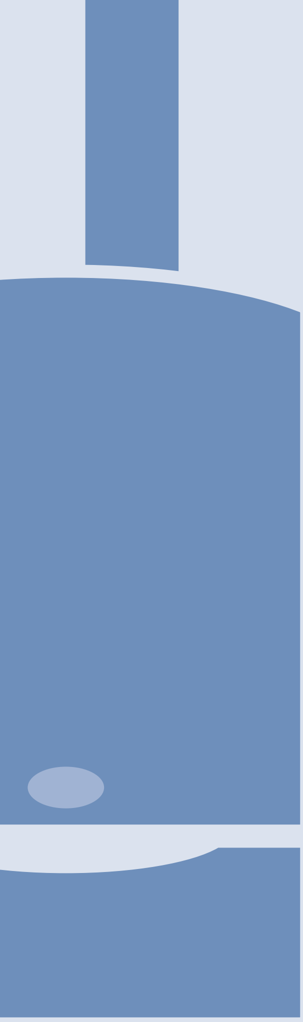
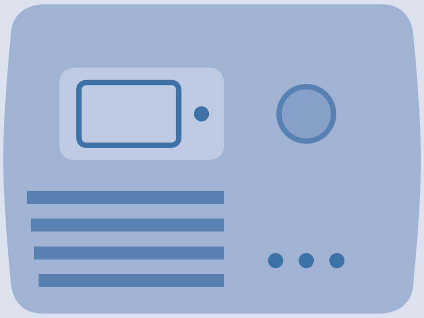
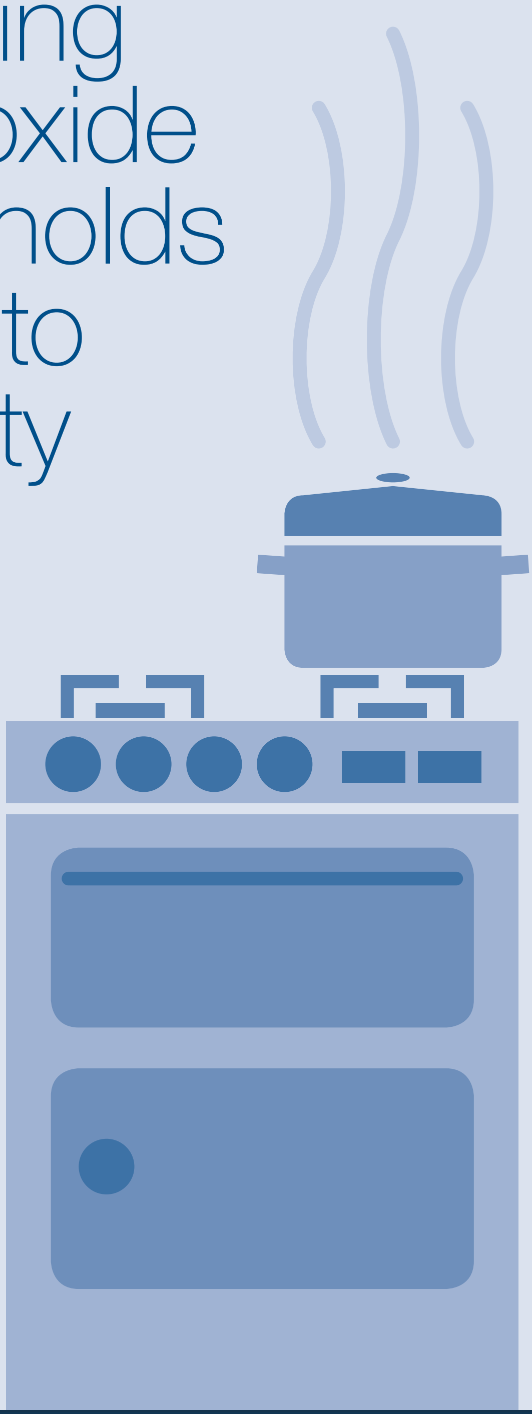
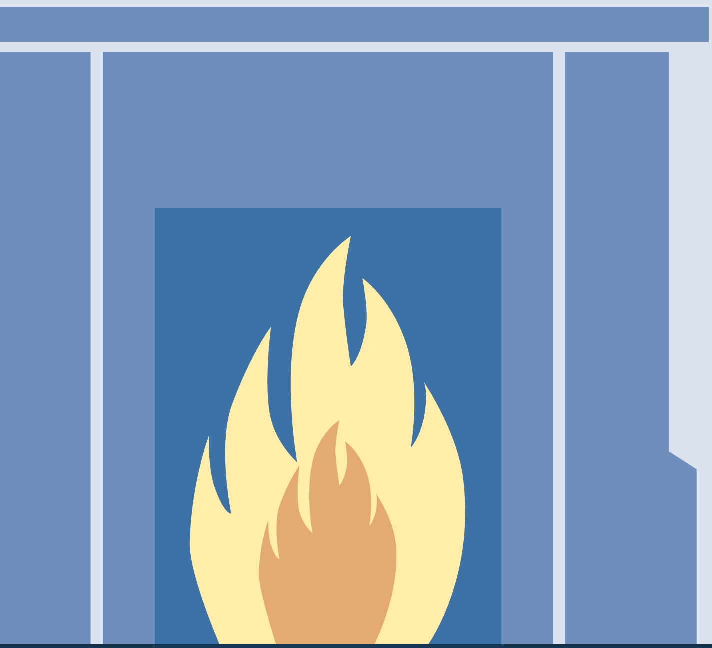



Action for Warm Homes

Understanding Carbon Monoxide Risk in Households Vulnerable to Fuel Poverty

This report has been prepared by Juliette Burroughs, National Energy Action.

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NEA Action for Warm Homes

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Executive summary

This research investigated the relationship between fuel poverty and carbon monoxide (CO) risk in households on low incomes and in vulnerable situations. Over the course of two heating seasons (October to April) in 2015/16 and 2016/17 NEA collected data from 349 households, targeting those on low incomes and with a range of vulnerabilities. The main conclusion to draw from this research is that the factors which cause or expose households to the risk of fuel poverty – low income, poor quality housing and the age and health of occupants – can impact on the heating and servicing behaviours of households to elevate CO risk in homes. Key findings emerging from this study are summarised below.

CO levels in homes

CO and temperature measurements were recorded in 90 homes. CO data showed 35% of properties with exceedances (spikes) greater than 10 ppm (the threshold at which prolonged exposure can have possible health effects) and 22% recorded spikes greater than 10 ppm lasting longer than 15 minutes. Fuel poverty characteristics were present in a number of these homes. In particular, statistical analysis (Pearson's correlation) undertaken by IEH Consulting for NEA observed significantly increased maximum CO levels in households reporting stress and anxiety about energy affordability ($p=0.026$; $r=0.237$). Also, the number of CO spikes above 10 ppm was significantly negatively correlated with the minimum temperature ($p=0.04$; $r=-0.23$) and the mean temperature ($p=0.003$; $r=-0.32$) in households. That is, the number of CO spikes increased in households with lower minimum and mean temperature. This could indicate a possible relationship between under-heating and elevated CO. Notably, one fifth of households with extended CO spikes (lasting longer than 15 minutes) reported rarely turning their central heating on and a number were fuel poor under the Low Income High Costs definition. Furthermore, working-age households, amongst which the highest fuel poverty rates are found across England, recorded lower mean temperatures in our study and also a greater number of CO spike events.

Boiler type and risk

Amongst homes where boiler type could be verified (n131), 63% were using safer and more efficient combi condensing models, some of which had been installed free of charge under government energy efficiency programmes such as the Energy Company Obligation (ECO). This confirms the importance of grant schemes to upgrade heating appliances in low income households. However a statistically significant relationship ($p<0.0001$) was observed between living in an off-gas and rural home and having an older and riskier (non-condensing) boiler type. This supports evidence that low income non-gas homes have disproportionately missed out on subsidised heating measures under government programmes such as ECO. Targeting these households in future schemes for both fuel poverty and CO safety reasons may therefore be beneficial.

Household heating behaviours

In addition to central heating boilers, nearly half of participants (47%) had combustion secondary space heating in their homes (mainly gas and solid fuel fires). These appliances emerged as a key source of warmth for households vulnerable to fuel poverty and a possible cause of CO spikes in these properties. Specifically, households displaying financial, structural, health and age vulnerabilities were more likely to be reliant on a gas or solid fuel fire; running it for extended periods in place of central heating or together with a primary system. Factors contributing to this behaviour were: low income (preventing a household replacing an inefficient boiler, installing first time central heating or causing occupants to ration central heating); a lack of agency amongst tenants (forced into using secondary heating to cope with a cold home); and susceptibility to the cold (where attempts to achieve adequate warmth led to households relying on a fire to supplement their primary system). Using these appliances frequently and for long periods increases opportunity to be exposed to CO from these sources, particularly if the appliances are older and not maintained.

Appliance servicing

While servicing rates of boilers in the sample were relatively high (77%), only 40% of gas fires were reported by households as checked over the past 12 months. Cost was cited as a factor by 21% of owner-occupants with un-serviced appliances. This group of households may be conscious of gas safety but do not always have the disposable income available to practise gas safe behaviour. When considering the reliance on secondary heaters such as gas fires amongst many households vulnerable to fuel poverty in our sample, it is worrying that such households are not always able to prioritise servicing of these appliances.

The other area of concern is gas cookers. While 59% of homes had a gas cooker fitted only one quarter report having this appliance checked. Amongst households monitored for CO (n89), maximum CO levels were significantly increased in homes with ovens fuelled by mains gas or LPG ($p=0.001$; $r=0.336$) and also hobs fuelled by mains gas or LPG ($p=0.019$; $r=0.247$). Worryingly, a lack of awareness that cookers can pose CO risk was observed widely in the sample. Additionally, in social rented properties, most tenant-owned cookers are going un-serviced as they are not covered by landlord safety checks. Neglect of these appliances is particularly concerning given 15% of households with gas cookers reported using the appliance for room heating. While this behaviour is not practised regularly, the factors which drive fuel poverty – living on a low income and in an inefficient home – are contributing to a small but notable number of households turning to their cooker occasionally as a source of 'cheap' and 'instant' heat or because their primary system is insufficient.

CO alarm ownership

Of 132 households where CO alarm ownership could be verified, 35% had an alarm fitted. Rates of ownership were highest in the owner-occupied sector (44%) while 22% of alarm owners reported receiving theirs from a charity, local authority or fire and rescue service. This underlines the importance of frontline service providers in supporting and protecting vulnerable households. One factor contributing to low alarm ownership rates may be a lack of awareness about the dangers of CO, particularly in comparison to the threat of fire in homes. CO-related behaviours were perceived by households to pose less risk relative to behaviours such as failing to fit a smoke alarm. Furthermore, not servicing a boiler was considered less risky than not having a CO alarm fitted. This is concerning given CO alarms should not replace maintenance of appliances.

Based on our findings, NEA makes the following observations and recommendations for policy makers and industry:

1. Join up fuel poverty and gas safety initiatives

Government energy efficiency programmes such as ECO replace old and inefficient boilers and install first-time boilers and central heating in low income households in order to alleviate fuel poverty. This is welcomed however CO risk will not necessarily be addressed in these households if occupants continue to use and rely on older room heaters such as gas fires. This research has shown it is not always correct to assume that households with modern boilers will favour them over other heating systems. Instead, amongst occupants vulnerable to fuel poverty, combustion room heaters may be preferred for cost reasons or both primary and secondary appliances will be run concurrently in attempts to achieve adequate warmth. Consideration should therefore be given to supporting households to replace or maintain appliances such as gas fires. Equally, it is critical that households are educated on their central heating systems and occupants on low incomes are supported to optimise use of these systems without compromising on energy affordability. A key role is required for frontline service providers such as local authorities and community organisations, who are already reaching and protecting households in need. These agencies should be supported to deliver integrated fuel poverty and CO safety initiatives, including providing measures such as CO alarms to fuel poor households. Here, there is a clear role for gas distribution network companies to support these agencies. The gas networks have existing obligations on fuel poverty and CO awareness under the regulator Ofgem's RIIO-GD1 price control model. Ofgem should further incentivise the gas networks to join up action on fuel poverty and CO awareness in the next price control period (after 2021).

2. Support non-gas households to replace old and risky boilers

Historically, non-gas homes have disproportionately missed out on heating measures under ECO and this study shows rural households with boilers not fuelled by mains gas are disproportionally older, riskier and inefficient models. Rural off-gas homes are at increased risk of living in severe fuel poverty, nor are they served by free safety checks of gas appliances offered to low income owner-occupants under the Priority Services Register (PSR). For both energy affordability and safety reasons these households must be targeted in future government energy efficiency programmes. Specifically, NEA recommends a minimum target for installation of first time central heating systems under the next iteration of ECO (from October 2018) and that this target is aligned to Ofgem's fuel poor network extension scheme to provide free connections to the mains gas network for fuel poor non-gas homes.

3. Promote the PSR as a pathway to free gas safety checks

Gas suppliers are required to offer free gas safety checks to low income and vulnerable households but the volume of these checks has historically been very low. This is unfortunate because this service can help to address CO risk in low income owner-occupant households who may be neglecting to service appliances for cost reasons but may also be more susceptible to adverse effects from CO exposure for reasons of age or ill health. The gas industry (suppliers and network distributors) must improve efforts to sign-up low income and vulnerable customers to the PSR and passport eligible households into annual free servicing plans.

4. Improve public awareness about the CO risks of combustion appliances beyond gas boilers

Households servicing gas boilers are not always extending this behaviour to include other gas appliances in the home. Gas cookers in particular are perceived to pose a low CO risk relative to boilers and households are largely unaware that such appliances require maintenance. Gas safety messages should be made clearer to communicate about the risks posed by different gas appliances and advised on their proper installation, use and maintenance. Gas fires and gas cookers should be prioritised in such messages and catch-all and ambiguous terms such as 'appliance' should be avoided.

5. Target and tailor CO safety messages to account for different household, appliance and fuel types

Safety may not always be the most effective message to prompt households to check their appliances. Instead, an understanding of the appliance and household type should inform CO campaigns. For example, emphasising reliability and comfort may help drive boiler servicing, particularly in older age households susceptible to the cold. While a focus on safety may be more suitable for appliances such as cookers. Amongst low income families and working-age households, integrated CO and fuel poverty interventions should be considered (elevated CO levels and lower mean temperatures were observed in these homes). Clear messaging about landlord and tenant responsibilities is also critical, particularly in social rented housing where appliances are more likely to be owned by tenants and not covered by landlord gas safety checks. Households off mains gas should be targeted with bespoke campaigns addressing servicing of oil, solid fuel and LPG appliances.

1. Introduction

1.1 Background

Carbon monoxide (CO) is a highly poisonous gas that cannot be seen or smelt. Estimates suggest that accidental CO poisoning causes 40 deaths each year in England and Wales, along with a further 200 hospital admissions and 4,000 attendances at emergency departments for treatment.[1] However, it is likely that exposure to and injury from sub-lethal levels of CO is under-reported as low-level poisoning is extremely difficult to diagnose, mimicking symptoms of common illnesses such as flu and food poisoning.[2] As such, many cases of CO poisoning may remain undiagnosed or misdiagnosed and death, injury and illness due to CO exposure could be far greater than what is documented.[3]

Symptoms of CO poisoning can range from headache and nausea to collapse and loss of consciousness. Alongside death and serious injury caused by acute CO poisoning, exposure at sub-lethal levels may result in lasting health problems with a growing body of evidence suggesting chronic exposure can produce neurological effects.[4] The health impacts of low-level poisoning are concerning given the number of people who may be exposed in their homes.

In domestic environments, the main source of CO is from combustion heating and cooking appliances, although outdoor pollutants and cigarette smoke can also contribute to indoor concentrations. In properties without indoor sources, average CO concentrations are approximately equal to average outdoor levels – around 1 to 4 parts per million (ppm).[5] It is important to note however that the gas can spread from homes with faulty appliances into neighbouring properties.

All carbon-containing fuels (gas, oil and solid fuels) and all domestic combustion appliances (including cookers, boilers, fires, space and water heaters) produce CO. However, if in good condition and properly ventilated, levels will not be dangerous to occupants – usually well below 10 ppm.[6]

Above average and potentially harmful levels of CO are produced from faulty or badly fitted appliances and also inadequate or blocked ventilation. Higher levels occur during colder months when appliances are used more, with the majority of CO incidents reported during the winter heating season.[7,8] Along with appliance faults, CO risk is a function of household behaviour; increasing if occupants use an appliance incorrectly, block ventilation, do not undertake regular servicing of appliances and fail to fit an audible CO alarm. In 2013/14 there were 29 reported CO incidents in domestic environments in Great Britain, causing 58 causalities and 3 fatalities. Investigations found a lack of regular servicing and issues with flues, including blockages, were key reasons for these incidents.[9]

Some individuals are more susceptible to adverse effects from CO exposure than others. In particular, older people, children, pregnant women and their unborn children and those with breathing problems or cardiovascular disease are all at increased risk.[10] These same categories of people are also more vulnerable to fuel poverty – when a household cannot keep their home warm at a reasonable cost. Under the Low Income High Costs (LIHC) definition of fuel poverty used in England 79% of English fuel poor households (2.0 of 2.5 million) are classed as vulnerable (containing children, the elderly and/or someone with a long-term illness/ disability).[11] Furthermore, previous research suggests that the factors which cause fuel poverty, including living on a low income and living in an energy inefficient property, may also increase CO risk.

[1] DOH and NHS England. 2013. Carbon Monoxide Poisoning: Recognise the Symptoms and Tackle the Cause. Available: *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/260211/Carbon_Monoxide_Letter_2013_FinalforPub.pdf.*

[2] Ibid.

[3] McCann, L. J. et al. 2013. Indoor Carbon Monoxide: A Case Study in England for Detection and Interventions to Reduce Population Exposure, Journal of Environmental and Public Health. Available: *http://dx.doi.org/10.1155/2013/735952.*

[4] Townsend, C. L. and Maynard, R. L. 2002. Effects on Health of Prolonged Exposure to Low Concentrations of Carbon Monoxide, Occupational and Environmental Medicine. Available: *https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1740215/pdf/v059p00708.pdf.*

[5] Croxford, B. et al. 2006. Real Time Carbon Monoxide Measurements from 270 UK Homes. *Available: http://discovery.ucl.ac.uk/5017/1/5017.pdf.*

[6] Ibid.

[7] WHO. 1999. Environmental Health Criteria 213: Carbon Monoxide (second edition). Available: *http://www.who.int/ipcs/publications/ehc/ehc_213/en/*.

[8] Downstream Gas Ltd for Gas Safety Trust. 2015. DIDR Carbon Monoxide Incident Report 2013/14. Available: *http://www.coportal.org/wp-content/uploads/gst_attachments/1c4ec123223e5fd6bc2a63592daefc4e/12102016104304-DIDR%20201314%20Complete%20Version_15June15.pdf*.

[9] Ibid.

[10] Ibid., 1.

[11] BEIS. 2017. Fuel Poverty Detailed Tables 2015 Data. Available: *https://www.gov.uk/government/statistics/fuel-poverty-detailed-tables-2017*.

For example, Ezratty et al. speculate that low income households may be exposed to unsafe levels of CO because in efforts to meet heating costs ***'they may reduce ventilation and use unsuitable heating appliances'***.[12] Similarly, Ormandy and Ezratty suggest that households in fuel poverty may resort to using inappropriate unflued heat sources while Sterling and Sterling cite the use of gas stoves for room heating in low income housing as an area of concern.[13,14]

Measuring CO concentrations in low income households, Croxford et al. found levels above recommended guidelines in 18% of homes, generally caused by old and poorly maintained gas appliances.[15] The authors speculate fuel poverty could increase CO concentrations if households reduce ventilation to retain heat while keeping their old and inefficient appliances. Meanwhile, a gas appliance check carried out by Croxford for the UK Health and Safety Executive (HSE) found a higher prevalence of problem and unsafe gas appliances in homes with occupants in receipt of benefits.[16] Kokkarinen et al. also found that residents in deprived areas of Liverpool and Coventry were less likely to own a CO alarm than residents in non-deprived areas, while homeowners were more likely to own alarms relative to tenants.[17] They suggest fuel poverty could be a reason for low alarm ownership rates; if households prioritise other basic needs over purchasing an alarm. In England, it is mandatory for private sector landlords to fit CO alarms only in properties which contain a solid fuel burning appliance such as a wood stove.

Reflecting on actual CO incidents in domestic properties, recent reporting shows that those over the age of 65 appear to be at risk with all four recorded fatalities in 2014/15 occurring in the over 80 age group.[18,19] Lack of servicing of older appliances was a contributory factor in the deaths. Historical reporting also shows twice the risk of a CO incident occurring in private rented housing relative to owner-occupied and social rented properties.[20]

Overall, these findings indicate a possible link between vulnerability to fuel poverty and elevated CO risk because households on low incomes and in vulnerable situations may be living with older, inefficient and riskier heating appliances, using heating appliances inappropriately such as reducing ventilation to retain heat or are unable to maintain or upgrade appliances or purchase a CO alarm for cost reasons. However, as both McCann et al. and Bolton note, further research is required to better understand the burden of CO in homes.[21,22] In addition, little qualitative research has taken place to date in households vulnerable to fuel poverty to understand the relationship between their heating behaviours and CO risk.

1.2 Research aims and objectives

This research aims to better understand the relationship between fuel poverty and CO risk in households on low incomes and in vulnerable situations. As detailed in the background section of this report, previous studies suggest a link between the factors which cause fuel poverty and those which drive CO risk but there is a lack of in-depth research with low income households. As such, the objectives of this research were to:

- Identify carbon-producing appliances in households on low incomes and in vulnerable situations
- Measure CO and temperature levels in these households
- Explore the heating and servicing behaviours of these households in order to understand if attempts to achieve adequate warmth, ration energy use and meet essential costs contribute to CO exposure risk.

[12] Ezratty, V. et al. 2011. Effectiveness of Campaigns on Carbon Monoxide Awareness Among Tenants of Public Sector Housing. Available: *https://studylib.net/doc/12448051/report--effectiveness-of-campaigns-on-carbon-monoxide*.

[13] Ormandy, D. and Ezratty, V. 2012. Health and Thermal Comfort: From WHO Guidance to Housing Strategies, Energy Policy. Available: *http://wrap.warwick.ac.uk/42205/1/WRAP_Ormandy_Ormandy-Ezratty%20FINAL%202011-10-31.pdf*.

[14] Sterling, T. and Sterling, E. Carbon Monoxide Levels in Kitchens and Homes with Gas Cookers, Journal of the Air Pollution Control Association. Available: *http://sterlingiaq.com/photos/1044923383.pdf*.

[15] Ibid., 5.

[16] Croxford, B. 2007. Gas Appliance Check Report. Available: http://www.hse.gov.uk/gas/domestic/uclgasfinal.pdf.

[17] Kokkarinen, N. et al. 2014. Investigation of Audible Carbon Monoxide Alarm Ownership, Smart and Sustainable Built Environment, 3: 72-86.

[18] Ibid., 8.

[19] See: http://www.gassafetytrust.org/news-and-press/2016/gas-safety-trust-announces-latest-didr-figures-highlighting-co-threats-to-vulnerable-customers.

[20] Ibid., 8.

[21] Ibid., 3.

[22] Bolton, J. 2016. CO Impact: Determining the Impact of Carbon Monoxide Poisoning on the UK Population. Available: *http://www.coportal.org/co-resources/*.

2. Methods

This study used a mixed methods approach combining qualitative and quantitative data collection and analysis, as described below.

2.1 Sampling strategy

NEA purposively targeted households at risk of fuel poverty to take part in the research. In England, under the LIHC indicator, a household is considered to be fuel poor if they have required fuel costs that are above average (the national median level); and were they to spend that amount, they would be left with a residual income below the official poverty line. The other measurement of fuel poverty commonly used in the UK is where a household needs to spend more than 10% of its income to achieve adequate energy services in the home.

As it was not possible to calculate fuel poverty status prior to recruiting households the research targeted occupants on low incomes – a key driver of fuel poverty. To recruit participants, NEA worked with trusted intermediaries from local and voluntary organisations that provide fuel poverty services to their clients. This included local councils, advice bureaus and energy charities. A full list of agencies that helped NEA reach and recruit our sample can be found in the acknowledgements section of this report. Different organisation types and geographic areas were targeted in order for the sample to cover rural as well as urban households, a mix of tenures and combustion heating fuels and a range of household demographics known to be vulnerable to the effects of both CO and living in a cold home. Specifically: older persons, families with children and householders with disabilities or long-term ill health.

2.2 Surveys and follow-up interviews

In-home survey

To capture data on households' combustion appliances, along with their heating and servicing behaviours, a survey was developed and carried out with participants in their homes by NEA research staff or their representatives. Research took place over two years: 73 households were surveyed during the 2015/16 heating season and 59 households were surveyed during the 2016/17 heating season. In-home questionnaires were completed in London, North East England and Yorkshire and The Humber. These geographic regions were chosen both to obtain rural and urban properties as well as a mix of fuel types, but also for logistical reasons – because surveyors were based in or near to these locations. At the end of visits, all participant households were gifted a CO alarm[23], an Energy UK guide about staying safe from CO poisoning[24] and an NEA energy advice leaflet.

Postal survey

To increase the sample size for analysis and test issues identified from Year 1 research, in Year 2 NEA developed a shorter questionnaire for self-completion by households on paper or online. The survey was administered in November 2016 and closed in March 2017. To reach the target population (low income households and vulnerable groups) 1500 paper questionnaires with free-post return envelopes were distributed to households via local fuel poverty service providers in England and Wales (see the acknowledgements section of this report for a full list of supporting agencies). In total, the postal[25] survey received 217 responses: 184 by post (equating to a 12% response rate) and 33 online. A prize draw was run to incentivise questionnaire completions and returns.

[23] NEA thanks Liverpool John Moores University, The Council of Gas Detection and Environmental Monitoring (CoGDEM) and Energy UK for providing these alarms free of charge to NEA to distribute to households.

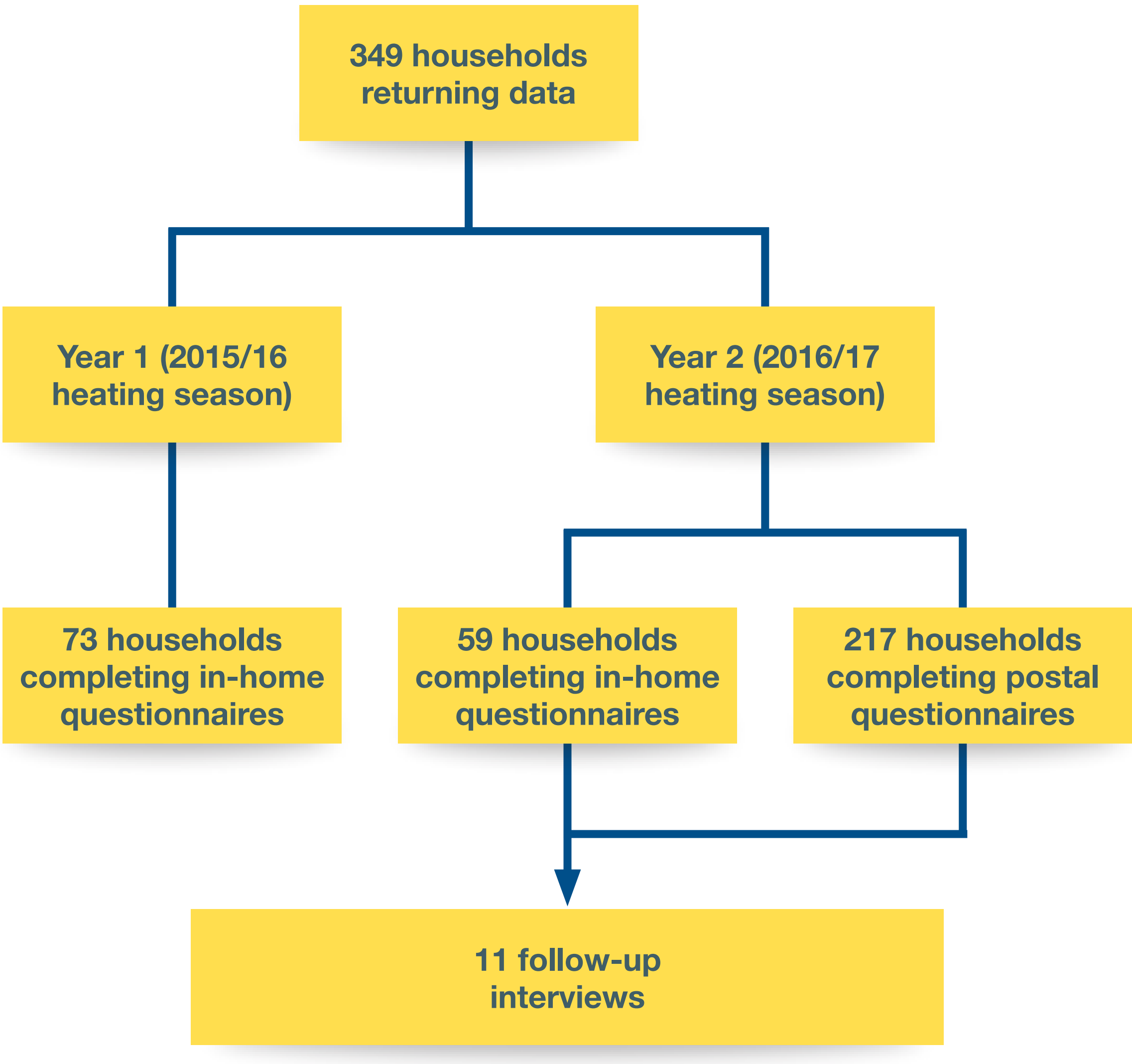
[24] See: *http://www.co-bealarmed.co.uk/wp-content/uploads/2014/09/CO-a-guide-to-staying-safe.pdf*. NEA thanks Energy UK for providing copies of this guide free of charge to NEA to distribute to households.

[25] Throughout this report 'Postal' is used to refer to the self-completion survey and 'In-home' is used to refer to the survey carried out with participants in their homes by NEA research staff or their representatives.

Follow-up interviews

To explore themes identified from questionnaire responses in more detail, and gain richer insight on household experiences, follow-up interviews were carried out with a small sub-section of the total sample (349 households). Interviews took place by telephone and lasted between 30 minutes and one hour. Participants invited to take part in follow-up interviews were those who completed either an in-home or postal questionnaire and whose answers characterised a particular fuel poverty and CO risk profile that would benefit from qualitative insight. Purposive sampling also sought to obtain a mix of geographic locations (urban and rural), heating fuels (on and off mains gas), tenure, household demographics and socio-economic factors. In total, 11 follow-up interviews were completed in March and April 2017. Interviews were recorded and transcribed and participants were each provided with a £15 shopping voucher to thank them for their time. Following a close re-reading, annotation and cross-comparison of interview notes and transcripts, alongside responses to relevant open-ended questions from in-home questionnaires, themes were identified using manual coding techniques. These themes are explored in more detail in the findings section of this report. In addition, some households interviewed have been profiled as case studies in this report. All participant names have been changed to preserve anonymity.

Figure 1. Research sample



2.3 Monitoring

To correlate findings from the questionnaires with temperature and CO data, monitoring equipment (data loggers) was placed in a sub-set of homes completing the in-home survey. Across both heating seasons a total of 95 households were monitored with 90 returning data, see Table 1 below.[26] In 81 households a full set of data was recorded (temperature and CO), one household returned temperature data only and eight households returned CO data only. Reasons for the nine households returning incomplete data included faulty loggers, lost loggers and faulty batteries.

Table 1. CO and temperature monitoring in households

	Year 1 (2015/16)	Year 2 (2016/17)	All
Participant homes returning temperature and CO data	36	45	81
Participant homes returning temperature data only	-	1	1
Participant homes returning CO data only	1	7	8
Total	37	53	90

The procedure for data monitoring was based on advice from Liverpool John Moores University which has carried out a larger project of CO monitoring using fire and rescue services. Specifically, one Lascar EL-USB-CO carbon monoxide data logger and one Lascar EL-USB-2 temperature and humidity data logger was placed in each household in the main living space (usually the living room). The loggers recorded CO concentrations in ppm at 5 minute intervals and temperature in degrees Celsius (°C) at half hourly intervals. Surveyors were instructed to place the loggers at chest height in a dry location away from direct sources of heat and cold. Loggers recorded CO and temperature levels in homes between October and March 2015/16 (Year 1 participants) and December and April 2016/17 (Year 2 participants).

Data was collected during winter as higher concentrations of CO over longer periods may occur during colder months when heating systems are used more and windows are generally closed – reducing ventilation.[27] Homes were monitored for a minimum of one week and up to three months, depending on when households were recruited to the project and interviews took place. NEA researchers or their representatives placed loggers in homes at the time of the in-home questionnaire and households were then provided with information on the loggers and advised not to move them. At the end of the monitoring period NEA contacted households by phone and post requesting return of the loggers using pre-paid envelopes. Shopping vouchers worth £20 were sent to households who returned loggers.

Once loggers were returned data was downloaded and cleaned for analysis. In cases where households returned data showing consistent patterns of high CO readings (20 ppm or more) attempts at re-contact were made and, where successful, households were advised of the readings and reminded of ways to stay gas and CO safe.

NEA acquired the services of IEH Consulting Ltd to carry out the statistical analysis of logging data. For this research, the significance threshold for statistical analysis was set at $p=0.05$. When considering the limitations of the data, Lascar reports the CO loggers used in this project can detect CO up to 1000 ppm and have an accuracy level of +/- 7 ppm.[28] The measurement range of the temperature loggers used is -35°C to 80°C with an error margin of +/- 0.55°C.[29] Alongside these error margins, there are limitations to using a measurement from one room as a proxy for household exposure; recognising factors such as property layout, air movement and household occupancy and heating patterns will all influence how representative measurements are of the home as a whole.[30]

[26] Five households failed to return the monitoring equipment.

[27] Ibid., 7.

[28] See: *https://www.lascarelectronics.com/easylog-data-logger-el-usb-co/*.

[29] See: *https://www.lascarelectronics.com/easylog-data-logger-el-usb-2/*.

[30] Ibid., 5.

3. Participant profile

The following chapter summarises the profile of the sample, including the prevalence of key vulnerability characteristics and fuel poverty risk.

3.1 Household characteristics

Table 2 below shows that, amongst in-home participants, average household size is the same as the UK average of 2.4.[31] When postal participants are taken into account, the average size decreases slightly to 2.2. In terms of property location, the sample is not representative of the Great Britain population, over-representing regions such as Yorkshire and the North East. Due to purposive sampling there are also more participants in the in-home sample from rural areas of England than for the nation as a whole (28% compared to 17%[32]), as well as using a fuel other than mains gas for their heating (26% compared to 15%[33]). The sampling strategy was successful in obtaining a mix of tenure, with more private rented housing in the in-home sample (32%) compared to national figures. The split in England is 63% owners, 20% private renters and 17% social renters.[34] When all respondents are taken into account, the sample is almost identical to this national picture, with participants dividing into 63% owners, 21% private renters and 16% social renters.

Table 2. Household profile

Characteristic		In-home sample prevalence % (n)[35]	Postal sample prevalence % (n)	Total sample prevalence % (n)
Sex	Male	66.7 (88)	67.0 (140)	66.9 (228)
	Female	33.3 (44)	33.0 (69)	33.1 (113)
Average household size		2.4 persons	2.0 persons	2.2 persons
Location	Greater London	8.3 (11)	8.3 (18)	8.3 (29)
	South East	-	0.5 (1)	0.3 (1)
	South West	-	12.0 (26)	7.5 (26)
	West Midlands	-	12.5 (27)	7.8 (27)
	North West	-	20.8 (45)	12.9 (45)
	North East	33.3 (44)	14.4 (31)	21.6 (75)
	Yorkshire and The Humber	58.3 (77)	13.4 (29)	30.5 (106)
	East Midlands	-	1.4 (3)	0.9 (3)
	East of England	-	-	-
	Wales	-	16.7 (36)	10.3 (36)
Rural-urban classification[36]	Rural	28.0 (37)	-	-
	Urban	72.0 (95)	-	-
Tenure	Owner-occupied	53.8 (71)	68.8 (148)	63.1 (219)
	Private rented	31.8 (42)	14.4 (31)	21.0 (73)
	Social rented	14.4 (19)	16.7 (36)	15.9 (55)
Main heating fuel	Mains gas	74.2 (98)	83.7 (174)	80.0 (272)
	LPG, bottled gas, oil, solid fuel	25.0 (33)	9.6 (20)	15.6 (53)
	Electricity	0.8 (1)	6.7 (14)	4.4 (15)

[31] See: *https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/families/bulletins/familiesandhouseholds/2016.*

[32] See: *https://www.gov.uk/government/publications/rural-population-and-migration/rural-population-201415.*

[33] Ofgem. 2015. Insights Paper on Households with Electric and other Non-gas Heating. Available: *https://www.ofgem.gov.uk/ofgem-publications/98027/insightspaperonhouseholdswithelectricandothernon-gasheating-pdf.*

[34] DCLG. 2017. English Housing Survey: Headline Report, 2015-16. Available: *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/595785/2015-16_EHS_Headline_Report.pdf.*

[35] Sample size (n) differs across variables as it is dependent on how many respondents answered the corresponding survey question.

[36] Addresses of in-home participants were used to identify them as living in rural or urban locations according to the UK Government's 2011 Rural-Urban Classification for small-area geographies.

3.2 Vulnerability characteristics

Overall, the sampling strategy used was successful in recruiting low income households with a range of vulnerability characteristics known to increase risk to fuel poverty and CO. Table 3 shows that the large majority of participants (78%) report their total annual household income before tax at less than £25,000, which is around the average (median) real terms household income before housing costs of people in the UK.[37] It is estimated that 16% of UK households are in relative low income (a household income below 60% of the median) before housing costs.[38] By contrast, over half of our sample (55%) reports an income of less than £16,000.

Investigating other indicators of low income shows that 42% of participants report receiving at least one means-tested benefit and 39% of the working age sample has no household members in paid work (equating to 21% of the total sample). As a rough comparator, 26% of the UK labour market (people aged 16-64) are unemployed or economically inactive; suggesting our sample is less well-off relative to the entire population.[39]

With regard to household age, the sample over-represents pensioner households. Nearly half of participant households contain an occupant aged 65 or over. In comparison, 28% of all English households were estimated to be headed by persons aged 65 and over in 2012.[40] This sampling bias toward older age households is a limitation of the research. First, older persons generally engage more with the service providers NEA used to reach and recruit households; and second, previous research has shown that older age groups are more likely to respond to questionnaires.[41] Nonetheless, nearly one third of the in-home sample (32%) are households with dependent children (15 and under).

In terms of health status, 65% of the total sample reports a household member with a long-term disability or health condition. Together, these age and health vulnerability profiles indicate that over three quarters of households are eligible for the Priority Services Register (PSR), an extra help scheme offered to vulnerable energy customers, but only 10% report being registered on their energy supplier's PSR. Households registered on the PSR and in receipt of means-tested benefits are eligible for an annual free gas safety check from their gas supplier.[42]

In conclusion, the sample has a high proportion of households on low incomes and in categories vulnerable to the risks of fuel poverty and CO. However, it does not constitute a representative sample of the target population and therefore there are limitations in extrapolating results to all low income or fuel poor households.

[37] DWP. 2017. Households Below Average Income. Available: *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/600091/households-below-average-income-1994-1995-2015-2016.pdf*.

[38] Ibid.

[39] ONS. 2017. UK Labour Market: June 2017. Available: *https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/employmentandemployeetypes/bulletins/uklabourmarket/june2017*.

[40] DCLG. 2015. 2012-based Household Projections - England: Household Types (Stage 2) and National Variants. Available: *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/481704/2012-based_household_projections_England_2012_to_2037_Stage_2_household_types_and_national_variants.pdf*.

[41] Sheldon et al. 2007. Increasing Response Rates Amongst Black and Minority Ethnic and Seldom Heard Groups. Available: *http://www.nhssurveys.org/Filestore/documents/Increasing_response_rates_literature_review.pdf*.

[42] For the full eligibility criteria see: *https://www.ofgem.gov.uk/consumers/household-gas-and-electricity-guide/extra-help-energy-services/priority-services-register-people-need*.

Table 3. Vulnerability profile

Characteristic		In-home sample prevalence % (n)	Postal sample prevalence % (n)	Total sample prevalence % (n)
Annual household income before tax (£)	<16,000	52.5 (63)	56.7 (102)	55.0 (165)
	<25,000	75.0 (90)	79.4 (143)	77.7 (233)
Means-tested benefits[43]	Yes	48.9 (64)	38.0 (76)	42.3 (140)
Employment status	Working[44]	37.4 (49)	31.6 (66)	33.9 (115)
	Working age but not in paid work[45]	26.0 (34)	18.1 (38)	21.2 (72)
	Retired	36.6 (48)	50.2 (105)	45.0 (153)
Living in 25% most deprived area of England[46]	40.2 (53)	35.8 (64)	37.6 (117)	
Occupant(s) 65+	39.4 (52)	51.8 (103)	46.8 (155)	
Children 15 and under	31.8 (42)	22.1 (44)	26.0 (86)	
Self-reported long-term disability or health condition	75.6 (99)	57.5 (115)	64.7 (214)	
Eligible for PSR[47]	Yes	80.9 (106)	76.2 (144)	78.1 (250)
Registered on PSR	Yes	10.4 (12)	-	-

3.3 Fuel poverty risk

Questions were asked of participants to understand their fuel poverty risk profile. Table 4 below shows that over one third of households (38%) report being in subjective fuel poverty – unable to keep their whole home comfortably warm during winter or when it is cold outside. Paying the energy bill is also a source of financial stress for many households, with 58% of participants reporting concern about affording their energy. A common coping strategy is rationing heating, with 35% of households reporting often or always having their heating on lower, less often, or in fewer rooms than desired during winter. Less common is cutting back on other essentials such as food to pay for energy, with 18% of the sample reporting undertaking this practice on a regular basis.

Table 4. Fuel poverty risk profile

Fuel poverty risk	In-home* sample prevalence % (n)	Postal sample prevalence % (n)	Total sample prevalence % (n)
1. In subjective fuel poverty - cannot normally keep home comfortably warm during colder weather	37.3 (22)	38.2 (79)	38.0 (101)
2. Difficulties paying energy bill	57.6 (76)	57.4 (116)	57.5 (192)
3. Regularly ration heating	28.8 (17)	36.6 (75)	34.7 (92)
4. Regularly cut back on other essentials to pay for energy	15.3 (9)	19.5 (37)	18.4 (46)

*Participants in Year 1 (2015-16) were not asked Qs 1, 3 & 4.

[43] Household in receipt of one or more means-tested benefits including Income-based Jobseeker's Allowance, Income Support, Income-related Employment and Support Allowance, Working Tax Credit, Pension Credit, Child Tax Credit, Council Tax Benefit, Housing Benefit, Warm Home Discount and Universal Credit.

[44] At least one household member in paid full or part-time work.

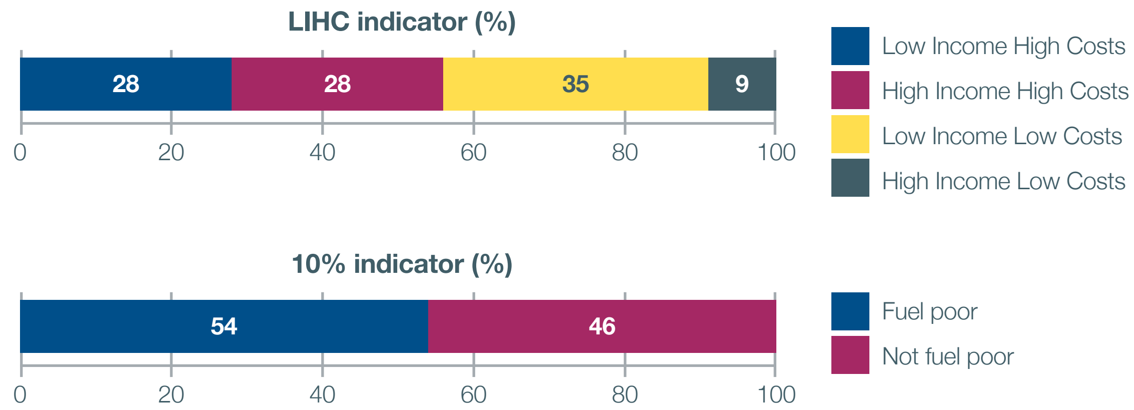
[45] No household members in paid work (unemployed, unable to work due to illness/disability/immigration status, full-time carer/parent/education).

[46] According to the 2015 English Index of Multiple Deprivation (IMD).

[47] Recording a household member aged 65 and over and/or reporting a long-standing physical or mental health condition or disability.

In order to obtain a more objective measure of fuel poverty the Year 2 in-home survey was adjusted to add questions that would enable NEA to calculate the fuel poverty status of households in line with both the LIHC and 10% definition. NEA used the Fuel Poverty Assessment Tool hosted on its website and designed by the Energy Audit Company to undertake this calculation.[48] Results show that 28% of the 54 households assessed in Year 2 are fuel poor under the LIHC definition and 54% are fuel poor under the 10% definition, see Figure 2. As such, the sample assessed has a much higher proportion of fuel poor households compared to the England population, in which 11% of households are estimated to be LIHC fuel poor.[49]

Figure 2. Fuel poverty status (n54[1])



[1] The fuel poverty status of five households in the Year 2 in-home sample (n59) could not be calculated due to a lack of data.

For households calculated to be LIHC fuel poor (28%, n15) the average fuel poverty gap (a measurement of the depth of fuel poverty in individual households) is £500 with a minimum of £58 and a maximum of £2,890. The mean figure is higher than the average household fuel poverty gap in England of £371.[50]

[48] See: http://www.nea.org.uk/fuel-poverty-assessment-tool-home/.

[49] Ibid., 11.

[50] Ibid.

4. Combustion appliances in homes

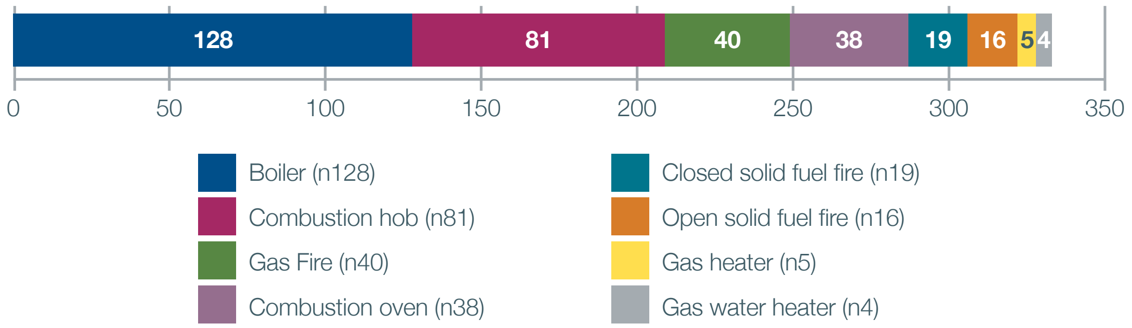
The following four chapters outline key findings from the study: beginning with a review of combustion appliances in participant homes, followed by a discussion of household heating and servicing behaviours and their impact on CO risk in homes, and finishing with findings from the programme of CO and temperature monitoring.

In households where participants completed an in-home questionnaire (n132), surveyors could accurately record details of combustion appliances. In these properties, the mean number is 2.5 (ovens and hobs are counted as separate appliances). All participants have at least one combustion appliance with a maximum of five in three households. Figure 3 shows that boilers are the most common type of appliance (128 out of 132 households have a central heating boiler), followed by combustion hobs (n81), gas fires (n40) and combustion ovens (n38).

Figure 3. Number of combustion appliances in homes (n132)

	All homes	Min	Max	Mean	SD[1]
Number of combustion appliances	331	1.0	5.0	2.5	1.1

[1] Standard Deviation



4.1 Boiler type and risk

Central heating boilers are fitted in 97% of in-home participants' properties. Three households have no central heating and one household has electric storage heaters. Across the entire sample (in-home and postal participants, n343), 95% of homes have central heating boilers.

Official reporting identifies boiler types at higher risk of being involved in a CO incident (relative to the safest boiler type – all condensing boilers). These are back boilers (relative risk factor of 8.7 out of 10), non-condensing regular boilers (risk factor 4.2) and non-condensing combi boilers (risk factor 1.8).[51] This is generally because these appliances are older and may have an open-flued design. Historically, central heating boilers have been a key source of domestic CO incidents because they are operated for long periods of time and occur in most homes. For example, two out of three fatalities in 2014/15 involved two boilers each over 30 years old.[52] Age is a factor in CO risk with a disproportionate number of CO incidents in recent years involving appliances more than 12 years old.[53] In addition, a gas appliance check carried out by Croxford found older appliances emitted higher CO concentrations.[54]

[51] Ibid., 8.
[52] Ibid., 19.
[53] Ibid., 8.
[54] Ibid., 16.

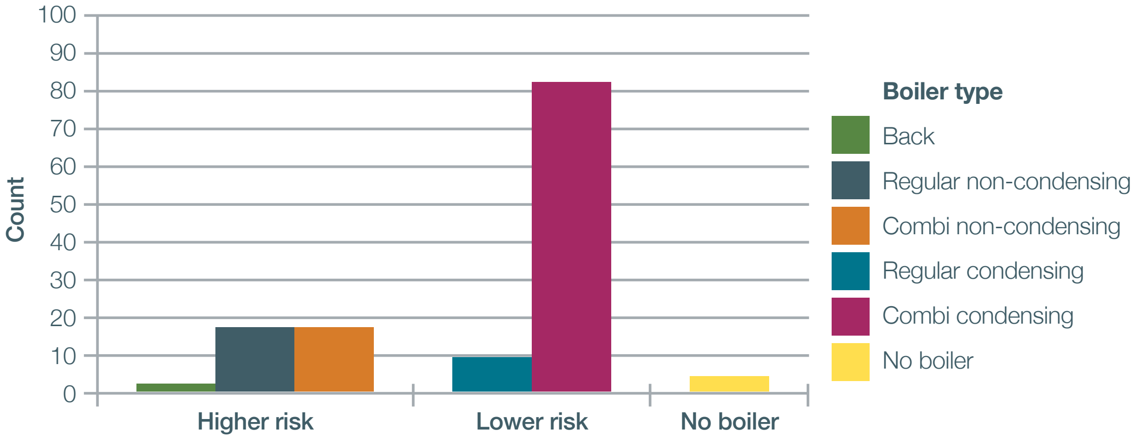
Not only are older non-condensing boilers less safe but they are also not as energy efficient; costing more to run in order to generate the same amount of heat. As such, households living with this boiler type are more likely to be in fuel poverty. Fuel poverty statistics for England show only 10% of households with condensing boilers are fuel poor compared to 15% of households with non-condensing (including back) boilers.[55] Since 2005, building regulations applying to England and Wales have mandated that all boilers installed in homes must be condensing.

Among the in-home sample, where details on boiler type were recorded in 131 households, 63% have the safest boiler type – a combi condensing boiler – and only two homes have a back boiler – the highest risk boiler type (see Figure 4). This proportion of homes with combi condensing boilers is higher than amongst the population of England as a whole, where it is estimated 39% of households have a combi condensing model, see Table 5. As such, there is no evidence that low income households in our sample are more likely to be living with an older, riskier boiler type than the general population. However it must be stressed the sample is not representative and therefore results cannot be extrapolated to all low income or fuel poor households. It should also be noted that some households in the sample with newer condensing boilers had received them free of charge under government energy efficiency programmes such as the Energy Company Obligation (ECO). This confirms the importance – for both energy affordability and safety reasons - of grant schemes to upgrade heating appliances in low income households.

Table 5. CO and temperature monitoring in households

	Proportion of households %	
	England	In-home sample (n131)
Combi condensing	38.9	62.6
Regular condensing	14.7	6.9
Combi non-condensing	12.9	13.0
Regular non-condensing	20.4	13.0
Back	3.2	1.5
No boiler	10.0	3.1

Figure 4. Boiler risk



[55] Ibid., 11.

Investigating boiler risk further using a chi-square test in SPSS Statistics V24, no statistical relationship was found in the in-home sample between living with a higher risk (non-condensing) boiler type and the following vulnerability factors:

- Living in the private rented sector
- Older age (at least one household member aged 65 or over)
- Younger age (children 0-15 in the household)
- Ill health or disability (households reporting someone with a long-standing disability or health condition)
- Low income (reporting an annual household income less than £16,000 before tax)
- Fuel poverty risk (reporting a lot of worry affording the energy bill or being in subjective fuel poverty)
- Fuel poverty status (households calculated to be fuel poor under the LIHC definition or the 10% definition).

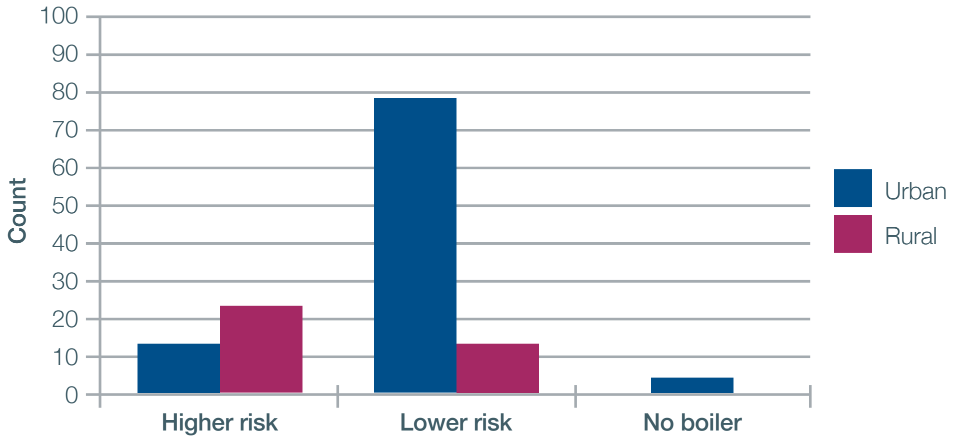
There was evidence of a statistically significant relationship between living with a higher risk boiler type and:

- Living in a rural area ($p<0.0001$)
- Using a fuel other than mains gas for primary heating ($p<0.0001$)
- Receiving means-tested benefits ($p=0.006$)
- Living in a non-deprived area ($p=0.001$).

This inconclusive relationship between income vulnerability and boiler risk suggests some low income households in our sample may fall into the lower risk category due to receiving newer boilers under grant schemes while others are making do with older appliances. The significance of living in a non-deprived area can be discounted because 97% of rural households in the in-home sample live in non-deprived areas. When these households are excluded from analysis there is no evidence of a relationship between deprivation and boiler risk.

What does emerge clearly from the analysis is a pattern of rural households not using mains gas for heating having older and risker boilers in their properties, see Figure 5. Of 36 higher-risk (non-condensing) boilers in the sample, 64% are in rural properties and 64% are non-gas (oil or solid fuel) boilers. This equates to 71% of rural households not using mains gas for their primary heating having a higher-risk boiler type, compared to only 28% of the entire in-home sample. These findings correlate with respondents to the postal survey where 58% of households not using mains gas for central heating report having a boiler aged over 12 years in their home, compared to 26% of the entire postal sample.

Figure 5. Boiler risk by rural-urban classification



Investigating the profile of the rural and off-gas in-home sample shows that households in this category are mostly retired older age owner-occupiers self-reporting ill health and in receipt of means-tested benefits. Qualitative insights reveal that for some households in this group financial and age barriers prevent them from upgrading or maintaining their older boiler. For example, a pensioner couple with multiple health problems that own their two-bedroom detached house in rural Yorkshire have a regular non-condensing floor-standing oil boiler over 12 years old that is broken and needs replacing. Worries about money and the cost-effectiveness of such a large investment given their advanced age were provided as reasons for not replacing the boiler. The couple is instead reliant on an open coal fire and electric heaters for warmth. If these secondary heating appliances are expensive to run or not properly maintained both fuel poverty and CO risk could be compounded.

Other households in this group expressed satisfaction with their old boilers and were reluctant to replace them with newer, untested models. For example, a pensioner couple living in the rural North East of England have a 40 year old regular non-condensing floor-standing oil boiler that the male occupant (a former heating engineer) maintains. They do not report difficulties affording their energy and are in a higher income bracket (£25,000 to £50,000). As such, behavioural and attitudinal factors are important considerations, alongside financial and age vulnerability, when examining why these older age off-gas rural households are making do with old and inefficient central heating that poses both a greater fuel poverty and CO risk.

Overall, the results suggest that that those living in an off-gas rural area are more likely to have an older and riskier boiler type than their urban and mains gas connected counterparts and supports evidence that non-gas homes have disproportionately missed out on heating measures under UK Government programmes such as ECO.[56] Rural off-gas homes are already at increased risk of living in severe fuel poverty: using more expensive, volatile or unregulated fuels to heat their homes and more likely to be living in the least efficient and hardest-to-treat housing stock.[57] Non-gas households are also not served by free safety checks of gas appliances offered to certain low income occupants under the PSR. Targeting rural and off-gas homes in future programmes for both fuel poverty and CO safety reasons may therefore be beneficial. CO messages may also require tailoring to reach this target group, for example emphasising that all combustion appliances, not only gas appliances, require regular maintenance.

Case study: rural and off-gas household with higher risk boiler type[58]

Jane is 66 and lives in rural Wales near the border with England. She owns her home, a three-bedroom semi-detached bungalow which is located off the mains gas grid. Until recently she relied for heating on an oil boiler that was over 20 years old and a source of constant problems. As Jane explains she had to call an engineer out at least once every winter because there was 'always something that didn't work but I just didn't have the money to buy a complete new boiler'. She lives alone, is retired and her primary source of income is from a modest pension. She spoke of being 'absolutely lost as to what to do' should her boiler break down. Compounding this anxiety was coping with a cold home: the radiators didn't heat up and the house was 'very, very draughty'. In the winter of 2016/17 Jane's worst fears were realised and the boiler finally 'died'. Left without central heating she shut rooms off and tried to make do with an electric fire and wood burning stove. However the log burner couldn't be used on windy days as smoke blew back into the room and on one occasion set off the CO alarm. Meanwhile relying on electric heating caused her energy bill to rise by £100 in four weeks. Unsure how she was going to finance a new boiler Jane admits 'I was getting desperate' and turned to local advice services for help. Initially advisors told her she was not eligible for a new boiler under any grant schemes because she was not claiming pension credit. However friends, concerned about her wellbeing, asked at the local council and through applying for council tax reduction she was passported into a boiler grant programme. With new double glazing also installed in the property she is finally able to keep warm at an affordable cost. Indeed, she notices 'how quickly it [the house] warms up now and I often have to turn the thermostat down'. Above all, Jane's overriding emotion is 'relief'. She no longer has to dread the onset of winter.

[56] See: NEA. 2017. In From The Cold: The Funding Gap for Non-gas Fuel Poor Homes Under ECO and a Proposal to Fill It. Available: *http://www.nea.org.uk/research/research-database/in-from-the-cold/*.

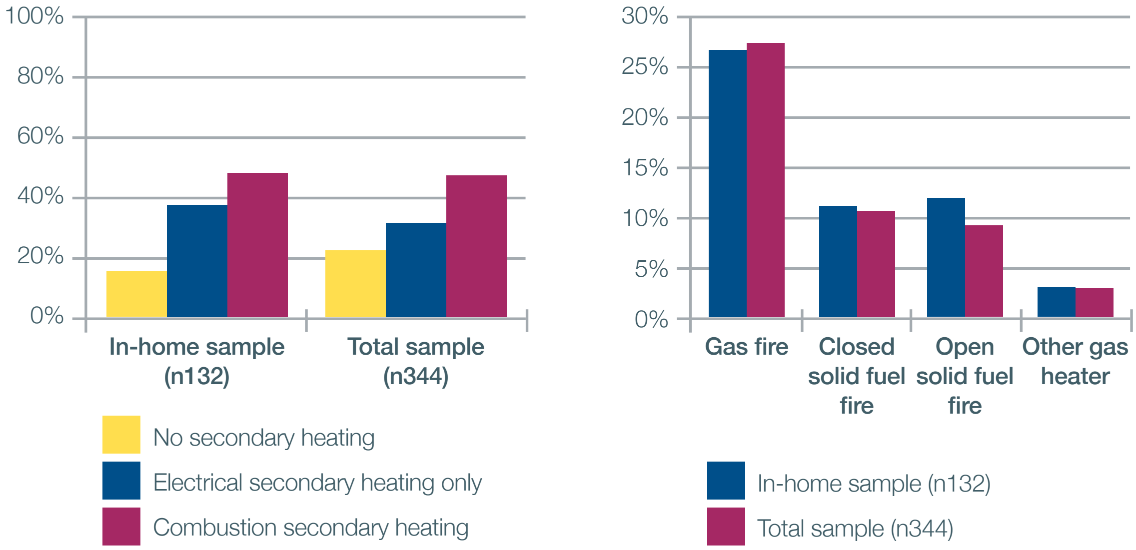
[57] Ibid.

[58] This case study is a composite composed of experiences from three households who took part in the research. All factual information and quotes in the case study are true. Participant experiences have been pulled together in order to represent a common household type observed in our research: rural and off-gas households with older and higher risk boilers at risk of fuel poverty.

4.2 Seconday space heating

In addition to central heating, nearly half of participants (47%) have at least one combustion secondary space heating appliance, see Figure 6. As such, secondary heating is a potential source of CO for around half of households.

Figure 6. Households with secondary heating (%)[1]



[1] Households with no central heating who are instead reliant on room heaters only (e.g. a gas fire) are included in the count of households with secondary heating.

As Figure 6 shows, the most common type of combustion secondary heating appliance in participants' homes (across both the in-home and total sample) is a gas fire. Significantly fewer households (mainly in rural areas) report having closed solid fuel fires (such as a wood burning stove) and open fires. Chapter 5 discusses the markedly different ways in which households use their secondary heating.

4.3 Water heaters

Only four households in the in-home sample (3%) have combustion water heating appliances in addition to or in place of a boiler. The appliance type in all four homes is a mains gas multipoint water heater. No question was asked in the postal survey about additional water heating.

4.4 Cookers

The majority of households have a combustion cooker: gas cookers are installed in 59% (n203) of the total sample. Similar to secondary heating, cooking is therefore a potential source of CO for just over half the sample. This proportion is similar to national figures, where it is estimated 55% of British households have a gas cooker (oven and/or hob).[59] The breakdown in our sample by type is presented in Table 6 below.

Table 6. Cooker fuel type (%)

	Electric hob and electric oven	Gas[1] hob and electric oven	Gas hob and gas oven	Oil hob and oil oven (range)
In-home sample (n132)	38.6	32.6	25.8	3.0
Total sample (n345)	39.7	28.4	30.4	1.4

[1] Includes mains, LPG and bottled gas

[59] Ibid., 8.

5. Household heating behaviours

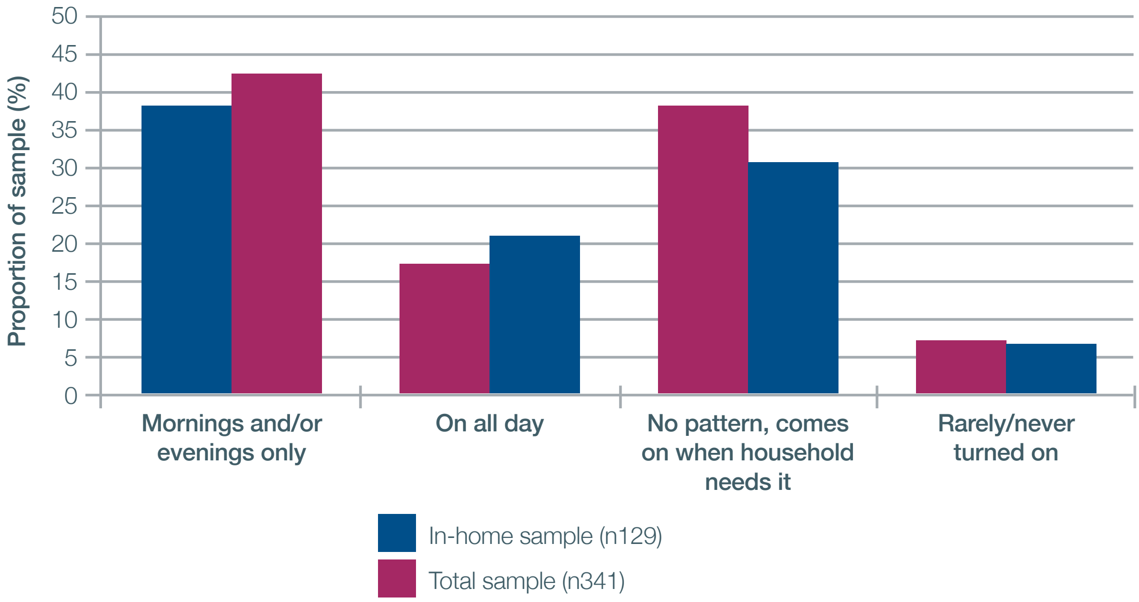
As noted by other authors, CO risk in homes is in part a function of how households use their combustion appliances.[60] This includes frequency of use, length of use and any improper use. This research study wanted to better understand if there is any relationship between the heating behaviours and patterns of households vulnerable to fuel poverty and behaviours which can elevate CO risk.

5.1 Occupancy patterns and central heating use

Households in the study spend significant periods of time in their homes, with 66% of all participants reporting at least one occupant normally home all day. This occupancy pattern is not surprising given only around one third of the sample report having a household member in paid work. A high proportion of the sample is economically inactive: either retired, of working age but unemployed or unable to work due to health reasons or caring responsibilities. As noted by Ezratty et al., vulnerability characteristics which lead to occupants spending above average time in their homes will increase opportunities to be exposed to unsafe levels of CO.[61]

Households in our sample with occupants at home during the day do not always use their central heating systems for long periods however. Only 21% of households report having their central heating switched on all day during a typical winter's day, see Figure 7. Instead, the most common heating pattern is using the central heating during mornings and/or evenings only, selected by 42% of participants. This result correlates to the UK Government's large-scale energy survey which found that households that are in during the day on weekdays use their heating for a shorter period (median 9.4 hours per day) than typically assumed in energy models.[62]

Figure 7. Household central heating pattern during typical winter day



[60] E.g. Ibid., 5., Ibid., 7.

[61] Ibid., 12.

[62] BRE for DECC. 2013. Energy Follow-up Survey 2011. Available: *https://www.gov.uk/government/statistics/energy-follow-up-survey-efus-2011*.

5.2 Secondary heating user typologies

In addition to primary central heating systems, nearly half of households in our sample have combustion secondary heating (for example a gas fire). Understanding how households use these appliances – at what times of year and day, for how long and for what reasons – is therefore critical to understanding CO risk in these properties.

Identifying secondary heating user types in Year 1

In Year 1 of the study (2015/16 heating season) 73 participants took part in the in-home survey. Along with recording details of all heating appliances, households were asked to describe to the surveyor their heating behaviours and patterns. What emerged from their answers is that households use their secondary heating in markedly different ways. Specifically, iterative manual coding techniques identified six typologies. Households with electric secondary heating only were excluded from analysis. The typologies and their characteristics are presented in Table 7 below. While these typologies serve to highlight key differences in user behaviour; in practise, a household may display characteristics from more than one group.

Table 7. Typologies of secondary heating users

Frequency of secondary heating use (least to most)

	Non-user	Rare user	Top-up user	Comfort user	Replacement user	Reliant user
Primary source of heating	CH system	CH system	CH system	CH system	Secondary appliance (e.g. fire)	CH system & secondary appliance
Use of SH in relation to CH	Never used / in case of emergency if CH breaks down	With CH during winter	Outside winter when CH is turned off; During winter as booster	With CH during winter	In place of CH during winter	With CH during winter; Outside winter when CH is turned off
Key drivers	CH breaks down	Cold snap; Special occasion (e.g. Christmas)	CH not turned on: outside of winter or programmed hours	Cosiness and aesthetics	No CH in home; CH not working and cannot repair (cost or tenure); View SH as cheaper to run	CH inneficient; Cold home; Susceptible to cold (age and/ or ill health)
Vulnerabilities associated with typology	-	-	-	-	Low income; Tenant; Home-bound (age, unemployment, ill-health)	Poor quality housing; Susceptible to cold (age, ill health)

CH - Central heating
SH - Secondary heating

Non-users have secondary heating but would use it only in case of emergency, for example if their central heating system breaks down.

Rare users light their appliance (e.g. a fire) very infrequently. A cold snap during winter may drive the household to seek extra warmth from their secondary heating or they may use it for aesthetic appeal on special occasions (e.g. when visitors are over or at Christmas). For the majority of the heating season, their central heating is sufficient.

Top-up users supplement their central heating with their secondary appliances in small bursts. This may be both outside the heating season as the weather turns colder (and before they switch their primary system on) or during winter for short periods as a booster, particularly on colder days. Motivations for this behaviour may be partly financial, for example they wish to avoid using 'whole-house' heating too early in the year or day. Nonetheless, convenience was observed as the main factor: secondary appliances are an easy source of 'instant heat' when the central heating is not in use or insufficient.

Comfort users also supplement their central heating with secondary appliances however do so more frequently than top-up users. They use their secondary heating not out of necessity but because they enjoy the extra warmth and cosiness generated by the appliance. This is partly for aesthetic reasons: they like the atmosphere created in a living room with a fire on, the tangible presence of a heat source and may take tactile pleasure from 'poking and prodding' a solid fuel fire. This user type has also been identified by Wrapson and Devine-Wright who found that, amongst rural off-gas households in South West England, considerable value was given to fires as providing *'a focal point of heat or cosy glow'*.[63] It is notable that households in the authors' sample were generally using low carbon primary systems and not in the lowest income brackets. Similarly, comfort users identified in this research were generally less vulnerable relative to other participants and could enjoy their secondary appliances without either having to ration or rely on them. An example is Ian, one half of a working couple earning over £50,000 per year. The household has a modern boiler but use their open log fire nightly during winter in conjunction with their central heating. Ian explains:

> *"Everyone's finally stopped working, we're going to eat some food and probably watch some TV [in the living room]…we probably use this [the fire] every night…and you have some kind of radiant pleasant heat in here that you can look at and sit in front of and talk...It's pretty, it glows, you can play with it, you can poke it, you can push it around…"*

Replacement users, unlike comfort users such as Ian and his wife, do not use their secondary heating out of choice but necessity. Structural and financial barriers prevent or impede use of the central heating system. This includes coping with a broken/under-performing central heating system that the household cannot afford to repair or replace or which the landlord (in the case of tenants) won't agree to fix or upgrade. In addition, some households in this group have no central heating and are unable to install it for cost or tenure reasons.

As such, replacement users are left to make-do with their secondary appliance(s), which often involves turning a fire on, closing the doors to the living room and the occupants huddling around the appliance to try to achieve adequate warmth. One example of this user type is Hayley, who lives with her partner and two young children in private rented accommodation in a deprived area of Bradford. The family reports an annual income of less than £16,000. The household is on-gas but has electric storage heaters which cause Hayley a great deal of stress, providing both inadequate warmth and proving very expensive to run. In the evening, when the storage heaters don't emit heat, the family rely on the gas fire in the living room which is run every night in winter from 5pm until the household goes to bed. During this time the adults and children camp out in the living room with the door closed. Hayley describes her frustration with this situation:

> *"These bungalows are not the warmest…they're freezing and this is why I say I've tried my damnedest in absolutely every way possible to get central heating and I just can't get further with it, it's horrendous. If I could have central heating I could control it more and it could save me loads more money."*

Here, both the structural barriers of an inefficient heating system and landlord inaction lead the household to rely on their gas fire during winter evenings. Another slightly different user type identified in this typology are those who may use the central heating in the morning or evening (for example before family members go to school/ work or after they return home) but will rely on a combustion room heater during the day. Motivations for this are financial; with the householder believing it is cheaper to heat one occupied room using a single appliance. Sabah, a stay-at-home mother whose family is in receipt of child and working tax credits, is an example of this:

> *"I use the gas fire when I'm on my own because I'm sitting in one room all day. But when the family comes, my children and my husband, in the afternoon, evening, then I turn the gas fire off and put the central heating on…I don't have both of them on, no, not at the same time, can't afford to because you get high bills!"*

[63] Wrapson, W. and Devine-Wright, P. 'Domesticating' Low Carbon Thermal Technologies: Diversity, Multiplicity and Variability in Older Person, Off Grid Households, Energy Policy, 67, p. 811.

Households in this group are characterised by occupancy patterns where one member is home-bound, usually due to older age, ill-health, disability, unemployment or caring responsibilities. So while such occupants may be particularly vulnerable to a cold home, central heating is viewed, to a certain extent, as a luxury and secondary heating emerges as an imperfect replacement.

Reliant users, unlike replacement users, run both primary and secondary heating systems concurrently in order to achieve adequate warmth. Reasons for this may be both structural – the central heating does not heat the home sufficiently due to an inefficient appliance or poor quality housing – and due to household vulnerability, where a member struggles to keep warm for age or health reasons. Households in this group are often heavy users of secondary heating, for example running a gas fire for long periods at night or throughout the year in their efforts to keep warm. Hassan, who lives with his family in social housing in Bradford, is an example of this. His young son has asthma and his daughter is diabetic and keeping the house warm is important. However, the boiler is an older non-condensing model and, as such, they rely on the gas fire in the living room for supplementary heat. When the family is home they spend as much time in that room as possible – with both the radiator and gas fire turned up:

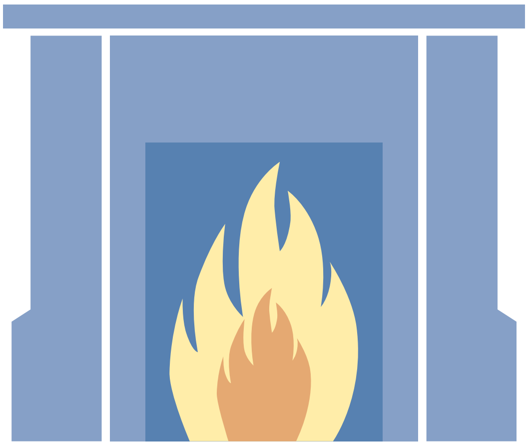
> *"We do need this gas fire because the central heating system is old and it's not working properly… because my daughter she became diabetic when she was 13 and my son has asthma…but it's costing, with the gas and electric, the bill is too much."*

Here, as for other low income households in this group, a dilemma emerges between achieving adequate warmth and keeping costs down.

Reflecting on the six typologies, replacement and reliant users both display a number of vulnerabilities associated with fuel poverty:

- Low income that either prevents them from replacing inefficient primary systems or installing primary systems (where there is no central heating in the home), leading to a reliance on secondary sources
- Low income that drives households to ration energy use by using their secondary source in place of their primary system; believing it is cheaper to heat a single occupied room
- Tenants who lack agency to address housing quality issues such as dwelling fabric and appliance inefficiency, forcing the household into coping strategies such as using a mixture of inadequate primary and secondary heat sources
- Susceptible to the cold for reasons including being home bound, of older age or in ill health; driving heavy use of combustion heaters such as fires to supplement or replace primary systems.

While it is not only households displaying replacement and reliant user behaviour that may be at risk of fuel poverty these two typologies are particularly relevant from a CO risk perspective. Specifically, if households are making frequent and heavy use of a combustion heater but this appliance is older or not properly maintained then exposure to high levels of CO could occur. This relationship between secondary heating, fuel poverty and CO risk is explored further below.



5.3 Prevalence of secondary heating user typologies

In Year 2 of the study we wanted to test the user typologies identified in Year 1. The aim was to understand what user behaviours associated with the typologies occurred most frequently in our sample and also investigate if there were other behaviours and profiles that had not been identified amongst Year 1 participants. To undertake this next phase of research we converted the range of motivations observed for using secondary heating into statements and presented these as a multiple-answer multiple choice question asking participants to identify the statements representing how the household mostly uses their secondary heating appliance(s). Both in-home and postal participants in Year 2 were asked this question. In total, 127 participants with combustion secondary heating returned valid answers.

Table 8. Main reasons for secondary heating use (households with combustion secondary heating only)[1]

Statement	Year 2 in-home sample % (n30)	Postal sample % (n97)	Total sample % (n127)	Corresponding typology	Typology prevalence % (n127)
In case of emergency, e.g. if my central heating breaks down	33.3	17.5	21.3	Non-user	27.6
I never use the heating appliance	3.3	7.2	6.3		
A special occasion e.g. Christmas	20.0	11.3	13.4	Rare user	13.4
To top up my central heating during winter. Most of the time my central heating is sufficient	23.3	36.1	33.1	Top-up user	52.0
For warmth outside of winter when my central heating is turned off	20.0	18.6	18.9		
For cosiness and atmosphere	36.7	22.7	26.0	Comfort user	26.0
In place of my central heating because my central heating is broken/ I don't have central heating	13.3	8.2	9.4	Replacement user	37.8
In place of my central heating to save money	30.0	27.8	28.3		
At the same time as having my central heating turned on because my central heating doesn't work very well/I'm living in a cold home	23.3	8.2	11.8	Reliant user	27.6
At the same time as having my central heating turned on because I feel the cold a lot	13.3	16.5	15.7		
Other	3.3	9.3	7.9	Other	7.9

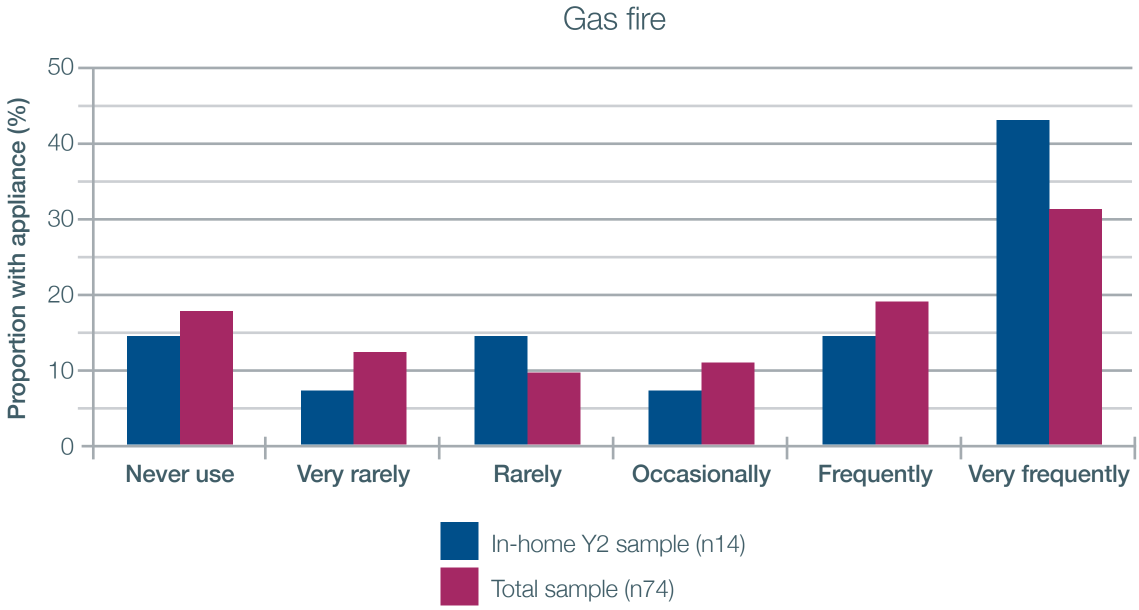
[1] 34% of households reported having electric secondary heating in addition to combustion secondary heating.

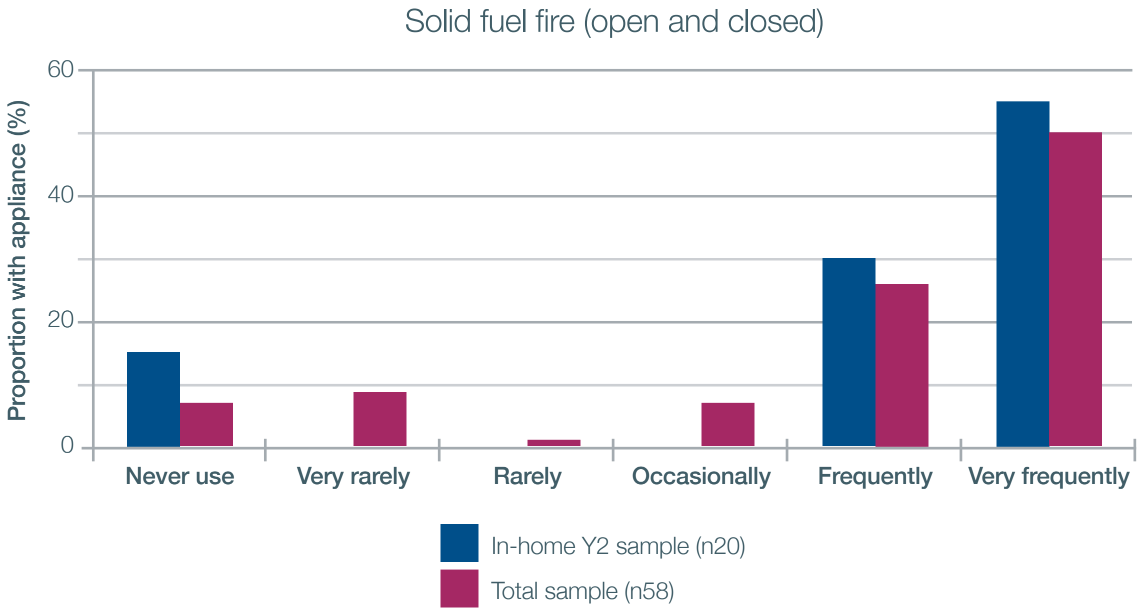
Table 8 shows the most commonly selected statement across all participants was using their secondary appliances to top-up the central heating during winter. This statement was selected by 33% of respondents. This is not surprising considering households with central heating systems would be expected to rely on them as their main heat source.

What emerged as particularly interesting is that the second most frequently selected statement across the total sample was using secondary heating in place of central heating to save money. This statement was selected by 28% of respondents. Overall, the characteristics of the replacement user profile were present in over one third of the sample (38%) and the characteristics of a reliant user were present in over one quarter of the sample (28%).

The prevalence of these two user profiles can be correlated with households' answers to how frequently they use their appliances. As Figure 8 shows, over half of households with a gas or solid fuel fire are using it at least weekly and often daily during winter. In cases where households have combustion and electric secondary heating the combustion source is used more frequently.

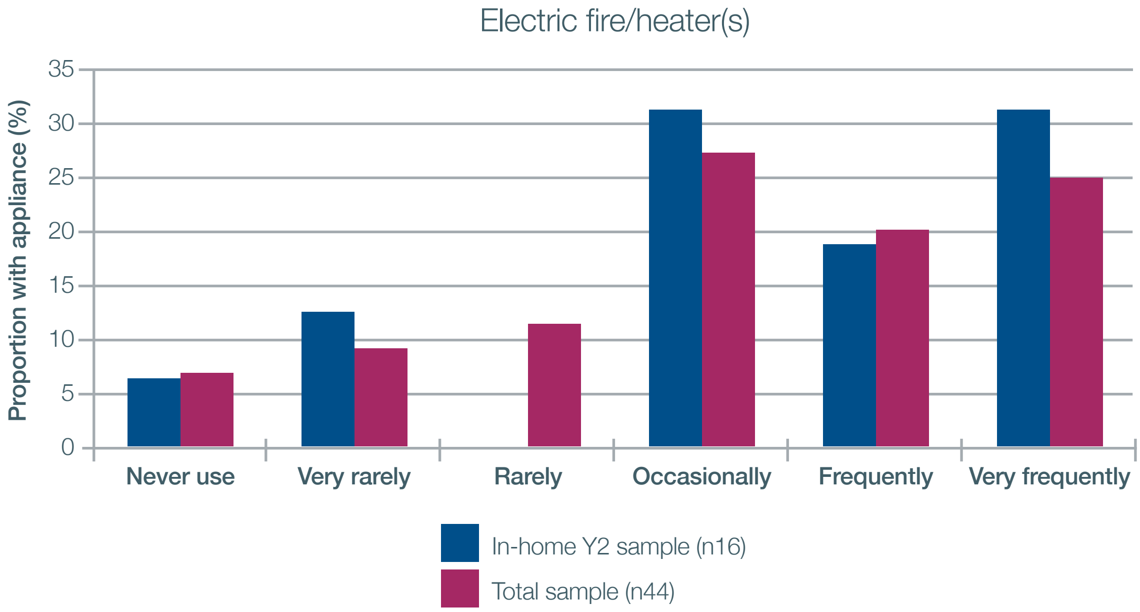
Figure 8. Frequency of secondary heating use[1]

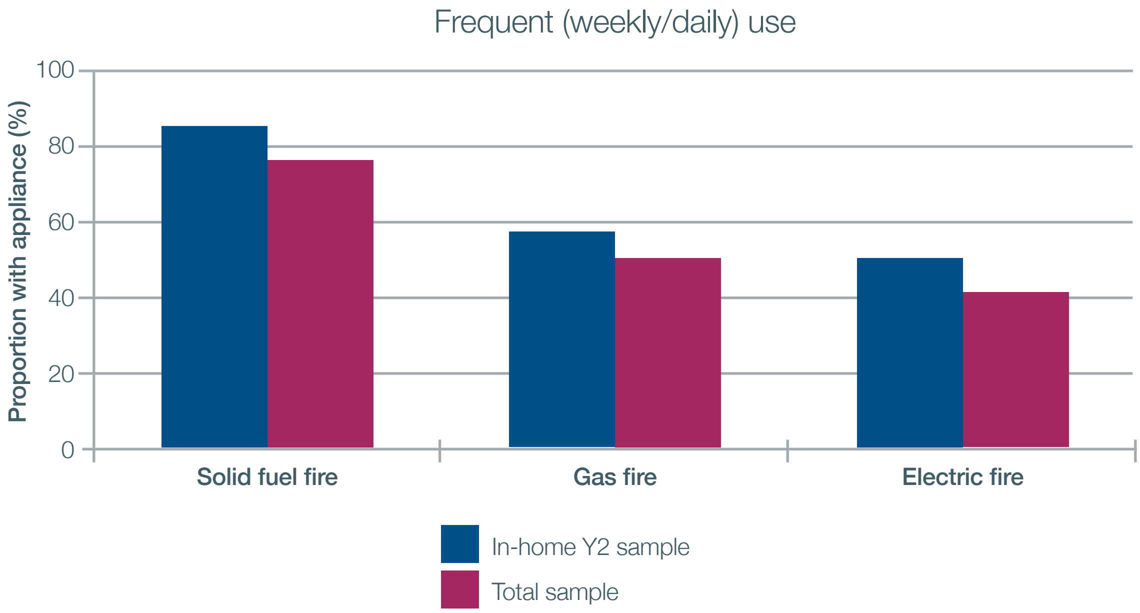




[1] Households reporting no secondary heating and households reporting electric secondary heating only were excluded from analysis. Year 1 in-home survey participants were also excluded as the question pertaining to this data was not asked in Year 1.

Figure 8. Frequency of secondary heating use[1] continued....





Never use = Have but never use	Occasionally = A few times each winter
Very rarely = Once a year or less	Frequently = Weekly during winter
Rarely = 2-3 times per year	Very frequently = Daily during winter

To better understand the prevalence of the different typologies, we investigated the in-home sample further to assign a primary user profile to each household reflecting how they mainly use their combustion secondary heating. Primary profiles were coded based on households' qualitative responses to the surveyor asking them to describe their heating behaviours and – in Year 2 – cross-referencing this answer with the statements selected from the multiple choice question (see Table 8). Using this method, the breakdown of the in-home sample with combustion secondary heating by user type is as follows:

Table 9. Primary secondary heating user type, households with combustion secondary heating (n63)

	Count	Proportion of sample % (n63)	Proportion all in-home participants % (n132)
Non-user	7	11.1	5.3
Rare user	6	9.5	4.5
Top-up user	8	12.7	6.1
Comfort user	9	14.3	6.8
Replacement user	19	30.2	14.4
Reliant user	14	22.2	10.6
Total	63	100.0	47.7

As Table 9 shows, when each household with combustion secondary heating is assigned a primary user type, replacement and reliant users emerge as the dominant typologies. Furthermore, our findings suggest that households on low incomes and vulnerable to fuel poverty are more likely to fall into these two typologies. Using a chi-square test to investigate the profile of replacement and reliant users found that – relative to the rest of the in-home sample – households in these categories are:

- More likely to be in the receipt of means-tested benefits and more likely to be in lower income brackets although neither relationship is statistically significant ($p>0.05$)
- More likely to be retired or of working age and not in paid work although neither relationship is statistically significant ($p>0.05$)
- Significantly more likely to have a higher risk (non-condensing) boiler ($p=0.025$) and significantly more likely to report not having had the boiler checked or serviced over the past 12 months ($p=0.007$)
- More likely to report paying the energy bill causes them a lot of worry although this relationship is not statistically significant ($p>0.05$)
- Year 2 replacement and reliant users, where further information on fuel poverty status was collected, are significantly more likely to report being in subjective fuel poverty ($p=0.006$) and also significantly more likely to be fuel poor under the 10% definition ($p=0.008$). They are also more likely to be LIHC fuel poor however this relationship is not significant ($p>0.05$).

5.4 Implications for CO risk

The reliance on combustion heating sources other than the boiler, observed in one quarter of participants and over half (52%) of those with combustion secondary heating, has the following implications for CO risk:

Frequency and length of secondary heating use increasing potential for CO exposure

Using combustion heaters such as gas and solid fuel fires daily during winter and often for long periods increases opportunity to be exposed to CO from these sources. An evidence review found that unvented and poorly vented gas heaters that are used for substantial periods of time appear to be major contributors to residential CO concentrations.[64] Another study which undertook gas safety checks of appliances in homes found gas fires to be the most frequently problematic appliance.[65] With regard to solid fuel fires, there is very limited data to understand to what extent fireplaces and wood-burning stoves contribute to indoor CO levels.[66]

[64] Ibid., 7.
[65] Ibid., 16.
[66] Ibid., 7.

In our study, it was observed that in some households making frequent use of gas fires the appliances are not always in good working order. For example, Margaret is 73 with no central heating in her home. She lives and sleeps in her ground floor living room as she is too frail to climb the stairs after being discharged from hospital where she spent nine months diagnosed with pneumonia. She is reliant for heating on her gas fire which is six years old. However she has been having issues with the appliance as she is unable to switch it on again after turning it off, in spite of repeated call outs to address the issue. Because of this she leaves the fire turned on all day and night:

> *"I do want to switch it off but I daren't…I wouldn't let myself get cold, I wouldn't let myself get in that position because I wouldn't want to get pneumonia [again]."*

Running it all day and night – in part to keep warm and in part because the appliance is misbehaving – not only increases potential risk of CO exposure but has also leads to very high gas bills, pushing the household further into fuel poverty. CO readings recorded in this property were 0 ppm.

Improper secondary heating use elevating CO risk

Households making use of unvented or open flued combustion heaters will increase CO risk if they block ventilation to retain warmth. There was evidence in our sample of households closing doors and staying in one room with a fire to try and keep warm (for example Hayley and Hassan, described earlier in this section). Overall however, no widespread pattern was observed of households reducing ventilation in risky ways.

Household profile more vulnerable to effects of CO poisoning

Many households in our sample reliant on combustion secondary heating to either replace or supplement their primary system are home-bound due to older age, ill health or unemployment. As such, they are not only more exposed to any indoor sources of CO in the home but also, in the case of age and ill health, display a profile more susceptible to the adverse effects of CO poisoning. Amira is an example of this, running her gas fire most of the year and all day and night due to a health condition:

> *"I've got something called Fibromyalgia and I always feel very cold all the time even with the central heating so I tend to put this [the gas fire in the living room] on as well and sit next to it…We have it on all the time, even at night time as well, because if I come in the morning [and the gas fire is switched off] then it will be cold again. So then it affects my health. So we'd rather keep it on all the time."*

In these cases, the heating behaviours and vulnerability profile of the households can compound to elevate CO risk.

Appliance age and lack of maintenance increasing CO risk

As noted earlier, replacement and reliant users of combustion secondary heating in the in-home sample are significantly more likely to have an older non-condensing boiler that has not been checked or serviced in the past year. By making do with these under-performing primary systems households are increasing CO risk relative to having a safer condensing model installed. Furthermore, CO risk will increase if these households are also failing to maintain their combustion secondary heaters. Servicing behaviours are explored in more detail in Chapter 6 with our findings showing that households are having their gas and solid fuel fires checked less frequently than their boilers. While the age of these secondary heaters was not recorded there is evidence from other studies that gas fires in homes are often older and more risky.[67] When combined with lack of servicing and heavy use CO risk will increase relative to using a boiler only.

[67] E.g. Ibid., 3, Ibid., 5, Ibid., 16.

Case study: household at risk of fuel poverty reliant on secondary heating[68]

Farid Ansari lives with his wife and three children in a private rented three-bedroom semi-detached house in a deprived pocket of Bradford, West Yorkshire. Since suffering a serious head injury he is no longer able to work regularly and the family relies on benefits and tax credits to make ends meet. Like so many households living in private rented dwellings, the Ansaris face issues with the quality of their housing. 'It's cold this house,' Farid laments and explains how air vents throughout the property wreak havoc when it's windy outside. To try and address the problem Farid's wife sticky-taped cardboard over the vents but was told by the landlord to remove the makeshift solution as it would exacerbate damp in the home. The family have a combi condensing boiler but according to Farid 'it's old and it's not working properly'. Because of this, they turn to their gas fire in the living room. Running the fire from around October until March it is used for several hours during the day and also at night. This causes a dilemma as the family cannot afford to have all radiators in the house turned up so they tend to prioritise the living room and 'camp in together' with the gas fire switched on until bedtime. Keeping warm is very important as Farid's youngest daughter has asthma. However Farid laments that the cost of running the fire and central heating is 'too much'. He also has doubts whether the fire is working property: 'when it's windy, I can here this breeze, this wind through the chimney and the gas fire goes a bit funny as well'. The landlord has had both the boiler and fire safety checked over the past year but Farid has never seen a copy of the gas safety certificate despite requesting it. There is no CO alarm fitted in the home.

5.5 Use of a gas cooker for room heating

Sterling and Sterling speculate that low income households living in poor quality housing may use their gas cooker as a source of heat during colder weather.[69] Because cookers are not vented relying on them for long periods for room heating has the potential to emit dangerous levels of CO. A study of CO incidents in social housing in London found cookers to be a major source of exposure, both due to methods of cooking and faults with the appliances.[70] There have also been a number of cooker-related fatalities in recent years, with two deaths in 2013/14 caused by CO poisoning involving a free-standing gas cooker.[71]

The All-Party Parliamentary Carbon Monoxide Group (APPCOG) found that 'misuse of cooking appliances is a topic which is not well understood and should be subject to further research to inform interventions'.[72] This study wanted to investigate if households vulnerable to fuel poverty are ever resorting to using their cookers for warmth. A question was asked on both the in-home and postal survey, see Figure 9.

Figure 9. Survey question about using cooker for room heating

Q16. Have you or has anyone in your home ever used your cooker for room heating, to help keep warm?

☐ Yes - hob only? ☐ Yes - oven only ☐ Yes - hob and oven ☐ No **Go to Q19**

Across the entire sample (n344), 15% of respondents answered yes to using their cooker (hob, oven or both) for room heating, to help keep warm. Breaking this result down, 19 households are using electric parts of their cooker only and two households are using their oil range. These households can be excluded from analysis as their behaviour does not pose a CO risk. Investigating the remaining respondents shows that, of 203 households with a gas cooker, 30 (15%) report using it for room heating, see Table 10.

[68] This case study is a composite composed of experiences from four households who took part in the research. All factual information and quotes in the case study are true. Participant experiences have been pulled together in order to represent a common household type observed in our research: households with a gas or solid fuel fire who are reliant on the appliance due to fuel poverty characteristics present in the home.

[69] Ibid., 14.

[70] Ibid., 3.

[71] Ibid., 8.

[72] APPCOG. 2015. Carbon Monoxide: From Awareness to Action, p. 41. Available: *http://www.policyconnect.org.uk/research/carbon-monoxide-awareness-action.*

Table 10. Households using gas cooker for room heating

	Count	Proportion of households with gas cooker % (n203)
Gas hob only	19	9.4
Gas oven only	8	3.9
Gas hob and oven	3	1.5
Total	30	14.8

Households reporting using their cooker for warmth were asked follow-up multiple choice questions to identify how often and for what reasons they undertake this behaviour. As Table 11 reveals, motivations for using a gas cooker for warmth are mixed however no respondents report being totally reliant on the appliance as their only source of heating. Furthermore, Figure 10 shows that the majority of households are not using the cooker for room heating regularly. This suggests that, amongst fuel poor households, the practice of using a gas cooker to heat the home is not widespread. Instead, the most frequently selected reason for using a cooker for heating is in the case of an emergency because the main heating source broke down. This reason was selected by over one quarter of respondents (27%). Amongst other users, three key factors were identified as contributing to this behaviour: financial vulnerability, structural vulnerability and convenience.

Figure 10. Households using gas cooker for room heating, frequency of use

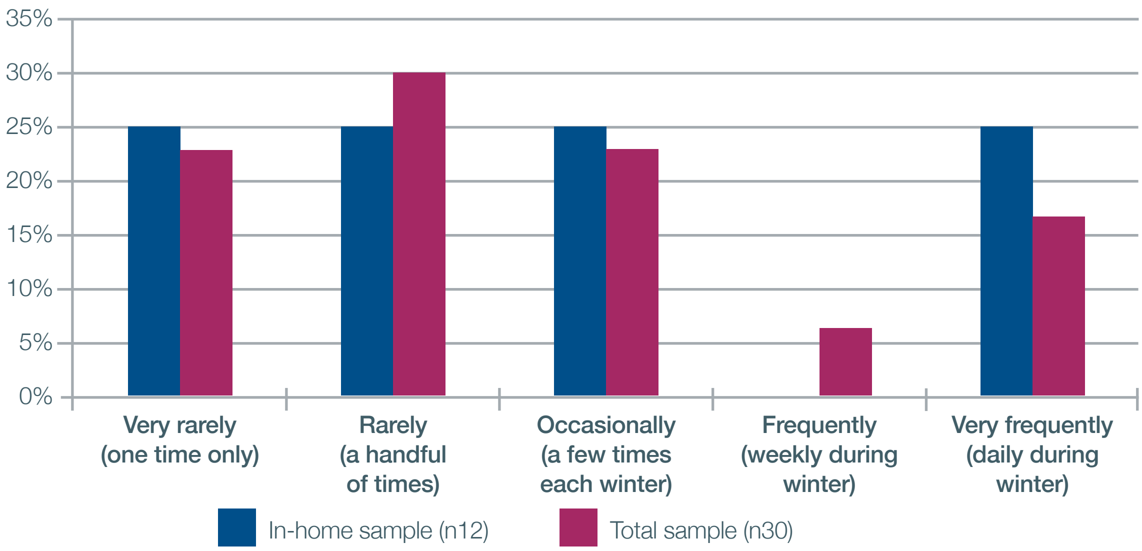


Table 11. Households using gas cooker for room heating, reason for use

Statement	In-home sample % (n12)	Total sample % (n30)
An emergency situation because my main source of heating broke down	33.3	26.7
To take the chill off the kitchen before my main source of heating kicks in	25.0	23.3
To warm the kitchen because there is no other heating source in the room	25.0	23.3
To save money by using it in place of my main heating source	16.7	16.7
Because I don't have any other source of heating	0.0	0.0
Other	0.0	10.0[1]

[1] Three respondents chose Other, citing: a 'cold atmosphere'; 'on very cold days'; and 'just while I get dressed in the mornings'.

Financial vulnerability

A very small number of households (n5, 2.5% of all households with gas cookers but 16.7% of those that use a cooker for room heating) report using the appliance to save money in place of their main heating source. Households in this group were either using their gas cooker infrequently to avoid having to turn the 'whole-house' central heating on, or, more worryingly, using it regularly in place of their central heating to save money. An example of the latter user type is Annie, a 69 year old pensioner who lives alone in a three-bedroom terraced house in a deprived area of Leeds. She is on a low income and in receipt of pension credit. A follow-up interview with the householder reveals that, despite receiving a modern combi condensing boiler free of charge under a grant programme in 2014, she rarely uses the appliance:

> *"Well I use the boiler for washing and bathing for hot water but I don't use the heating because I can't afford it…I tend to live in the kitchen and I like my little gas cooker."*

She has a gas hob and a gas oven, nine years old, and she uses the top oven for warmth, running it from around 3:00 p.m. in winter until she goes to bed. This is despite having a central heating radiator in the kitchen. She believes the gas cooker costs her less to run:

> *"Oh it's much cheaper [the gas cooker than central heating]! My gas bill last year was only about £280. The gas bill was less than the electric bill."*

In this case, due to low income, the householder is making a conscious choice to ration her heating as she reports preferring to prioritise other costs. She is in good health so a cold home for her does not cause the same concern as for households with illnesses and, in addition, cultural factors are important:

> *"I'm of a generation when we were young and there wasn't central heating…You just wrap up and put up with it. It's my choice so I can't let it annoy me…oh I get down because I'm cold but I mean, you just carry on."*

A maximum CO reading of 24.5 ppm was recorded in this property (see the methods section for follow-up action taken with higher risk households). In effect, households like Annie are replacement users where their gas cooker becomes their secondary heating source used either occasionally or regularly in place of their primary system. While cost is the key factor driving this behaviour it is also important to recognise attitudinal factors, such as an expectation of living in a cold home amongst older generations, when considering what messages and interventions are appropriate.

Structural vulnerability

Seven households (3.5% of all households with gas cookers and 23.3% of those that use a cooker for room heating) report using the appliance for warmth because there is no other heating source in the kitchen. Most households in this group appear to be using their gas cooker infrequently during a very cold snap when driven to seek extra heat. In some cases, living in a cold energy inefficient home is a key factor contributing to this behaviour. An example is a single parent asylum seeker family living in a two-bedroom terraced house in Leeds. Rashmi, the female occupant, reports problems with the radiators not heating up and also cites issues with the quality of housing, including draughts due to gaps in doors and broken windows. She has previously used the hob rings during a very cold winter because there is no radiator in the kitchen:

> *"It was just really cold, especially in the morning, it just doesn't heat up [the kitchen]…The central heating was on, it just didn't heat up and so it was basically to warm up the kitchen a bit so I can do what I need to do. It's very rare that I do that still unless I'm cooking in the morning…"*

Rashmi reports that the cooker causes her problems, sometimes taking up to five minutes to ignite with the gas turned on. Despite this issue, she has not complained to the housing provider. What is apparent here is that structural barriers increasing fuel poverty risk, namely living in a cold home and lacking agency due to her asylum status, are driving a behaviour that may also increase CO risk. A maximum CO reading of 50.5 ppm was recorded in this property.

These structural barriers leading to higher risk behaviour were also observed in low income households with no central heating. An example is Barry, who is 60 years old and lives alone in a one-bedroom terraced house. The kitchen is located in the cellar and he complains of it being 'freezing' during the colder months. Because there is no other heat source in the room he uses the gas hob daily during winter; lighting the rings for around half an hour at a time. Barry is in a very vulnerable situation, home-bound and unable to work due to multiple health conditions, in receipt of means-tested benefits and reporting an income of less than £10,000 per year. The only source of hot water in the house is an electric shower as the water heater was previously condemned. The occupant cites being in subjective fuel poverty due to both living in a cold home and frequently cutting back on heating and other essentials in order to afford the energy bill. CO levels are unknown for this property as the logger was not returned.

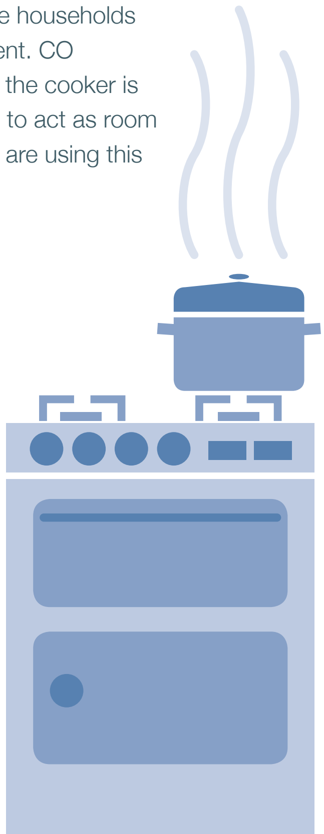
Convenience

Households in this group are motivated to use their cooker to take the chill off the kitchen before their central heating kicks in. This reason was cited by 3.5% of all households with gas cookers and 23.3% of those that use a cooker for room heating. For these households, the convenience of the cooker as a quick and easy source of 'instant heat' is a key motivating factor. The householder turns to the cooker often first thing in the morning before the central heating switches on from a timer, or before they begin to cook. While financial vulnerability is not an overriding reason for this behaviour cost may be a factor in cases where the occupant wants to avoid having the central heating turned on for too long. In addition, households in this group can be undertaking this practice regularly, sometimes using the cooker for short bursts to warm the room or their hands daily during colder weather. Amira, living with her family in Bradford, explains:

> *"Sometimes I go downstairs [to the kitchen] and if I'm really, really cold I'll put it [the gas hob rings] on and start warming myself and my hands…My son, he's seen me do it and he's gone down and said: "Mum, mum it's really cold!" and so he's put it on and warmed his hands."*

In this example Amira's fibromyalgia, which causes pain and muscle stiffness, contributes to her behaviour as she uses the gas flame to increase circulation in her joints. This property was not monitored for CO.

It is important to remember that these three user types – turning to a gas cooker to warm their homes for financial, structural or convenience reasons – are not prevalent in our research. Nor are they necessarily using the cooker for long periods to heat the home. Nonetheless, it is clear from this study that the factors which drive fuel poverty – living on a low income and in an inefficient home – are contributing to some households turning to their cooker as a source of 'cheap' heat or because their primary system is insufficient. CO exposure resulting from this behaviour will depend on a number of factors, including how long the cooker is used for, the condition of the appliance and ventilation in the home. Cookers are not designed to act as room heaters however and it is therefore concerning that a small but notable number of households are using this appliance inappropriately.



Case study: household using a gas cooker for room heating

Mary is over 75 and lives alone in the house which she owns in a former coal mining town in the West Midlands. She is dependent on support from the local council. In 2014 it was the council who she believes arranged for a check of her gas boiler. At this point the engineer noticed the gas wall heater in her kitchen and it was condemned. Mary explains: 'I was having it [the gas wall heater] on and then I'd think I don't feel right, I've got these sick headaches you know. I didn't think of the heater at all'. Unable to afford to replace the appliance she was without a heating source in the kitchen, the room in which she 'lives'. The property has no central heating downstairs and although there is a gas fire in the front room Mary is unable to use it as she can't switch the appliance on or off due to gout in her hands. These structural, financial and health vulnerabilities have compounded to result in Mary turning to her gas oven for warmth. She runs this on cold days concurrently with an electric portable bar radiator in the kitchen:

> *"What I do, I put my oven on, heat the oven up and then I open the oven door and leave it on coming in the room and I've got that little [electric] fire. If it's really, really cold or it's frosty or anything like that. See I've got heart problems and I feel the cold really bad. I've got bad circulation."*

Mary is unsure when her gas appliances were last safety checked. She believes the council may send someone but she would not arrange for an engineer visit herself, explaining 'I don't like anybody to come to my house. I've got to know them, I've got to know where they're from'. Local services are an incredibly important support network to her and the fire service has visited to fit smoke and CO alarms in the home. Reflecting on CO poisoning, she does not believe she could recognise any symptoms, stating: 'I don't know anything about it. I didn't even know about the gas fire [and] having a headache'.

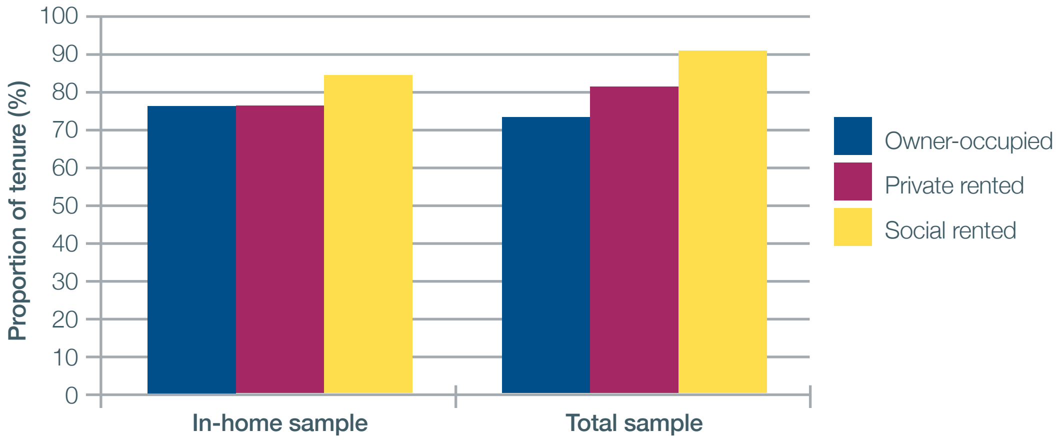
6. Appliance servicing

An annual service or safety check of combustion appliances is a key part of minimising risk to CO exposure in homes. A service is more thorough than a safety check; where the latter assesses whether the appliance is safe to use the former may involve inspecting and cleaning internal parts of the appliance. By law, engineers servicing gas appliances or carrying out gas safety checks must be Gas Safe registered. It is recommended oil and solid fuel burning appliances are checked by OFTEC and HETAS technicians respectively. In rented accommodation it is law for the landlord to arrange for a gas safety check to be carried out annually on out each gas appliance/flue in the property unless the appliance has been installed by the tenant. A record of this check (the CP12 certificate) must be provided to tenants within 28 days of the engineer's visit. The importance of yearly maintenance is underlined by the number of faulty appliances in homes that, unless safety checked, could potentially be emitting harmful levels of CO. Croxford estimates up to 39,000 homes could be living with a problem gas appliance while lack of servicing was a contributory factor to four deaths caused by CO poisoning from gas appliances in 2014/15.[73,74]

6.1 Servicing rates

Figure 11 shows that, of households in our sample, those living in social rented accommodation are most likely to report having someone visit their home over the past 12 months to safety check or service a combustion appliance.[75] Indeed, servicing rates are very high in this sector: 48 of 53 social tenants (91%) report having a check. This figure is not surprising given social housing providers will likely have annual maintenance plans in place covering their entire stock.

Figure 11. Households reporting a check or service of a combustion appliance over the past 12 months, by tenure



Overall, servicing rates are high across all tenures: 77% of respondents (n339) report an engineer visiting their home over the past 12 months to check a gas, oil or solid fuel appliance. Although it should be noted that a limitation of the study is that findings are reliant on the household's assessment of whether maintenance has been carried out. No evidence was provided (e.g. an engineer's certificate) to confirm servicing.

Servicing rates by appliance type

Investigating servicing rates by appliance type provides greater insight into CO and gas safety behaviours. Namely, it enables us to understand what appliances households are prioritising for an annual check and what appliances are neglected.

[73] Ibid., 5.

[74] Ibid., 19.

[75] This study did not ask households to distinguish between having a full service or safety check only of their appliances and, as such, throughout this report the terms 'service' and 'check' are used interchangeably.

Figure 12. Households reporting a check or service of a combustion appliance in the home over the past 12 months, by appliance type

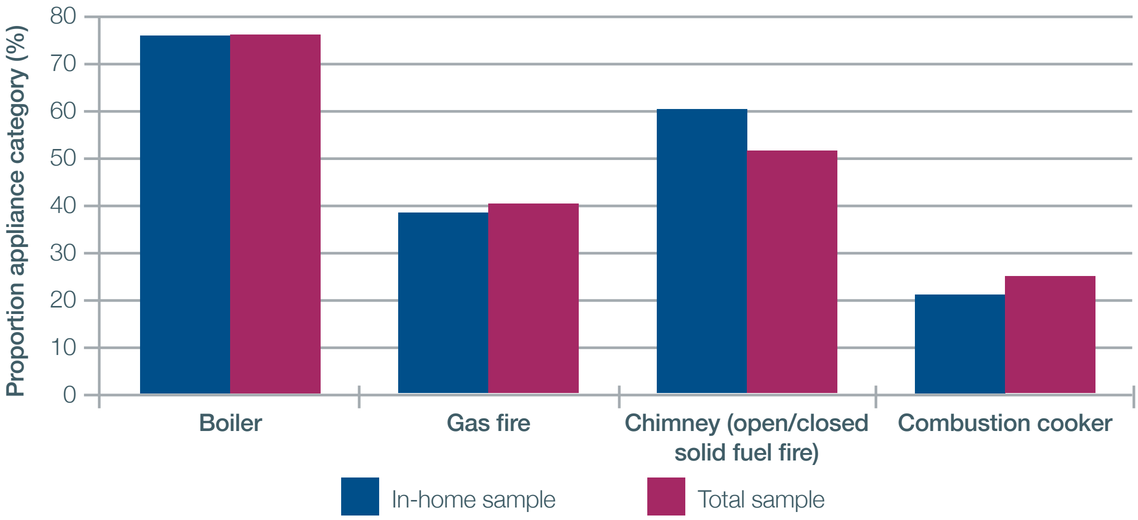


Figure 12 shows that while servicing rates for boilers are high – 77% (n238) across all respondents – only 40% (n38) of gas fires have been checked in the past 12 months and even fewer households with combustion (mainly gas) cookers report having the appliance checked in the past year (25% of all combustion cookers, n194). With regard to solid fuel fires (n56), households report cleaning the chimney over the past 12 months in around half of the sample (52%).

These findings correlate to Croxford's gas appliance check project.[76] Although maintenance rates were lower overall in Croxford's sample, a similar pattern was observed of much lower incidences of gas fires and gas cookers being checked annually relative to gas boilers. Furthermore, gas boilers in the author's sample were generally newer appliances and it was older fires and cookers which were the most common source of high CO emissions. Croxford's findings chime with McCann et al's 2011 study of CO incidents in social housing, which identified 30% of gas cookers and 25% of gas fires as defective, compared to only 10% of boilers.[77]

Overall, these servicing behaviours show that while checking a boiler is relatively common, other combustion appliances such as a gas fire or cooker can be going unchecked or under-serviced for years. Reflecting on the heating behaviours observed in our sample (Chapter 5), in which a reliance on combustion fires (and in some cases gas cookers) for room heating is identified amongst households more vulnerable to fuel poverty, the fact these households are not always prioritising servicing of these appliances is concerning. An older and under-maintained appliance that is frequently used will increase CO risk. Furthermore, households relying on such appliances and on low incomes cannot access free replacements through grant programmes such as ECO (which do not count individual room heaters or cookers as eligible measures).

6.2 Reasons for non-servicing

Understanding why households are not maintaining their appliances is important when considering how to support and target them. Amongst owner-occupiers, who are responsible for servicing their own appliances, the following key factors were identified from our research, and are outlined below.[78]

Lack of awareness: Not knowing an appliance requires checking is identified by 23% of owner-occupants with un-serviced appliances. It is a particularly common answer in relation to cookers where many participants in the in-home sample report never having their cooker checked (unless there is a fault). For example Annie, a pensioner profiled earlier in this report who is using her cooker for room heating, is vigilant about arranging an annual check of her boiler but having her gas cooker checked has never occurred to her. Similarly, Myra has her boiler checked annually and it is clear public messaging about the importance of boiler maintenance is a factor in her behaviour:

[76] Ibid., 16.

[77] Ibid., 3.

[78] In-home participants were asked an open-ended question about non-servicing while postal participants were asked to select reasons for non-servicing from a multiple choice question.

> *"I was told that you must have your boiler checked every year, it's like you get your car serviced, or your teeth serviced. It's just so that things are kept working."*

This behaviour does not extend to her gas cooker which is 10 years old and has never been checked:

> "I never knew it should be done. Nobody ever mentioned it. Nobody gets it checked. None of my friends, nobody. I've never heard of anybody getting their gas cooker checked. I've been told that there is a danger with a gas boiler. I've never heard of dangers with gas cookers."

From these examples it is apparent that households who may be careful to carry out annual maintenance of their boilers do not always replicate this behaviour for other gas appliances in the home. Social norms (copying what friends and family do), public messaging and awareness (hearing and acting on messages about boiler maintenance but not hearing messages about other appliances) and perceptions of risk (believing appliances such as cookers pose fewer dangers than boilers) all emerge as factors in this pattern of behaviour. Considering cookers are a source of CO incidents, including fatalities, these findings are concerning and suggest messages need to be clearer about what appliances require checking, for what reasons and how often.

Cost: Cost is cited as a factor by 21% of owner-occupants with un-serviced appliances although no statistical relationship was found between low income and lack of servicing. Investigating qualitative answers of households in this group show many respondents know a service is overdue but are unable to prioritise it due to living on a fixed and limited income. David is one concerning example: a pensioner who is home-bound, he runs his gas fire, which is around 15 years old, all day and night, including outside of winter. During colder weather he supplements the fire with his central heating. He reports ongoing problems with both appliances but none of the boiler, fire or gas hob have been checked in the past year. This is for cost reasons: he is aware a service is overdue but cannot afford it on his pension. A maximum CO reading of 19 ppm was recorded in this property. It is clear from such a case that financial vulnerability, while not the only factor to explain non-servicing in low income households, is the key determinant amongst some vulnerable owner-occupants. This group of households may be conscious of gas safety but do not have the disposable income available to practise gas safe behaviour.

Neglect: Households can be aware an annual check is required but simply haven't got around to it: this reason is identified by 20% of respondents with un-serviced appliances. Households in this group may have no trigger to prompt the check. Indeed, only 38% of owner-occupants in our sample report having a service contract for one of their combustion appliances. Disruption to normal routine – such as moving property or a household member falling ill – can be a factor in such behaviour. For example Margaret, reliant on her gas fire for room heating, did have a service contract for the appliance until her son cancelled her direct debits when she was in hospital for an extended period of time. She has not yet reinstated the contract.

Perceptions of risk: Perceptions about CO risk are a contributory factor to non-servicing observed in a number of households. This is both in relation to appliance type, frequency of use and fuel type. First, some households view their gas cooker as less risky than their gas boiler, leading them to leave this appliance unchecked unless a problem occurs. This perception of risk relates to public messaging (they have been told a boiler can leak CO but have not heard of similar issues with a cooker), appliance set-up (believing a problem with a cooker can be identified from the colour of the flame) and self-maintenance (some households report cleaning their hob jets). Second, appliances which are rarely used by a household, for example an open fire, are sometimes not included in annual maintenance schedules; instead the household arranges a check as and when they feel it is necessary. Third, qualitative interviews with non-gas households reveal that in some cases these households do not associate CO risk with oil and solid fuel appliances.

Non-servicing in rented properties

In rented properties, landlords are legally responsible for checking gas appliances and therefore it would be expected that any non-servicing can be explained by landlord inaction and not tenant behaviour. As noted, servicing rates are high in the rented sample however exploring cases of non-servicing does provide some interesting insights.

Tenant-owned appliances: Appliances owned and installed by the tenant are not always included in landlord safety checks and the appliance owner will not always arrange for a check themselves. In our sample, 92% of social rented tenants report not having their cooker checked in the past 12 months, compared to 62% of private rented tenants and 82% of owner-occupants. This correlates with findings of a behaviour change report which concludes that renters are less vigilant about gas safety than home-owners and often leave safety concerns to the landlord.[79] It also emphasises the importance of clear messaging about landlord and tenant responsibilities, particularly in social rented housing where appliances are more likely to be owned by tenants.

Lack of agency: Where tenants report landlord-owned appliances not being serviced (noting this is not widespread) a lack of agency for tenants to pursue the matter is present in a number of cases. In particular, households in private rented housing can be reluctant to complain when a safety check has not been arranged because previous requests to their landlord have gone unheeded. An example is Andreas, living in a small converted studio in North London. He reports the condensing boiler has not been checked over the past 12 months but does not believe it is worth complaining to the landlord after his previous request to replace a broken smoke detector was ignored. Similarly, Hayley, living with her children in Bradford in a private rented bungalow for the past three years reports receiving a gas safety certificate for the fire and water heater when she first moved in but believes neither appliance has been checked in the past 12 months. She has not requested proof of servicing due to past experiences:

> *"I know previously with the things that are broke in the property and I've rung the landlord and asked him to try and get it sorted out and he's just like: 'Yeah, ok, ok.' And I think that's the downside of renting is they're just not interested, they just fob you off, fob you off and you just get to a point sometimes where you think: 'You know what? I really can't be bothered.'"*

Worryingly, this lack of agency can combine with a lack of awareness, particularly amongst more vulnerable households. For example, Rashmi, living in asylum seeker accommodation, does not recall anyone visiting to safety check the gas appliances but is also not aware of any legal obligation on the landlord to do so. As such, she makes do with a problematic gas cooker than can take up to five minutes to ignite with the gas turned on. As discussed in the next section, high CO readings were observed in this property.

In conclusion, non-servicing is complex and relates to a number of factors including financial vulnerability in owner-occupant properties, power relations in tenant properties but also general neglect and a lack of awareness. The latter is a particular issue in the case of 'secondary' appliances such as cookers and fires, with high numbers going left unchecked for years.

6.3 Reasons for servicing

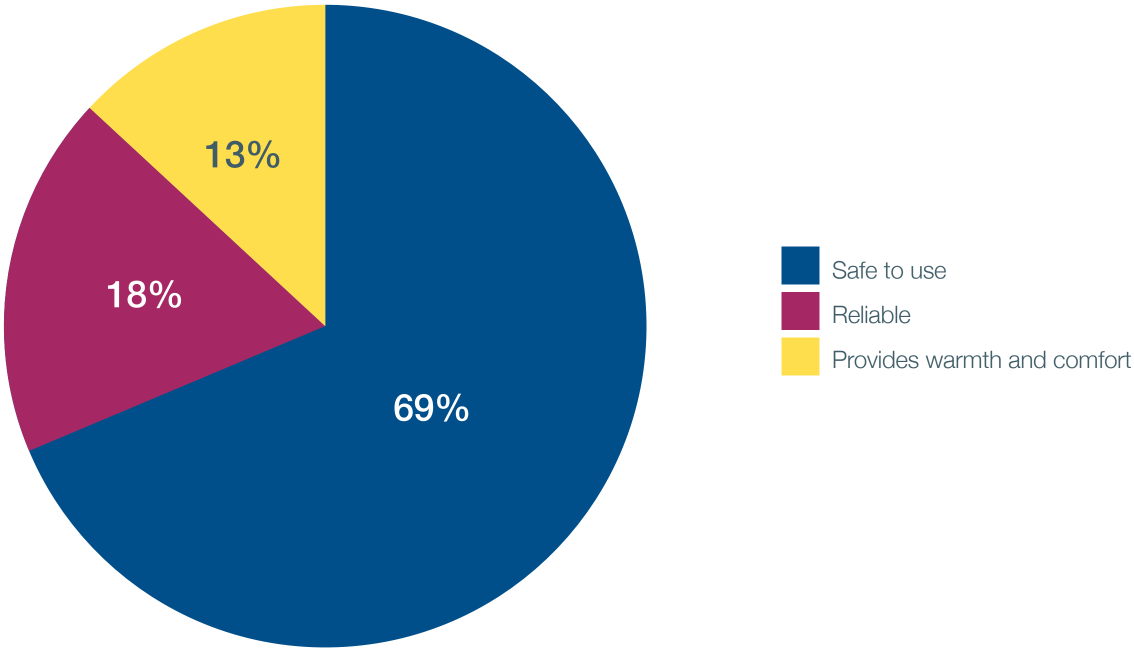
Understanding what motivates a householder to take the step to arrange a servicing appointment is necessary to develop effective public safety messages. In our survey households were asked to rank three reasons to service a heating appliance from most important to least important:

- The appliance is reliable
- The appliance is safe to use
- The appliance provides warmth and comfort.

[79] Wise Cat for Gas Safe Register. 2012. Being Gas Safe: Audience Research and Segmentation to Support Behaviour Change. Available: *http://www.policyconnect.org.uk/appcog/sites/site_appcog/files/gas_safe_behaviour_change_report.pdf.*

Results show that safety was ranked number one by 69% (n194) of respondents, see Figure 13. The mean rank (on a scale from 1 to 3) for safety was 1.4, followed by reliability (2.1) and warmth and comfort (2.4).

Figure 13. Most important reason to service a heating appliance identified by households (n282)



These results indicate that safety is the key motivator for arranging an appliance check. However, what emerged from qualitative interviews is that many households susceptible to living in a cold home for age or health reasons prioritise heating and paying the energy bill even where low income drives them to cut back on other essentials. In turn, the reliability of their main heating appliance (usually the boiler) is of overriding importance and this motivates the household to undertake a regular programme of maintenance. Philip, one half of a pensioner couple, is characteristic of this group. On arranging to have his boiler checked each summer he states:

> "I don't want it breaking down during the cold weather…My wife and I are not in very good health and it's a priority we keep ourselves warm…You keep the place warm and you make yourself feel better."

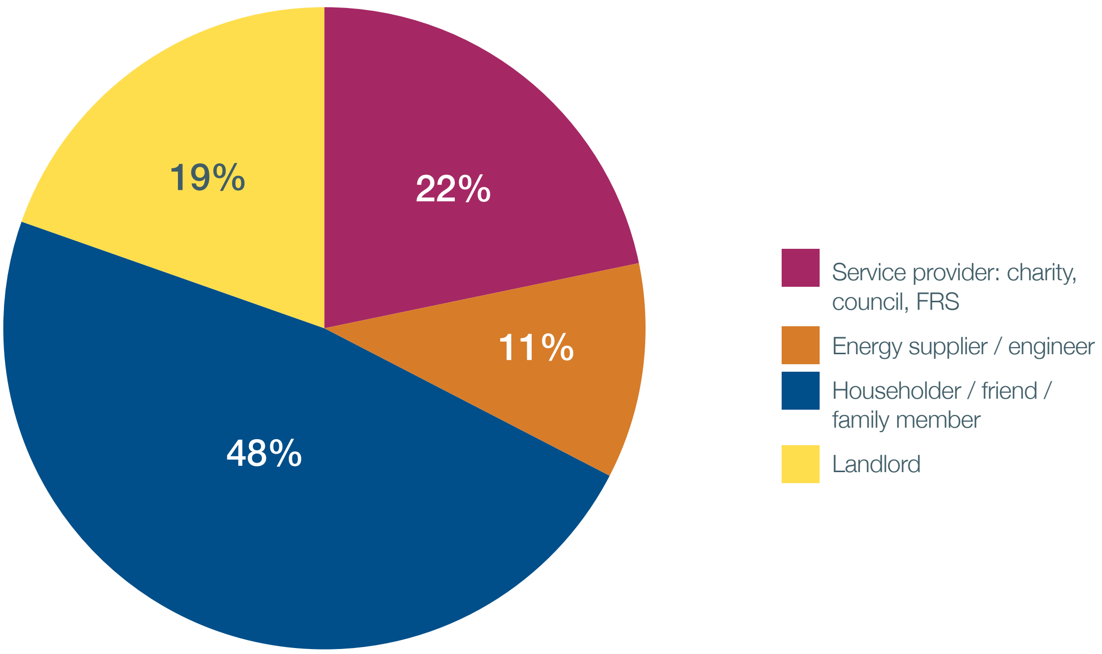
These findings indicate that consideration needs be given to both the appliance and the household type when developing safety messages. For example, while reliability and comfort may be appropriate to drive boiler servicing in older person households, occupants with gas cookers may need to be made aware of CO risk associated with these appliances.

6.4 CO alarm ownership

Audible CO alarms should be fitted in homes to act as a second line of defence after regular servicing. Amongst the in-home sample, where CO alarm ownership could be verified, 35% of households were found to have an alarm fitted. This rate of ownership is higher than in a large scale study undertaken by Liverpool John Moores University with fire and rescue services. Here, the average rate of owning a CO alarm was 9.1% in Liverpool and 3% in Coventry although it should be noted property visits took place in 2011. Roughly five years on, ownership rates would be expected to have increased.

Investigating our sample shows rates of ownership are highest in the owner-occupied sector (44%) followed by the private rented sector (33%). Only 5% of social housing occupants in the sample report having an alarm fitted. When investigating who provided households with alarms 22% of alarm owners report receiving theirs from a charity, local authority or fire and rescue service (FRS), see Figure 14.

Figure 14. Source of CO alarms, in-home sample (n46)



This demonstrates the importance of front line service providers in supporting and protecting vulnerable households. Nonetheless, it remains concerning that 65% of households are living with (at least one) combustion appliance but have no reliable means of CO detection in the property.

One factor contributing to low alarm ownership rates may be a lack of awareness about the dangers of CO, particularly in comparison to the threat of fire in homes.

Figure 15. Mean risk score by behaviour

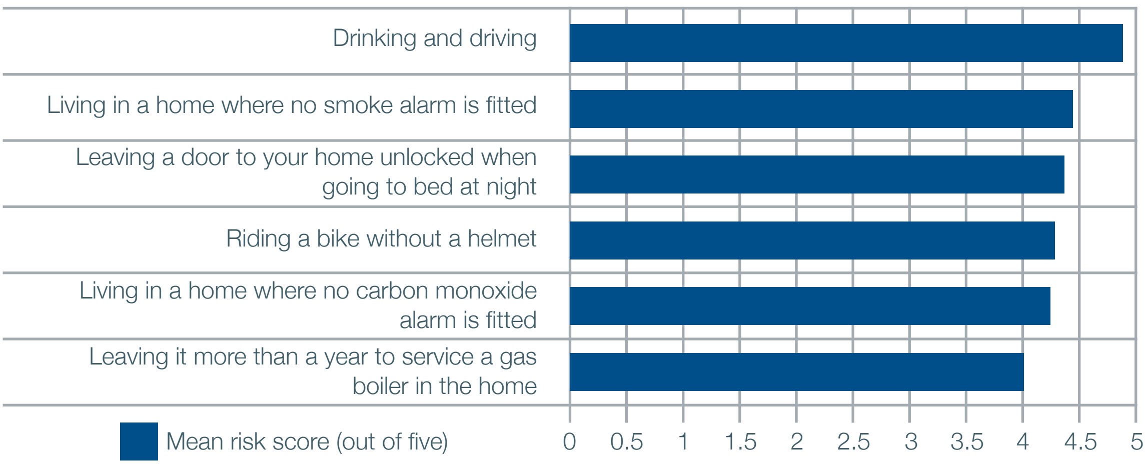


Figure 15 displays results from a question on our survey that asked households to rank the above behaviours in terms of level of risk to a person's health and safety from 1 (Not at all risky) to 5 (Extremely risky). Drinking and driving receives a mean score of 4.9 out of 5, equating to 319 of 339 respondents ranking the behaviour as extremely risky. Interestingly, the two CO-related behaviours are perceived to pose the least risk and failing to service a boiler is considered less risky than failing to fit a CO alarm. In total, 30% of respondents (n103) perceive waiting more than a year to service a boiler as posing no more than a moderate level of risk[80] and 20% of respondents (n68) consider living in a home with no CO alarm fitted to be of moderate risk or lower. These results suggest the potentially deadly consequences of CO have not yet infiltrated the public consciousness to the same extent as other public safety messages which have been the subject of high-profile campaigns (e.g. Fire Kills).

[80] Respondents selecting either Not at all risky, A little risky or Somewhat risky.

7. CO and temperature monitoring

To measure CO and temperature in homes monitoring equipment was placed in the main living area of participant properties (see Section 2.3 for full details of the methodology). The purpose of monitoring was to understand exposure to low levels of CO, which can have lasting health impacts, and correlate this data with survey findings.

Surveyors fitted data loggers when completing in-home questionnaires and IEH Consulting analysed data returned from households. Monitoring occurred during two heating seasons:

- 2015/16 with the first recording taken in October 2015 and the last recording taken in March 2016
- 2016/17 with the first recording taken in December 2016 and the last recording taken in April 2017.

For the purposes of data analysis, no distinction was made between the two monitoring seasons. In 81 households a full set of data was returned (temperature and CO), one household returned temperature data only and eight households returned CO data only. On average, homes were monitored for between two and three months, with a maximum of 113 recording days and a minimum of nine recording days, see Table 11.

Table 11. Overview of CO and temperature monitoring in households

Number of households monitored	Number of monitoring days				
	Min	Max	Mean	Median	SD
90	9	113	74.4	81.5	30.4

7.1 CO levels in homes

Table 12 summarises peak (maximum recorded) CO readings in homes. It shows that in 18% of homes (n16) all measurements were 0 ppm and in 35% of homes (n31) a peak reading of greater than 10 ppm was recorded. Four homes (5%) recorded a reading of greater than 50 ppm.[81] This represents a smaller proportion of homes with high readings compared to a similar study conducted by Kokkarinen et al. in Liverpool and Coventry during the 2011/12 heating season.[82] In the authors' sample of 173 properties, 67% recorded maximum readings greater than 10 ppm and 21% recorded readings above 50 ppm.

Table 12. Overall summary table of CO measurements

	Number of monitored homes	Proportion of monitored homes %
Maximum reading 0 ppm	16	18.0
Maximum reading > 0 ppm	73	82.0
Maximum reading > 10 ppm	31	34.8
Maximum reading > 50 ppm	4	4.5

[81] All households in the study were provided with an audible CO alarm and information on staying safe from CO poisoning. In cases where households returned data showing consistent patterns of high CO readings (20 ppm or more) attempts at re-contact were made and, where successful, households were advised of the readings and reminded of ways to stay gas and CO safe.

[82] Ibid., 7.

Exceedances of WHO guideline values

The World Health Organisation (WHO) recommends time-weighted average exposure limits for CO. These are set at 87 ppm for 15 minutes, 52 ppm for 30 minutes, 26 ppm for 1 hour, 9 ppm for 8 hours and 6 ppm for 24 hours.[83] When taking the time-weighting of WHO averages into account, only one home in our sample exceeded any of the WHO guideline values. This exceedance – in which the 1 hour moving average was greater than 26 ppm for 35 minutes – was recorded on 19 January 2016 between 7:15 a.m. and 7:45 a.m. The CO monitor was placed in the living room. At the time of the exceedance the mean recorded temperature was 21°C.

The property in which the exceedance was recorded is a two-bedroom detached house located in rural Yorkshire and is occupied by a low income retired pensioner couple with multiple health vulnerabilities. They have been living in their home (which they own) for over 20 years. Heating is provided from an oil-fired, regular non-condensing floor-standing boiler that is located in the ground-floor kitchen. The boiler is over 12 years old, has not been serviced in the past 12 months and, at the time of visiting, the household reported it broken and were not using it. They expressed reluctance to invest in a new appliance due to both the cost and their advanced age. Indeed, in accordance with the secondary heating user typologies identified in Section 5.2, the couple can be characterised as vulnerable replacement users, reliant for room heating on an open coal fire in the living room whose chimney has not been cleaned in the past 12 months. No other combustion appliances are present in the home and none of the occupants smoke. No CO alarm is fitted in the property.

Spikes in homes

Noting that homes can have moving averages below the WHO guideline but that occupants can still be exposed to constant low levels of CO, the data was further explored by evaluating any spikes in concentration and examining the duration of such spikes. A spike is defined as any measurement that exceeded 10 ppm (the threshold at which prolonged exposure can have possible health effects).

A total of 31 homes had exceedances (spikes) greater than 10 ppm. The total number of spikes in each home ranged from 1 to 361. That is, one home recorded only one reading greater than 10 ppm and another home recorded 361 readings greater than 10 ppm. As shown in Table 13 the duration of spikes ranged from 5 minutes to 160 minutes, with a median of 35 minutes. That is, when a spike above 10 ppm in a home occurred, on average the recorded CO concentration did not drop below 10 ppm for over half an hour.

Table 13. Overall summary table of spikes (measurements exceeding 10 ppm) recorded in 31 homes

	Min	Max	Mean	Median	SD
Number of spikes in homes (n)	1	361	43.7	18.0	80.1
Duration of spikes (minutes)	5	160	50.5	35.0	45.5
Number of spikes lasting longer than 15 minutes in homes	0	30	3.8	1.0	7.3

There are 20 homes (22% of monitored homes) recording a spike lasting longer than 15 minutes. These homes were chosen for further investigation because 15 minutes is the duration for the short-term WHO CO guideline value. Table 14 summarises spikes in these properties.

[83] Ibid., 7.

Table 14. Homes recording spikes (measurements exceeding 10 ppm) lasting longer than 15 minutes (n20)

Household	Number of spikes	Number of spikes > 15 minutes	Maximum duration of spike (minutes)	Maximum CO reading (ppm)
A	18	1	90	38.5
B	19	2	35	16
C	39	3	45	14
D	7	1	20	12.5
E	59	6	70	58
F	16	1	80	13.5
G	20	1	85	14
H	235	20	160	50.5
I	29	1	145	23.5
J	36	3	60	20.5
K	7	1	30	15
L	47	3	115	17
M	361	30	105	63
N	23	2	70	24.5
O	64	6	95	17
P	13	1	25	12.5
Q	203	24	90	32.5
R	91	6	100	23
S	24	4	35	96.5
T	6	1	30	17.5

Investigating the time profile of spikes, a significant majority of exceedances occurred after midday. Of spikes lasting longer than 15 minutes (n117), 47% occurred in the evening (between 6:00 p.m. and 12:00 a.m.), 43% occurred in the afternoon (between 12:00 p.m. and 6:00 p.m.) and only 10% started before midday. This suggests that spikes could be related to afternoon/evening heating and cooking practices. No pattern was observed of spikes occurring on a regular basis in individual households, for example on consecutive days each week or the same day in the week.

Table 14 shows the profile of the 'spike group' (n20): households in which spikes lasting longer than 15 minutes were recorded. Relative to the entire CO monitoring group (n89), the average household size is larger. This could be because there are fewer older age households in the spike group (25% compared to 47%) and also more families with children (35% compared to 28%). Statistical investigation of all monitored homes was conducted by IEH Consulting to test for significant correlation coefficients (Pearson correlation) between CO concentrations and household characteristics. This shows the number of spikes (measurements greater than 10 ppm) is significantly lower in homes with two or more people aged 65 or over ($p=0.046$; $r=-0.212$). This correlates with Croxford[84] who found that problem gas appliances were more prevalent in younger households and supports evidence from focus groups which shows older consumers to be more cautious about gas safety.[85]

[84] Ibid., 16.
[85] Ibid., 72.

The breakdown of the spike group by location, rural-urban classicisation and tenure mirrors the entire monitoring sample. Although the spike group does contain a slightly higher number of rented properties, a chi-square test does not show this to be significant. Overall, the spike group appears to be slightly worse off: 65% report an annual household income below £16,000 and 55% live in deprived areas. This compares to 54% and 39% of the total monitoring group respectively. Interestingly, of households in the spike group from the Year 2 in-home sample (when fuel poverty status was calculated), 5 of 8 (63%) are LIHC fuel poor. This compares to only 27% of all Year 2 monitored households. Furthermore, statistical investigation by IEH shows maximum CO levels are significantly increased in homes which report paying the energy bill causes them a lot of worry (p=0.026; r=0.237). These findings and the profile of the spike group reveal that income and fuel poverty vulnerabilities are present in a number of homes reporting higher CO levels.

Table 15. Profile of spike group (S) and monitoring group (M) [86]

Property	S %	M %
Household size		
Mean (n)	2.8[5]	2.3[3]
Location		
Greater London	5.0	7.9
North East	30.0	29.2
Yorkshire and The Humber	65.0	62.9
Rural-urban classification		
Rural	25.0	29.2
Urban	75.0	70.8
Tenure		
Owner-occupied	50.0	58.4
Private rented	35.0	33.7
Social rented	15.0	7.9
Heating fuel		
Mains gas	80.0	74.2
Oil, bottled gas, solid fuel	20.0	25.8
Smoking		
Smoking household	55.0	22.5

Vulnerability	S %	M %
Income		
Low income < £16,000	65.0[1]	53.5
Means-tested benefits	45.0[2]	44.3
Living in deprived area	55.0	39.3
Employment		
Working	55.0	31.8[2]
Not in paid work	30.0	22.7[2]
Retired	15.0	45.5[2]
Age		
Occupant(s) 65+	25.0	47.2
Children 15 and under	35.0	28.1
Health		
Disability or health condition	70.0	72.7[2]
PSR		
Eligible	75.0	78.4[2]
Registered	15.8[3]	11.8[4]
Fuel poverty status		
LIHC fuel poor	62.5[5]	26.5[6]
10% fuel poor	62.5[5]	53.1[6]

[1]n86; [2]n88; [3]n19; [4]n76; [5]n8; [6]n49

Table 15. Profile of spike group (S) and monitoring group (M)[86] *continued….*

Heating and cooking	S %	M %
Central heating		
Central heating boiler	100	97.8
Higher risk boiler	20.0	25.6[1]
Older age boiler (>12Y)	29.4[2]	25.3[3]
Secondary heating		
Combustion secondary heating	30.0	47.2
Gas fire	25.0	25.8
Solid fuel fire	5.0	24.7
Occupancy pattern		
Home all day	55.0	52.8
Heating behaviours		
Central heating AM/PM only	45.0	43.7[4]
Central heating rarely turned on	20.0	5.7[4]
Secondary heating replacement user	50.0[5]	38.1[6]
Cooker		
Gas cooker	80.0	60.7
Use gas cooker for room heating	25.0[7]	14.8[8]

Servicing	S %	M %
Combustion appliances in home		
Mean (n)	2.7	2.5
Median (n)	3.0	2.0
Servicing overview past 12 months		
Appliance(s) checked	70.0	80.9
Appliance(s) not checked	70.0	62.7[9]
Appliances checked past 12 months		
Boiler	70.0	79.1[1]
Gas fire	20.0[10]	30.4[11]
Gas cooker	25.0[7]	23.5[12]
CO alarm ownership		
CO alarm fitted in property	30.0	39.3

[1]n86; [2]n17; [3]n79; [4]n87; [5]n6; [6]n42; [7]n16; [8]n5; [9]n83; [10]n5; [11]n23; [12]n51

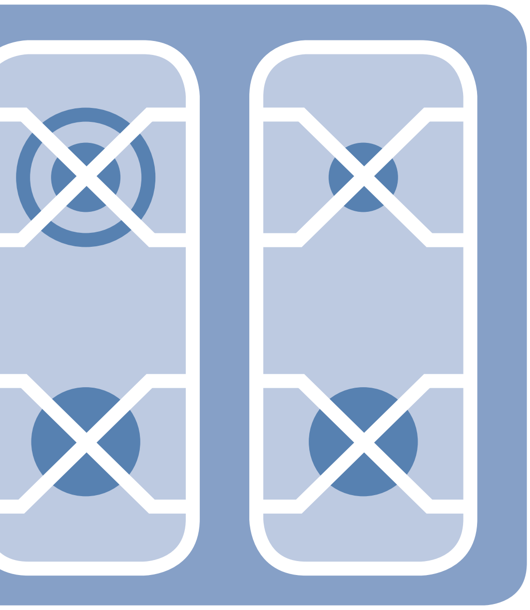
Reflecting on combustion appliances in homes which recorded extended spikes, all properties have central heating boilers, of which 20% are a higher risk (non-condensing) type and 29% are aged over 12 years. This profile of boiler age and risk is not notably different to the entire monitoring sample. With regard to secondary heating, fewer monitored homes with spikes have combustion secondary heating compared to the entire monitoring group (30% versus 47%) although the number of properties with gas fires is nearly identical (25% compared to 26%). Notably, of households with combustion secondary heating in the spike group, 50% can be identified as replacement users (heavily reliant on their secondary heaters and using the appliance(s) in place of their central heating). Indeed, one fifth of the spike group report rarely turning their central heating on, compared to only 6% of all monitored households. This suggests that CO levels can indeed be elevated in the homes of households who are reliant on their combustion fires due to financial, structural and health vulnerabilities.

[86] Percentages refer to proportion of households in group. Spike group n20 and monitoring group n89 unless otherwise specified.

Another notable finding is cooker fuel type. This shows that 80% of households in the spike group have a gas cooker compared to 61% of the entire monitoring sample. The disparity in oven fuel type is even starker: 60% of monitoring homes showing extended spikes have gas ovens relative to 28% of all homes in the monitoring group. Statistical investigation by IEH using Pearson's correlation shows a significant relationship between cookers and maximum CO levels, which are significantly increased in homes with ovens fuelled by mains gas or LPG ($p=0.001$; $r=0.336$) and also hobs fuelled by mains gas or LPG ($p=0.019$; $r=0.247$). These findings suggest gas cookers are a source of higher CO levels observed in some households in this study, which would correlate with previous research showing gas cookers to be a major source of CO exposure.[87]

Alongside combustion appliances, it is plausible that one cause of CO spikes in this study is smoking events. Pearson's correlation shows the number of spikes greater than 10 ppm to be significantly reduced in homes of non-smokers ($p<0.001$; $r=-0.431$) and maximum CO levels are also lower in homes of non-smokers ($p=0.002$; $p=-0.330$). This finding appears to contradict Croxford who found no significant difference between mean CO concentrations of smokers and non-smokers while passive cigarette smoke has been shown to increase a non-smoker's exposure by an average of only about 1.5 ppm.[88] However this research differs by investigating spike events, rather than means, and suggests future studies should consider collecting data on smoking in order to provide greater insight into the contribution of this source to CO concentrations in dwellings.

Five cases from the spike group are profiled below to explore in greater depth possible sources of high CO levels and vulnerabilities present in these homes.



[87] E.g. Ibid., 3., Ibid., 7.

[88] Ibid., 5.

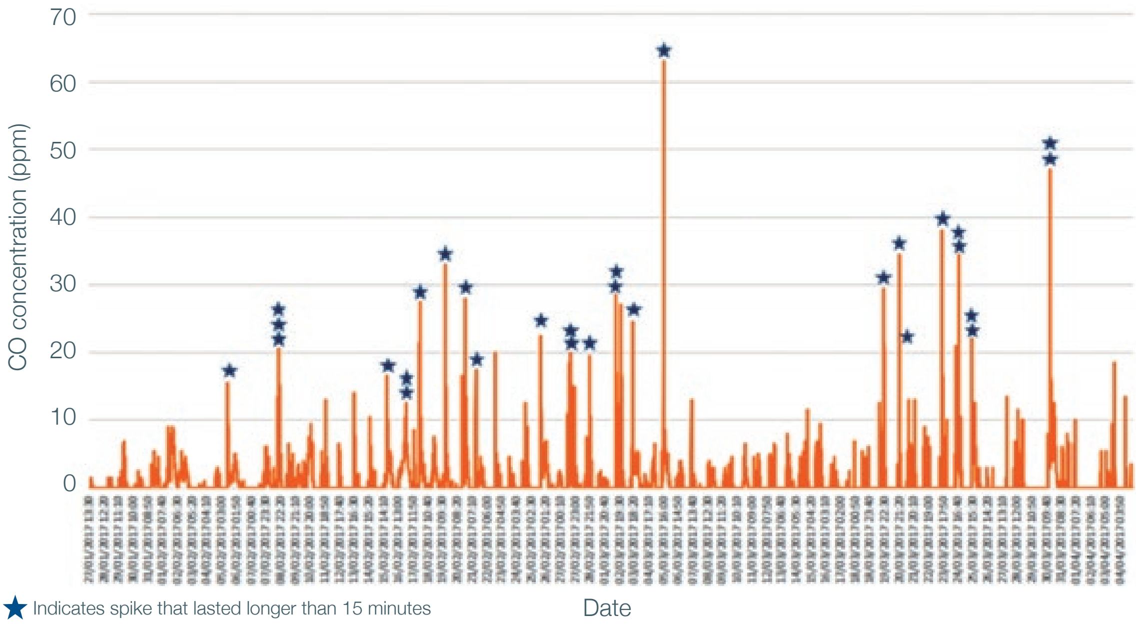
Household M: Low income private renters in fuel poverty

Monitoring days: 68 (27 January to 5 April 2017)

CO	
Min (ppm)	0
Max (ppm)	63
Spikes >10 ppm (n)	361
Spikes lasting >15 minutes (n)	30
Maximum spike duration (minutes)	105

Temp (°C)	
Min	12
Max	25
Mean AM (07:00-09:00)	15.4
Mean PM (16:00-23:00)	16.5
Mean Daily	16.0

Figure 16 CO readings from data logger left in property for 68 days



Loggers in Household M were placed in the living room. The property is a privately rented three-bedroom terraced house located in a deprived area of urban Leeds. Graphing CO measurements in the home (Figure 16) show peaks occurring in the afternoon, evening and late evening. This household had the most number of spikes of all monitored homes (361 over 68 days), 30 of which lasted longer than 15 minutes. The maximum recorded CO reading was 63 ppm, observed during a spike lasting from 4:00 p.m. until 5:15 p.m. on 5 March 2017. During this time the mean recorded temperature was 19°C. The timing and duration of spikes suggests the source could be the mains gas fire, located in the living room and which the household reports using in place of the central heating to save money. According to Anna, one of three occupants aged between 28 and 40, it costs 50 pence on the prepayment meter before central heating begins to have an effect but 10 pence on the gas fire and the living room is warm. Temperatures recorded in the home are low, with an evening mean during the monitoring period of 16.5°C. This is in spite of household members being home during the day with two occupants unemployed and another unable to work due to their asylum status. The household reports being in subjective fuel poverty and our calculation found them to be LIHC fuel poor. Other potential sources of CO in the home are a mains gas combi condensing boiler located in the cellar (less than 3 years old), a mains gas cooker (hob and oven) and cigarette smoke (occupants frequently smoke in the house). Anna reports issues with the cooker, including a rush of flame when lighting the oven manually with a match. To her knowledge, none of the gas appliances have been checked over the past year and she has never requested proof of servicing. No CO alarm is fitted in the property.

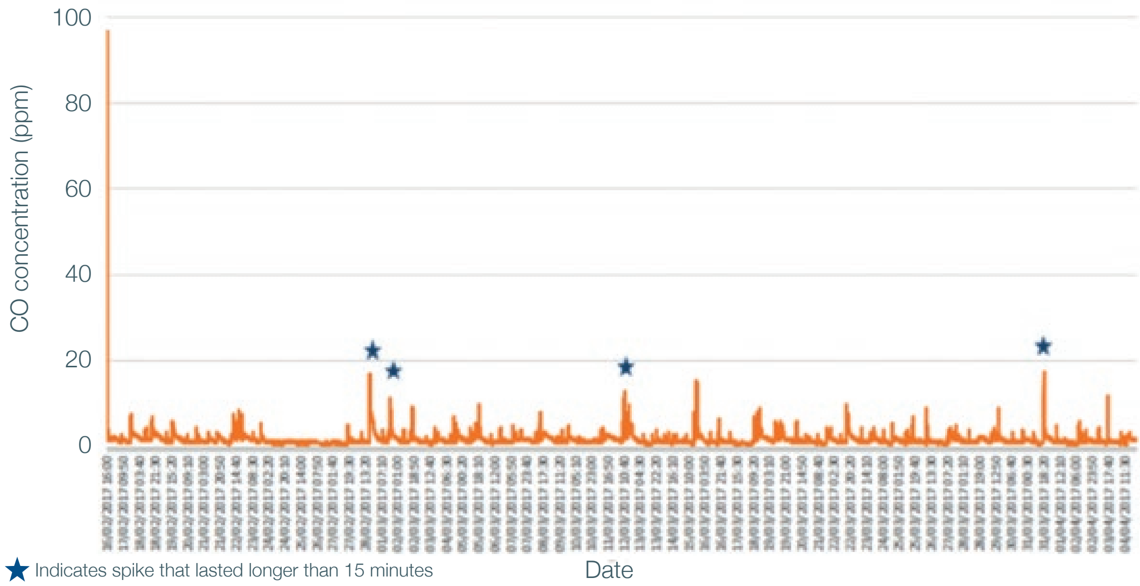
Household S: Low income rural off-gas pensioner couple

Monitoring days: 48 (16 February to 5 April 2017)

CO	
Min (ppm)	0.5
Max (ppm)	96.5
Spikes >10 ppm (n)	24
Spikes lasting >15 minutes (n)	4
Maximum spike duration (minutes)	35

Temp (°C)	
Min	16
Max	25
Mean AM (07:00-09:00)	18.8
Mean PM (16:00-23:00)	20.8
Mean Daily	19.8

Figure 17. CO readings from data logger left in property for 48 days



Loggers in Household S were placed in the kitchen.[89] The property is an owner-occupied three-bedroom semi-detached house with insulated cavity walls located in a non-deprived area of rural Yorkshire. Figure 17 shows that a maximum CO reading of 96.5 ppm was recorded on 16 February at 4:05 p.m. There are 23 other spikes above 10 ppm, mainly starting in the afternoon (around 4:00 p.m.) or early evening (around 6:00 p.m.). The spikes are shorter than in Household M and this, along with the CO logger's location, suggests the LPG gas hob and oven may be the source. The household, a low income pensioner couple with multiple health conditions and in receipt of means-tested benefits, report previously using the oven for room heating when their boiler broke down. A new oil combi condensing boiler is now installed in the property on the ground floor in the landing. The boiler is the only other source of CO in the home. The couple have a contract to service the boiler but the LPG cooker has not been checked and the household reports problems with the grill on the appliance. Affording their energy bills causes them a lot of worry as they prioritise heating for their health, preferring to cut back on other essentials. Our calculation found them to be LIHC fuel poor. An evening mean of 20.8°C was recorded during the monitoring period. No CO alarm is fitted in the property.

[89] This placement of loggers in the kitchen could have been because the household reported this room as their main living space or a mistake on the part of the surveyor.

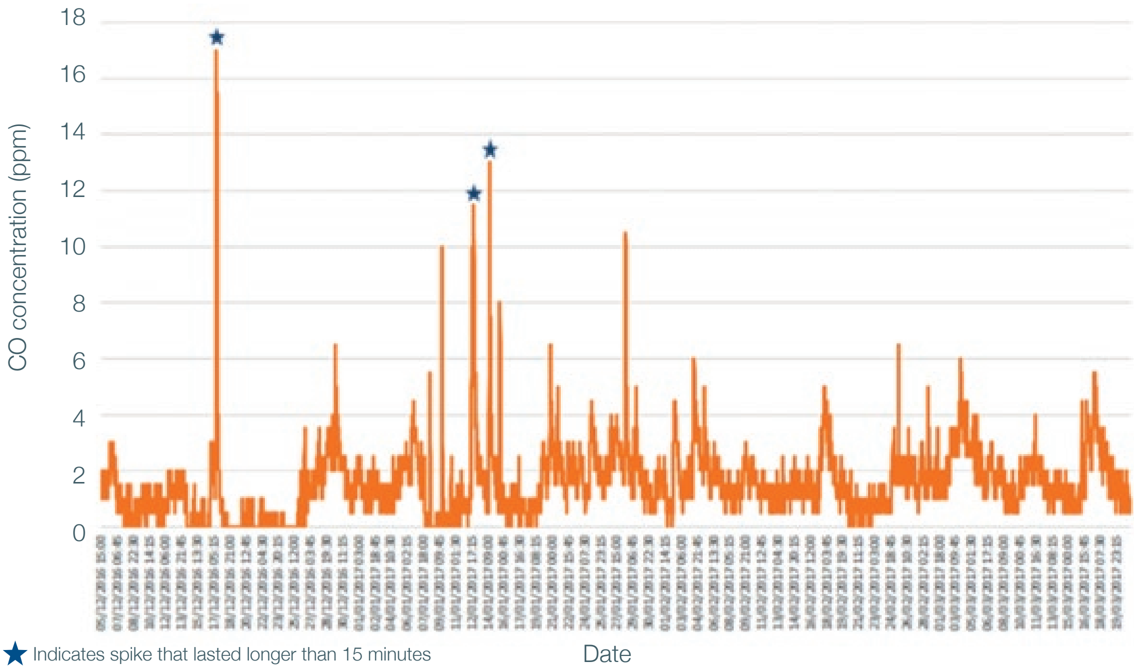
Household L: Park home on bottled gas

Monitoring days: 106 (5 December 2016 to 21 March 2017)

CO	
Min (ppm)	0
Max (ppm)	17
Spikes >10 ppm (n)	47
Spikes lasting >15 minutes (n)	3
Maximum spike duration (minutes)	115

Temp (°C)	
Min	12
Max	25
Mean AM (07:00-09:00)	16.8
Mean PM (16:00-23:00)	19.8
Mean Daily	18.8

Figure 18. CO readings from data logger left in property for 106 days



Loggers in Household L were placed in the living room. The property is a park home located in rural Yorkshire. Graphing CO measurements (Figure 18) shows constant low readings with 47 spikes above 10 ppm, one lasting for nearly two hours (115 minutes). This spike occurred from 11:05 a.m. until 1:00 p.m. on 17 December, during which time the maximum reading reached 17 ppm. In general, spikes start around lunchtime or in the evening however some are also observed in the late morning. This irregular pattern may correlate with the household's heating behaviour. The occupants, an older age couple, report they come and go in the property (both work part time) and put the heating on as needed. The combi condensing boiler, which runs on bottled gas, is located in the kitchen. The household report issues with the boiler, which can 'plug up' and 'vibrate'. The couple do not smoke and the only other combustion appliance in the home is a bottled gas hob. The boiler has been checked during the past year but not the hob. A CO alarm (supplied previously by a charity) is fitted in the property and the household report no worries about keeping warm or affording the energy bill. A mean daily temperature of 18.8°C was recorded during the monitoring period.

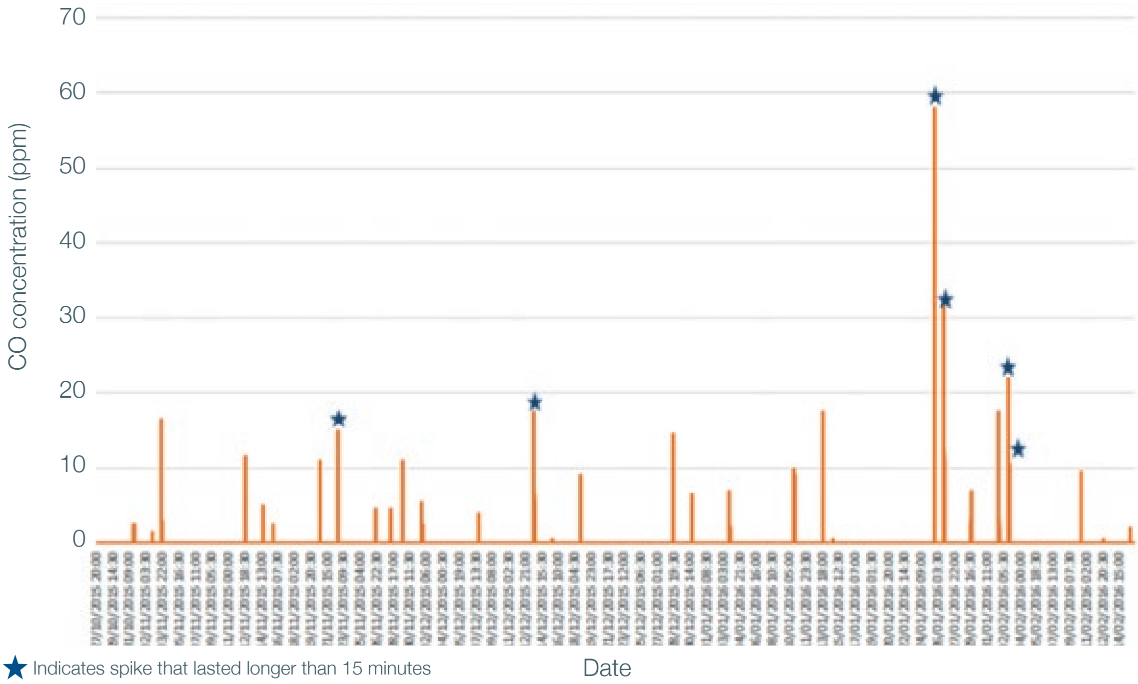
Household E: Home-bound private tenant with back boiler

Monitoring days: 112 (27 October 2015 to 16 February 2016)

CO	
Min (ppm)	0
Max (ppm)	58
Spikes >10 ppm (n)	59
Spikes lasting >15 minutes (n)	6
Maximum spike duration (minutes)	70

Temp (°C)	
Min	15
Max	27.5
Mean AM (07:00-09:00)	19.6
Mean PM (16:00-23:00)	22.3
Mean Daily	21.5

Figure 19. CO readings from data logger left in property for 106 days



Loggers in Household E were placed in the living room. The property is a privately rented three-bedroom semi-detached house located in a deprived area of urban Leeds. As shown in Figure 19, this household has extended periods of zero readings followed by high peaks. A maximum reading of 58 ppm was recorded at 7:00 p.m. on 25 January 2016. During this spike the concentration stayed above 10 ppm for 70 minutes and the mean temperature was 24°C. The high temperatures recorded in the property and the duration and timing of spikes (observed in the late afternoon and early evening) suggest the heating could be a source. The survey respondent, Glenn, is home all day: unable to work due to illness, his wife cares for him. The couple receive means-tested benefits and report an annual income less than £16,000. Glenn uses the central heating mornings and evenings on a timer, and occasionally overrides the programmer during the day. Space heating for the property is supplied by a gas fire with back boiler installed in the ground floor living room. As previously noted, back boilers pose the highest CO risk relative to other boiler types. The only other combustion appliance in the home is a gas hob and, in addition, Glenn smoke cigarettes and cigars in the house. The occupants report having no problems with either the hob or back boiler while living in the property (less than two years). A gas safety check (arranged by the landlord) of all combustion appliances has been carried out over the past 12 months. There is no CO alarm fitted in the property.

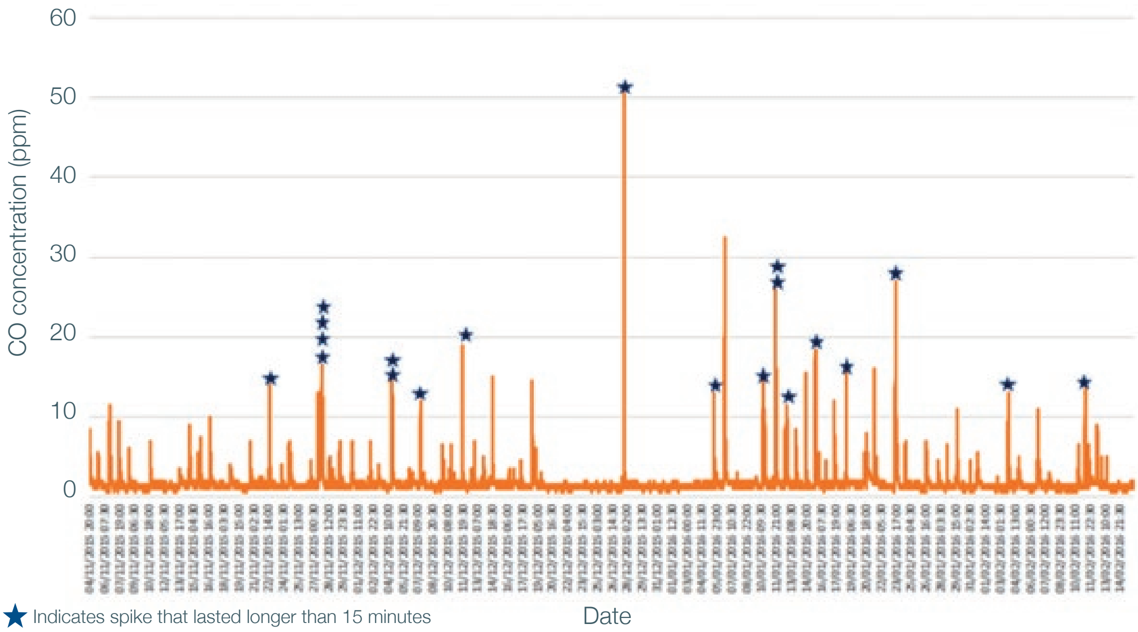
Household H: Single parent living in asylum seeker housing

Monitoring days: 104 (4 November 2015 to 16 February 2016)

CO	
Min (ppm)	0.5
Max (ppm)	50.5
Spikes >10 ppm (n)	235
Spikes lasting >15 minutes (n)	20
Maximum spike duration (minutes)	160

Temp (°C)	
Min	8.5
Max	23.5
Mean AM (07:00-09:00)	17.1
Mean PM (16:00-23:00)	17.3
Mean Daily	17.3

Figure 20. CO readings from data logger left in property for 104 days



Loggers in Household H were placed in the living room. The property is a two-bedroom terraced house located in a deprived area of urban Leeds. The occupant is Rashmi, profiled previously in this report, an asylum seeker who lives in the property with her young son. Figure 20 shows a concerning number of spikes in the property: 235 with 20 lasting longer than 15 minutes and one lasting nearly three hours (160 minutes). A maximum reading of 50.5 ppm was recorded at 6:00 p.m. on 27 December 2015. Another high reading of 32.5 ppm was recorded on 6 January 2016 at 5:45 p.m. Most of the extended peaks occur during the evening although some were recorded during the late morning and early afternoon. Temperature in the property is relatively low, with an evening mean of 17.3°C. While Rashmi is not responsible for paying the energy bills she does report a cold and draughty home. Furthermore, she is unable to work due to her asylum status. Combustion appliances in the property are a combi condensing boiler located in the first floor bedroom (age unknown), a gas fire in the living room which was condemned and is no longer used and a gas hob and oven. The householder also reports rarely smoking cigarettes in the property. As profiled earlier, Rashmi complains of problems with both the central heating and the cooker and has used the latter previously for room heating. The householder has never received proof of servicing since she moved in (three years ago at time of interview) and she is not aware of landlord obligations regarding gas safety. There are two CO alarms fitted in the property (kitchen and bedroom), supplied by the housing provider.

7.2 Relationship between CO and temperature in homes

Loggers placed in the main living space of homes recorded temperature levels at half hourly intervals. The mean temperature recorded in households (n82) was 19.1°C, shown in Table 16. This includes all measurements taken from all households and has not been adjusted for any outliers (the minimum recorded temperature was 3°C and the maximum recorded temperature was 31°C).

Table 16. Temperatures recorded in the main living space of homes (n82)[90]

	Mean	SD	Min	Max	Median
Min °C	13.1	3.4	3	20	13.5
Max °C	24.9	2.3	18.5	31	25.0
Mean, overall °C	19.1	2.5	10.4	26.3	19.4
Mean morning temperature °C[1]	18.2	2.6	10.1	26.6	18.5
Mean evening temperature °C[2]	19.8	2.6	10.8	26.2	20.5

[1] Morning = 07:00-09:00; [2] Evening = 16:00-23:00

Taking heating hours into account, Table 16 shows morning and evening temperatures. A standard 9 hour heating regime was chosen, in accordance with SAP methodology, and reflecting that the largest proportion of households in this study report using central heating during morning and/or evening hours only. No adjustment to heating patterns was made for weekends, household or property characteristics, location of dwellings or external temperature; all factors which will affect the length of time that heating is required. As such, these results have limitations but nonetheless provide a guide to temperatures households in the sample are achieving. As Table 20 shows, the mean morning temperature (7:00 to 9:00 a.m.) was 18.2°C and the mean evening temperature (4:00 to 11:00 p.m.) was 19.8°C (although the median is 20.5°C).

A limitation of these findings is that temperatures included in the calculations are recorded across two heating seasons (2015/16 and 2016/17) and the period of measurement differs by household, depending on when loggers were placed in homes. As such, results do not represent temperatures in the sample across a standard heating period. Because of this 28 households (34% of the temperature monitoring group) were chosen for further investigation. In these households temperatures achieved during the winter months of December 2015 and January 2016 were calculated. This sample and time period were chosen because it represents the largest proportion of the monitoring group recording temperature at the same time over a significant period of colder weather.

Table 17. Temperatures recorded in the main living space of homes (n28) during December 2015 and January 2016

	Mean	SD	Min	Max	Median
Min °C	13.4	3.0	6	18	14
Max °C	24.1	2.9	15	30.5	24
Mean, overall °C	18.7	3.1	11.6	22.6	19
Mean morning temperature °C[1]	17.8	2.8	6	25	18
Mean evening temperature °C[2]	19.4	3.2	7.5	30.5	19.5

[1] Morning = 07:00-09:00; [2] Evening = 16:00-23:00

As Table 17 shows, the mean recorded temperature during December 2015 and January 2016 was 18.7°C with a morning mean of 17.8°C and an evening mean of 19.4°C. Again, results were not adjusted for outliers and show similar but slightly lower means compared to Table 20.

[90] Temperatures were recorded in homes across two heating seasons: between 14 October 2015 and 24 March 2016 and 5 December 2016 and 28 April 2017.

Across the temperature monitoring group, daily, morning and evening means achieved are within the recommended zone to heat indoor living spaces to between 18-21°C. Public Health England stresses maintaining the 18°C threshold is particularly important for the health of older persons and occupants with pre-existing health conditions.[91] WHO advises that dropping below 16°C can present additional health risks, particularly from respiratory and arthritic diseases.[92]

Table 18. Homes (n82) not achieving 16°C, 18°C and 21°C temperature thresholds

	<16°C		<18°C		<21°C		≥21°C	
	AM[1]	PM[2]	AM	PM	AM	PM	AM	PM
Proportion of homes %	18.4	7.3	42.7	23.2	90.2	65.9	9.8	34.1
Mean °C	14.3	14.1	15.9	16.3	17.8	18.5	22.6	22.3
SD °C	1.7	1.9	1.8	1.8	2.3	2.1	1.8	1.1
Min °C	10.1	10.8	10.1	10.8	10.1	10.8	21.1	21.1
Max °C	15.9	15.9	17.9	17.9	21.0	21.0	26.6	26.2
Median °C	14.7	14.5	16.7	16.8	18.1	18.9	22.2	21.9

[1] Morning = 07:00-09:00; [2] Evening = 16:00-23:00

Table 18 shows that 18% of the temperature monitoring group recorded a mean temperature in the morning of less than 16°C and 7% did not achieve the 16°C threshold in the evening. Meanwhile approaching half the sample (43%) recorded a mean temperature below 18°C in the morning and 23% during evening heating hours. While these results do not account for any outliers (for example very low temperatures owing to a household being absent from the property) they do indicate that households are not always reaching expected thresholds during shorter heating periods in the morning and nearly a quarter of homes may be under-heating their living spaces relative to recommended temperatures in the evening.

IEH investigated the statistical relationship between CO indices and temperature. Results using Pearson correlation show the number of spikes above 10 ppm was significantly negatively correlated with the minimum temperature ($p=0.04$; $r=-0.23$) and the mean temperature ($p=0.003$; $r=-0.32$) in households. That is, the number of spikes increased in households with lower minimum and mean temperature. This could indicate a possible relationship between under-heating and elevated CO although further investigation would be required to understand and draw firm conclusions from these results. One possible factor may be the relationship between the age of occupants, temperatures achieved in the home and CO levels. In our sample mean temperatures were higher in households where occupants are aged 65 years or over and the number of CO spikes was also reduced in homes with two or more occupants aged 65 or over. This is interesting when considering that, across England, the highest fuel poverty rates are found in working age households.[93] The prevalence in this research of lower mean temperatures and a greater number of CO spike events in non-pensioner homes suggests families and younger-person households should be a focus for integrated CO safety and fuel poverty interventions.

[91] PHE. 2014. Minimum Home Temperature Thresholds for Health in Winter. Available: *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/468196/Min_temp_threshold_for_homes_in_winter.pdf.*

[92] WHO. 1987. Health Impact of Low Indoor Temperatures. Available: *http://www.theclaymoreproject.com/uploads/associate/365/file/Health%20Documents/WHO%20-%20health%20impact%20of%20low%20indoor%20temperatures%20(WHO,%201985).pdf.*

[93] Ibid., 11.

8. Conclusions and insights for policy

The main conclusion to draw from this research is that the factors which cause or expose households to the risk of fuel poverty – low income, poor quality housing and the age and health of occupants – can impact on the heating and servicing behaviours of households to elevate CO risk in homes. In particular, the following key findings emerge from this study:

- **Fuel poverty characteristics are present in homes recording elevated CO levels.** Statistical analysis (Pearson's correlation) undertaken by IEH Consulting for NEA observed significantly increased maximum CO levels in households reporting stress and anxiety about energy affordability ($p=0.026$; $r=0.237$). Also, the number of CO spikes above 10 ppm was significantly negatively correlated with the minimum temperature ($p=0.04$; $r=-0.23$) and the mean temperature ($p=0.003$; $r=-0.32$) in households. That is, the number of CO spikes increased in households with lower minimum and mean temperature. This could indicate a possible relationship between under-heating and elevated CO. Notably, one fifth of households with extended CO spikes (lasting longer than 15 minutes) reported rarely turning their central heating on and a number were fuel poor under the LIHC definition. Furthermore, working-age households, amongst which the highest fuel poverty rates are found across England, recorded lower mean temperatures in our study and also a greater number of CO spike events.

- **Combustion secondary heating is a key source of warmth in homes vulnerable to fuel poverty and a possible cause of CO spikes in these properties.** Households displaying financial, structural, health and age vulnerabilities are more likely to be reliant on a gas or solid fuel fire: running it for extended periods in place of central heating or together with a primary system. Factors contributing to this behaviour are: low income (preventing a household replacing an inefficient boiler, installing first time central heating or causing occupants to ration central heating); a lack of agency amongst tenants (forced into using secondary heating to cope with a cold home); and susceptibility to the cold (where attempts to achieve adequate warmth lead to households relying on a fire to supplement their primary system). In some households reliant on combustion fires and using the appliance daily elevated CO readings were recorded.

- **Households relying on gas and solid fuel fires are often not maintaining them.** Servicing rates of these appliances were low compared to boilers: households reported checking only 40% of gas fires in the past 12 months compared to 77% of boilers. A key reason for this behaviour is low levels of awareness that all combustion appliances, not only gas boilers, require servicing. Financial vulnerability is also a factor in non-servicing in some low income owner-occupant households. Such households may be able to benefit from free gas safety checks through the PSR however they are currently likely to be missing out. We found three quarters of households surveyed in the study were eligible for the PSR but only 10% reported being registered with their energy supplier. For households who are having appliances checked regularly, safety is not always the key consideration. In particular, reliability and comfort drives regular boiler maintenance in older person households where keeping warm is the core concern.

- **Living with a higher risk boiler is correlated with living in an off-gas and rural property.** We observed a statistically significant relationship ($p<0.0001$) between living in an off-gas and rural home and having an older and riskier (non-condensing) boiler type. Amongst all homes where boiler type could be verified (n131), 70% were using safer and more efficient condensing models, compared to only 29% with condensing models in rural households not using mains gas for their primary heating. A number of condensing boilers had been installed free of charge under government energy efficiency programmes such as ECO. This underlines the importance of such schemes in supporting low income households to stay safe and warm in their homes but indicates these schemes have not been successful in reaching non-gas homes, with implications for both fuel poverty and CO safety.

- **Gas cookers may be a significant source of CO exposure in homes but awareness about CO risk from these appliances is very low.** Statistical investigation (Pearson's correlation) showed maximum CO levels were significantly increased in homes with ovens fuelled by mains gas or LPG ($p=0.001$; $r=0.336$) and also hobs fuelled by mains gas or LPG ($p=0.019$; $r=0.247$). However the vast majority (75%) of homes with a gas cooker fitted are not having this appliance checked regularly. A lack of awareness that cookers can pose a CO risk was observed as the main factor in this behaviour. Additionally, in social rented properties, most tenant-owned cookers are going un-serviced as they are not covered by landlord safety checks. Neglect of these appliances is particularly concerning given homes with gas cookers were more likely to record higher CO readings but also because 15% of households with gas cookers reported using the appliance for room heating. While this behaviour is not practised regularly, the factors which drive fuel poverty – living on a low income and in an inefficient home – are contributing to a small but notable number of households turning to their cooker as a source of 'cheap' or 'instant' warmth to supplement or replace their primary heat source.

- **Front line service providers are undertaking critical work to support and protect vulnerable households.** Cases were observed in the research of households in vulnerable situations being supported to receive fuel poverty and/or CO safety interventions. This includes new boilers, appliance servicing and CO alarms. Of 132 households where CO alarm ownership could be verified, only 35% were found to have an alarm fitted. However 22% of those alarm owners reported receiving theirs from a charity, local authority or fire and rescue service.

These findings have implications for both policy makers and industry. NEA makes the following observations and recommendations:

1. Join up fuel poverty and gas safety initiatives

Government energy efficiency programmes such as ECO replace old and inefficient boilers and install first-time boilers and central heating in low income households in order to alleviate fuel poverty. This is welcomed however CO risk will not necessarily be addressed in these households if occupants continue to use and rely on older room heaters such as gas fires. This research has shown it is not always correct to assume that households with modern boilers will favour them over other heating systems. Instead, amongst occupants vulnerable to fuel poverty, combustion room heaters may be preferred for cost reasons or both primary and secondary appliances will be run concurrently in attempts to achieve adequate warmth. Consideration should therefore be given to supporting households replace or maintain appliances such as gas fires. Equally, it is critical that households are educated on their central heating systems and occupants on low incomes are supported to optimise use of these systems without compromising on energy affordability. A key role is required for frontline service providers such as local authorities and community organisations, who are already reaching and protecting households in need. These agencies should be supported to deliver integrated fuel poverty and CO safety initiatives, including providing measures such as CO alarms to fuel poor households. Here, there is a clear role for gas distribution network companies to support these agencies. The gas networks have existing obligations on fuel poverty and CO awareness under the regulator Ofgem's RIIO-GD1 price control model. Ofgem should further incentivise the gas networks to join up action on fuel poverty and CO awareness in the next price control period (after 2021).

2. Support non-gas households to replace old and risky boilers

Historically, non-gas homes have disproportionately missed out on heating measures under ECO and this study shows rural households with boilers not fuelled by mains gas are disproportionally older, riskier and inefficient models. Rural off-gas homes are at increased risk of living in severe fuel poverty, nor are they served by free safety checks of gas appliances offered to low income owner-occupants under the Priority Services Register (PSR). For both energy affordability and safety reasons these households must be targeted in future government energy efficiency programmes. Specifically, NEA recommends a minimum target for installation of first time central heating systems under the next iteration of ECO (from October 2018) and that this target is aligned to Ofgem's scheme to provide free connections to the mains gas network for fuel poor non-gas homes.

3. Promote the PSR as a pathway to free gas safety checks

Gas suppliers are required to offer free gas safety checks to low income and vulnerable households but the volume of these checks has historically been very low. This is unfortunate because this service can help to address CO risk in low income owner-occupant households who may be neglecting to service appliances for cost reasons but may also be more susceptible to adverse effects from CO exposure for reasons of age or ill health. The gas industry (suppliers and network distributors) must improve efforts to sign-up low income and vulnerable customers to the PSR and passport eligible households into annual free servicing plans.

4. Improve public awareness about the CO risks of combustion appliances beyond gas boilers

Households servicing gas boilers are not always extending this behaviour to include other gas appliances in the home. Gas cookers in particular are perceived to pose a low CO risk relative to boilers and households are largely unaware that such appliances require maintenance. Gas safety messages should be made clearer to communicate about the risks posed by different gas appliances and advised on their proper installation, use and maintenance. Gas fires and gas cookers should be prioritised in such messages and catch-all and ambiguous terms such as ‘appliance’ should be avoided.

5. Target and tailor CO safety messages to account for different household, appliance and fuel types

Safety may not always be the most effective message to prompt households to check their appliances. Instead, an understanding of the appliance and household type should inform CO campaigns. For example, emphasising reliability and comfort may help drive boiler servicing, particularly in older age households susceptible to the cold. While a focus on safety may be more suitable for appliances such as cookers. Amongst low income families and working-age households, integrated CO and fuel poverty interventions should be considered (elevated CO levels and lower mean temperatures were observed in these homes). Clear messaging about landlord and tenant responsibilities is also critical, particularly in social rented housing where appliances are more likely to be owned by tenants and not covered by landlord gas safety checks. Households off mains gas should be targeted with bespoke campaigns addressing servicing of oil, solid fuel and LPG appliances.

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