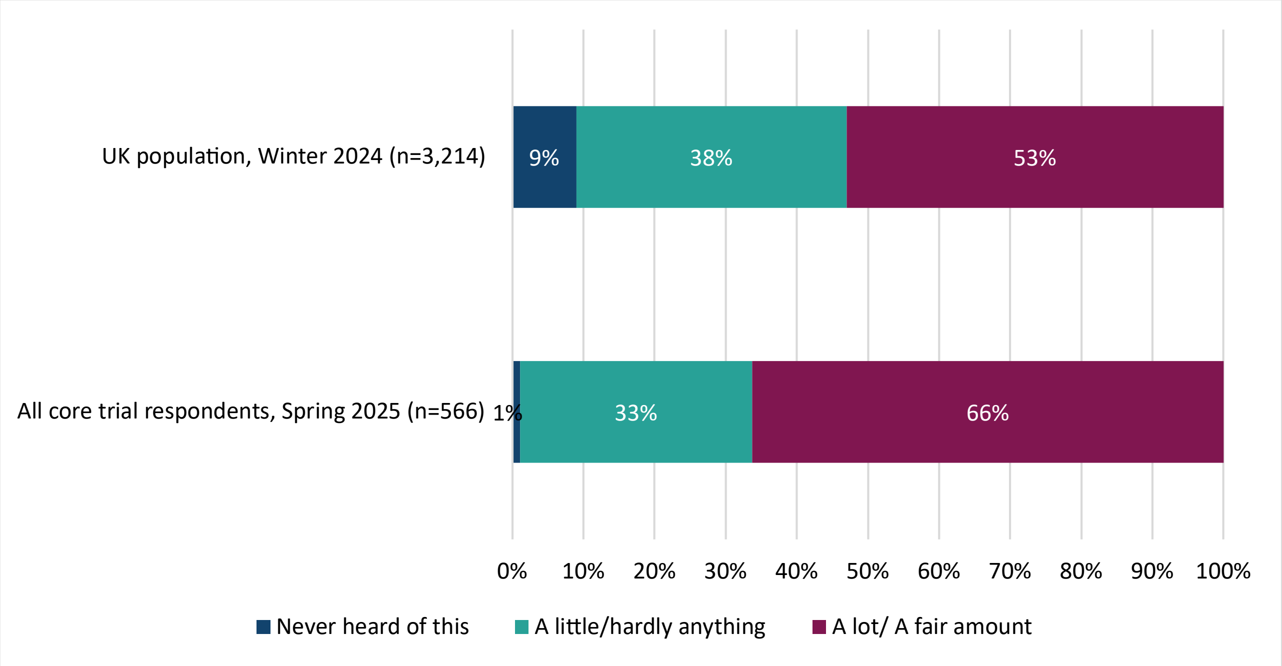
[30] DESNZ Public Attitudes Tracker: Net Zero and climate change, Spring 2025, UK (https://www.gov.uk/government/statistics/desnz-public-attitudes-tracker-spring-2025))

Figure 51: The UK government is aiming to reduce UK greenhouse gas emissions to 'Net Zero' by 2050. This will involve significantly reducing emissions produced by our industries, transport, food, and homes. Any remaining emissions will be balanced by actions that reduce greenhouse gases already in the atmosphere, such as planting trees. Before today, how much, if anything, did you know about the concept of 'Net Zero'?



2.9.3. Participant experience and comfort in their homes

Participants were asked a range of questions at baseline and again in April to understand their general experience, and comfort in their homes. This included questions about:

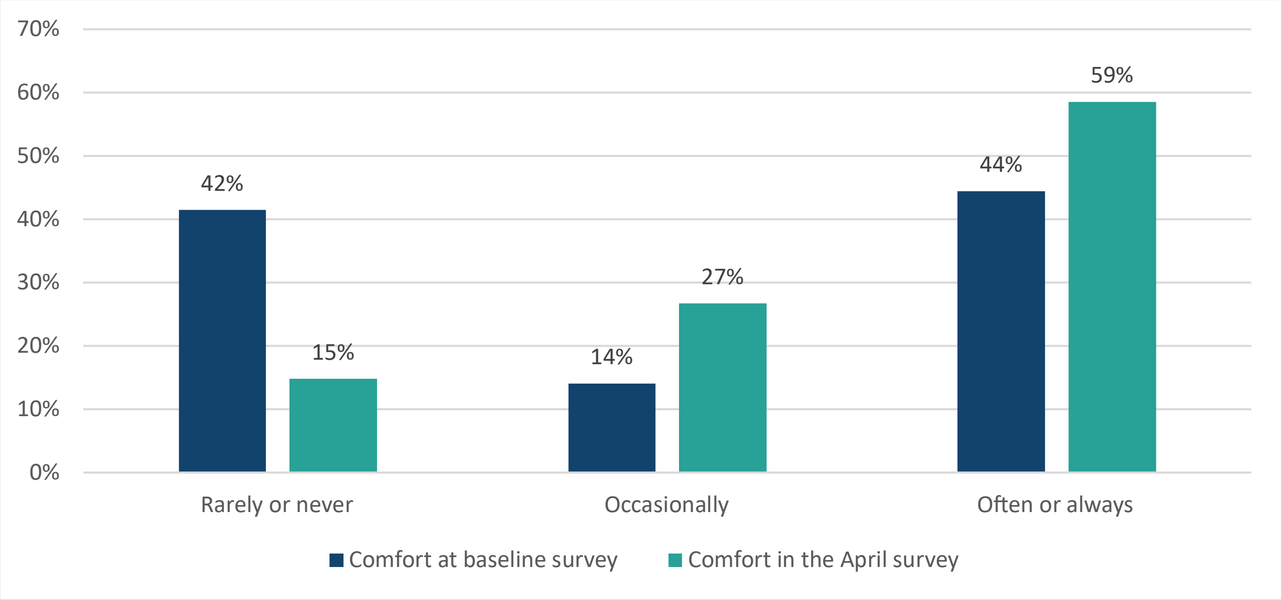
- Their ability to be comfortable in their bedrooms at night
- Their ability to be comfortable in their living rooms during the day
- Their level of satisfaction with life
- Their perception of the affordability of energy for them

The data were explored to understand if there were any changes in these for either those who received measures or those who didn't.

2.9.3.1. Change in participants' ability to be comfortable in their homes over the course of the trial

Compared to baseline, respondents who received measures reported being more able to keep comfortably warm in their bedroom during the night (Figure 56**).** Respondents who received measures shared how comfortable they were in their bedrooms during the night at baseline and in the April surveys (*n*=135). A Wilcoxon signed-rank test was used to understand if there is any significant difference detected between the ratings at baseline and in April, as well as a post-hoc McNemar test to understand the directionality of the relationship. A significant shift in responses on reported comfort was found (Z = 1100.00, p = 0.001). Post-hoc McNemar's tests were applied to assess the direction of individual shifts and to determine whether, relative to baseline, reported ratings improved or worsened. The post-hoc tests revealed a significant increase in respondents more '*often*' or '*always*' being able to maintain a comfortable temperature at home ($\chi^2 = 18$, $p = 0.014$). The same was found for those in the core trial who did not receive a measure (*n*=407, Z = 9251.00, p = 0.001, $\chi^2 = 18$, $p = 0.014$).

Figure 52: "During the cold weather this winter 2024/25, I could normally keep comfortably warm in my bedroom" (received measure)



Control group respondents showed a reduced ability to keep comfortably warm in living rooms during the day compared to baseline (Figure 57**).** Respondents in the control group shared how comfortable they were in their living rooms at baseline and in the April surveys (*n*=407). A Wilcoxon signed-rank test was used to understand if there is any significant difference detected between the ratings at baseline and in April, as well as a post-hoc McNemar test to understand the directionality of the relationship. A significant shift in responses on reported comfort was found (Z = 9414.50, p = 0.001). A post-hoc McNemar's tests were applied to assess the direction of individual shifts and to determine whether, relative to baseline, reported ratings improved or worsened. The post-hoc tests revealed a significant decrease in respondents more '*often*' or '*always*' being able to maintain a comfortable temperature at home ($\chi^2 = 36$, $p = 4.32$) and an increase in those neutral ($\chi^2 = 20$, $p = 1.14$) or less able to ($\chi^2 = 35$, $p = 0.013$) maintain comfort. No significant result was found for those with measures and their comfort in the living room.

Figure 53: "During the cold weather this winter 2024/25, I could normally keep comfortably warm in my living room" (control group)

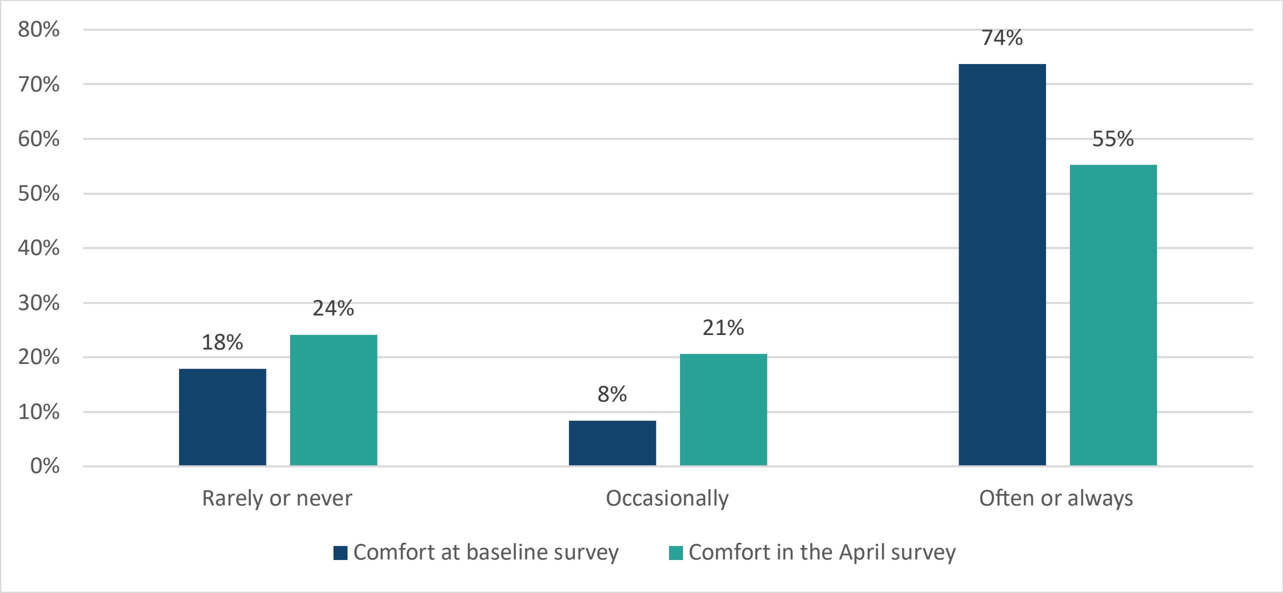
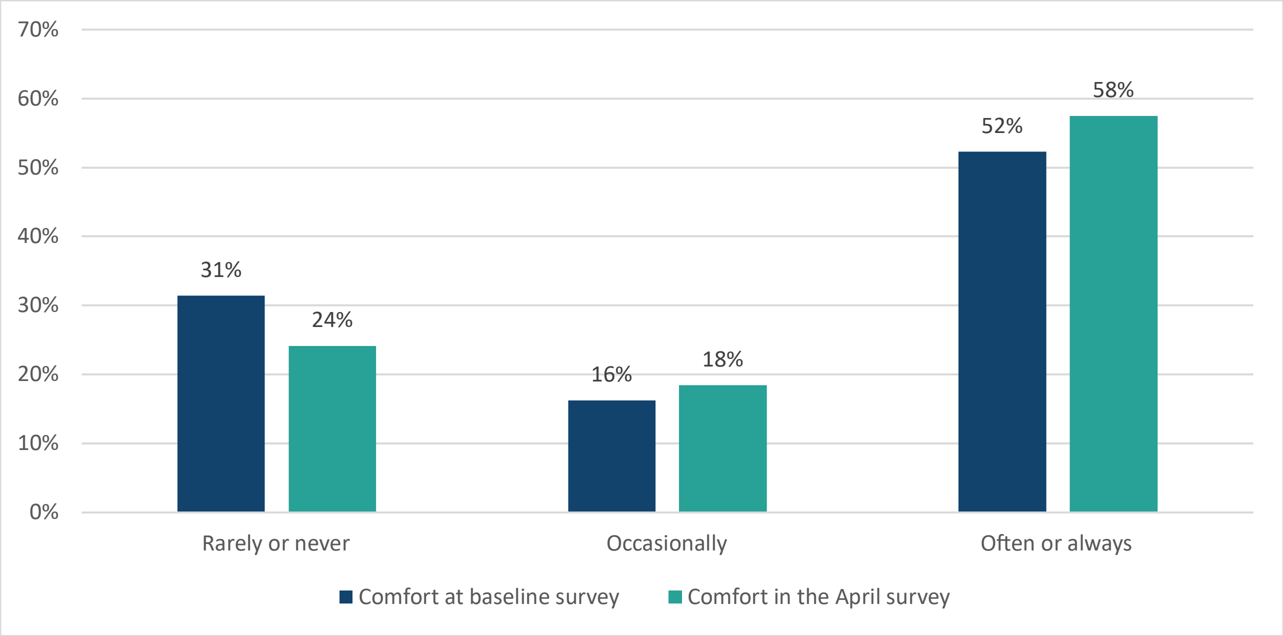


Figure 54: "During the cold weather this winter 2024/25, I could normally keep comfortably warm in my bedroom" (control group)



In summary, those who did not receive measures were more comfortable in their bedroom at night (Figure 58) but were less able to remain comfortable in their living room during the day during the cold weather (Figure 57), compared to the baseline. Participants who received measures also reported being more able to keep comfortable in their bedrooms at night during cold weather but did not report the same reduced ability to remain comfortable during the day. This could suggest some perceived improvement in ability to keep comfortable in their homes of those who received measures.[31]

There were no changes to either life satisfaction levels or energy affordability for any groups since the baseline.

2.9.4. Feedback on installed measures

Participants in the core trial had physical measures installed as part of the trial (*n*=197), between August 2024 and February 2025. Additionally, all participants received tado° controls in their homes.

A breakdown of the interviews and surveys conducted is summarised in Table 13.

To evaluate their experiences of receiving measures:

- Nine interviews were conducted in October and November 2024 with those who had measures newly installed,
- Survey questions were included in the April 2025 survey to core trialists. 566 participants responded to this survey, of which 137 had received measures.

Table 13: A breakdown of interviews conducted as well as surveys across different measures and participant Net Zero awareness score once they joined the trial[32].

	Interviews			**Survey**		
Measures installed	**Higher Net Zero awareness**	**Lower Net Zero awareness**	**Total**	**Higher Net Zero awareness**	**Lower Net Zero awareness**	**Total**
Boiler MOT		2	**2**	36	14	**50**
Boiler MOT+	1	1	**2**	13	6	**19**
Draught proofing	1	1	**2**	5	0	**5**
Loft insulation	1	1	**2**	36	20	**56**
Loft insulation and draught proofing		1	**1**	1	0	**1**
Boiler MOT and loft insulation	0	0	**0**	5	1	**6**
Total	**3**	**6**	**9**	**96**	**41**	**137**

Interviews gathered feedback from participants receiving measures on the process of having physical measures installed in their home, the impact of the installation and their preferences for the types of physical measures installed in the home. One participant who

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[31] It is worth noting that the time of year participants completed their baseline survey varied depending on when they were admitted to the trial – potentially some answered some months after the winter so were relying on memory of how comfortable they were able to be in their home during cold weather. However, everyone answered the April survey following winter, so should have had a good memory of their ability to stay comfortably warm or not. Also, some participants had measures installed part-way through the winter we were asking them about, up until February 2025.

[32] Note: The number of participants who had multiple measures was low, so those who received a boiler MOT and loft insulation and those who had loft insulation and draught proofing are merged into one for the purposes of analysis

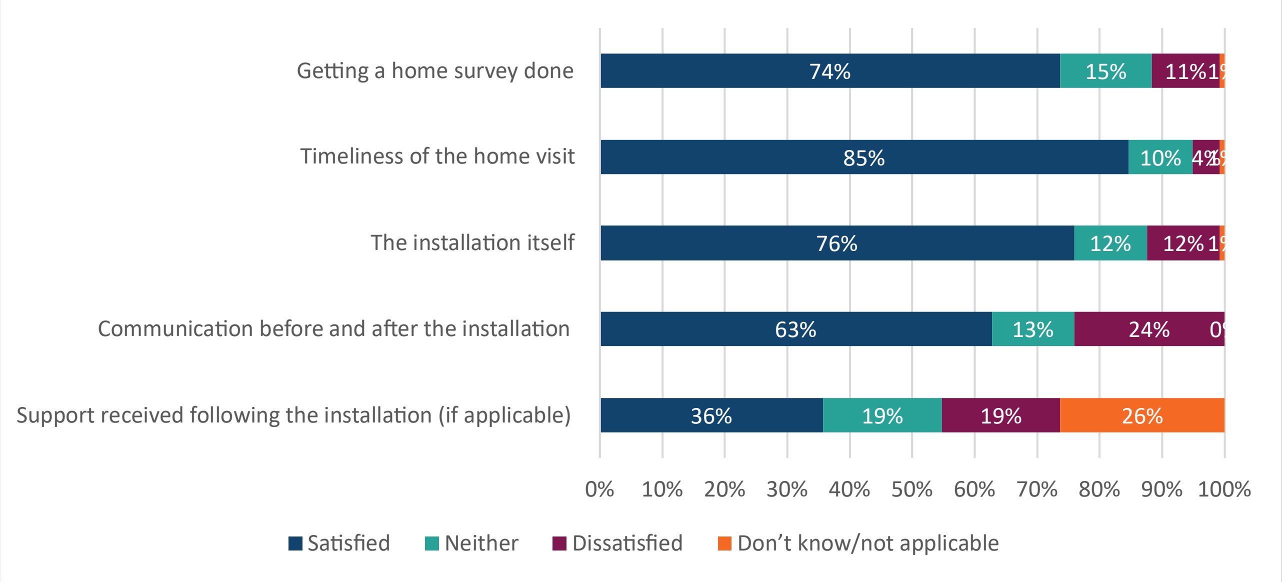
received a boiler MOT as part of the trial had a newly renovated home with modern heating systems already in place prior to the intervention. As their property does not meet the criteria of a 'hard-to-treat' home, their experience of the measure differed significantly from others. Some of their feedback is highlighted separately here, with more general contributions included further in the report. While they felt the measure improved comfort, they did not perceive any gains in energy efficiency and expressed concern that their energy bills might increase as a result.

2.9.4.1. Installation of measures

The process of installing measures included first conducting home surveys and was followed by installation of the measures.

Overall, respondents were satisfied with the process of getting their measures installed. As Figure 59 shows, the majority of those who received measures (*n*=137) were mostly satisfied with the timeliness of the home visit (85%), as well as the installation itself (76%) and the process of getting a home survey done (74%). More than half of respondents were satisfied with the communication before and after the installation (62%). Of those that received support (101 out of 137) following the installation, less than half (48%) were satisfied with the support provided. Whilst most of the process was satisfactory, some improvements in post-installation support are needed for respondents and would be valued, as feedback from interviews illustrates.

Figure 55: Thinking of your experience of getting the measures installed, how satisfied were you with the following[33].



Experiences of the installation: positive or negative experiences were considered against the impact of the measures. Positive experiences of installations were associated with installations that resulted in both high as well as low physical disruption.

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[33] Responses were grouped into three categories: ‘Satisfied’ includes those who reported being satisfied or very satisfied, while ‘Dissatisfied’ includes those who were dissatisfied or very dissatisfied.

Interviews indicated that positive experiences were mostly attributed to quick and seamless installation, as well as good quality work, and a satisfying result. Most participants recounted negative experiences of disruption related to unclear communication or cancellations from installers, prior to the installations. Whilst communication from the installer is important, such experiences were at times redeemed by positive outcomes of the installation.

Positive experiences

Participants who received refreshed loft insulation and/or boiler MOT's shared experiences of smooth installations, some being impressed by the efficiency of work, quality of the material, and the result.

> "The quality of what arrived, I thought looked better than I expected." *(respondent who received loft insulation).*

Some participants shared additional value they gained from the installations, which included taking the opportunity to ask the installer questions related to current installations and future home improvements.

Some installations exceeded expectations and added additional benefit

Participants shared that they were mostly looking forward to having a warmer home that heats up quicker and more efficiently. Those who received draught proofing, boiler MOT+'s, including someone who received both draught proofing and loft insulation, shared that their expectations were met or exceeded. The installations of measures served pre-existing problem areas that individuals wanted to tackle and acted as an enabler to continuing to improve their home by virtue of freeing up additional money that individuals could put forward to other home improvements.

> "It was much more efficient process, getting from start to finish than I thought it would be." *(respondent who received Boiler MOT+)*
>
> "It would probably take us quite a lot of time to build up the funds to move over to these radio smart thermostats and everything else. So, it would be something we would consider in the future, but it would probably be a few years down the line. So, this has basically done what we were planning to do ahead of time." (r*espondent who received Boiler MOT+)*

Negative experiences

Negative experiences were attributed to either disruption in the home or to working life, due to delays and changes, or dissatisfaction with outcome, or the time taken when considered with the outcome.

Concern with accuracy and quality

Two individuals were concerned with the survey report. One person who had checked their new EPC banding expressed concern that the home survey conducted was wrong. Others felt that the rooms most badly needing to have measures installed were not treated. Issues raised by respondents who were concerned about the quality of the work and installations were addressed accordingly by the project team.

Some installations did not meet expectations

Two individuals with draught proofing installations and one with a loft insulation installation felt their expectations were not met because they had different ideas of what the process of the installation would be. Individuals did not feel a noticeable difference following the installation and expected to experience better warmth and energy efficiency than it was at the time of interview.

An opportunity for more impact: better communication and sharing of information

In interviews, individuals shared they wanted more information on the implications of the measures on their home, for example, detail on how the measures would impact their EPC.

> "It would have been quite nice to know if [the loft insulation] impacted our energy certificate, because we are an energy certificate E but after the survey and after the loft installation, I don't know if that's changed or not, or if that's something I could find out…. So, I wonder, when I come to sell the house that I don't really have anything to prove that I've done some improvements to the house, it'd be quite nice to have on a piece of paper to say on this date I had something installed." *(respondent who received loft insulation).*

There was clear interest from this cohort to understand their homes better and make further informed and proactive changes to their home. All of those who had loft insulation, as well as some who had draught proofing and boiler MOT+, expressed interest in wanting to understand their homes better through receiving the reports of the surveys that were conducted of their homes. Others were expecting to receive the survey reports of the home, since they had been done.

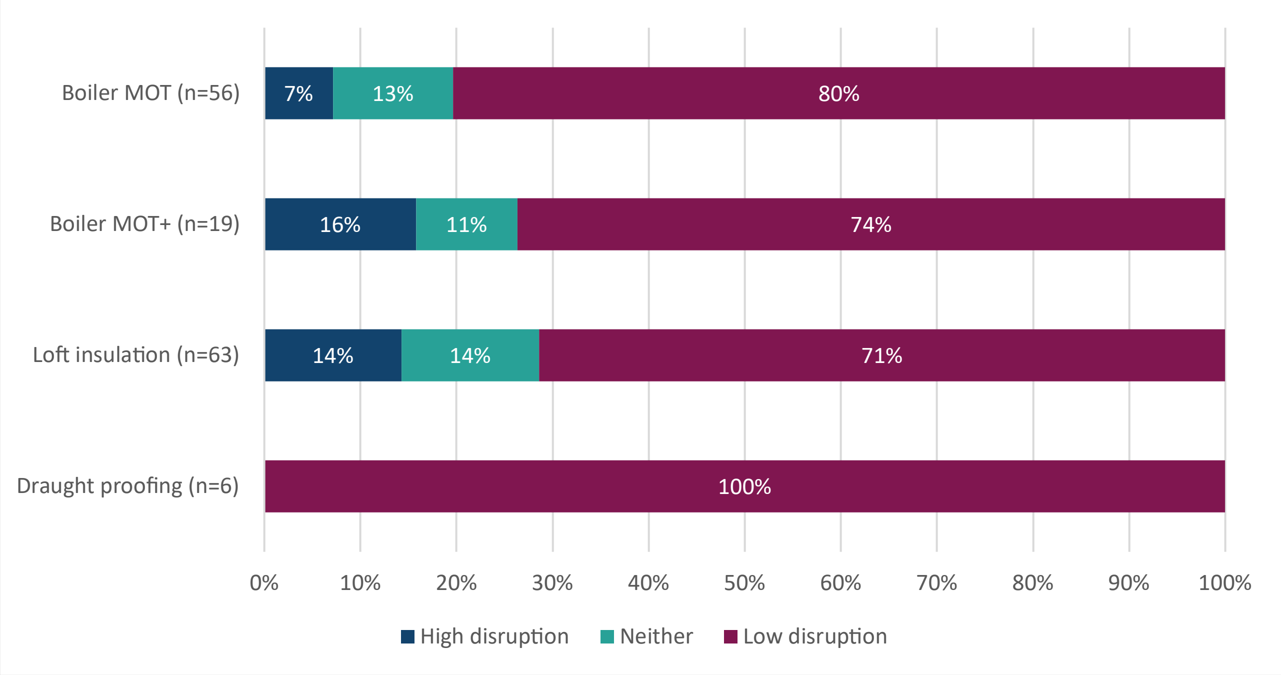
Better communication of the incoming measures across all participants could have enhanced the efficiency and outcome of installations. Whilst most participants had keen interest in getting measures installed in their homes, some participants, particularly those who received loft insulation, generally felt unclear on what the process of installation would entail before receiving the measures. Several respondents contacted installers in order to confirm whether they are going to do the installations, to find out if there was any pre-installation preparation they needed to do, or if they had failed to show or cancelled on the initial times specified. Not knowing when installers would arrive caused difficulties where preparatory work would be needed before the installation, with one individual foregoing an installation due to this. Communicating clearly about the process of the installation and the time of installation is a key area where installers could improve.

> "Just having a list of exactly what the process is, doesn't need to be too complex and go into detail, but it just gives that extra knowledge." (r*espondent who received Boiler MOT+).*

2.9.4.2. Impact of installation disruption

Three in four participants felt the disruption of the installations was low. Most participants found the measures resulted in low disruption (Figure 60). 100% of those that received draught proofing[34] felt that disruption was low. Within those who reported some level of disruption (*n*=55), the most frequent disruption reported was having people in their home for prolonged periods of time, followed by cleaning the space.

Figure 56: "On a scale of 1 to 5 where 1 is not disruptive at all and 5 is very disruptive, how disruptive was the measure?"[35]



Boiler MOT+

Three out of 19 recipients found the boiler MOT+ disruptive, possibly due to the additional depth and steps involved in this measure. Reasons cited for disruption experienced by those who had a boiler MOT+ include two respondents who weren't comfortable with having people in their homes for prolonged periods of time, and one respondent who reported that others in their home were uncomfortable during the installation, agreed that it

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[34] There were six people that had draught proofing and responded to the survey.

[35] Responses were grouped to simplify interpretation: scores of 1 and 2 were combined to represent 'low disruption,' while scores of 4 and 5 were combined to represent 'high disruption.' Responses of 3 were retained as a neutral midpoint. The total of those answering equated to 144 due to the 7 participants who had two measures giving feedback on both.

created a mess in their home, and felt it was time-consuming and negatively impacted their comfort levels.

Boiler MOT

Of the 56 people receiving a Boiler MOT, 29 people reported experiencing some disruption, however only four (7%) of them found it highly disruptive (scored '*4'* or '*5'* on scale of disruption). Of the 29 that reported some level of disruption, around a quarter (8) felt the installation was too time-consuming, finding clearing the space for it to happen difficult (6), and that the installation created a mess in their home (4), with some (3) being uncomfortable with having people in their homes for prolonged periods of time.

Loft insulation

Of the 63 participants who had a loft insulation refresh, nine (14%) found that the measure resulted in high disruption (ranked 4 or 5 for disruption). Of the 39 that experienced some level of disruption (ranked 2-5) from the installation of loft insulation, more than half (23) found clearing the space for the measure difficult[36], and 11 respondents felt like it created a mess in their home, which was supported by qualitative feedback. Some (5) also found themselves uncomfortable with having people in their homes for prolonged periods of time.

Respondents were tolerant of some disruptions. In interviews, respondents indicated they were more tolerant to disruptions such as installers taking a longer time than expected to install the measures or having to adjust their schedules to accommodate any installs. They were less tolerant where extra work was needed from them in preparing for installation or where work done was dissatisfactory.

Whilst the installation itself was efficient for most, one individual who received a boiler MOT+ felt it was a slow process with lots of delays and changes, with it taking about a year for the measure to be fully installed.

Respondents who were not able to work from home were more inconvenienced by disruptions and delays of the installations. Some shared experiences of installations such as loft insulation taking a full day to do or experiencing multiple cancellations. Instances where the installations took a long time or were delayed were less disruptive and ultimately resulted in more positive experiences for participants who were able to work from home during the installations

> "The loft insulation seemed like a not too intrusive way to hopefully make quite a big difference." *(respondent who received loft insulation).*

However, those who had less flexibility in their work felt this disruption was high, which was exacerbated when installers cancelled or didn't show up. One person who received

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[36] Originally, this measure was to include clearing the loft by the installer; however, the contractor couldn't fulfil this due to liability concerns for damaging possessions

draught proofing had taken time off work to accommodate the installation, as they were not able to work from home, and ultimately felt disappointed by the result.

> “Not worth the day off” *(respondent who received loft insulation).*

Some would not choose to install the measures themselves, especially if there was little change or very high disruption and effort involved. Some who considered the measures as making insufficient change e.g. having only certain windows draught proofed, or pre-existing draught proofing replaced, would not choose or pay for these measures themselves. In one case, a respondent’s home was in a conservation area, meaning only a replacement of pre-existing draught proofing was possible. Similarly, in one case of loft insulation where disruption was reported as very high in the installation and preparation stage, items from the loft were moved into the living areas, affecting day-to-day living and daily life of the residents.

> “The hassle that it's caused and the fact that the information wasn't there beforehand about the boarding and stuff like that, we absolutely would not.” *(respondent with loft insulation).*

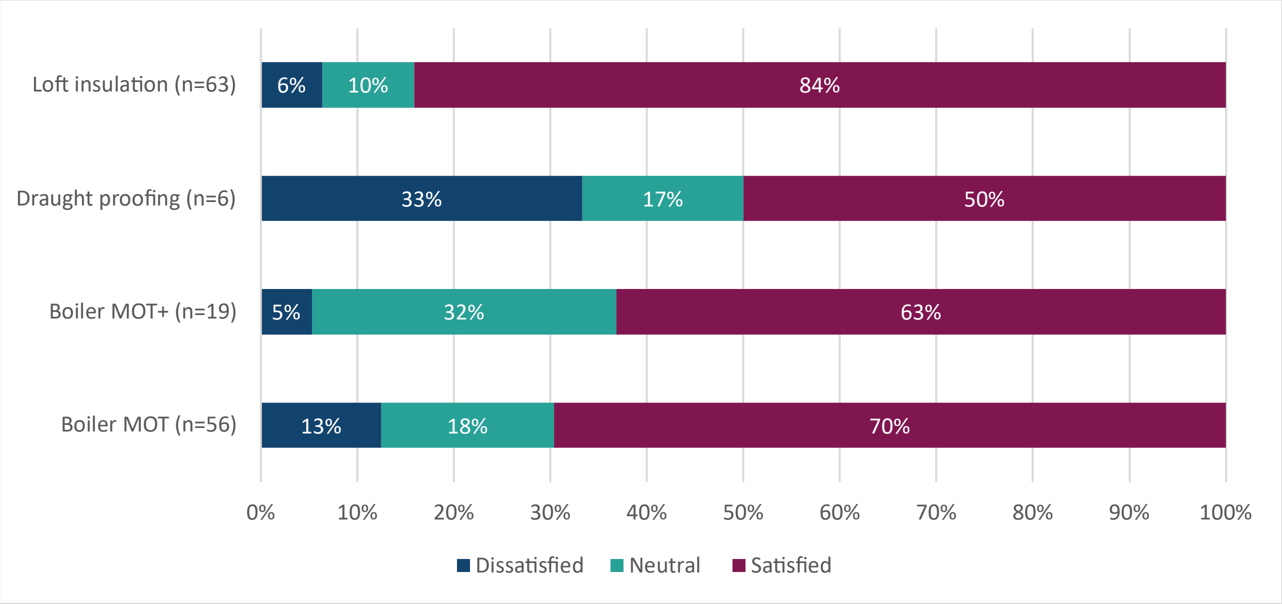
Participants would choose and pay for the measures that delivered tangible benefits, if they had the means. Respondents we spoke to with measures such as boiler MOT (1 participant), MOT+ (2) and those with loft insulation (2) felt tangible benefits of reduced bills and improved comfort would be worth choosing and paying for. Some of these participants mentioned wanting to do the measures before they had heard about the trial. Respondents shared that the reason they had not previously had this measure done was more to do with cost than concern over the level of disruption.

A respondent who received loft insulation and draught proofing said it was too soon to see what the savings on energy bills would be and how much warmer it would be in colder weather, in order to decide if it would be worth it. This was a limitation of the interviews being done swiftly after the installation. Although this approach was more likely to gather more accurate reflections of the process of installation, more time would be needed in colder months to assess the impact of the measures.

2.9.4.3. Benefits and comfort of measures

More than half of participants were satisfied with most measures (Figure 61).

Figure 57: On a scale of 1 to 5, how satisfied are you with the (measure) that was done in your home? (1 = very dissatisfied: 5 = very satisfied).[37]



Measures resulted in various improvements to respondent homes. Most participants who received measures experienced increased warmth and comfort at home (Figure 62).

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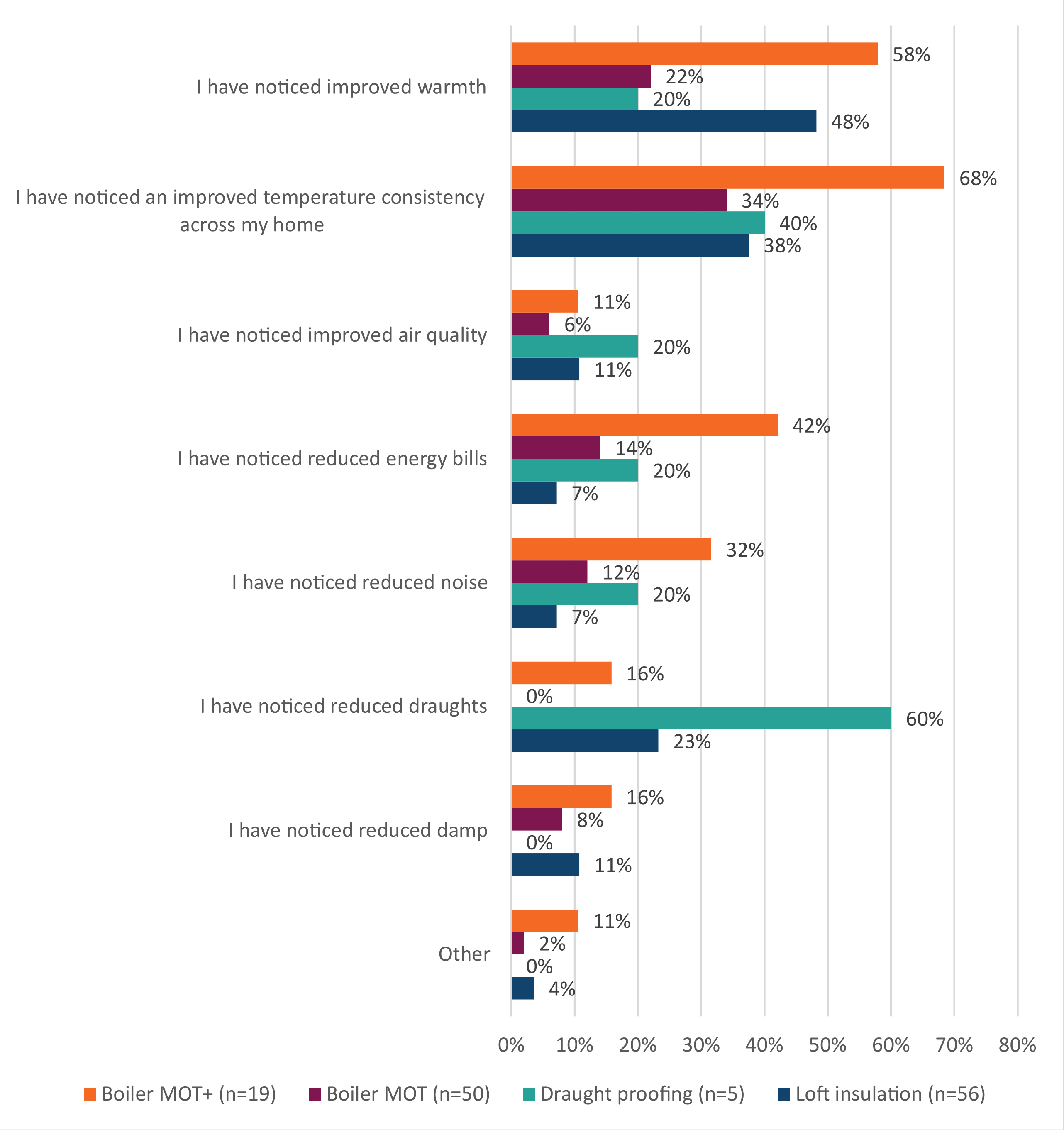
[37] Responses were grouped to simplify interpretation: scores of 1 and 2 were combined to represent ‘dissatisfaction’ while scores of 4 and 5 were combined to represent ‘satisfaction’. Responses of 3 were retained as a neutral midpoint. The total of those answering equated to 144 due to the 7 participants who had two measures giving feedback on both.

Figure 58: Since having the (measure) done, how much do you agree with having noticed any changes around your home? (multiple choice). Percentages shown are those who 'agree' and 'strongly agree' with the benefits of the installed measures



Boiler MOT

More than half of those who received a Boiler MOT were satisfied with the measure (70%), which corroborates with respondent satisfaction in interviews. Over a third (34%) reported that they noticed an improved temperature consistency across their home as a result of the measure. Less than a quarter of respondents (22%) felt improved warmth.

> "What we've had done is probably the most efficient" – *(respondent who had Boiler MOT)*

Boiler MOT+

Nearly two-thirds of respondents were satisfied with the Boiler MOT+ and reported high benefits of the measure (63%). More than two-thirds of respondents who received this measure reported that they noticed an improved temperature consistency across their home as a result of the measure (68%). More than half of those who had Boiler MOT+ reported improvement in warmth (58%), the highest compared to the other measures. Additionally, 42% of respondents said they'd noticed reduced energy bills and 32% noticed reduced noise because of the measure.

In interviews, most respondents shared there was a noticeable improvement in the warmth and comfort of the home and for some, how quickly the rooms warm up. Those who received boiler MOT+ (two interviewees), also found that it increased how comfortable they felt at home as they were able to occupy parts of the house that they used to find too cold during cold weather. They also mentioned being able to use fewer layers and blankets, as well as keeping the heating on for longer. Participants recounted increased comfort taking at home, which was facilitated by the tado° system which helped them heat specific rooms they would use.

> "It's noticeable when you're turning on the heat, and in other parts it's quite quick to heat up. It turns off when it's getting to that temperature so it's a nice and comfortable temperature" *(respondent with boiler MOT+).*
>
> "It does seem a lot nicer, because before, we just couldn't use the top floor at all in the winter because it was just so cold. " *(respondent with boiler MOT+).*

Loft insulation

Despite some difficulties with installations, most respondents (84%) were satisfied with loft insulation. Almost half of respondents (48%) experienced improved warmth in their home, due to the measure. Over a third (38%) reported that they noticed an improved temperature consistency across their home and just under a quarter of respondents noticed reduced draughts (23%).

Draught proofing

One third of survey respondents who received draught proofing were dissatisfied with what was installed, possibly due to dissatisfaction with the outcome mentioned earlier. Three respondents reported noticing reduced draughts and two noticed improved temperature consistency across their home.

A participant who had both loft insulation and draught proofing, shared in an interview that they felt their expectations were met and they were happy with the outcome. This individual described their home as being quite old and poorly insulated, with stained glass windows that would leak a lot of heat, making the home uncomfortably cold in cold weather. Following the installation of the measures, they had felt noticeable difference in comfort and bills, sharing that there is reduced draft and that the heating is on for less time whilst resulting in more comfort and feeling more in control of it.

> “I’m very pleased and I can already feel a difference in the entrance area." *(respondent with draught proofing and loft insulation about a previous problem area in the home).*

However, another participant with draught proofing thought the measures did not lead to improvement in comfort, reporting their home was still as draughty as it was before. They still had to use additional heating (gas fires), as well as throws and blankets to stay comfortable.

Monitoring equipment
tado° temperature and humidity technologies were used by all participants in the trial and was positively received. Those who had an MOT+ had tado° smart thermostatic radiator valves installed; they reported enjoying more control and ability to toggle heat in specific areas of the house and achieve better efficiency at home as well as savings on their bills. A few interview respondents shared that they had bought more or were planning to buy more tado° smart radiator thermostats for their home. Some did prefer “simpler” pre-existing ways of controlling energy at home and weren’t sure how to make best use of them.

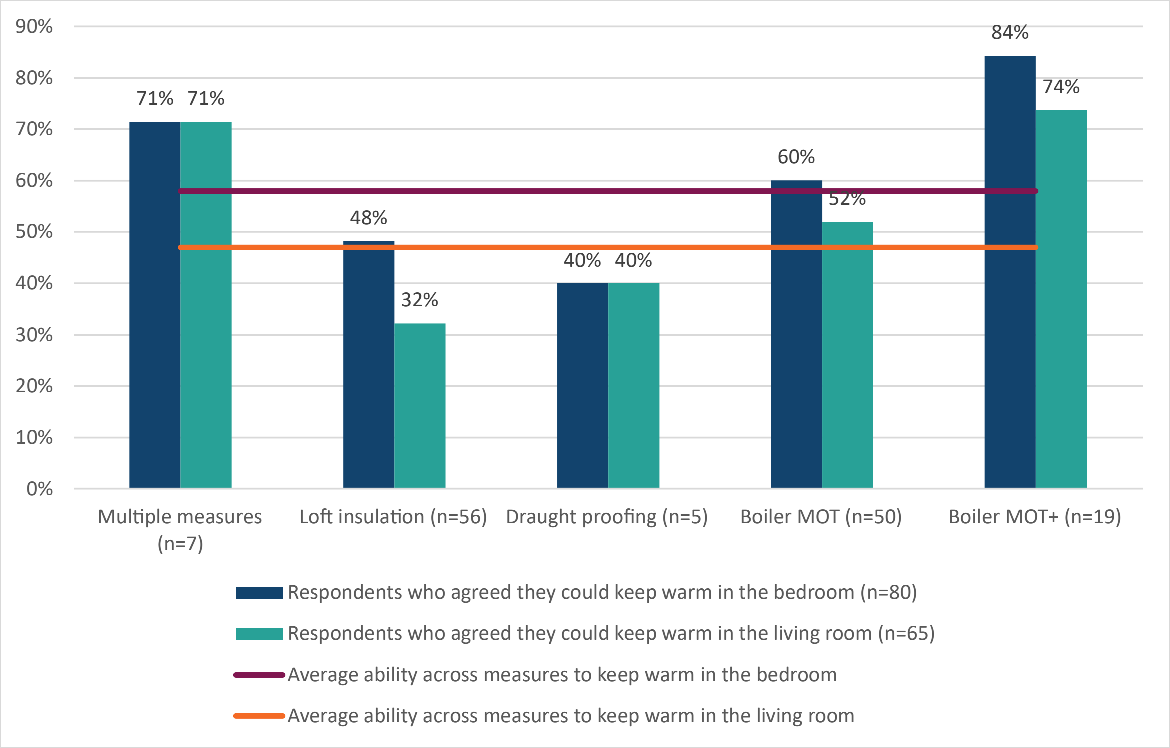
When participants were asked what additional measures, they would be interested in having installed in their home, a few mentioned they would choose to get more smart heating controls.

Respondents with certain measures reported being better able to keep comfortably warm than others.

Respondents who received multiple measures, boiler MOT, or MOT+, more often agreed they could keep comfortably warm in their homes compared to those who received loft insulation or draught proofing in isolation (see Figure 63). However, such differences should be interpreted with caution due to varying sample sizes across measure groups.

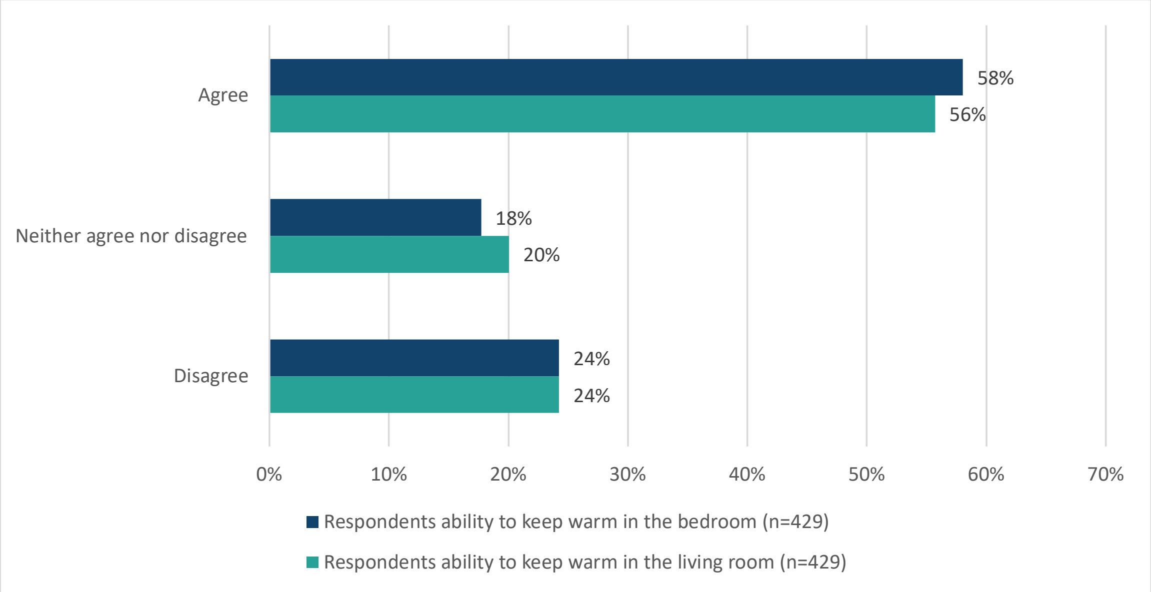
Across respondents who had measures, respondents more often agreed that they could normally keep comfortably warm in the bedroom when compared to the living room. Exploratory analysis indicates a significant association between type of measure installed and self-reported ability to be comfortable warm in their living rooms (or bedroom). However, the small sizes of the groups limit the reliability of this results and larger sample sizes are needed to robustly determine the direction and strength of this relationship.

Figure 59: "After I had the measure(s) installed, I could normally keep comfortably warm in my (bedroom/living room)" Graph shows numbers of those who 'agree' and 'strongly agree' combined.



For those who did not receive measures, ability to keep warm was similar across the living room and bedroom (Figure 64).

Figure 60: "During the cold weather this winter 2024/25, I could normally keep comfortably warm in my (bedroom/living room)"



2.9.4.4. Favoured measures

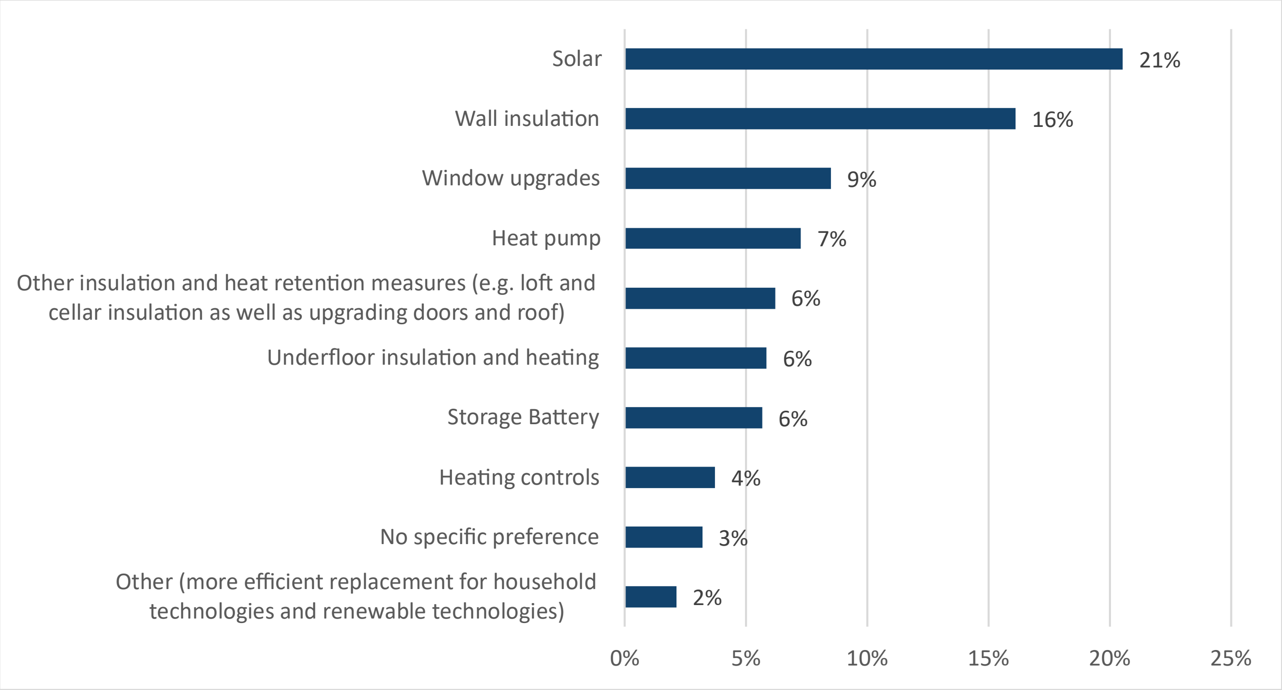
All core trial respondents were asked how interested they would be in having certain measures installed in their home. Overall, respondents were open to any measures that provided benefit to the home (*n*=566). Loft insulation (39%) and the boiler MOT (44%) were less popular with respondents that draught proofing (66%) and boiler MOT+ (also 66%). Respondents were able to select more than one measure.

Respondents would be interested in additional measures such as solar, wall insulation, and window upgrades. However, cost and home suitability is still a prohibitive factor.

Participants are interested in installing additional measures, especially those that improve insulation and warmth in the home. In interviews, most (five out of nine) participants shared wanting to upgrade their windows in order to prevent heat leaking. Participants also talked about being interested in measures such as underfloor heating, more insulation around the home as well as new back doors and solar panels. Heat pumps were mentioned by six of those we interviewed, however, each respondent shared potential barriers to adopting this measure such as cost, the suitability of heat pumps for their home, as well as uncertainty about the readiness of the technology. Some participants are looking out for new technologies that are coming to market that would suit hard to treat homes, and those in conservation areas.

This corroborates with the responses in the survey, where participants were asked about any other energy efficiency measures, they might be interested in installing. Similarly, solar, wall insulation, and window upgrades were amongst the most considered measures by respondents (Figure 65).

Figure 61: "Are there any other energy efficiency measures, not previously mentioned, that you would be interested in installing?"



There was interest in such additional measures, but 8% of respondents also voluntarily mentioned concerns regarding the cost of these measures, and how the cost can be prohibitive when compared with the returns or benefits. This at times, regardless of interest, prevents installation and adoption of these measures.

> “I certainly wouldn't be going for an air source heat pump or anything, because they just don't work properties like mine.” *(interview respondent with draught proofing in a conservation area).*

> “The cost is too much to actually deal with it. We can't have a heat pump because the property is too big to negate the cost. It would need two heat pumps.” *(interview respondent with draught proofing).*

Some respondents had no specific preference, with others mentioning additional barriers such as *“The age, build and design of the house, built in 1894, make most modern net zero ideas not easy or cheap to implement.”,* illustrating the difficulty in adopting newer more efficient technologies at times. Another respondent raised additional concerns about the air quality that the monitoring device indicates poor air quality at home. They were interested in what measures would help improve this.

2.9.4.5. Additional benefits of measures

In interviews, individuals shared more detail about how the measures had improved their homes.

Improved understanding and encouragement to do more

Three people interviewed said they valued information from the installer which helped them understand more about the measures installed and how to maintain them.

> *“I did ask the guys in terms of the radiators and other bits… it wasn't part of the process, but things like that, it's worth knowing.”*

A further 4 interviewees told us that the experience of having the measures installed improved their understanding of their home and how to make it more energy efficient. Most of this came from the installer during installation, but a few told us that they’d learned a lot from their tado app.

> *“I individually do the rooms that need the heating. Then getting information from the app, what the temperature of the room is, what the humidity is, and everything and sort of turning on the radiators in those rooms individually. Okay, I think that's a major change that I've done because I've got control.”*

Some (4 interviewees) felt having these measures has encouraged and enabled them to do further work on their homes.

> *"Motivated me to do a bit of what I could on my own"*

Reduced costs and increased control

A participant receiving loft insulation, and another receiving loft insulation and draught proofing told us that the measures had saved them money – allowing them to have the heating on less but being more comfortable and leading to a reduction in bills compared to previous year.

> “*Our bills are meant to be £110 a month, um, but this month, I've looked on the Smart Meter, and we've only used like, £48, and it's nearly the end of the month.” (respondent with Loft insulation)*

Others (one participants who received MOT and one with loft insulation and draught proofing) also experienced reduced bills, which they attributed to the tado controls allowing them to choose where the heating is on in the home.

> *“Last year, it might have been maybe towards the middle or end of November, but I was using about eight pound a day, seven pounds something a day, both gas and electricity together, whereas at the moment, is about £4.50.”*

tado°’s were also appreciated by participants who worried about the cost of energy (3 receiving boiler MOTs or MOT+). They shared they were able to feel more at ease about being able to control their heating and bills:

> *"When it comes to the colder months, last year, I was constantly turning it off when, you know, I was like, get a dressing gown on, get a jumper on, get whatever on. But now I feel like I could just leave the heating on, which is obviously a bit more comfortable for us, because we don't have to kind of worry."*

Improvements in air quality and noise pollution

A couple of participants told us that they had experienced improved air quality and were more optimistic about mould issues around the home (2 with draught proofing and/or loft insulation).

> *"The extractor fans made a huge difference. So, because there wasn't any ventilation in the kitchen, if I was to cook for longer than 30 minutes, the windows would steam up."*

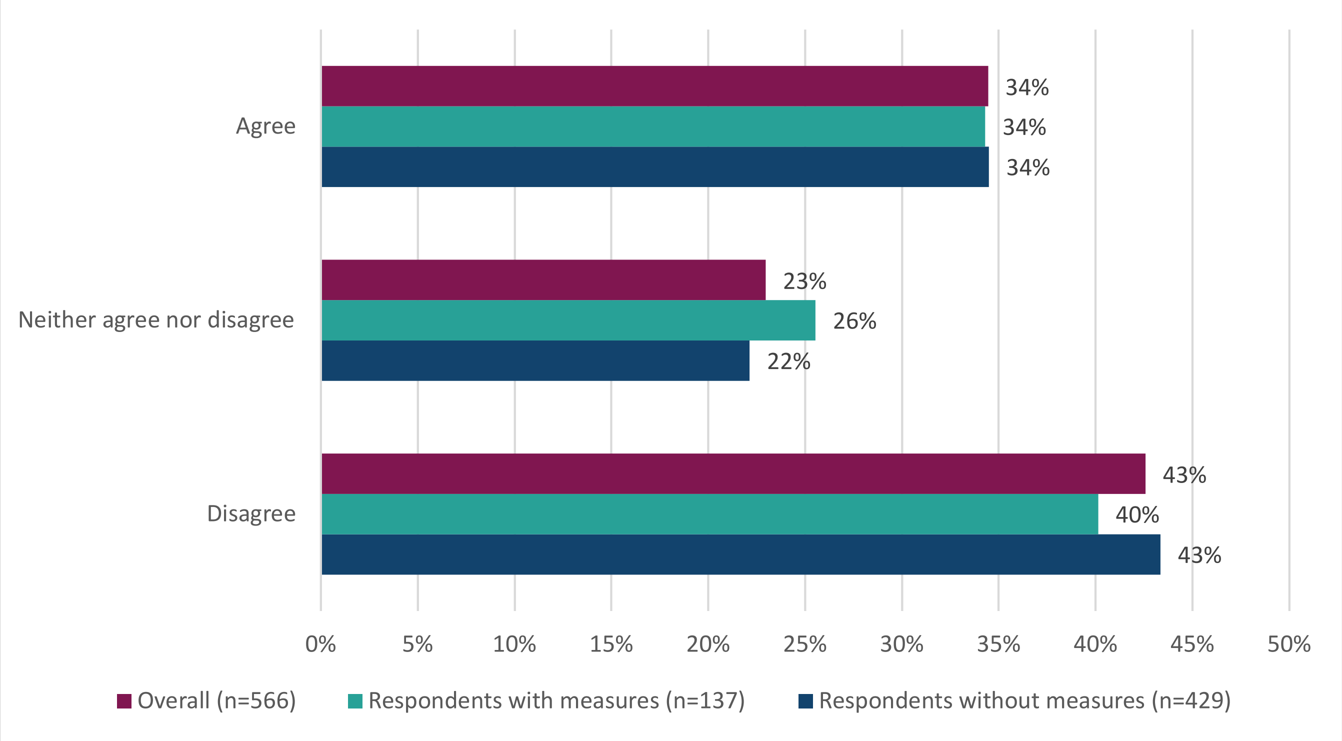
Another couple (2 with draught proofing and/or loft insulation) discussed noticed improvements in noise pollution.

> *"It reduced the noise pollution as well outside… the house is Victorian, so the front door's quite an old wooden style door… there'll be small gaps and stuff, but the insulation kind of filled all of those up."*

Home temperatures impact participants' physical and mental wellbeing

Overall, over a third (34%) of respondents in the April survey agreed that the temperature of their home in winter negatively affects their physical wellbeing (Figure 66). No differences were found between those receiving and not receiving measures.

Figure 62: “During this winter (2024/2025) I felt the temperature of my home negatively affected my physical wellbeing”.



When asked in what way the temperature negatively affects their physical wellbeing, participants mainly felt discomfort and low mood because of the cold, mostly feeling cold in their ‘bones’ and ‘extremities’. People expressed that pre-existing conditions were exacerbated by the cold, as well as new issues being created by it for other residents. Sickness such as colds and flus were common and attributed to a cold home, with movement and quality of sleep also being affected.

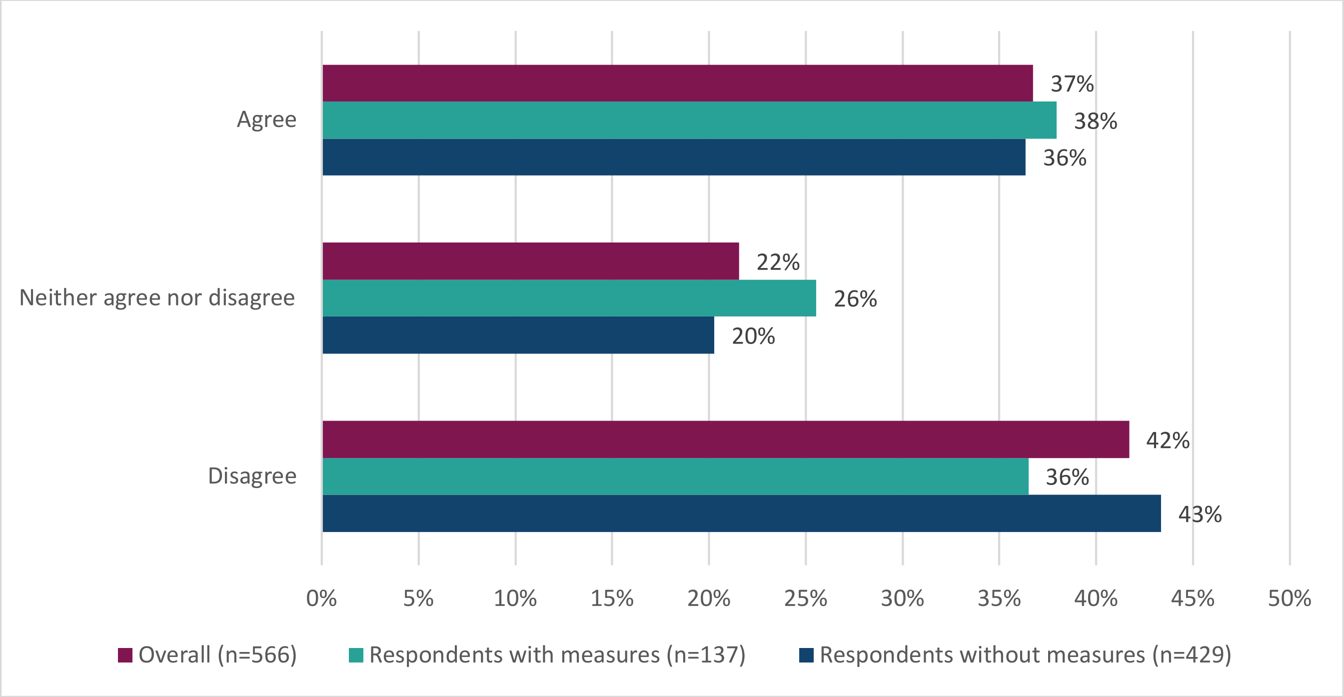
> “I suffer from asthma and the cold (particularly the first real cold of winter) causes issues with my breathing. For the past two years I have had to seek medical help and intervention.” *(control group respondent).*
>
> “With a newborn in the house, I have to constantly worry about keeping the environment warm and safe. We’re constantly trying to balance staying warm with keeping the bills manageable, and that tension affects everything from our routines to how well we sleep. Cold temperatures indoors affect every part of our daily life.” *(control group respondent).*

Respondents were also asked in the April survey if, in winter, the temperature of their homes negatively affects their mental wellbeing. Overall, over a third (37%) of respondents agreed (Figure 67). No differences were found between those receiving and not receiving measures.

The main ways in which the temperature affected the mental wellbeing of participants was by creating a low mood, lethargy, as well as stress. Stress and anxiety were linked to worries about the cost of heating and not being able to afford to heat it to a healthy temperature. Participants also felt their mental health worsen, and at times the cold either induced this or made pre-existing conditions worse. The cold temperatures of homes have made some people concerned about their health and the health of their families.

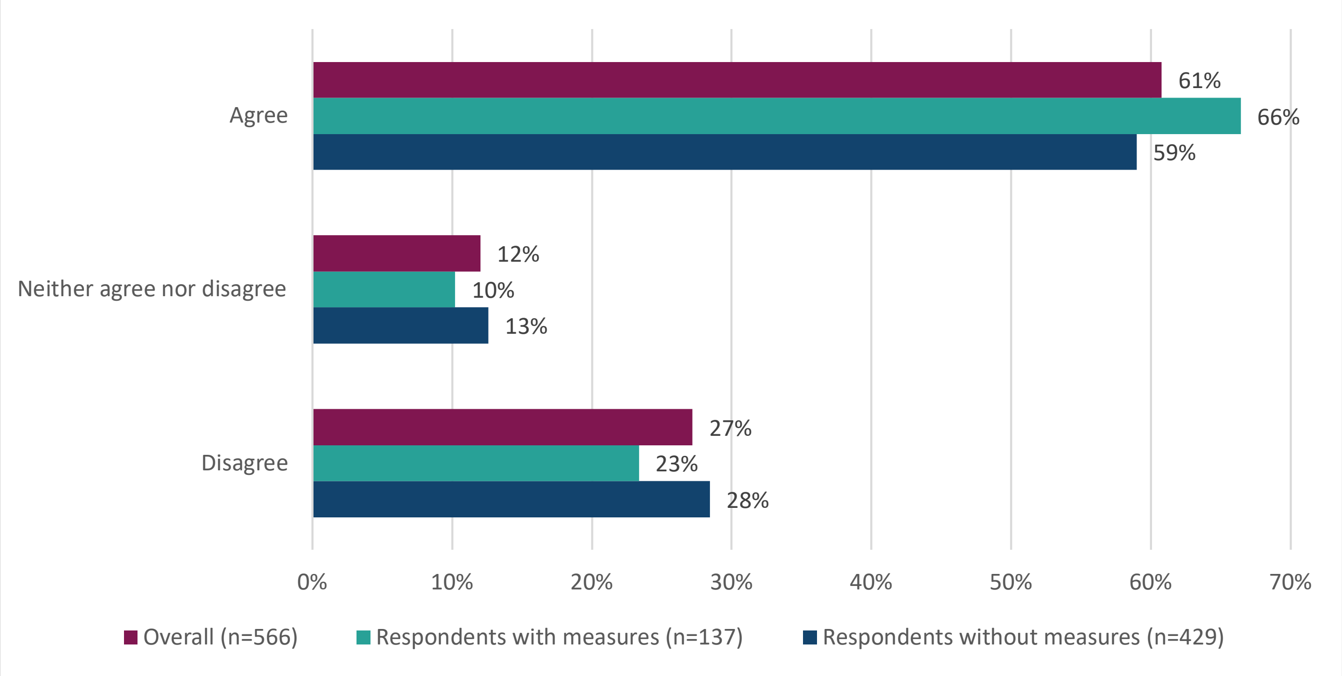
> "When my home is cold, it becomes hard to feel comfortable or relaxed, and that constant discomfort takes a toll over time. It's difficult to focus, rest, or even feel safe in your own space when you're always bundled up and still shivering. That kind of environment increases stress and drains my motivation to do anything—whether it's cleaning, cooking, or even just getting out of bed." *(control group respondent).*

Figure 63: "During this winter (2024/2025) I felt the temperature of my home negatively affected my mental wellbeing".



An increase in problems experienced with condensation, damp or mould amongst respondents without measures was significant. Overall, 61% of respondents agreed that they experience problems because of condensation, damp or mould in their home (Figure 68). This was slightly higher for those who received measures than those who didn't (66% of those who received measures vs 59% who didn't - not significant), but it was also significantly higher for those with measures at the start of the trial (59% vs 45% Z=2.85, $p<0.05$).

Figure 64: "I experience problems with condensation, damp or mould in my home"



To investigate this further, Wilcoxon signed-rank tests were performed separately for respondents with measures installed (n = 137) and without measures (n = 429) to understand if there was any change in condensation, damp or mould experienced by participants between baseline and April (see Figure 69). Although no significant difference was found for those with measures, there was a statistically significant difference in problems experienced associated with condensation, damp or mould for those *without* measures ($Z = 11108.50$ $p < 0.01$) between baseline and the April survey. A post-hoc McNemar test revealed that those who did not receive measures experienced 14% more problems associated with condensation, damp or mould than they did at baseline ($\chi^2 = 49$, $p < 0.01$).

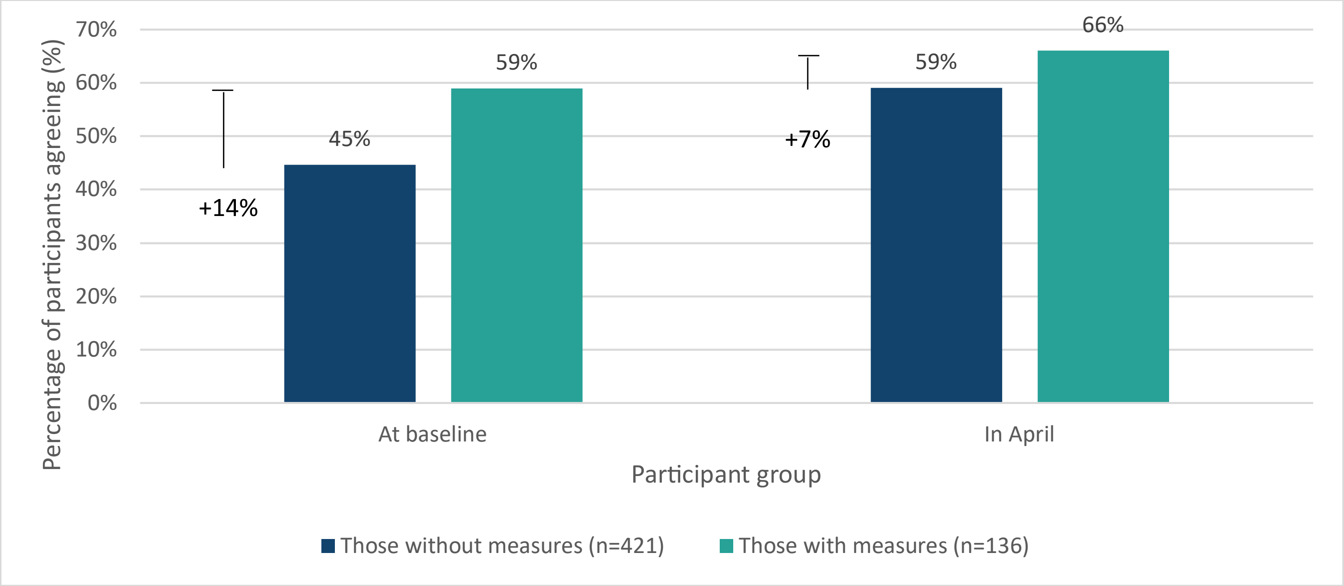
Therefore, whilst there is a trend towards more issues with mould and damp for all trial participants this increase does seem to be more pronounced for those without measures.

However, the implications of this finding are hard to interpret.

Firstly, it is not clear why there was an overall increase in problems with damp and mould. It may be because the April survey was fielded immediately after winter when these issues are usually worse and so more prevalent in people's minds, whereas the baseline survey was fielded whenever participants entered the trial which for many was in summer.

Secondly, whilst the smaller magnitude of the increase in damp and mould problems for those who received measures could be due to those measures, it could be that there was less scope for issues to worsen as they were already significantly worse for these participants at the start of the trial.

Figure 65: ***"I experience problems with condensation, damp or mould in my home"***



2.9.5. Limitations

Since interviews were done in October and early November in line with the original contract end date, and at times only a week or so after the installation, this might have contributed to individuals with certain measures not feeling a noticeable difference.

Whilst the approach of doing the interviews soon after the installations was more likely to gather more accurate reflections of the process of installation, more time would be needed in colder months to assess the impact of the measures.

In addition, small sample sizes made it hard to always draw statistically significant conclusions about the difference in experience of the experimental and control groups.

2.9.6. Key findings and future plans

This section of the report has presented findings from surveys of core trial participants. The following are key findings:

- Across measures, Boiler MOT+ was well received, delivering relatively high impact and any disruption being considered worth the outcome. The measure resulted in most reports of higher comfort and warmth consistency at home (bearing in mind small sample sizes).

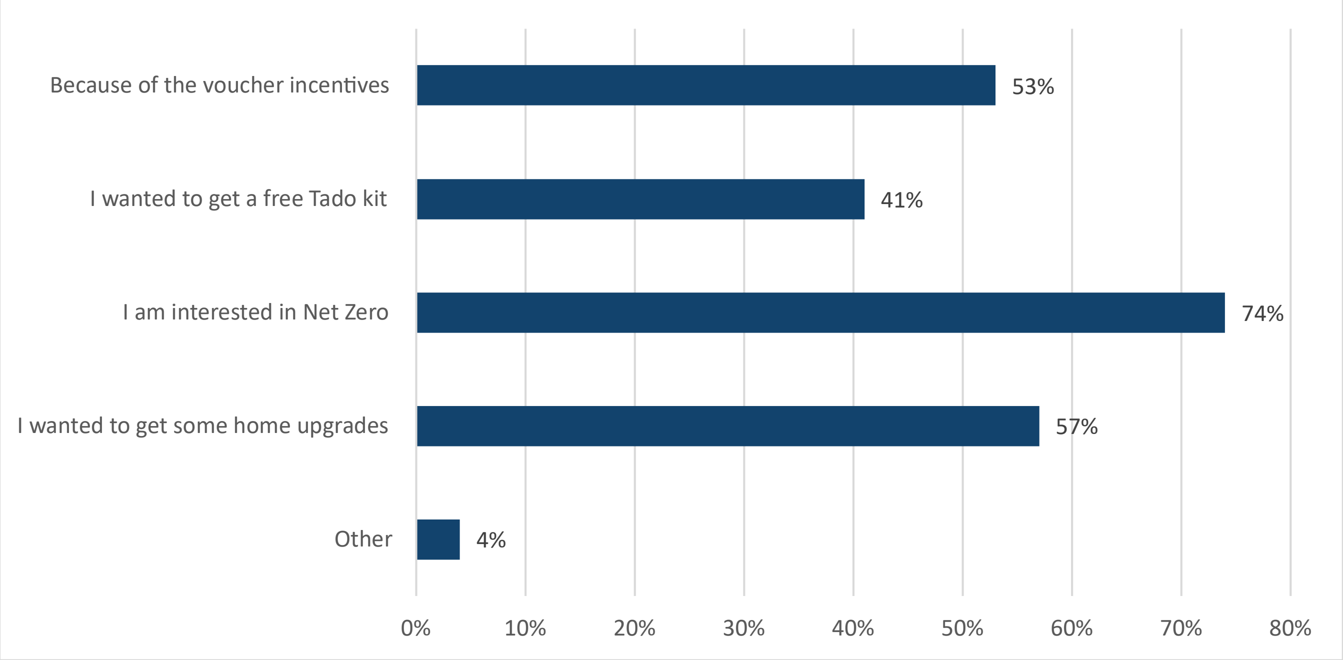
- Tado smart TRVs increased the impact of heating the MOT+ measure and provided the ability for respondents to target energy use, be more economical with energy use, and perceive a saving of money on bills.
- Respondents felt draught proofing was the least effective measure, with least impact and satisfaction with the outcome due to the small difference. In some cases, this was successful, when coupled with loft insulation, but in other cases, where this was done to a small degree, it was not well received.
- Loft insulation encouraged more stated comfort taking from participants, and most respondents were quite satisfied with the measure.
- Problems with condensation, damp or mould are worsening for participants, especially for those without measures. However, this could be partly to do with people answering this survey after a period of wetter and colder weather.
- Control group respondents indicated a reduced ability to keep comfortably warm in living rooms during the day, compared with their baseline measures. Those with measures showed an improvement in comfort in their bedrooms during the night.

This survey will be repeated again in early 2026 and will be conducted with participants on both trials.

2.10. Participant experience of the trial

Most participants found out about the trial through E.On (69%), the Catapult’s Living Lab (25%) with the remaining finding out through internet searches and word of mouth (*n*=566).Figure 70 shows that trial participants mainly signed up to the trial due to their interests in Net Zero (74%), the desire for home upgrades (57%), the incentives (53%), as well as a free Tado kit (41%).

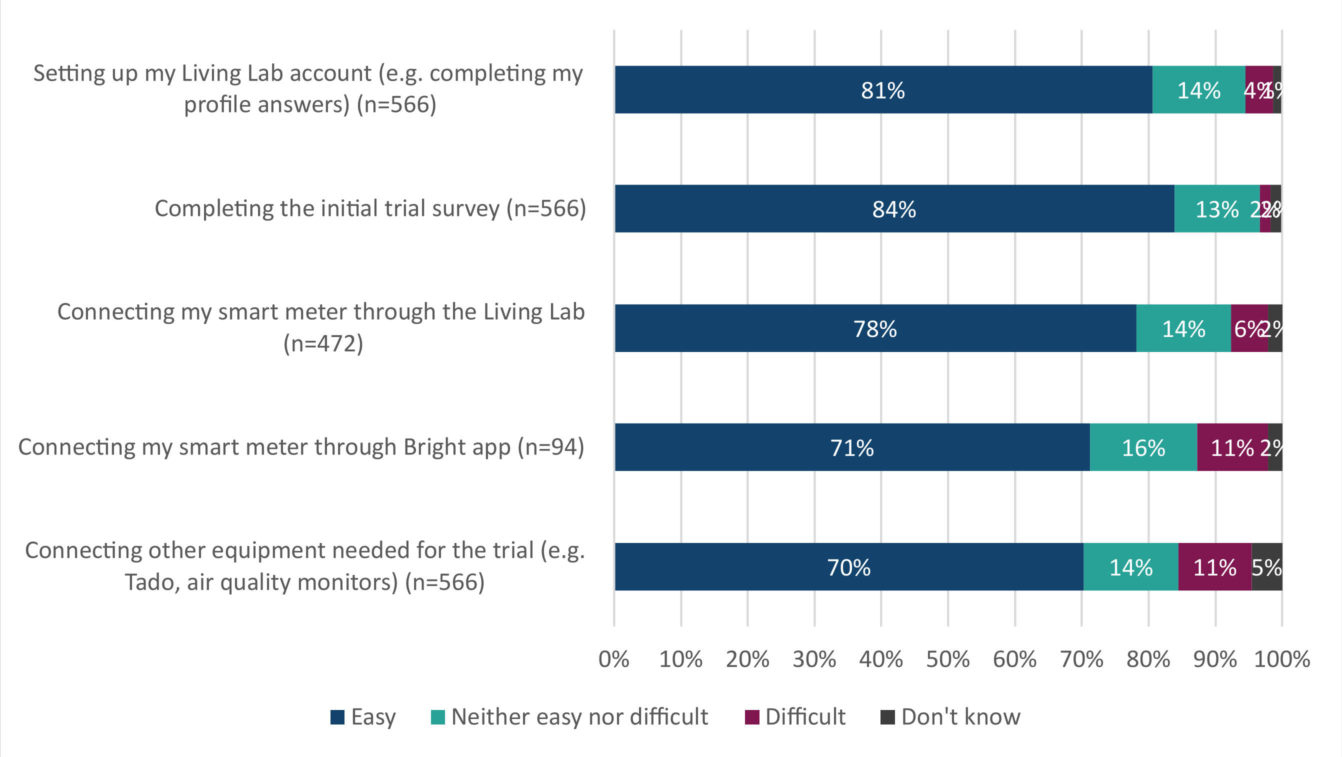
Figure 66: Why did you sign up to the trial? (multiple choice)



Participants mostly found it easy getting set up on the trial

The easiest aspects of getting signed up to the trial were completing the initial trial survey (84%) and setting up their accounts (81%), as shown in Figure 71. Whilst still being score relatively easy, some individuals struggled with connecting monitoring equipment for the trial (70%) and connecting their smart meters through an app (71%).

Figure 67: "How easy was it to do the following?" Note: Some respondents connected their smart meter directly through the Living Lab, or an app if they could not do it directly.



Overall, the majority (76%) of participants were satisfied with their overall experience of the trial thus far.

Participants who were satisfied mainly valued the measures and monitoring equipment they received and the benefit they have had on their homes. Participants found it was easy to participate in the trial and enjoyed informative aspects such as advice on how to manage their energy efficiency as well as contributing to making a positive impact to Net Zero. Participants were also satisfied about the incentives gained through the project, as well as the potential energy savings made from the equipment provided.

> *"The trial has identified things I can do myself to improve the efficiency of my heating system, and the kit has allowed me to get a good consistent temperature balance in my house, the surveys prompt questions and give additional nudges, I hope that the data my system is feeding back is useful "*
>
> *"The trial has made us more aware of energy use and air quality by linking and providing items for us to monitor these items more."*
>
> *"We've been able to install some key energy efficiency related kit that enables us to control our heating better. I feel better informed on energy efficiency and factors affecting climate change as a result. I'm certainly more conscious on carbon footprint and helping where we can."*

Primary reasons for respondent dissatisfaction with the trial were issues with the installer performance, as well as being uncertain of the value of their participation in the project. Some were also dissatisfied with the technological issues they experienced in setting up the equipment provided and dissatisfaction with not being selected for physical measure installation. A smaller proportion would have also liked more updates on the impact of the trial and better communication.

> *"I took part in a home energy assessment but got no feedback of the results of this survey or any recommendations for improvements. It would have beneficial for me to have seen the results of the survey, and suggest that this is something that could be done in future survey"*

> *"The general process was ok. I found it easy to onboard. However, after the house survey was completed, I got very little feedback or information, and I didn't know what measures to expect or what the next steps were for when I expected house visits (installs). I thought we would have a whole house retrofit survey shared with the resident so they could choose to take further action, but this was not the case. It's a shame as the surveys were specific to our houses."*

> *"We were supposed to have loft insulation fitted, but despite asking on numerous occasions for 2 weeks' notice of the install date, the company contacted us last-minute, making it very difficult for us to accommodate around work and commitments. When contacted some months later to try again, our new baby had arrived, so we opted to forgo the loft insulation."*

> *"I've not really seen a benefit or disbenefit of being included in the trial."*

2.10.1. Key findings and future plans

This section of the report has focussed on participants' experiences and perceptions of the trials. Most joined because of their interest in Net Zero. Participants completed many tasks to sign up and participate in the trials, all of which was most frequently found to be easy to do. Overall, participants were satisfied with the trial.

The survey will be repeated again in early 2026 and analysis of findings will be included in the next report.

3. Conclusion

This report is the second in a series to report progress on the Homes for Net Zero project. The report focusses on activities undertaken during 2025 and includes analysis of quantitative data for the summer period assessing overheating and air quality, as well as insights from surveys and interviews with consumers in the trials.

With the summer of 2025 being the hottest on record in the UK, it is unsurprising that householders reported that they found it difficult to be comfortable in their homes, both during the day and overnight. An assessment of data from temperature and humidity sensors in trialists homes found that, on average, homes were above a threshold for overheating (26°C) overnight for nearly an hour a day during summer months. When days classified as a *heatwave day* only were included in analysis, this increased to nearly 5 hours per night. Many reported using passive cooling measures, such as curtains and blinds and opening windows to improve their comfort but often were unsuccessful.

An analysis of data from triallists with heat batteries found that they were slightly more expensive to run when compared with gas or oil boilers, or air-source heat pumps. However, the tariff chosen by the household, as well as the location of the heat battery, can both make significant differences and bring running costs in line with alternative systems. Householders mentioned the upfront costs of the technology, with some relying on grants and trials to be able to afford it. Householders highlighted both positives (e.g., cheaper upfront than an ASHP, indoor only unit, fast and low-disruption install) and negatives (e.g., more hand-on management required, need for boost on cold days due to inadequate battery capacity) from the lived experience with the technology.

An analysis of data from air quality sensors found that most households had a level of air quality that met guidelines set, for example, by the World Health Organisation. In some instances, some households had extreme values that exceeded healthy thresholds, but often only for short periods of time; these may be explained by activities in the home, such as cooking or use of wood burners.

Nearly a fifth of the households in the core trial had measures installed during earlier phases of the project; most reported that installation of these measures caused a low level of disruption and left householders highly satisfied. The most positive experiences were from those who had the Boiler MOT+ measure (radiator upgrades, heating system service and powerflush, reduced flow temperature); they frequently reported being warmer, with a more consistent temperature in their home, and reduced bills.

The HfNZ project is continuing into 2026 and will report again on the findings from winter 2025/26 in due course.

4. Appendices

Appendix 1: Project research questions

Trial	Research Question ID	Research Question
Core	1.1	What are the energy savings of individual measures?
Core	1.2	What are the energy savings of different packages of measures?
Core	1.3	Are initial energy savings maintained over time?
Core	1.4	What is the cost of delivering individual measures?
Core	1.5	What is the relative cost of delivering individual measures vs packages of measures?
Core	1.6	How long will it take for measures to pay back?
Core	1.7	What additional benefits do measures provide?
Core	1.8	Have measures led to comfort taking (increasing either the time or temperature homes are heated following improvements to energy efficiency)?
Core	1.9	Have measures led to improvements in occupant comfort?
Core	1.10	Do improved controls lead to higher mean internal temperatures?
Core	1.11	How disruptive did consumers find the installation of the measures? Would this impact them choosing these measures if they were paying for them?
Core	2.1	What impact can simple, low-cost measures have on the cost and suitability of homes to install low carbon heating such as heat pumps?
Core	2.2	Which measures, of those offered, are more or less attractive to consumers?
Core	2.3	Are there other measures, not offered, that consumers are interested in installing?
Core	2.4	What are the measures that most homes can take to put them on the path to a Net Zero compatible home?
Core	2.5	Which of these measures are most effective and should be prioritised?
Core	2.6	What is the opportunity for incremental improvement compared to whole house retrofit?
Core	3.1	What is the current distribution of energy consumption in homes within the monitored sample?
Core	3.2	How does the energy consumption of the trial homes compare with a representative sample of homes?
Core	3.3	How does the sample of trial homes compare to the wider population of England and Wales in terms of: - Occupancy - Tenure - Level of energy efficiency - Heating systems - Construction
Core	3.4	How do the trial participants compare to the wider population? Including: - Interest and awareness of climate change and Net Zero policies - Age, gender, income level, education level, language
Core	4.1	What is the current level of overheating according to recognised definitions in sample homes?
Core	4.2	What is the perceived level of overheating in sample homes?
Core	4.3	What measures are occupants taking to manage overheating?
IAQ	4.4	What is the current level of air quality inside homes?
IAQ	4.5	What factors influence indoor air quality (IAQ) in homes in the trial? Including but not limited to; behavioural, location e.g. proximity to external sources of pollution, internal sources e.g. wood burning stoves, cooking, ventilation, occupancy.
AEH	5.1	What are the costs associated with designing, installing, operating and maintaining RAAHP systems in homes? What additional technologies are needed to provide comfort and DHW requirements?
AEH	5.2	How are systems sized for heating and what cooling capacity does this provide?
AEH	5.3	How efficient are RAAHPs in providing space heating to homes when they are the sole space heating device and when in combination with other technologies?
AEH	5.4	How efficient are RAAHPs when providing cooling and is the capacity sufficient for occupant comfort?
AEH	5.5	What is the electricity demand profile for different system designs?
AEH	5.6	What factors led to consumers choosing to install a RAAHP system? How much of a factor was the ability to provide space cooling?
AEH	5.7	What is the occupant's lived experience with RAAHPs? o What are the comfort levels in cold weather? o Are they easy to control and use? o What are comfort levels in hot weather? o How is indoor air quality affected and how does this compare with homes that do not have space cooling? o Are there any issues with noise from the internal or external units?

Heat battery	6.1	What is the occupant’s lived experience with heat batteries? 1. Do they provide required comfort when needed? 2. Are they easy to operate and control?
Heat battery	6.2	How effective are heat batteries at storing and discharging required levels of heat?
Heat battery	6.3	What proportion of heat demand is met by secondary heating in homes with heat batteries?
Heat battery	6.4	How efficient are heat battery systems in-use?
Heat battery	6.5	What are the costs of (a) installing, maintaining and (b) operating heat battery systems?
Heat battery	6.6	What additional systems are required when using heat batteries, e.g. domestic hot water (DHW) provision, secondary heating?
Heat battery	6.7	What proportion of a household’s total electricity demand do heat batteries account for?

Appendix 2: Additional Assumptions and Data Sources (heat battery trial)

Hot Water Demand

In some homes the ZEB is used to provide hot water, while others use an alternative heat source for hot water such as an immersion heater. To make these costs comparable, we add 6.25 kWh to the daily heat demand of those consumers that use alternative hot water sources. This number is based on a typical annual value of 2281 kWh.[38]

In the case of the ZEB, we assume that the hot water is provided by a 3-kW immersion heater. Such a heater would need to run for about 2h 5min to meet the daily heat demand. We also assume that the immersion heater operates off-peak as hot water tanks have low intraday heat loss rates. For consumers on Agile or Cosy tariffs, we use the cheapest contiguous time window of 2h 5min.

For the counterfactual costs, we assume that the counterfactual technologies themselves provide hot water.

Efficiencies of Boilers

Gas boiler efficiencies are taken from the 2009 report "Final Report: Insitu monitoring of efficiencies of condensing boilers and use of secondary heating"[39], which includes figures for both combi boilers and regular boilers. The efficiency we use in this report is **84%** which is an average between different boiler types to represent the stock average.

We assume the efficiencies of oil boilers are identical to those of gas boilers.

Heat Pump Efficiencies

The type of heat pump we assume as a counterfactual technology are air to water heat pumps.

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[38] https://www.gov.uk/government/publications/domestic-hot-water-use-in-the-uk

[39] https://assets.publishing.service.gov.uk/media/5a75149be5274a3cb28697f7/In-situ_monitoring_of_condensing_boilers_final_report.pdf

Our source for their efficiencies is the Catapult's Interim Heat Pump Performance Data Analysis Report[40], which states:

The seasonal performance factor (SPF) of a heat pump is the ratio of the total heat supplied to a building (by the heating system) to the electricity used by the heat pump and other components of the heating system over the year.

We use SPFs for heat pump counterfactuals which means we use yearly averages for heat pump efficiencies, instead of using values that depend on outside temperatures or the time of the year.

On p.51 one finds the definition of different efficiency boundaries, which are denoted by H1, H2, H3 and H4.

For the overall heat pump SPF, we use the H3 boundary (**median efficiency of 2.89)**, as this boundary includes immersion heaters and all the heat pump's heat output but does not include auxiliary equipment like circulation pumps (equivalent to the heating system components included in the ZEB's electricity consumption measurements).

Inflation Adjustment

To adjust for inflation, we convert all costs into 2024 £, using the Consumer Price Index.[41]

Gas and Electricity Prices

For gas and electricity, we have used Ofgem's price caps as unit rates. For counterfactual technologies we assume consumers would be on a flat-rate electricity tariff, so the unit rate is always equal to the Ofgem price-cap and does not vary by time of day. Since Ofgem's price caps change every quarter, we have used historical values to align them with the month of use.

We do not use the information about where each home is geographically located and instead use national average prices.

The prices we use include VAT.

Oil Prices

Oil prices are taken from the table 2.13a of the gov.uk source "Domestic energy price indices".[42] The cost per kWh is significantly cheaper than gas.

Standing Charges

To compare operating costs of gas boilers and ZEBs we assume that consumers using a gas boiler would pay the gas standing charge while ZEB consumers do not. This adds about £10 per month of savings of the ZEB compared to gas boilers.

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[40] https://es.catapult.org.uk/wp-content/uploads/2023/03/EoH-Interim-Heat-Pump-Performance-Data-Analysis-Report-1.pdf

[41] https://www.ons.gov.uk/economy/inflationandpriceindices/timeseries/d7bt/mm23

[42] https://www.gov.uk/government/statistical-data-sets/monthly-domestic-energy-price-statistics

Standing charges are not applicable to oil boilers, increasing the savings of operating an oil boiler compared to a gas boiler.

Appendix 3: Submetering RAAHP systems

The intent of the alternative electric heating trial is to install electrical submetering to record the energy consumption of all heating systems in each home – both the new RAAHP and any existing heating appliances which remain in use. This will help to build a clear picture of how the different heating systems contribute to the homes' overall heating requirements. However, the variety of electrical configurations encountered in the homes in the trial posed frequent challenges for achieving complete metering setups.

In this trial, electrical submeters which fit in the home's electrical distribution board (also known as the "consumer unit", "fuse box" or "breaker panel") and monitor the energy consumption of individual circuits in the home are being used. For the electricity consumption of heating appliances to be metered accurately, they must be supplied by dedicated electrical circuits, so that a submeter can be connected to the corresponding circuit in the distribution board. In many cases, however, heating appliances were found to be supplied from a general ring main circuit, which also supplies other appliances via sockets. In some cases, the heating appliances themselves were plug-in appliances, whether portable or permanently wall mounted (see Figure 3).

Figure 68: Photo from site showing permanent wall-mounted heater which appears to be plugged into a ring-main socket. An absence of dedicated heating circuits in this home's distribution board supports this conclusion.

In several cases, unclear labelling of circuits in the distribution board made it difficult to deduce how heating was supplied, and therefore how many submeters would be required, and whether complete submetering of heating would be possible (see Figure 4). Software used by surveyors to generate survey documentation reduced the resolution of photos, which also contributed to circuit labelling being illegible.

Figure 69: Photo from site showing distribution board with poor labelling of circuits

Another difficulty was encountered in some homes where a large number of heating circuits are present. Every heating circuit needs to be connected to its own submeter, and a common setup in homes with electric heating is for every room heater to be served by its own circuit, meaning a meter would be required for every room. The installation contractor was not prepared to alter the wiring configuration of the existing circuits to allow multiple heating circuits to be monitored from a single submeter, due to the liability they would then take for the condition of those existing circuits.

Initially, the Catapult was procuring meter hardware (which had been used in previous projects) which occupies two spaces ("ways") in a distribution board (see Figure 5), but as the challenge of large quantities of meters became apparent, meters which occupy a single space to make installations more manageable were used.

Figure 70: Photo from site showing submetering arrangement in newly installed distribution board[43].

Homes with storage heaters often have a standalone distribution board for heating circuits (see Figure 6), which is only energised during overnight off-peak hours. This presents a convenient option to meter all existing heating with a single submeter, by connecting the entire distribution board downstream of the submeter. However, this option requires the home to have an isolator switch present (see Figure 6) to allow the distribution boards to be disconnected from the mains supply, so that they can be safely worked on. Many homes do not have an isolator switch installed; historically, electricians have relied on removing the main incoming fuse to isolate the distribution board, but it is considered bad practice for electricians to interfere with this fuse, which is property of the distribution network operator (DNO). Householders can request the installation of an isolator switch from either their energy retailer or their regional DNO, and this is sometimes provided free-of-charge, or for a modest fee.

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[43] From left to right: a double-width submeter (occupying ways 9 & 10), three single-width submeters (ways 5-8), the gateway which transmits meter readings to the remote data platform (ways 4 & 5) and three circuit breakers supplying various heating circuits (ways 1-3)

Figure 71: Photo from site showing separate distribution boards for off-peak heating (top left) and all other circuits (top right), each with isolator switch (bottom centre). Smart meter (bottom right) and DNO incoming fuse (between meter and isolator switches)

In two cases, participants were asked to obtain an isolator switch, because it was not possible to connect the RAAHP downstream of their existing distribution board, and so it was necessary to isolate the distribution board and connect the RAAHP upstream. This can be due to a lack of spare ways available to supply the RAAHP from the existing distribution board, or a distribution board which would require obsolete circuit breaker components. The experience with these requests was that energy retailers have been quick and cooperative, arranging the installation within a few working days either free of charge or for under £100, and the installation itself was straightforward and undisruptive.